High Fidelity, Shipboard Real-Time, Rotor Wake Module with Shipboard Interactions

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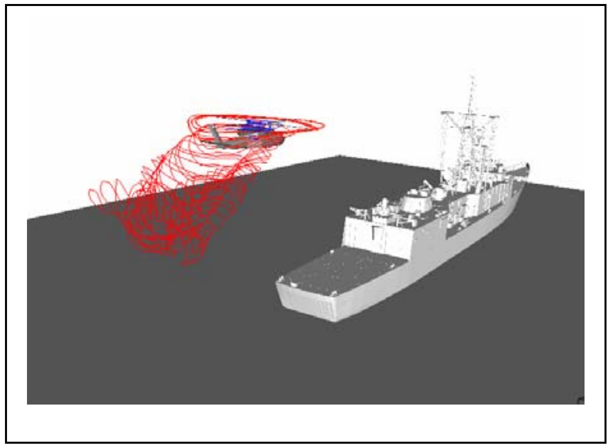

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PROBLEM STATEMENT

Accurate modeling of the aerodynamic and induced flow field in the vicinity of naval rotorcraft operations is an important aspect for developing high fidelity simulation and training models. One of the most difficult piloting tasks presented to a naval aviator is the challenge of landing an aircraft (helicopter) onto the flight deck of a moving ship in high sea-states with gusty wind conditions. This task is compounded by the aerodynamic disturbances that result from the flow around the ship superstructure, which is in close proximity to the landing spot. The spatially- and time-varying flow field associated with this ship airwake can lead to significant pilot control activity and workload during approach and recovery, station-keeping, and vertical replenishment (VERTREP) tasks. Flight simulation has been recognized as valuable tool for augmenting engineering development and pilot training in naval aviation operations, in particular due to the benefit of the availability of any sea state, wind condition, and surface ship, provided that the underlying simulation mathematical model has appropriately characterized the complex aerodynamic environment including interactions between the rotorcraft and ship airwake.

Historically, rotorcraft flight simulation models used for pilot training have been based around simplified aerodynamic models to meet real-time computational requirements in legacy systems. These models inadequately represent the unsteady and three-dimensional nature of the aerodynamic environment near the rotor/airframe and typically require extensive tuning to capture relevant response characteristics. Examples include fundamental rotorcraft performance metrics, blade dynamic stall (a key mechanism affecting rapid maneuvers), and vortex ring state (a potentially hazardous flight condition encountered in steep descent). Rotorcraft shipboard operations introduce additional unique phenomena including full/partial ground effect near moving flight decks and interactions between the rotorcraft and ship airwake. Reliance on excessively simplified modeling assumptions and limited bodies of experimental data potentially undermines the realism necessary for effective pilot training. A revised approach to simulations is needed to provide improved training and safety for the war-fighter using a physics-based simulation model that can capture known vehicle behaviors without relying on expensive and sometimes risky flight test activity to provide simulation source data.

WHO CAN BENEFIT?

The full range of Navy rotorcraft programs can benefit from the development of advanced aerodynamic and induced flow field modeling technology that captures the relevant characteristics in the shipboard operational environment. The modeling approach described below can be applied to any rotorcraft system currently fielded, including the SH-60/MH-60 Blackhawk, CH-53 Super Stallion, and MV-22 Osprey. The modeling technology is generic and modular to support integration within current generation training systems (as part of trainer upgrade to enhance modeling fidelity of the shipboard operational environment).




The modular analysis software under development here can also be applied to unmanned systems such as the MQ-8B Fire Scout autonomous helicopter. Such vehicles face unique challenges in shipboard integration and interoperability, and extensions of the modeling software developed here can capture some of the challenging ship/aircraft and aircraft/aircraft interactions that can impact prospective UAV operations.

BASELINE TECHNOLOGY

Current rotorcraft flight simulations and trainers have difficulty capturing the unsteady three-dimensional nature of the aerodynamic environment near the rotor by relying in many cases on aerodynamic modeling methods that sacrifice substantial physical realism to meet the real-time turnaround requirement of pilot-in-the-loop operation. Existing modeling methods are rooted in decades-old analysis techniques that have been long bypassed in vehicle design studies. This baseline technology does not capture the complex behavior of rotor flow field, in particular during maneuvering flight and unsteady flow states (such as ground effect). As a consequence, the use of simplified models leads to a dependence on empirical data (including both wind tunnel and flight test data) to “tune” the underlying model. Supporting experimental databases are expensive to acquire, operationally difficult to use, and are inherently limited in application to the particular configurations tested. As an example, acquiring the flight data to validate the performance of the V-22 aircraft in steep descent alone required over 120 dedicated flight hours, and the utility of the data was restricted to that aircraft alone.

Illustration of Rotor Wake Structure in Flight Simulation of a Generic Helicopter Configuration

Modeling of the ship airwake disturbance environment in rotorcraft trainers historically has also relied upon empirical methods, although the advent of computational fluid dynamics (CFD) has been used to improve modeling fidelity in recent years. The development of CFD-based ship airwake models have been the focus of Navy/DoD, industry, and university research, and since this analysis is computationally intensive, trainer integration is performed using a CFD-generated airwake database that is determined from off-line analysis. While providing a higher fidelity model, this approach neglects interactions between the rotorcraft, rotorcraft wake, and airwake disturbance. These interactions can be important, in particular for the simulation of at-sea rotorcraft launch and recovery operations.

TECHNOLOGY DESCRIPTION

The technology to address shortcomings of current methods for real-time rotorcraft simulation builds upon proven rotor aerodynamic modeling software developed by Continuum Dynamics, Inc. (CDI). The development goals have focused on improved training of the shipboard environment using a physics-based simulation model that can capture known vehicle behaviors without relying on expensive and sometimes risky flight test activity to provide simulation source data for current and projected Navy rotorcraft. The target product is an advanced rotorcraft/shipboard induced velocity for use in conjunction with existing simulation/training systems. Key advantages of this technology for Navy and Marine rotorcraft systems are:

Features	Advantages	Benefits
• Common technology • State-of-the-art design tools	Captures high-end analyses results	• Increased confidence in simulation • Greatly facilities validation and assessment of real-time operation
Full time-domain maneuvering model with ground/deck surface and airframe effects	Suitable for realistic maneuvers in flight at altitude and near ground	• Increased realism in training • No need for expensive wind tunnel or flight test data
General physics-based modeling	Not tied to specific vehicle or database	Suitable for both current and follow-on designs

Through this and prior efforts, CDI has developed breakthrough technologies in lifting panel and free-vortex wake methods that address the need for predictive accuracy while maintaining real time turnaround. This modeling technology originated from the CDI CHARM (for Comprehensive Hierarchical Aeromechanics Rotorcraft Model) analysis and has been incorporated into wake induced velocity blade aerodynamic modules for integration within engineering design and simulation tools. Adoption of a modular software architecture has led to its ready acceptance as an important component of numerous rotorcraft analysis and flight simulation software tools. Copies have been licensed by all major U.S. airframe manufacturers, as well as NAVAIR, revolutionizing the quality of rotor wake modeling in real-time flight simulation.

Illustration of Navy and Marine Aviation Systems Modeled with CHARM

The focus of the present SBIR Phase II effort is the development, integration, and demonstration of an extended CHARM Module with Shipboard Interactions to yield a real-time rotorcraft induced velocity model to enhance naval rotorcraft training systems. Building on prior CDI-developed modeling techniques, the present effort will develop a novel approach for integrating rotorcraft and ship airwake interactions based around the real-time, free-wake modeling approach in the CHARM family of software. This approach leverages existing CFD-based ship airwake solutions, focusing on the integration in a pilot-in-the-loop trainer setting. A hierarchy of improved real-time, physics-based methods for modeling partial ground effect, ship motion, and wake/fuselage interactions will be developed, with emphasis on flexible, robust modules that may be installed across multiple helicopter simulations and will be scalable to leverage increasing capable computer hardware. The end product will be incorporated into a Navy rotorcraft flight trainer providing unprecedented high fidelity flight simulation for shipboard operations. Improved modeling fidelity of flight trainers, particularly at the edge of the flight envelope, will allow safer and superior preparation for aviators flying in unsafe conditions (e.g. vortex ring state, blade stall, maneuvering flight, and dust/sand-induced “brownout”).

CURRENT STATE OF DEVELOPMENT

The current Phase II SBIR effort involves extending the modular CHARM rotor wake analysis to incorporate critical interactions for real-time simulation of the shipboard operational environment. The table below provides an overview of past and projected milestones in the current Phase II, which will conclude in September 2010.

Milestone	TRL	Risk-Test	Measure of Success	TRL Date
Prototype software with shipboard interactions	4	Moderate	Validated inflow model with prototype ship airwake interaction model	9/2009
Integration with helicopter trainer	5	Moderate	Prototype software module integrated with Navy simulation	12/2009
Pilot simulation evaluations	5	Moderate	Module validation including pilot evaluation	6/2010
Final software module completed and validated	6	Moderate	Final module with validated shipboard interactions models	9/2010

REFERENCES

TPOC phone: (301) 342-3733

Technology summaries and integration studies of the CHARM model are available in the following publications, as well as on the CDI web site at www.continuum-dynamics.com.

- Wachspress, D.A., Keller, J.D., et al, “High Fidelity Rotor Aerodynamic Module for Real Time Rotorcraft Flight Simulation,” American Helicopter Society 64th Annual Forum, Montreal, Canada, May 2008.
- Spoldi, S. and Ruckel, P., “High Fidelity Helicopter Simulation using Free Wake, Lifting Line Tail, and Blade Element Tail Rotor Models,” American Helicopter Society 59th Annual Forum, Phoenix, AZ, May 2003.
- Horn. J.F., Bridges, D.O., et al., “Implementation of a Free Vortex Wake Model in Real Time Simulation of Rotorcraft,” American Helicopter Society 61st Annual Forum, Grapevine, TX, June 2005.

ABOUT THE COMPANY

CDI provides research and engineering services and licenses software and related intellectual property to a wide range of customers in the aerospace, electric power generation, forest management/agrochemical, and pharmaceutical fields. CDI has been a leader in the development of advanced aerodynamic models for rotorcraft for over 20 years. We supply state of the art rotorcraft analysis software to all the major U.S. and overseas rotorcraft manufacturers (Boeing Helicopters, Sikorsky Aircraft, Bell Helicopter Textron, Agusta Westland, and Eurocopter), and we develop and support similar software for the U.S. Navy (NAVAIR Rotary Wing Test Directorate), the U.S. Army (AMCOM Aviation Engineering Directorate), and NASA/Ames Research Center, Aeromechanics Branch. CDI has also led aerodynamic analysis for the improved rotor system supplied by Carson Helicopters to the U.S. Navy VH-3D and Royal Navy Sea King helicopter; CDI software has also been featured in several real world aircraft design projects ranging from the Advanced Apache Rotor Program (AARP) for the U.S. Army AH-64 to the Schiebel Company S100 UAV rotorcraft development (now in service in Afghanistan).