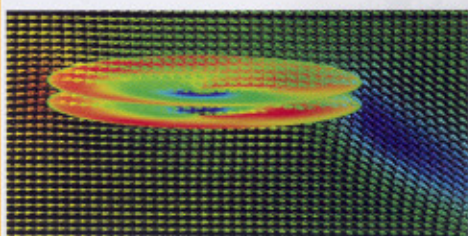


Velocity Vectors Colored by Downwash



Vorticity Iso-surface Colored by Downwash

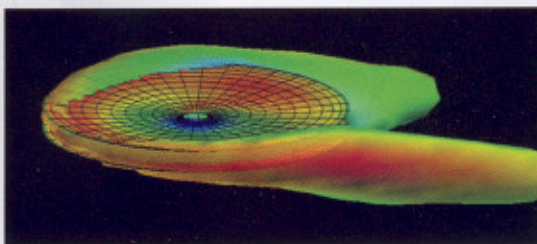


Figure 8. Fluent coaxial rotor flow field prediction

sources that augment the momentum equations in existing CFD analyses. Currently, OVERFLOW and Fluent have been modified to include these simplified rotor models for interactional aerodynamic studies. To make the model suitable for design purposes, control systems and trimmers were included to ensure realistic rotor loadings. A “gridless” formulation precludes the need to remesh when rotor geometry is modified. Multiple rotors are also easily modeled to handle any new designs that may arise in the future.

### Continuum Dynamics

The past two years have seen an expansion and diversification of Continuum Dynamics, Inc.’s software products and engineering services to provide timely, accurate aerodynamic design tools for a broad range of new aircraft concepts and retrofittable upgrades for contemporary airframes. CDI has performed and supported numerous rotor and propeller designs using its CHARM comprehensive modeling software and related tools. It has also recently focused on enhancing its ability to predict aerodynamic and aeroacoustic characteristics of micro-rotors, coaxial rotors and ducted rotors as described in several recently published technical papers.

A key recent accomplishment of CDI has been the development of a high fidelity, full span free-vortex wake model with real-time capability that can couple

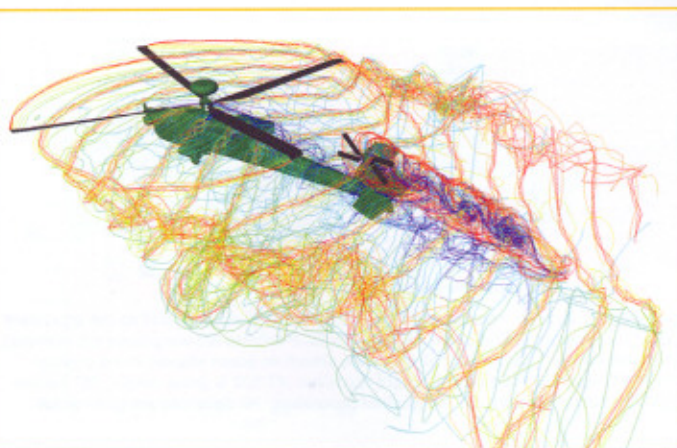


Figure 9. CHARM full-span free-vortex wake model (and fast panel fuselage model) of the AH-64D

easily into both flight simulation and analysis software (Figure 9). The CHARM wake module is now in use at major US manufacturers, government research labs and Department of Defense (DoD) agencies involved in rotorcraft modeling and research, often providing a much higher level of

wake modeling fidelity than previously available for critical flight dynamics applications and general aircraft design. The CHARM module includes a fast panel fuselage/empennage model fully coupled with the wake solution for both high fidelity and real-time applications.

CDI recently developed a new wake modeling technology to support the modeling of wake interactions and induced velocities associated with a mixture of fixed- and rotary-wing aircraft operating in the vicinity of one another as well as the ground and/or a sea vessel (Figure 10). This Multiple Aircraft Simulation Technology (MAST) includes a capability to model wake-on-wake interactions between aircraft, variable gust fields and structure wakes in and out of ground effect. MAST features a new long-time free-vortex wake model with a real-time turbulent decay formulation extensively corre-



Figure 10. MAST simulation of Navy shipboard downwash survey test

lated with test data. Operating in real-time, the MAST wake model has correlated well with test data from the Navy’s Full-Scale Rotorcraft Downwash Survey Test as described in a paper presented at the 2004 AHS Forum. MAST has been incorporated into both stand alone software and a module suitable for coupling into flight simulation software (Figure 11).

Brownout is the visual obscuration caused by the entrainment of dust and ground debris by the rotor wake during take-off and landing. In recent work for the US Army, CDI has been developing a high fidelity, physics-based aerodynamic analysis of brownout suit-

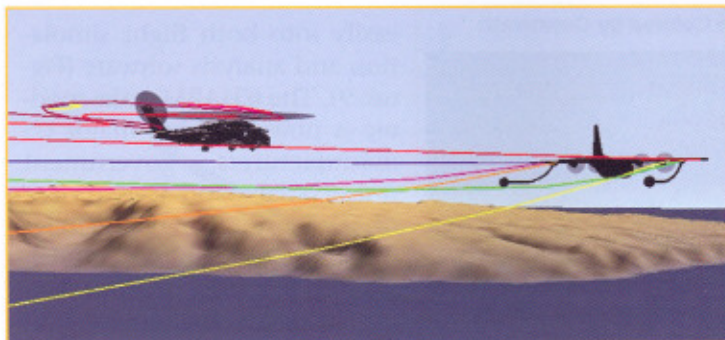


Figure 11. Coupled MAST and CHARM model of a UH-60 refueling scenario

able for engineering research and flight simulation. Central to this analysis is the ability of CDI's CHARM real-time free-wake and fast panel model to predict rotorcraft wake aerodynamics during transient maneuvering flight near the ground.

CDI has been collaborating with Glasgow University in developing techniques for readily incorporating numerical methods for preventing the numerical diffusion of vorticity into primitive variable CFD codes. These first principles methods, based on the fast adaptive techniques employed by the Vorticity Transport Model, naturally preserve the strength, structure and evolution of vorticity, and are being packaged in a modular form for use in an assortment of Eulerian and Lagrangian tools. Initial work coupled a prototype wake module (VorTran-M) to CDI's unstructured Navier-Stokes solver RSA3D, while current work seeks to improve the functionality of the model and to couple it to OVERFLOW 2.0.

## US Government and Academia

### NASA Ames

Two small-scale wind tunnel tests were conducted in the US Army 7 ft by 10 ft Wind Tunnel at NASA Ames Research Center to investigate tiltrotor formation flight (see Figure 12). The first test took place from June to October 2004 and focused on formation flight at speeds of 50 kt and below. The second test was conducted from August to December 2005 and studied formation flight at speeds from 50 to 110 kt. These tests used two 1/48-scale V-22 models that were operated in a variety of simulated flight conditions, including climb, descent, and level flight at various flight speeds and spatial separations. Forces and moments experienced by the trail aircraft were used to deduce the influence of the lead aircraft on the trail aircraft. Particle Image Velocimetry (PIV) data were collected

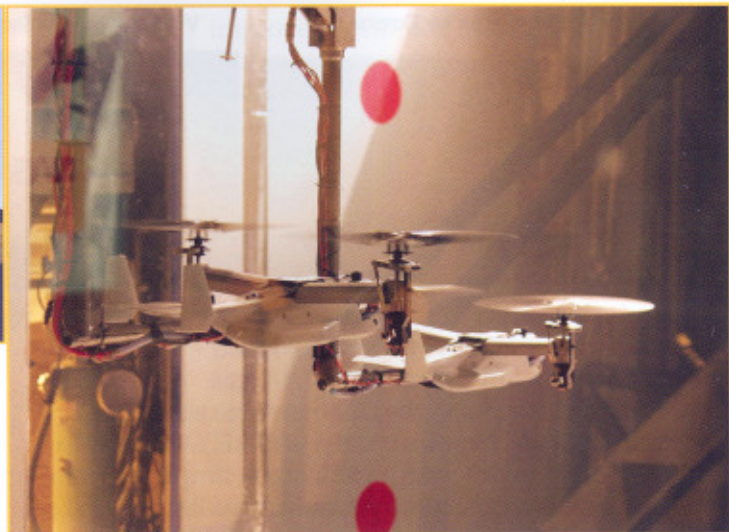
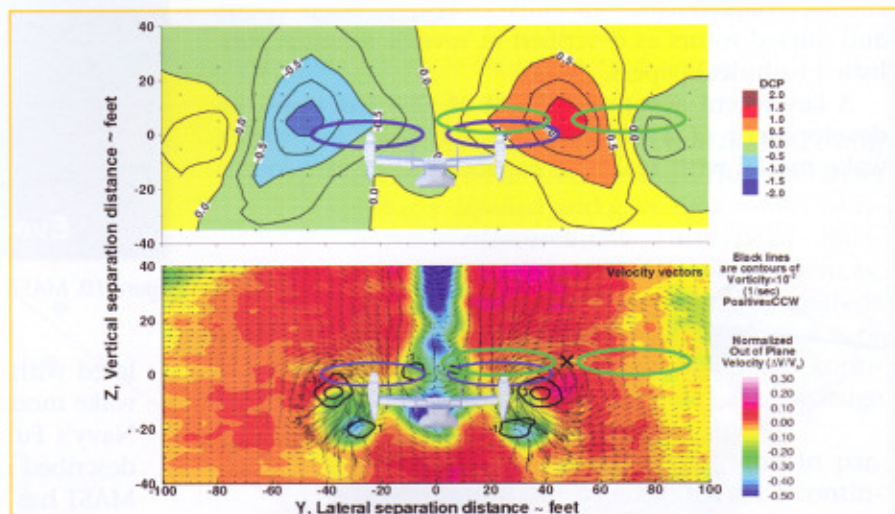


Figure 12. Small-scale tiltrotor models mounted in the US Army 7 ft by 10 ft wind tunnel at NASA Ames Research Center

to relate these forces and moments to features in the lead aircraft wake.

In general, the roll induced on the trail aircraft was shown to be maximum when the aircraft were laterally offset by a full wingspan and the trail aircraft was vertically positioned so as to be in the wake of the lead aircraft (Figure 13, upper plot). Interaction between the two aircraft was most severe when the formation flight speed was 50 kt or below, the formation was in climb, or when the lead aircraft rotor thrust was increased to simulate a high gross weight. PIV data indicate that the roll moment arises largely from differential inflow to the trail aircraft rotors due to vortices in the wake of the lead aircraft (Figure 13, lower plot). The spatial location of peak interaction between the aircraft closely tracks these



Representative roll measurement (top) and PIV measurement (bottom). Roll moment is plotted as the equivalent differential collective pitch (DCP) required to neutralize the roll (positive DCP reflects left-wing-down roll moment). The lead aircraft is shown with blue rotors. The trail aircraft rotors are shown as green ellipses in the position where the trail aircraft experienced maximum roll moment. Flight condition: 47,500 lb gross weight, 75° nacelle tilt, 80 knots flight speed, 1000 fpm rate of descent, 50' longitudinal separation. All distances are given at full scale.

Figure 13. Trail aircraft roll measurement and lead aircraft flow field measurement