*Program Progress Report*
**CDRL A002**

# Pilot-in-the-loop Method Development

## 2012 Basic and Applied Research in Sea-Based Aviation

**ONR #BAA12-SN-0028**

REPORT No. 5/C576

PERIOD 20 January 2014 to 20 February 2014

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# Pilot-in-the-loop Method Development

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## 1 PROJECT OVERVIEW

The goal of this project is to integrate novel numerical modeling and computer hardware approaches to compute the non-linear aerodynamic coupling between the ship and aircraft in such a way that execution times are at real-time speeds, allowing for pilot-in-the-loop CFD to be integrated in the piloted flight simulation environment. To achieve the speed gains required, three areas will be targeted for implementation into the CFD simulation framework: (1) numerical algorithms, (2) novel domain boundaries, and (3) Graphical Processing Unit (GPU) hardware. A framework will be established to link the CFD with realtime simulations. A building block approach will be employed to first demonstrate non-realtime integration of the CFD simulation framework with helicopter flight dynamic models, then realtime execution for a minimum fidelity airwake/aircraft simulation, then build to higher fidelity realtime simulations.

### 1.1 Project Technical Objectives

The project involves the following seven tasks to accomplish the technical objectives of the project:

Task 1: Implement modular implicit/explicit solver
Task 2: Apply structured numerics
Task 3: Apply subdomain with immersed boundary
Task 4: Implement higher order explicit solver for GPU execution
Task 5: Integrate with the GENHEL-PSU flight dynamics model
Task 6: Demonstrate flight simulation in the PSU Rotorcraft Simulation Facility
Task 7: Demonstrate flight Simulation in NAVAIR Manned Flight Simulator

## 2 WORK SUMMARY

To date, all ship airwake CFD work at CRAFT Tech has involved the unstructured CRUNCH CFD® code. During this reporting period, some preliminary structured airwake simulations were performed using the CRAFT CFD® solver. An example LHA ship geometry was used to build a structured airwake grid. Some initial results and performance comparisons are given for these test simulations.

### 2.1 Example LHA Ship Geometry

The LHA ship geometry was chosen for these initial calculations because of the availability of geometry data from previous CFD studies and the relative simplicity of the geometry which lends itself to a structured grid topology (typical ship CFD grids used in the past have been unstructured tetrahedral/prism topologies). The geometry was extracted from GridTool files in the form of boundary curve segments that were imported to the Pointwise grid generator. For this geometry, all surfaces are planar creating a faceted shape near the bow. Some simplifications were made to the geometry to minimize the number of perpendicular surfaces from which boundary layer spacing would propagated through the structured topology, thereby minimizing total grid size. For example, the following features were removed to simplify the shape: exhaust stacks on the superstructure, the deck edge cutouts at the bow and stern, the port elevator protruding from the deck edge, and the tall block structure behind the superstructure that represents the crane.

A multi-block fully contiguous grid was constructed using Pointwise with similar edge length and $\Delta s$ wall spacing parameters as the original unstructured LHA grid. Because the boundary layer spacing at all surfaces propagate to the outer boundaries in a contiguous structured grid topology, the resulting grid was quite large: 27 million cells. The simplified geometry and structured grid are illustrated in Figure 1.

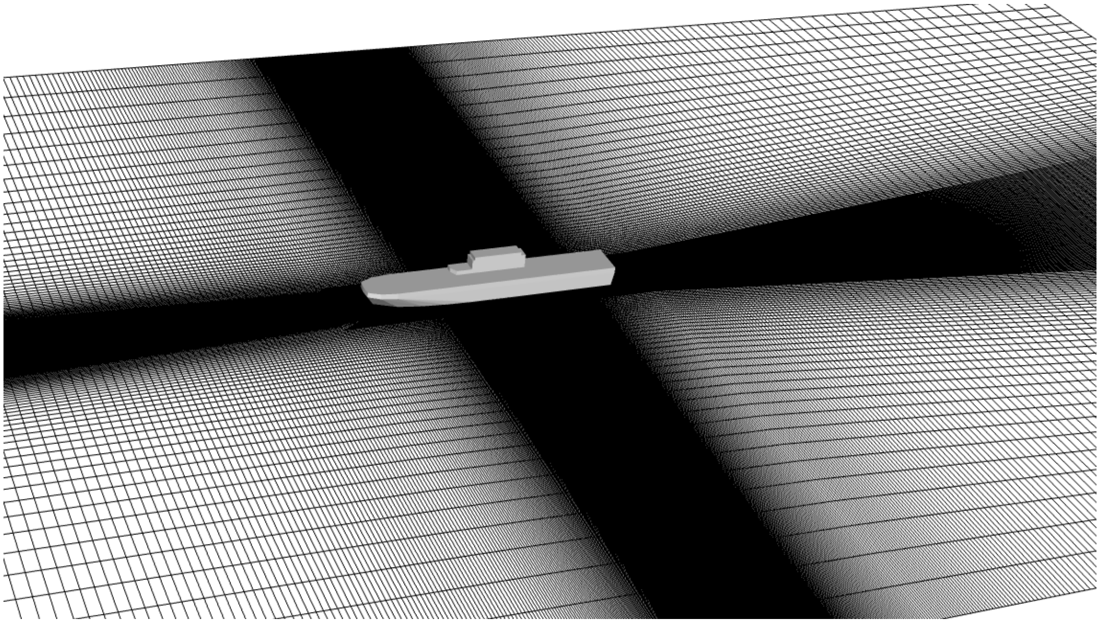

**Figure 1: Structured Grid for Full Scale, Simplified LHA Ship Geometry.**

### 2.2 Structured Solution and Performance Comparison

A time accurate, implicit airwake simulation was run with the CRAFT CFD solver for wind-over-deck conditions of P0 = 1 atm, 25 knots, 0°. A time step of 0.01 seconds was used. Some initial modeling issues from using the structured solver were investigated such as:

1. The use of 2nd vs 5th order spatially accurate solver schemes: The CRAFT CFD solver offers a 5th order scheme that is not available in an unstructured approach
2. Preconditioning: Past unstructured solutions used the preconditioned solver in CRUNCH CFD for low-speed airflows, however this scheme is not currently implemented in the structured CRAFT CFD solver.

An unsteady solution was obtained and initial comparisons with CRUNCH CFD results running on the same grid show an immediate 5 to 10X speed up for the structured calculation vs the unstructured solver for the same grid. An illustration of the unsteady airwake solution from the CRAFT CFD simulations is shown in Figure 2.

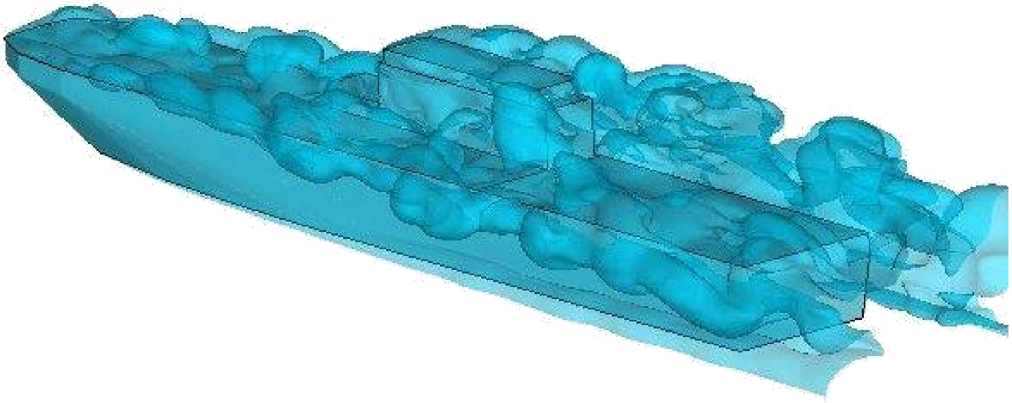

**Figure 2: Vorticity Isosurfaces showing the Unsteady Shedding in the Structured Airwake Solution.**

## 3 TECHNICAL/COST STATUS AND PROBLEM AREAS

No technical or financial problems have been encountered.

## 4 MEETING AND/OR TRAVEL

N/A

## 5 CONTRACT SCHEDULE

The program is proceeding as planned.

## 6 PLANNED ACTIVITIES FOR NEXT REPORTING PERIOD

The results presented in this progress report represent initial structured calculations of an example LHA airwake using CRAFT CFD to investigate possible performance gains over an unstructured solver approach and to identify modeling characteristics of CRAFT CFD for airwake calculations. The next step will be to perform more rigorous calculations using an LHD geometry (the intended platform going forward) and comparisons with unstructured calculations to quantify the performance gains for both the same structured grid and the standard unstructured mesh approach. Requirements for adding preconditioning to the structured solver scheme will be investigated.

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