Analysis of Advanced Rotorcraft Configurations

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Advanced rotorcraft configurations are being investigated with the objectives of identifying vehicles that are larger, quieter, and faster than current-generation rotorcraft. A large rotorcraft, carrying perhaps 150 passengers, could do much to alleviate airport capacity limitations, and a quiet rotorcraft is essential for community acceptance of the benefits of VTOL operations. A fast, long-range, long-endurance rotorcraft, notably the tilt-rotor configuration, will improve rotorcraft economics through productivity increases.

A major part of the investigation of advanced rotorcraft configurations consists of conducting comprehensive analyses of vehicle behavior for the purpose of assessing vehicle potential and feasibility, as well as to establish the analytical models required to support the vehicle development. The analytical work of FY99 included applications to tilt-rotor aircraft.

Tilt Rotor Aeroacoustic Model (TRAM) wind tunnel measurements are being compared with calculations performed by using the comprehensive analysis tool (Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD II)). The objective is to establish the wing and wake aerodynamic models that are required for tilt-rotor analysis and design. The TRAM test in the German-Dutch Wind Tunnel (DNW) produced extensive measurements. This is the first test to encompass air loads, performance, and structural load measurements on tilt rotors, as well as acoustic and flow-visualization data. The correlation of measurements and calculations includes helicopter-mode operation (performance, air loads, and blade structural loads), hover (performance and air loads), and airplane-mode operation (performance). Figure 1 shows an example of the comparison of TRAM-measured performance with calculations. The figure shows the difference in calculated rotor power obtained by using an aerodynamic model (wing and wake) appropriate for helicopter rotors, instead of a tilt-rotor aerodynamic model. The span loading and wake formation are very different on tilt rotors and helicopters, so it is essential to use model features specific to tilt rotors in order to adequately predict the behavior. Future analyses will be concerned with TRAM tests in the Ames 40- by 80-Foot Wind Tunnel, which will produce data over a much larger operating envelope for two rotors and the airframe, including advanced flow-visualization results, and with XV-15 rotor tests in the Ames 80- by 120-Foot Tunnel in order to obtain tilt-rotor data at a larger scale (although no air loads data) with different blade planform and twist.

The quad tilt-rotor configuration has been proposed in order to meet the objective of a large rotorcraft; it is hoped there will be fewer difficulties

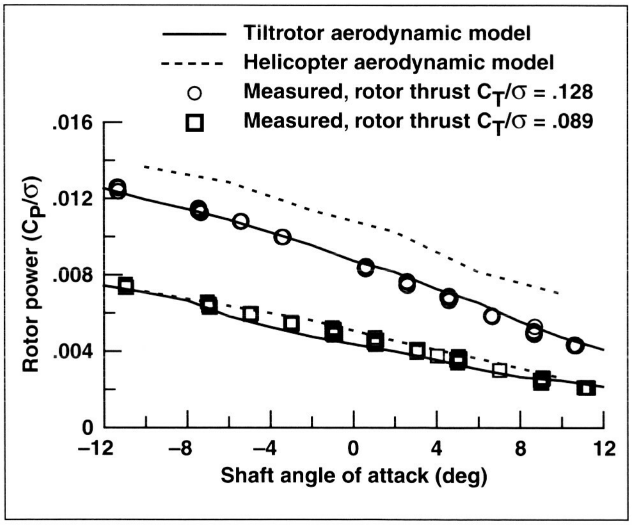

Fig. 1. Comparison of measured and calculated tilt-rotor power; helicopter-mode operation, at wind tunnel speed = 0.15 times rotor-tip speed.

associated with scaling the rotors to large size (since there are four rather than two rotors to lift the gross weight). The technical issues in the development of quad tilt rotors include aerodynamic interference (performance, control, and handling qualities; wing-to-wing, rotor-to-wing, and wing-to-rotor); vibration and blade loads; and whirl flutter. Figure 2 shows results from CAMRAD II calculations for a quad tilt rotor, illustrating the aerodynamic interference issues. The calculations were performed with a rigid airframe and a free-wake model (for 2 wings, and 12 blades on 4 rotors).

The views in figure 2 are from forward/port, for two rotor azimuth angles. Shown are the wing section lift, the rotor blade section thrust, and the wing and rotor-tip vortices. The wing-to-wing aerodynamic interference is evident in the influence of the front-wing tip vortices on the rear-wing span loading, producing an increased loading at the rear-wing tip; this interference will affect efficiency and handling qualities. The rotor-to-wing interference is evident in the loading at midspan of the rear wing. Three-per-revolution loading variation is produced by the rotor-tip vortices, hence the different loading in the two pictures. This interference will produce increased vibration and structural loads. The wing-to-rotor interference is evident in the loading on the rotor blades when in front of the wing, compared to outside the wing, as in the two pictures; this interference will affect proprotor efficiency, vibration, and blade loads. Also of concern is whirl flutter (coupled aeroelastic stability of the rotor on the flexible wings), since the rear wing has a larger span than the front wing, and thus lower frequencies and less stability if the two wings have the same sectional stiffnesses. Investigations being conducted at Ames Research Center promise design solutions other than stiffer and heavier wings as a means to produce an acceptable level of whirl flutter stability.

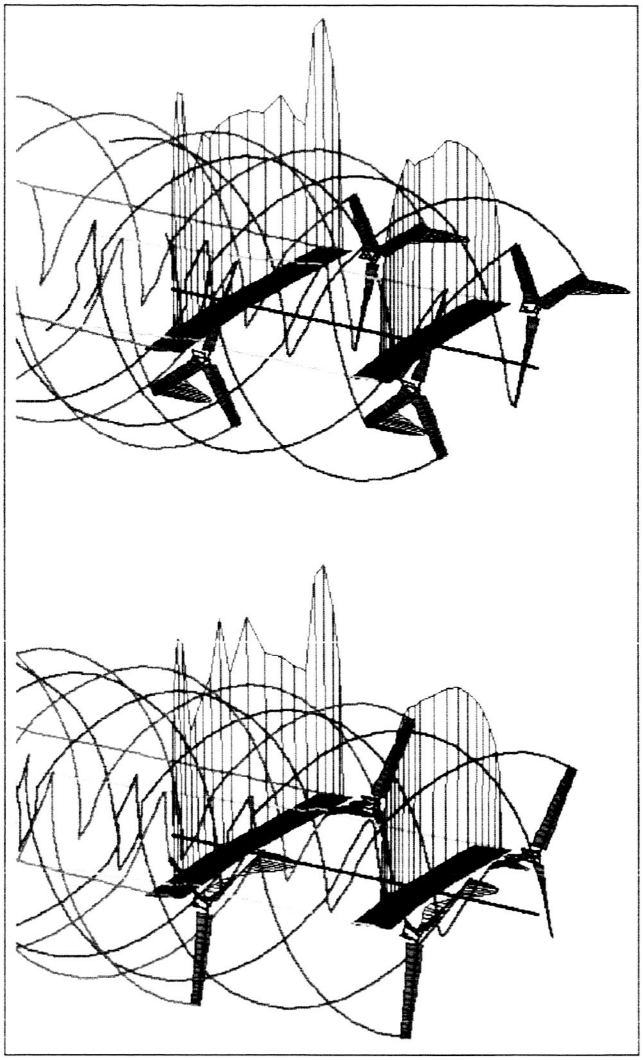

Fig. 2. Analysis of quad tilt-rotor aerodynamic interference (98,000 lb gross weight; flight speed, 250 knots).

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