N91-13333

CALCULATION OF ROTOR IMPEDANCE FOR USE IN DESIGN ANALYSIS OF HELICOPTER AIRFRAME VIBRATIONS

by

LTC Kip P. Nygren
Associate Professor of Aerospace Engineering
U.S. Military Academy
West Point, NY 10996

ABSTRACT

Excessive vibration is one of the most prevalent technical obstacles encountered in the development of new rotorcraft. The majority of vibrations problems are not even identified until the flight testing phase of development. The inability to predict these vibrations is primarily due to deficiencies in analysis and simulation tools. The Langley Rotorcraft Structural Dynamics Program was instituted in 1984 to meet long term industry needs in the area of rotorcraft vibration prediction. As a part of the Langley program, this research endeavors to develop an efficient means of coupling the rotor to the airframe for preliminary design analysis of helicopter airframe vibrations.

Due to the very different dynamics and structural configurations of the rotor and fuselage, these two structures have historically been analyzed separately. The coupling of the two structures has normally been accomplished by the calculation of the forces acting on the fixed rotor hub and then the application of these fixed hub forces to the fuselage for vibration analysis. This method neglects the very important dynamic interaction between the two structures and as a result is not adequate for vibration analysis.

Two different methods are available to correctly couple the rotor and airframe in order to account for these interactions. The first method couples the rotor and airframe equations directly through constraint equations and thus creates a merged set of equations representing the combined structures. The second method, called impedance matching, equates the forces and displacements at the rotor and fuselage connection for a given frequency.

In impedance matching, the loads transmitted by the rotor hub to the airframe, F, are represented as a combination of the fixed-hub loads, F_0, and a linear correction to account for hub motions, x (eqn 1).

$$F = F_0 + [A]\,x \qquad \text{(eqn 1)}$$

The A matrix, which provides the hub forces due to hub motions, is the rotor impedance matrix. The forces due to motion of the fuselage can also be represented in terms of impedance (eqn 2), where B is the fuselage impedance matrix.

$$F = [B]\,x \qquad \text{(eqn 2)}$$

By equating the forces and displacements of the rotor and fuselage at the rotor hub, the following relation is obtained for the hub motion (eqn 3). The coupled hub forces can now be found from equation 2.

$$x = [B - A]^{-1} F_0 \qquad \text{(eqn 3)}$$

The great utility of this result to the airframe designer lies in the independence of the fuselage properties, represented by the B matrix, from the rotor properties. If the fuselage structure is changed, only the fuselage impedance changes and no additional rotor analysis is required.

Although the fuselage impedance, B, can be readily calculated, the rotor impedance, A, is considerably more difficult to obtain.

The main effort of this research has been to modify an existing computer program for modeling the dynamic and aerodynamic behavior of rotorcraft called DYSCO (DYnamic System COupler) to calculate the rotor impedance. DYSCO was recently developed for the U.S. Army by Kaman Aerospace Corporation and has proven to be adaptable for the inclusion of new solution methods. The solution procedure developed to use DYSCO for the calculation of rotor impedance is shown below.

1. Start with a trimmed rotor-fuselage coupled model.

2. Create a separate model from the Rotor Component only.

3. Find the Hub Fixed Forces.
   a. Run the rotor component as a separate model with only the blade degrees of freedom (DOFs), no hub DOFs, in a time history solution. This produces the motions of the blades with the hub fixed. Write the resulting rotor state vectors to a file.
   b. Create a second rotor model which includes the hub DOFs. Add to the model, the steady forces required to keep the rotor hub in equilibrium.
   d. Run this model with the Rotor Impedance Solution, SRI1. The SRI1 solution modifies blade state vectors to add elements for the hub DOFs. Each of the hub DOF elements will be zero, however, they are required to calculate the fixed hub forces. SRI1 calls the Interface Force Solution, SII3 to calculate and save the Fixed Hub Forces for future use.

4. Find the Forces due to Hub Imposed Displacement.
   a. Create a third Rotor Model by modifying the second model to increase the Hub Mass (and/or Hub Moment of Inertia) to 10^6 times the actual hub and rotor mass.
   b. Run this third model with SRI1 to obtain the state vectors of the rotor hub and blades corresponding to the harmonic displacement of the rotor hub. The model will be run for the cosine and sine displacements of each hub DOF in succession, and the resulting state vectors are saved to a file. Input the force magnitude necessary to produce the desired displacement.

5. Calculate the Impedance Matrix.
   a. Return to the second rotor model, which consists of the true representation of the rotor hub. Run SRI1 for the third time to obtain the Hub Interface Forces caused by the harmonic displacement of each of the hub DOFs from the state vectors just produced with the heavy hub model.
   b. Subtract the fixed hub forces from the hub forces due to hub motion. Perform a harmonic analysis of the resulting forces and the Fourier coefficients become one column in the impedance matrix.
   c. Form the entire matrix from the columns of Fourier coefficients obtained for each cosine and sine motion of every hub DOF.

Verification of the procedure by comparison with a known solution for a simple wind turbine model is about 75 percent completed, and initial results are encouraging. After the wind turbine impedance is confirmed, the verification effort will continue by comparison to solutions of a more sophisticated rotorcraft model. Future work includes determination of the sensitivity of the rotorcraft airframe vibrations to helicopter flight conditions and rotor modeling assumptions. When completed, this research will ascertain the feasibility and efficiency of the impedance matching method of rotor-airframe coupling for use in the analysis of airframe vibrations during the preliminary rotorcraft design process.