AIRLOADS AND WAKE GEOMETRY CALCULATIONS FOR AN ISOLATED TILTROTOR MODEL IN A WIND TUNNEL

Wayne Johnson
Army/NASA Rotorcraft Division
NASA Ames Research Center

Submitted for Presentation at the
27th European Rotorcraft Forum
11-14 September 2001
Moscow, Russia

Abstract

The tiltrotor aircraft configuration has the potential to revolutionize air transportation by providing an economical combination of vertical take-off and landing capability with efficient, high-speed cruise flight. To achieve this potential it is necessary to have validated analytical tools that will support future tiltrotor aircraft development. These analytical tools must calculate tiltrotor aeromechanical behavior, including performance, structural loads, vibration, and aeroelastic stability, with an accuracy established by correlation with measured tiltrotor data. For many years such correlation has been performed for helicopter rotors (rotors designed for edgewise flight), but correlation activities for tiltrotors have been limited, in part by the absence of appropriate measured data. The recent test of the Tilt Rotor Aeroacoustic Model (TRAM) with a single, 1/4-scale V-22 rotor in the German-Dutch Wind Tunnel (DNW) now provides an extensive set of aeroacoustic, performance, and structural loads data.

This paper will present calculations of airloads, wake geometry, and performance, including correlation with TRAM DNW measurements. The calculations were obtained using CAMRAD II, which is a modern rotorcraft comprehensive analysis, with advanced models intended for application to tiltrotor aircraft as well as helicopters. Comprehensive analyses have received extensive correlation with performance and loads measurements on helicopter rotors. The proposed paper is part of an initial effort to perform an equally extensive correlation with tiltrotor data. The correlation will establish the level of predictive capability achievable with current technology; identify the limitations of the current aerodynamic, wake, and structural models of tiltrotors; and lead to recommendations for research to extend tiltrotor aeromechanics analysis capability.

The purpose of the Tilt Rotor Aeroacoustic Model (TRAM) experimental project is to provide data necessary to validate tiltrotor performance and aeroacoustic prediction methodologies and to investigate and demonstrate advanced civil tiltrotor technologies. The TRAM project is a key part of the NASA Short Haul Civil Tiltrotor (SHCT) project . The SHCT project is an element of the Aviation Systems Capacity Initiative within NASA.

In April-May 1998 the TRAM was tested in the isolated rotor configuration at the Large Low-speed Facility of the German-Dutch Wind Tunnels (DNW). A preparatory test was conducted in December 1997. These tests were the first comprehensive aeroacoustic test for a tiltrotor, including not only noise and performance data, but airload and wake measurements as well. The TRAM can also be tested in a full-span configuration, incorporating both rotors and a fuselage model. Figure 1 shows the wind tunnel installation of the TRAM isolated rotor. The rotor tested in the DNW was a 1/4-scale (9.5 ft diameter) model of the right-hand V-22 proprotor. The rotor and nacelle assembly was attached to an acoustically-treated, isolated rotor test stand through a mechanical pivot (the nacelle conversion axis).

The TRAM was analyzed using the rotorcraft comprehensive analysis CAMRAD II. CAMRAD II is an aeromechanical analysis of helicopters and rotorcraft that incorporates a combination of advanced technologies, including multibody dynamics, nonlinear finite elements, and rotorcraft aerodynamics. The trim task finds the equilibrium solution (constant or periodic) for a steady state operating condition, in this case a rotor operating in a wind tunnel. For wind tunnel operation, the thrust and flapping are trimmed to target values. The aerodynamic model includes a wake analysis to calculate the rotor nonuniform induced-velocities, using a free wake geometry. Figure 2 shows the CAMRAD II model of the TRAM.

The paper will present the results of CAMRAD II calculations compared to the TRAM DNW measurements for hover performance, helicopter mode performance, and helicopter mode airloads. Figures 3 to 7 are typical results. Figure 3 is an example of the hover performance results, comparing both measurements and calculations for the JVX (large scale) and TRAM (small scale) rotors. Figure 4 is an example of the helicopter mode performance, showing the influence of the aerodynamic model (particularly the stall delay model) on the calculated power, induced power, and profile power. Figure 5 is an example of the helicopter mode airloads, showing the influence of various wake and aerodynamic models on the calculations. Good correlation with measured airloads is obtained using the multiple-trailer wake model. Figures 6 and 7 show the corresponding calculated wake geometry. The paper will present additional results, and describe and discuss the aerodynamic behavior in detail.

Figure 1. Tilt Rotor Aeroacoustic Model in the German-Dutch Wind Tunnel (TRAM DNW).

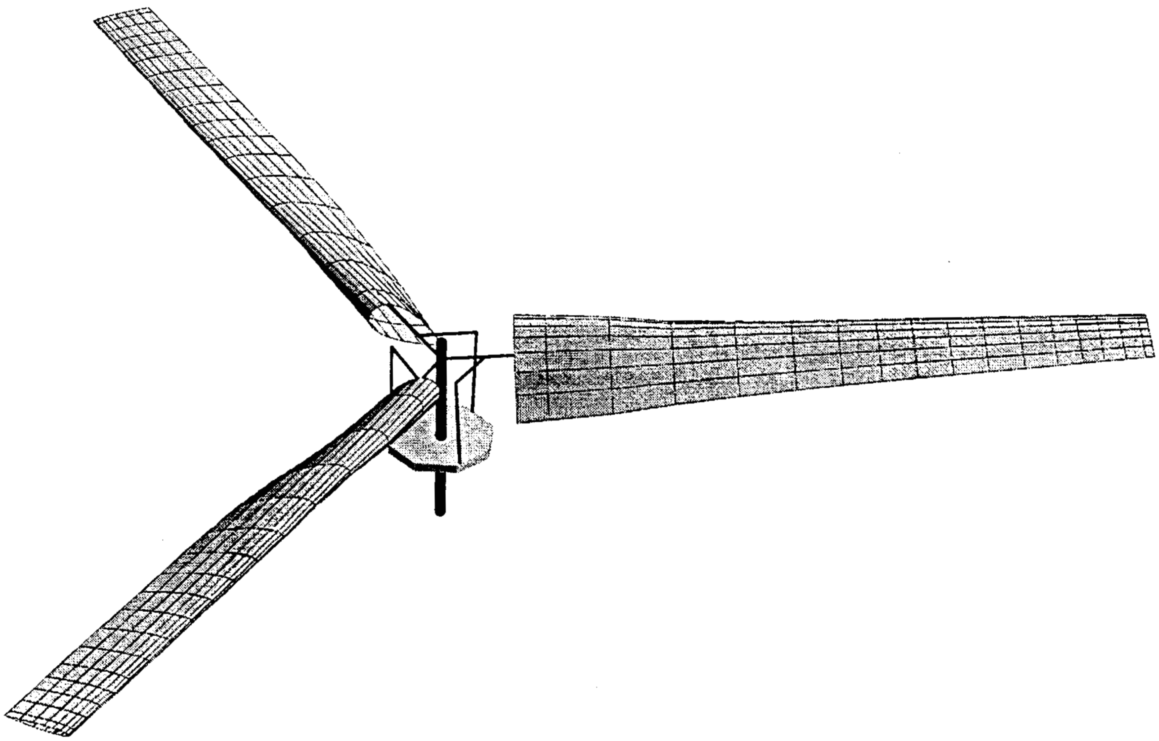

Figure 2. CAMRAD II model of TRAM.

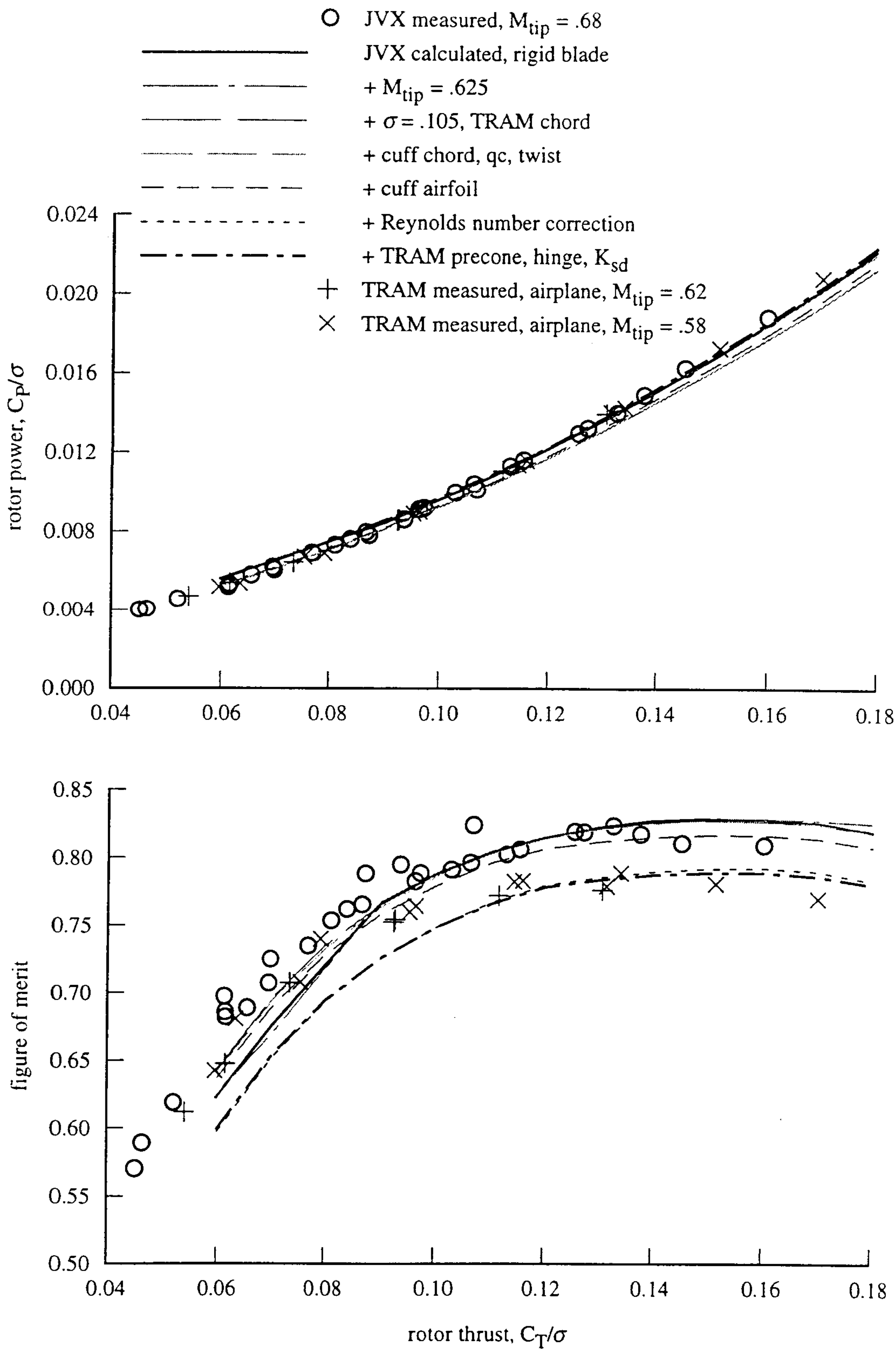

Figure 3. Comparison of JVX and TRAM calculated hover performance.

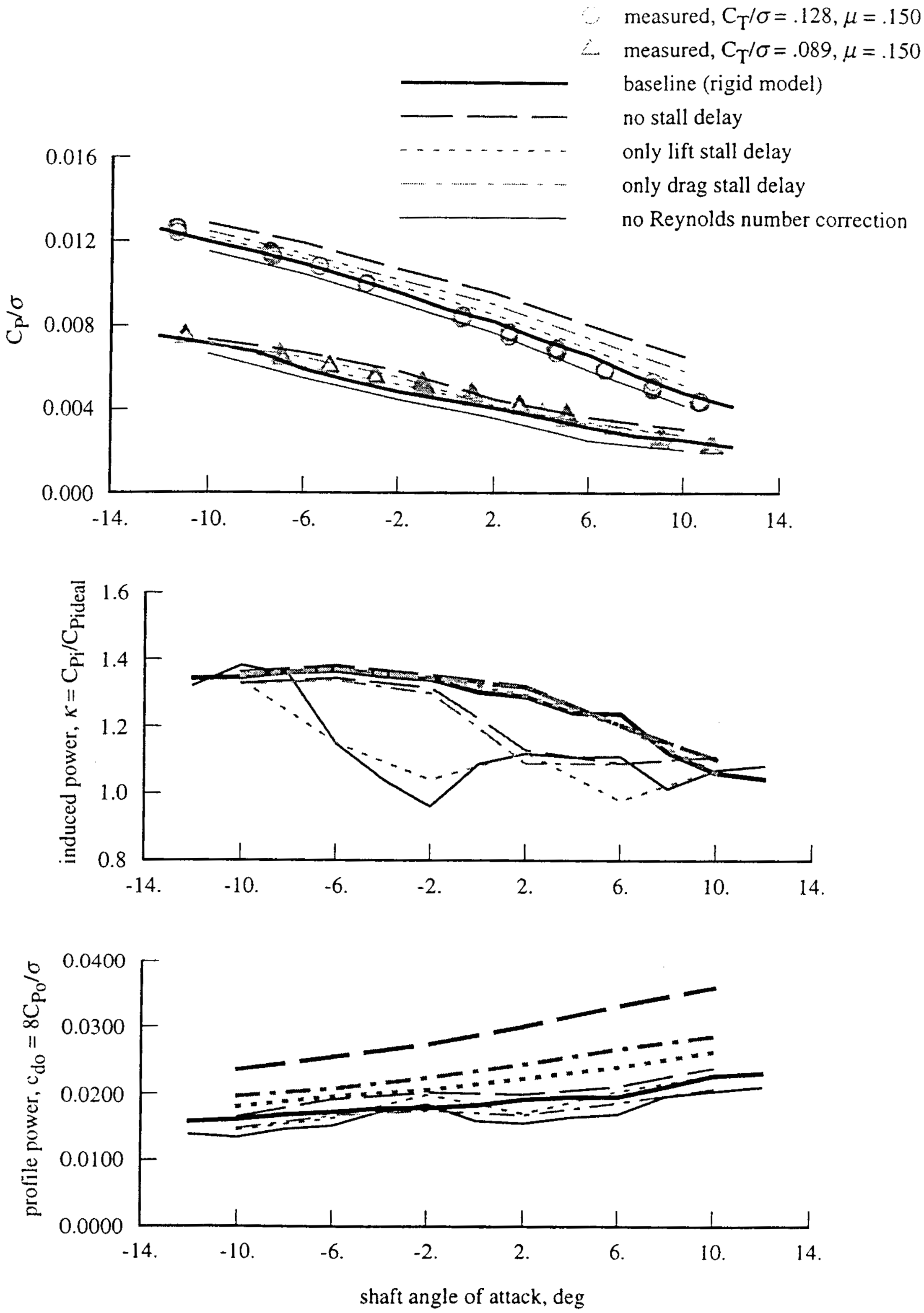

Figure 4. Influence of aerodynamic model on calculated TRAM helicopter mode performance ($\mu = 0.15$; in lower two figures, heavy line $C_T/\sigma = 0.128$, thin line $C_T/\sigma = 0.089$).

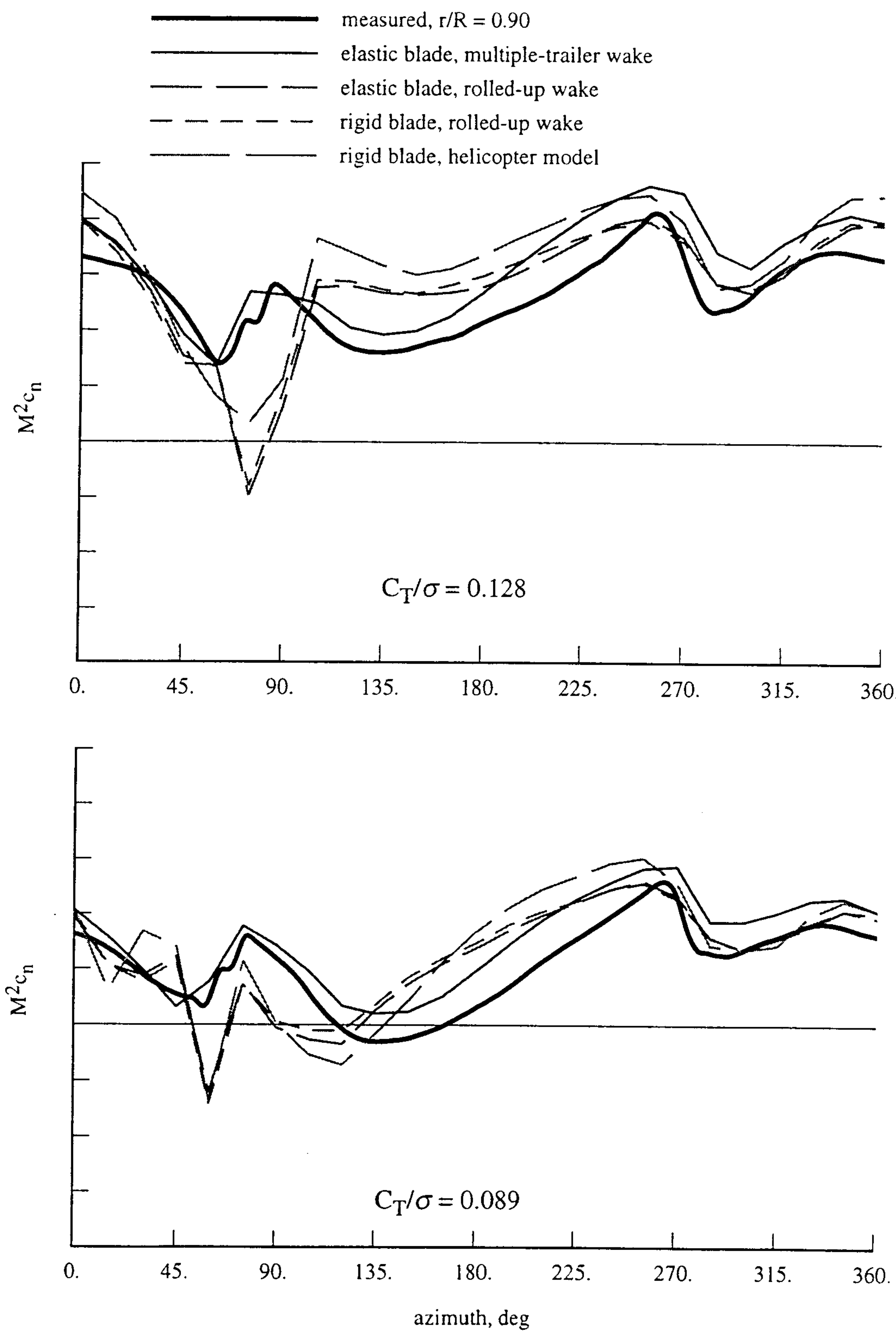

Figure 5. Measured and calculated TRAM helicopter mode airloads for μ = 0.15 and $\alpha_s = -6$; radial station r =-0.90R.

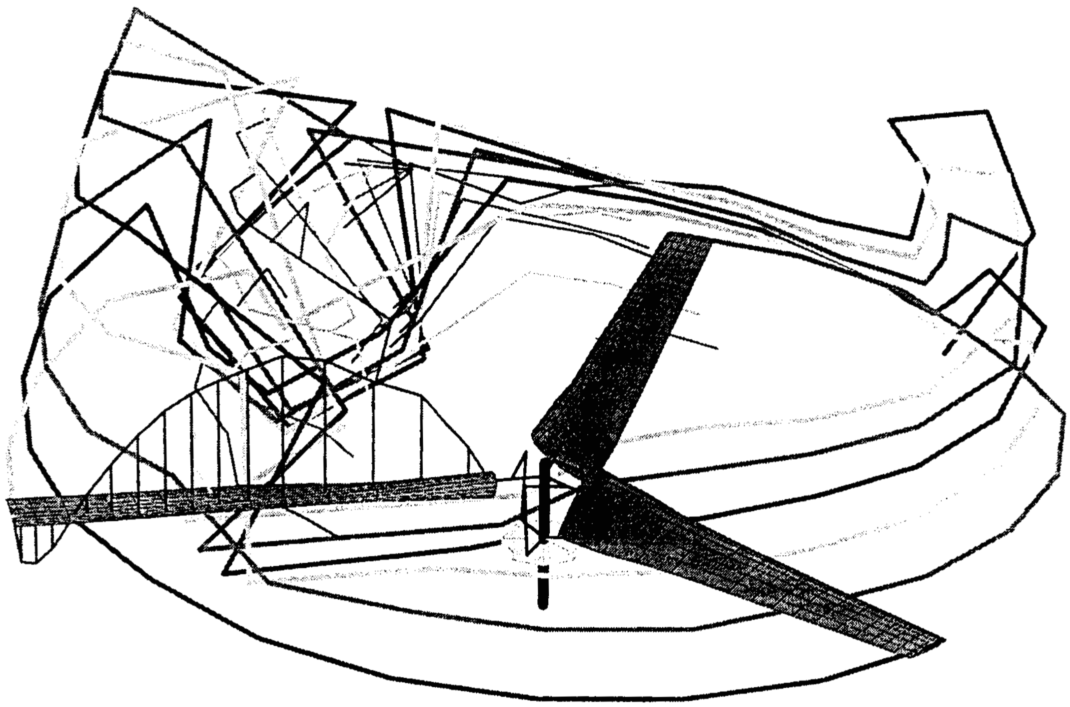

Figure 6. Calculated TRAM wake geometry and loading for $\mu = 0.15$, $\alpha_s = -6$, $C_T/\sigma = 0.089$. Rolled-up wake model, azimuth of reference blade = 105 deg.

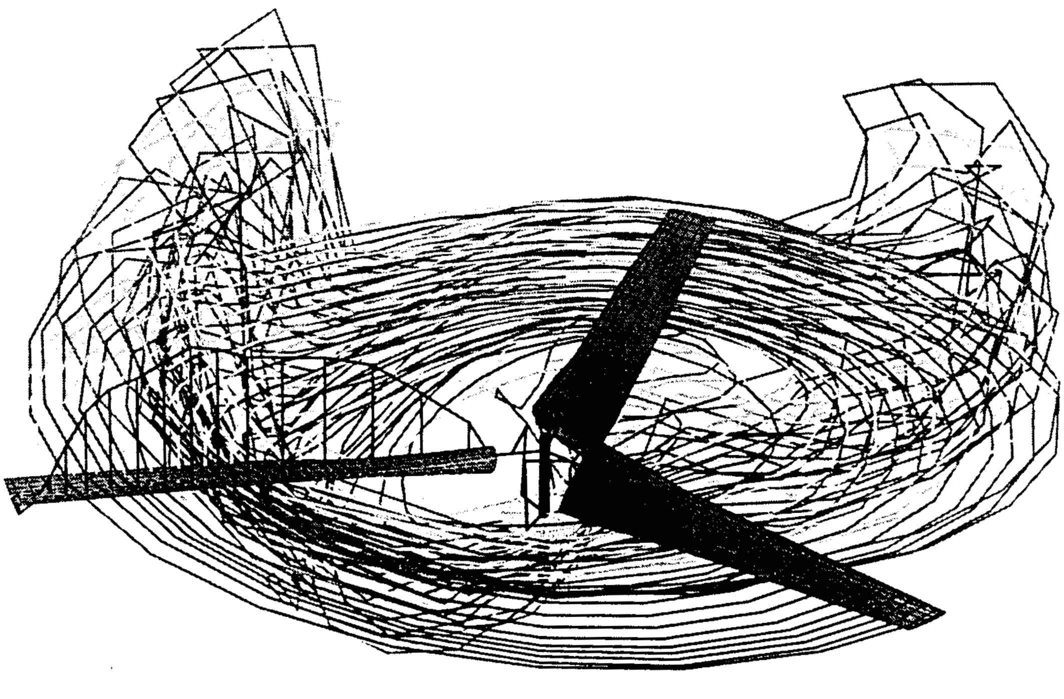

Figure 7. Calculated TRAM wake geometry and loading for $\mu = 0.15$, $\alpha_s = -6$, $C_T/\sigma = 0.089$. Multiple-trailer wake model, azimuth of reference blade = 105 deg.