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D.I TESTING CHALLENGE: DEVELOPMENT OF SHIP / ROTORCRAFT AIRWAKE MODEL BY SIMULATION METHOD

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ABSTRACT

Recent work in Dynamic Interface (DI) simulation is described whereby the free wake module was coupled to a lower-order ship air wake model. A novel physics-based computational method of representing the unsteady air wake of ships is modeled using vortex elements shed from sharp edges of the ship superstructure, and the approaching rotorcraft is described by a panel-based fuselage model and freely distorting wake analysis. The air wake model representation provides an appropriately detailed level of fidelity to capture handling qualities features of importance to shipboard rotary-wing aircraft operations, while maintaining high computation throughput. This approach promises to revolutionize "dynamic interface (DI)" simulation by combining physics-based models of helicopter flight dynamics, rotorcraft free wake representations, and unsteady ship air wake generation. This paper describes also an ongoing effort to develop a high fidelity modeling and simulation tool to support rotorcraft/ship dynamic interface testing.

Keywords: Air wake, Computational Fluid Dynamics (CFD), Free Vortex, Simulation Method.

1. INTRODUCTION

The work described here represents the first stages of developments that could potentially revolutionize the manned flight simulation of helicopter and other VTOL aircraft operating from ships by directly calculating the unsteady aerodynamic environment that exists in the landing zone of the ship in real time. This direct computation of the ship "air wake" using a novel hybrid scheme, would represent an extension of fast vortex-based flow modeling that has recently allowed the coupling of a helicopter free-wake calculation with a real-time flight simulation model. This new model would be implemented in a framework that could accommodate not only this revolutionary real time capability, but also an array of existing and projected non-real-time air wake models, ranging from empirically based treatments through wind tunnel data table lookup approaches, to CFD methods capturing complex viscous flow effects. For ex-ample, modern shipboard helicopters are used for attack, search and rescue, cargo and troop ferrying, anti-submarine operations, and mine sweeping. Shipboard helicopter crews regularly face hazardous flight conditions that land-based helicopter crews do not. High winds, low visibility, a moving landing platform, and unusual airflow around ships increase the difficulty of shipboard rotorcraft operations. Shipboard rotorcraft Modeling and simulation of the rotorcraft/ship dynamic interface represents a challenging technical area of research and development. The dynamic interface problem involves determining the rotorcraft shipboard operational performance and envelope. Since rotorcrafts are highly nonlinear dynamic systems, especially when operated at the edge of the flight envelope, obtaining an accurate solution is a very challenging task.

To improve all aspects of shipboard rotorcraft operations, rotorcraft/ship dynamic interface tests have to be conducted [1&2]. Typically, the dynamic interface tests are performed to determine and quantify the rotorcraft's operational capabilities under various shipboard flight conditions. The dynamic interface tests are also used to evaluate the adequacy and safety of shipboard aviation facilities and procedures. However, the test process is very expensive and logistically challenging. The dynamic interface tests create serious concerns about flight safety due to adverse shipboard operational conditions. To support conventional dynamic interface testing, a capability to simulate the dynamic interface test and evaluation process is needed. This can be achieved by developing a user-friendly high fidelity rotorcraft/ship interaction modeling and simulation tool.

2. TURBULENCE AND SHIP AIR WAKE

The aerodynamic environment in which rotorcraft operate during shipboard activities is dramatically different from land-based operations. There is a significant variation of the air wake due to the ship's superstructure and the ambient surface conditions. Typically, the ship air wake is highly non-uniform and unsteady with turbulence. Moreover, the rotorcraft operation introduces an aerodynamic interaction with the ship air wake that complicates the matter further. For years, many studies have focused on investigation of the ship air wake. Generally speaking, three avenues exist for the investigation of the ship air wake. They are numerical simulation, model-scale testing, and full-scale testing. Full-scale testing is accurate because all the relevant aerodynamic qualities of the atmosphere and geometric qualities of the ship are measured. However, the conditions during the full-scale tests are far from controlled. Also, significant costs are usually incurred in any full-scale testing. Model-scale (Fig.1&2) tests are more affordable and offer a controlled testing environment, but accurate simulation of the atmosphere and geometric characteristics of the ship is difficult due to environment and scale errors. Numerical simulation of the ship air wake via CFD offers the greatest amount of detail, but usually requires a significant amount of computing resources. In addition, the air wake flow around a ship tends to be unsteady and separated in nature, making accurate numerical simulation very challenging. A simple ship air wake simulation model behind a ship's hanger has been presented [3]. In this model, the ship air wake was approximated by the flow around a cube. The airflow consists of an inverted U-shaped vortex and numerous horseshoe vortices.

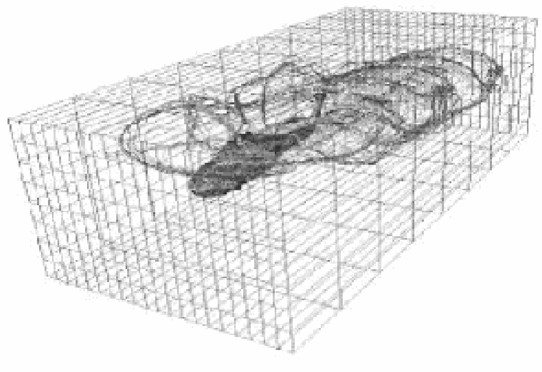


Fig.1: Typical rotor body wake for the HFV method

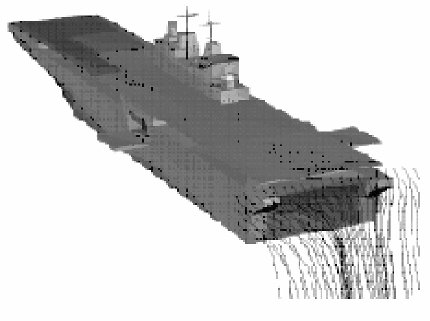


Fig.2 : Simulation of VISTOL aircraft with the FPV model

The air wake was also found to be highly unsteady or turbulent, but also contained some strongly periodic features. All these investigations have paved the way for successful development of the rotorcraft/ship dynamic interface modeling and simulation tool. However, the integration of these air wake data or solutions into a comprehensive simulation program to create a simulation tool for rotorcraft/ship dynamic interface flights envelop prediction has not yet been accomplished.

3. SHIP/ROTORCRAFT INTERACTIONS

The rotorcraft/ship dynamic interface involves the most complicated rotorcraft aerodynamic modeling problems and represents one of the most challenging technical areas of research and development. Rotorcraft/ship interaction is a problem of two-way interference. On one side, the ship induced air wake effects the rotors and airframe aerodynamics due to changes in their angles of attack and dynamic pres-sure variation. On the other side, the rotor or airframe induced wake impacts the ship deck/structure, which changes the air wake distribution. A few unique phenomena associated with rotorcraft/ship interaction include partial ground effect, dynamic ground effect, rotor wake recirculation, and multi-rotor/multi-rotorcraft interaction. The partial ground effect condition occurs when only a portion of the rotor operates above the ship deck. Such is the case when a single main rotor helicopter approaches for a ship landing. This condition can also occur for a multi-rotor configuration. The dynamic ground effect condition is due to the motion of the ship. During shipboard landing, the distance of the rotor hub from the landing deck varies dynamically when the ship deck undergoes sea-induced heaving, rolling, and pitching motions.

A free vortex model with ground interaction has also been developed at ART [4]. The free vortex model addresses the complicated "ground" vortex phenomena resulting from the rotor wake/ground interaction. This free vortex model is suitable for modeling the interaction of the rotor wake, ship structure, and ship air wake. An advanced panel model for fuselage and wing interference calculation was also developed at ART [5]. The integrated panel model coupled with boundary layer analysis methods and separated wake models was used to address the limitations of the conventional panel model for viscous drag and flow separation. It was also enhanced with an unsteady flow solution for interaction with an unsteady rotor wake. A combined rotor finite state dynamic wake and panel solution can provide a strongly coupled rotor wake and ship air wake aerodynamic interaction solution for the rotorcraft ship-board landing problem. For simulation of rotorcraft shipboard landing, the rotor wake and its interaction with the ship's structure and other ship related environmental variables remains an essential issue. Although work has been done in measuring and understanding the phenomenon, further effort is needed in order to accurately simulate the shipboard rotorcraft operations.

4. DYNAMIC INTERFACE (D.I) TESTING CHALLENGE

Perhaps the most difficult piloting task presented to an aviator is the challenge of landing a helicopter onto the flight deck of a moving ship in high sea-states at night with gusty wind conditions. The goal of safely landing the aircraft onto what is often a minimalist platform, located on the aft deck of what is referred to as a "non-aviation" ship [6], is compounded by the highly unsteady wake produced by the ship superstructure immediately ahead of the landing zone. This ship air wake is generated from the bluff-body aerodynamic interaction of the ship towers, hangars, exhaust stacks, and other components with the oncoming wind over deck and ship-motion Induced flows. This process, called "dynamic interface" (D.I) testing, is expensive, resource-constrained, and time consuming. Proper qualification of aircraft/ship combinations requires that the two assets are available (Fig.3&4) during the testing period (along with the pilots and test crews), and that sufficiently variable winds and sea-state conditions exist to properly cover the range of operation anticipated for fleet use.

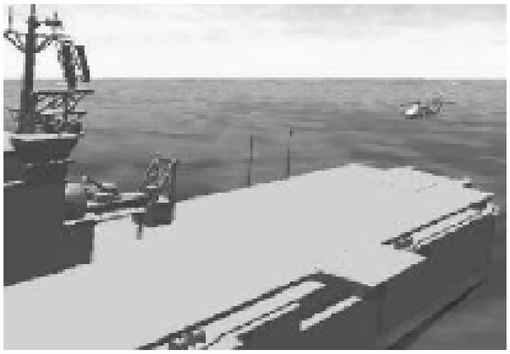


Fig.3: DI Trajectory for an aircraft landing on a LHA

Fig.4: Quick look DI assessment tool

A typical example of an operational envelope is shown in Fig.5. One potential alternative to the cost, resource and time requirements of traditional at-sea DI testing is the use of simulation. An obvious benefit from using simulators is the Ref. [9], availability of any sea state, wind condition, aircraft and surface ship, provided one has appropriately detailed mathematical models that characterize their respective influence on the DI landing and take-off task. Computer simulation of the D.I environment is very complex, however, due to the need to model all aspects of the test environment that may dictate the particular bounds on a launch recovery envelope (or, ship-helicopter operating limit (SHOL) chart). These factors include: proper modeling of the ship motion in the particular sea-state condition; the atmospheric turbulence seen by the ship superstructure; the air wake over the ship arising from external winds and ship-generated motion; the helicopter response to both pilot inputs and air wake disturbances; the interaction of the helicopter induced velocity with the ship structure in the landing zone; and the visual, aural and motion cues associated with the piloting of the helicopter in the at-sea environment.

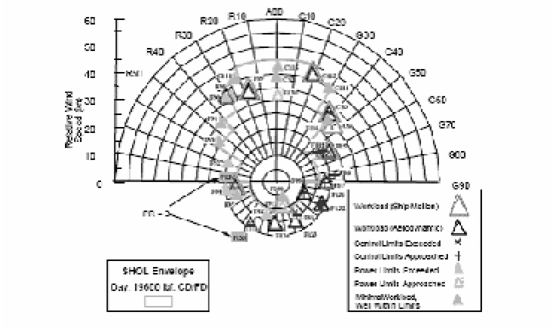


Fig.5: Seahawk/FFG7 operational envelope showing maximum winds

5. COMBINATION OF FREE AND GROUND VORTEX WAKE MODEL

The vortex wake method is a robust and versatile tool for rotor aerodynamic solution, and has gained popularity over the last two decades. Vortex methods range from classical rigid or empirical prescribed wakes to modern force free "distorted" wake methods. The vortex methods have an inherent advantage in dealing with complex wake distortion effects by virtue of their Lagrangian formulation. Modeling of viscous effects like vortex growth and decay, however, remains a challenge requiring further exploration. The primary limitations of most existing distorted vortex wake models are based on the assumption of wake periodicity, and they are thus limited to steady-state and periodic flight applications. In this model, the tip vortex is allowed to move force-free for wake distortion effects. A free vortex model is its inclusion of a ground vortex due to the wake roll-up at low speed in the vicinity of the ground. The vortex wake [6 &7] model provides a solid basis for rotorcraft shipboard landing simulation. For a low forward speed rotor at a low altitude above the ground, the rotor wake is prevented from spreading away due to the ground and the ambient wind that comes from the opposite direction of the rotor wake movement. Under some circumstances, the rotor wakes could form the "ground" vortex. The ground vortex phenomenon (Fig.6) substantially alters helicopter performance and control characteristics. This is due to the rolled-up rotor wake strongly affecting the induced flow variation. For a rotorcraft approaching the ship deck, the ground vortex phenomenon could also occur due to the interaction of the ambient wind, ship deck, and rotor wake. The rotor wake coupled with the unsteady air wake causes an even more hazardous environment. In shipboard landing, the coupling effects of the ship interference on the rotor vortex solution can be addressed in two aspects. One is the first order effect on rotor blade circulation strength calculation via the ship air wake influence on the blade angle of attack and dynamic pressure. The other is the nonlinear impact of the air wake on vortex wake geometry.

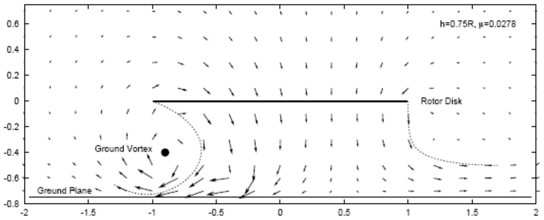


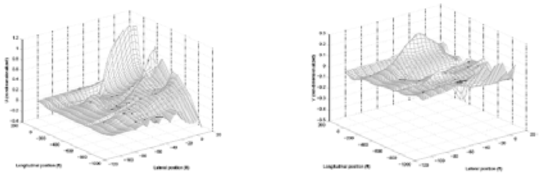
Fig.6: Induced velocity field due to the rotor/ground interaction

6. SHIP AIR WAKE AND DYNAMIC MODEL

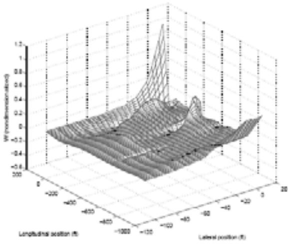
Two approaches were taken for the ship air wake modeling. The first approach is to utilize CFD prediction or measured data. This approach allows for a closely coupled solution between the ship air wake and the rotor wake since the rotor wake effect on the ship air wake solution can be computed on line in a coupled fashion.

The CFD and measured ship air wake models were integrated into table and map look-up functions. The table look-up utilizes a rectangular grid to interpolate the ship air wake velocity between the data points. The map model allows for a non-rectangular grid, but is more computationally intensive. The table/map look-up of the ship air wake velocity is performed at each aerodynamic computational point of the rotor blade elements, wing, fuselage, and tail surfaces. The panel ship deck model is based on a potential flow solution. Integration of the panel model in a rotor- craft/ship aerodynamic interaction simulation provides [8&10] a two-way aerodynamic interaction between the rotor and ship air wake. That is, the rotor down wash effect is reflected in the ship air wake solution. In both the look- up and the panel ship deck models, the ship air wake interference velocity is always computed at each of the aerodynamic computational points on the rotor and airframe. Since the rotor blade is modeled using the blade element method, the ship air wake velocity distribution effect can be well reflected on the rotor blade dynamic response.

Two kinds of methods describing ship motion have been implemented in rotorcraft/ship dynamic interface simulation. One is the sinusoidal motion model where the ship motions (including heaving, swaying, yaw, roll, and pitch) are described using a summation of a set of periodic [11&12] functions. The forward motion is solved by integration of a constant specified ship speed. The other method is the prescribed time varying model where the ship motions are determined externally using ship hydrodynamic analysis or experimental data. In the time varying model, the ship motion is described by an external process where a sophisticated ship dynamics model can be applied. In the current implementation, the ship deck c.g. coordinate system is used as the ship motion reference frame. In the ship deck c.g. reference frame, the x-axis (in Fig.7) points forward, the y-axis point's star- board, and the z-axis points downward.



(a) x-component (b) y-component



(c) z-component

Fig.7: Distribution of the in-plane (x, y and z) components of the ship air wake

7. CONCLUSIONS

This paper summarizes the on-going efforts to develop a high fidelity modeling and simulation tool to support rotorcraft/ship dynamic interface testing. The efforts address not only the enhancement of each individual modeling discipline that is related to the simulation of rotorcraft ship board testing, but also their integration into a comprehensive simulation environment to allow for rotorcraft/ship interaction. The accomplishments include:-.

- Development of a prototype of the analysis and simulation utilities for rotorcraft/ship dynamic interface testing including station keeping, approach, departure, lift off, and descent.

- Development of a prototype of a rotor craft shipboard operating envelope prediction tool with coupled rotorcraft/ship aerodynamic interaction and integrated flight envelope analysis utilities.

- Integration of the ship air wake module within a networked simulation environment provides a means to distribute the computational load across separate processors during simulation, while providing a straight forward approach to integrate with an array of simulation tools.

8. ACKNOWLEDGEMENT

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