NAVAIR Airwake Modeling & More!

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HPC User Group Forum

15 April 2008

- **Background**
  - Why is airwake important?
  - JSHIP
- **SAFEDI**
  - Goal
  - Products
  - Airwake Predictions & Validation
- **Highlights**
- **Way Ahead**

- **Background**
  - **Why is airwake important?**
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Background

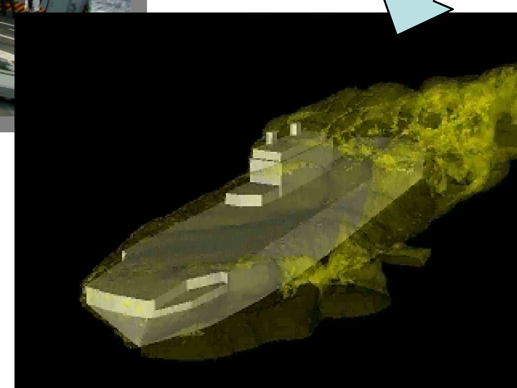
Shipboard Operations

- **Shipboard operations are among the most challenging of any piloting task for fixed or rotary wing aircraft**

Low visibility & poor visual cues

Ship Motion

Ship airwake primary driver of WOD envelope → operational capability



Airwake turbulence

Restricted landing area

Recent Airwake Related Issues

V-22/LHA:

- Lateral Instability Resulting in PIO Experience During Sea Trials
- Uncommanded Roll on Deck Due to Upwind Aircraft
- *Complex Ship Airwake Characteristics Determined to be Contributing Factors in Both Incidents*
    - Wind tunnel test(s) at NASA Ames 7x10
    - High and moderate fidelity CFD analysis

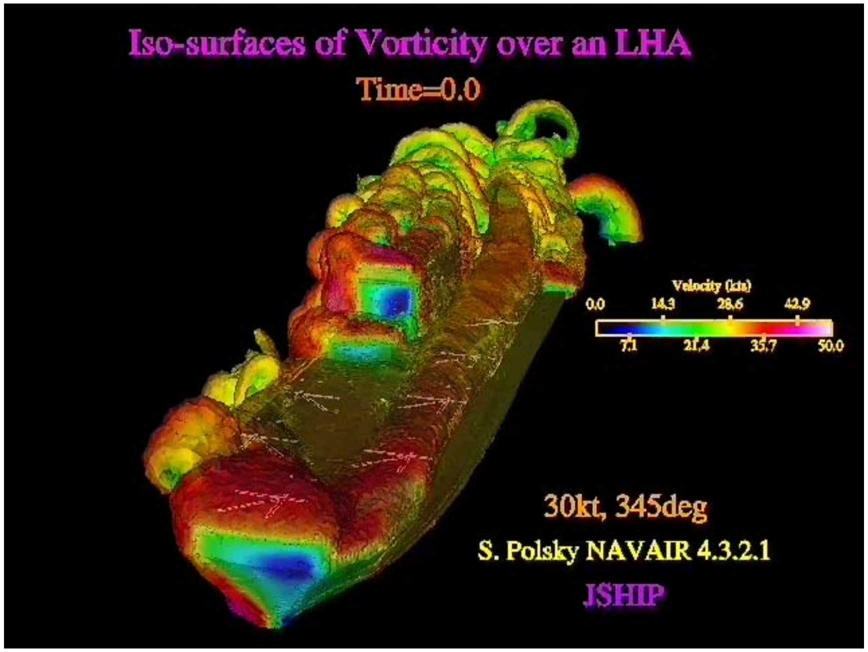
British AOR:

- Ship Designed and Built with Two Landing Spots and Hangar to Accommodate Two Helicopters
- *DI Testing Revealed Forward Landing Area Was Unusable for Flight Operations Due To Turbulent Airflow*

Recent Airwake Related Issues

OH-58/LHA:

- Prevailing airwake stream caused wake from upwind aircraft to impact tail rotor of parked aircraft
- Airwake driving factor in incident
    - JSHIP program used SAFEDI airwake analysis to determine cause.



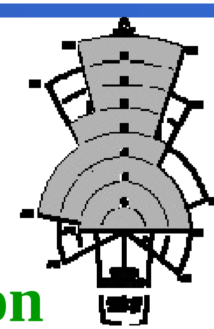
Background

Need for High Fidelity Airwake Models

Aircraft T&E

Go to the ship and fly it

High Fidelity Real-time Simulation for initial evaluation/pilot training/expansion



Simulation

Airwake is Turbulent "Noise"

WOD and ship configuration don't matter!

Not realistic enough for training/envelope eval.

Time-accurate Airwake Model generated by CFD

Desk-top Airwake Evaluation Capability

Design

Airwake not a design parameter

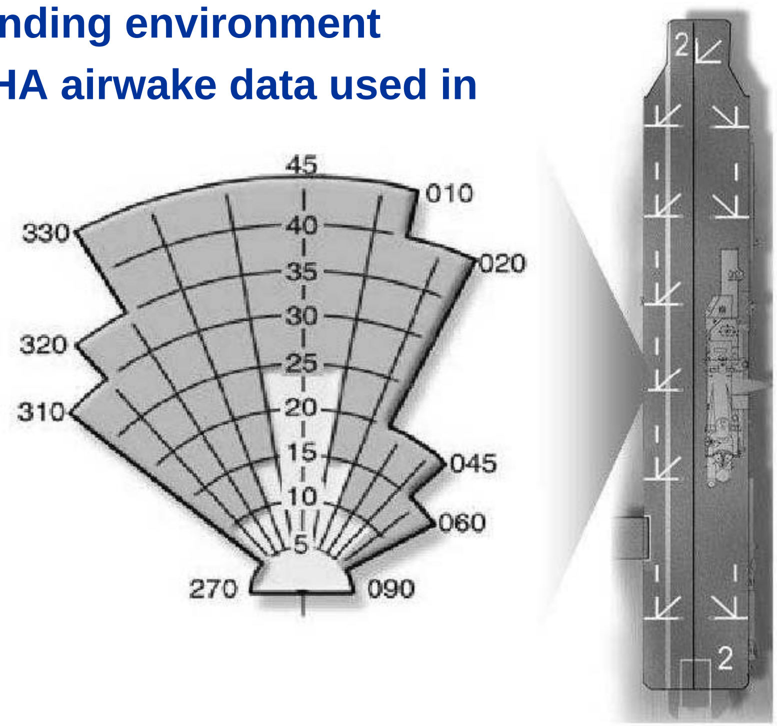
Flight ops/ship maneuverability restricted by airwake characteristics

Airwake Evaluation Capability for all Ship/Aircraft combinations

Background

JSHIP Program

- **Joint Shipboard Helicopter Integration Process**
  - **OSD funded**
  - **Increase interoperability of joint shipboard helicopter operations**
  - **Facilitate interface of Army and Air Force helicopters with Navy ships**
  - **Dynamic Interface Modeling and Simulation System**
    - **Develop flight envelopes using modeling and simulation**
    - **Enhance training of shipboard landing environment**
    - **NAVAIR develop and provided LHA airwake data used in piloted simulations**
    - **Ship airwake primary driver of WOD envelope**



SAFEDI

- Background
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- **SAFEDI**
  - **Goal**
  - **Products**
  - **Airwake Predictions & Validation**
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SAFEDI

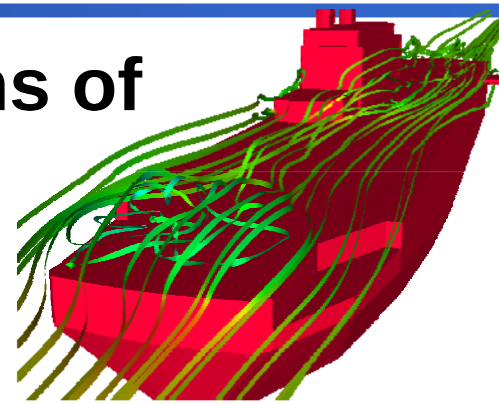
Goals

Ship Aircraft Airwake Analysis for Enhanced Dynamic Interface

Develop CFD Airwake Technology to Enhance Ship Related Air Test & Evaluation and Ship Design Through Analysis & Simulation

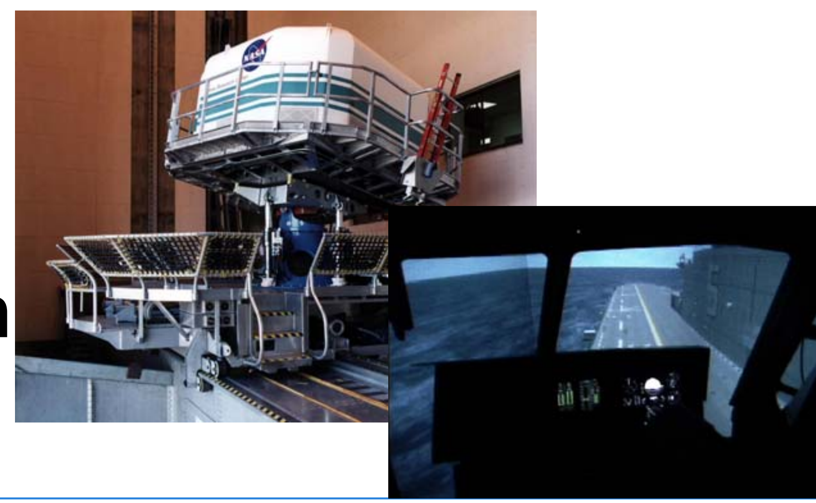
SAFEDI Products

1) Accurate predictions of ship airwake



2) Analytical tool for offline airwake evaluation

3) Manned flight simulation with validated airwakes

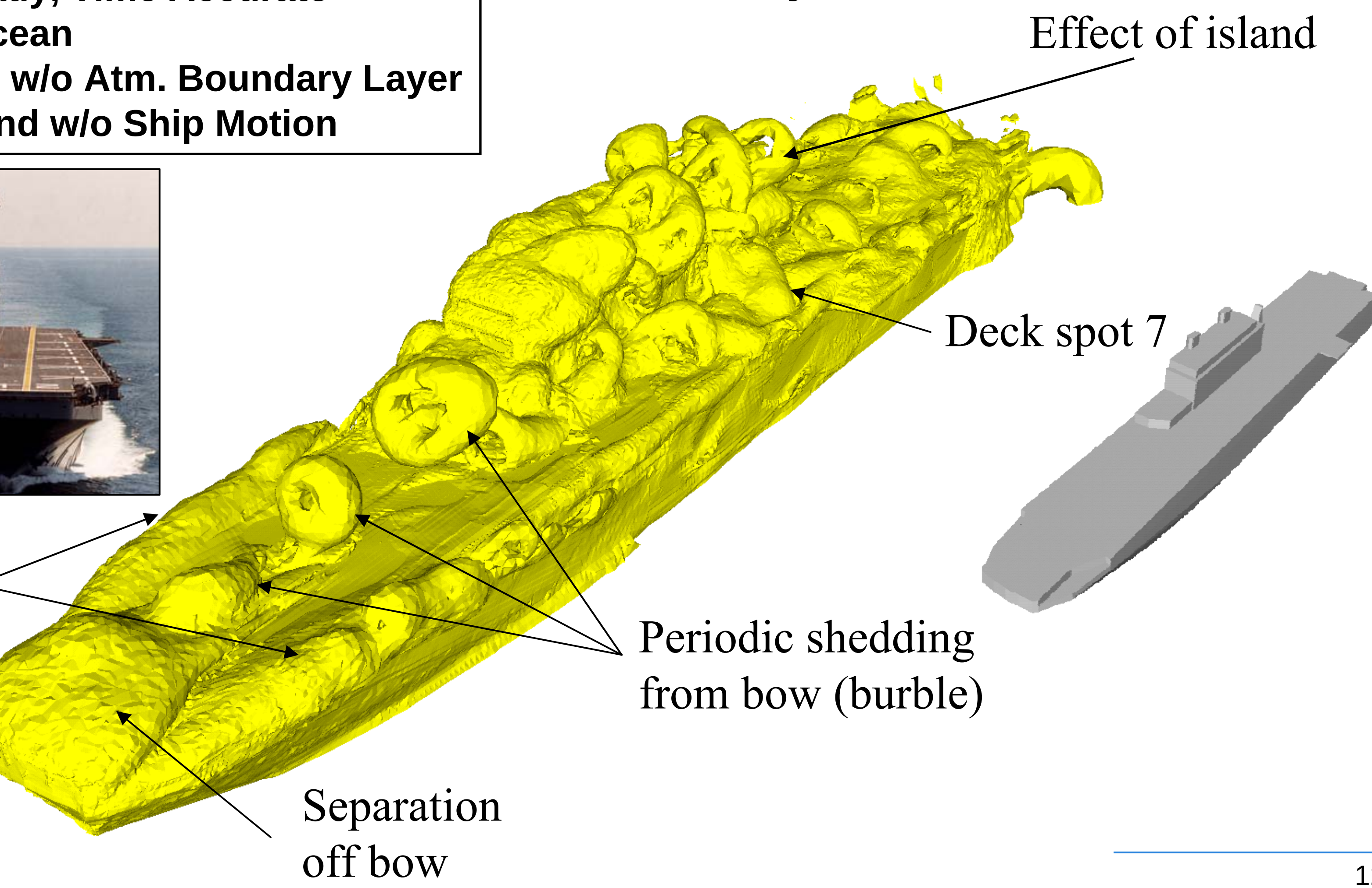


SAFEDI

Development of Airwake Databases

Baseline Calculations
- Fully Viscous
- Unsteady, Time Accurate
- Flat Ocean
- With & w/o Atm. Boundary Layer
- With and w/o Ship Motion

LHA with opaque iso-surfaces of vorticity



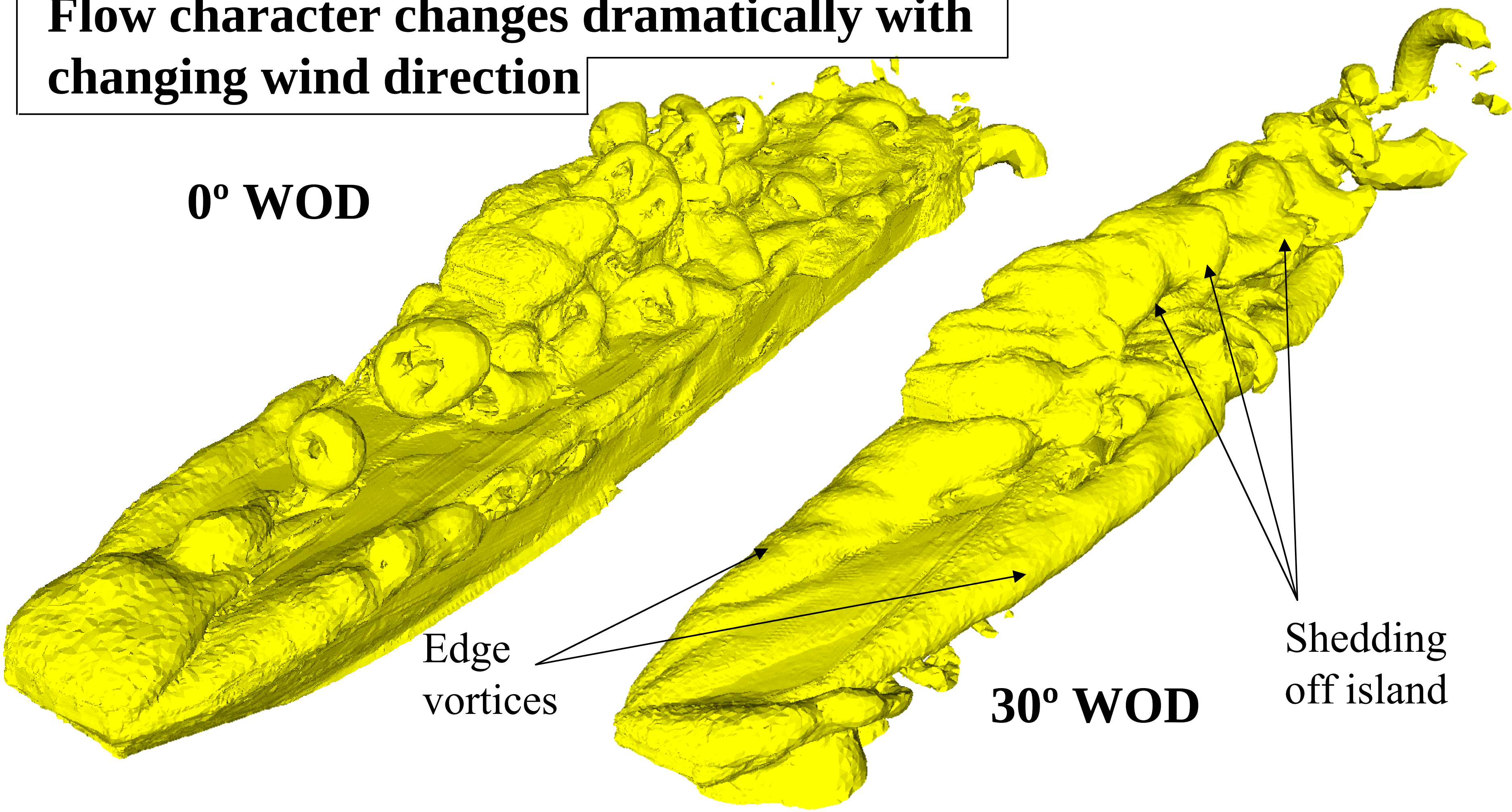
SAFEDI

Development of Airwake Databases

SAFEDI

Wind Azimuth Variations

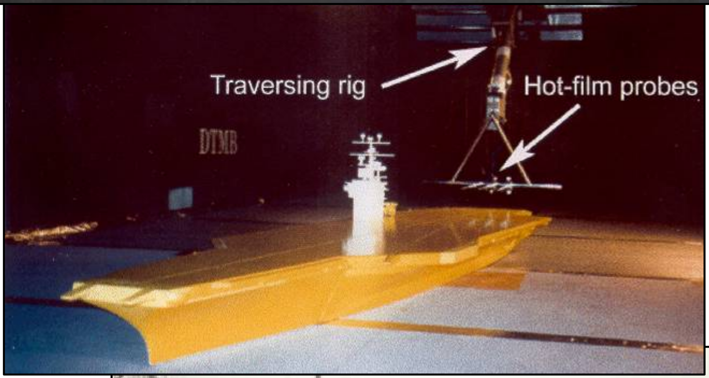
Flow character changes dramatically with changing wind direction



CFD Validation

Wind Tunnel & At-sea Tests

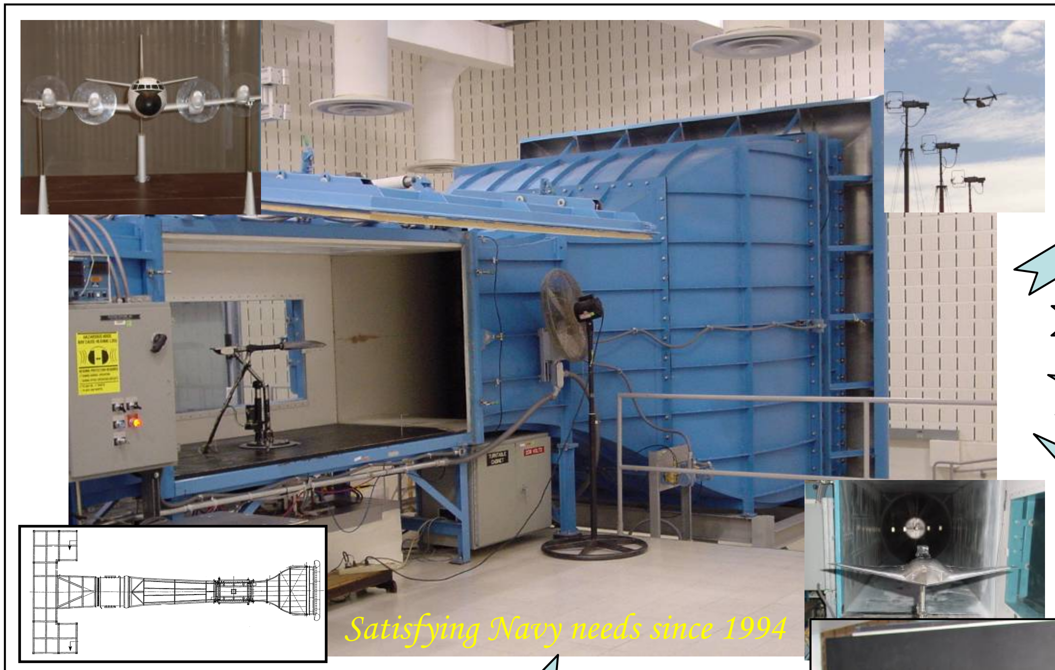
- **Wind tunnel data**
  - Controllable environment (incoming wind)
  - All areas around ship accessible for measurement
  - Stereolithography can provide highly detailed models
  - Reynolds number & scaling issues
- **Full-scale data**
  - Collect "real world" data (ultrasonic anemometers)
  - Environment unpredictable & difficult to measure
  - Currently limited to measuring 0-20ft above deck

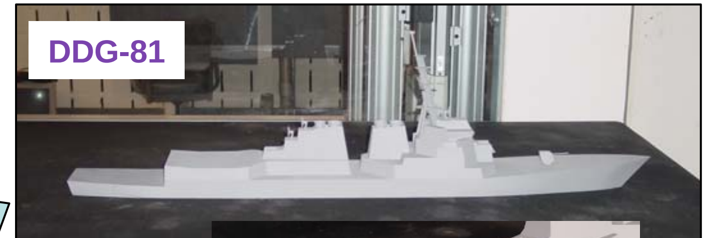


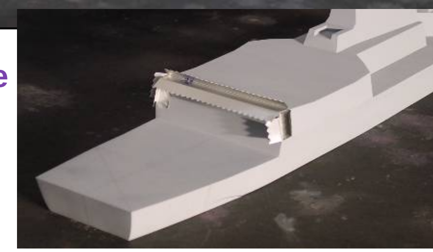
CFD Validation

NAVAIR Pax River Assets: Sub-scale

The Naval Aerodynamic Test Facility
Subsonic Wind Tunnel at Patuxent River, MD

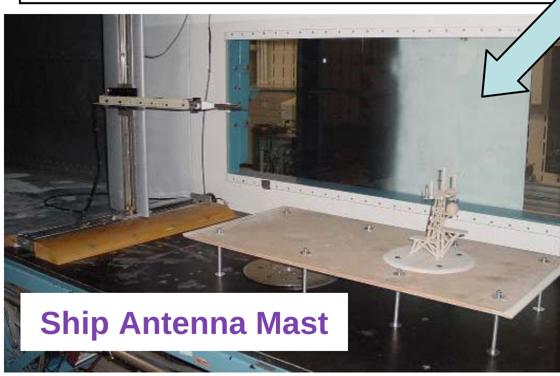






Airwake control device testing

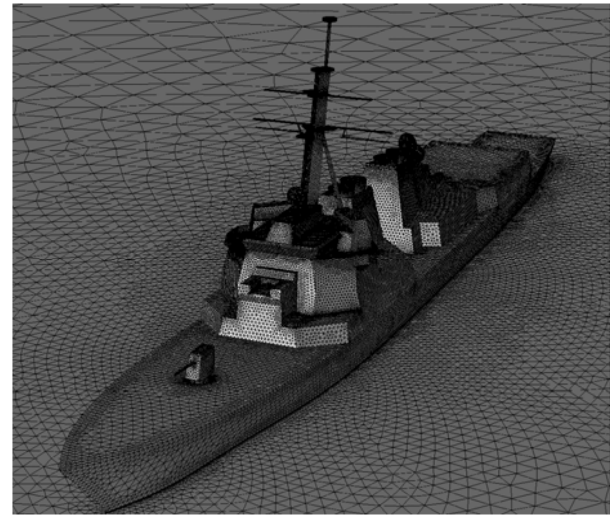
Ultrasonic anemometer calibration

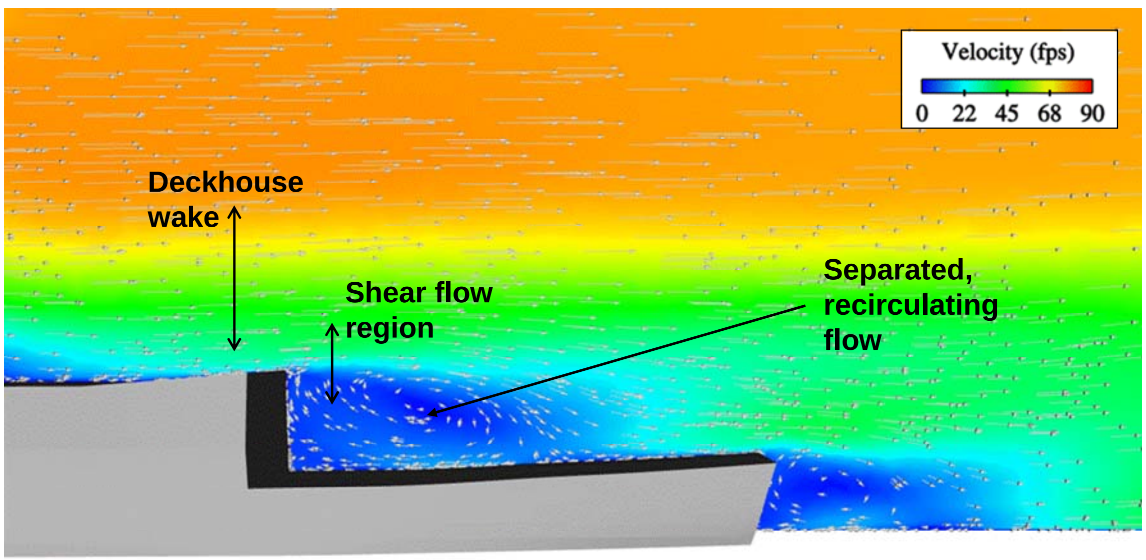


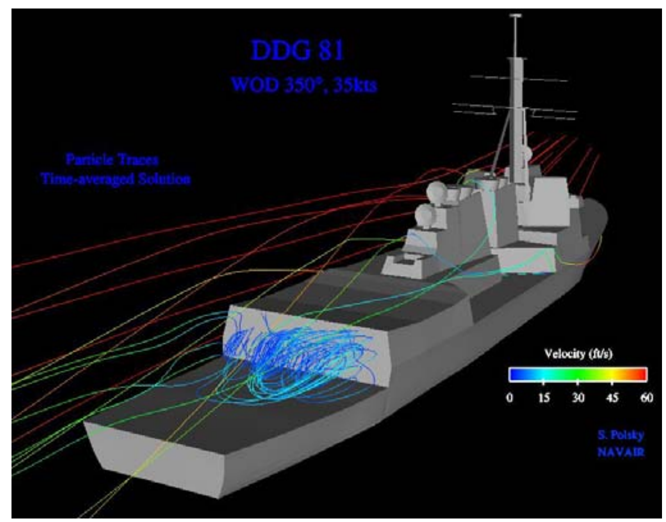
Validation Efforts

Ship Airwake Modeling

- **Past validation efforts**
  - **CVN (73 & 76), LHA, LHD**
- **Current Effort**
  - **Destroyer (DDG)**
    - **Preparation of H-60/DDG coupled calculations**
    - **Dominant flow features significantly different from flat deck ships**



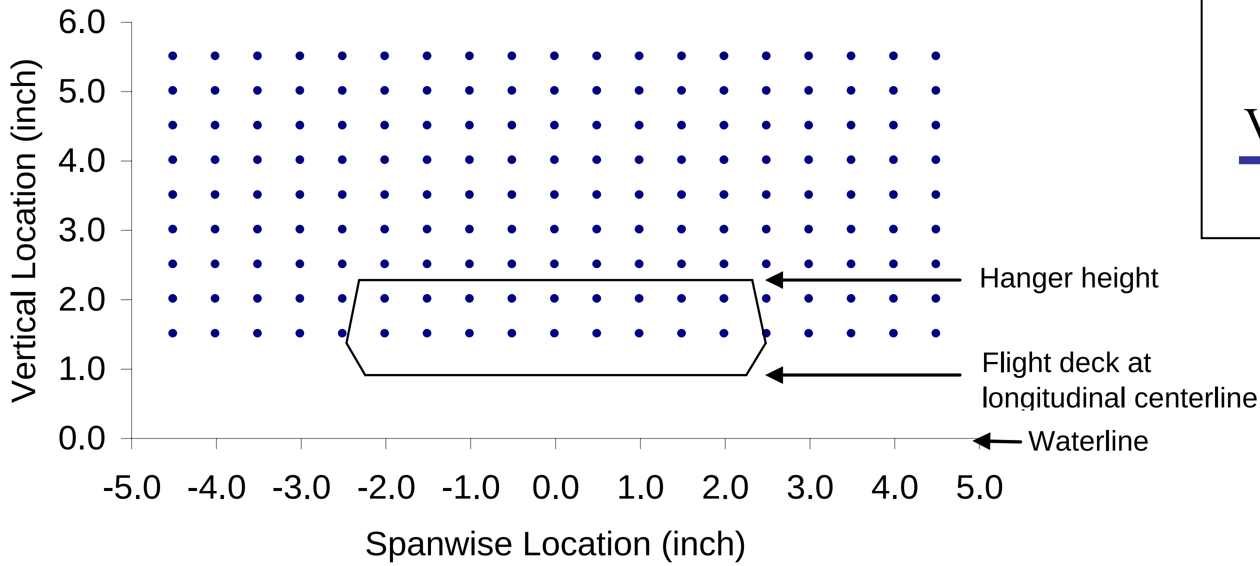


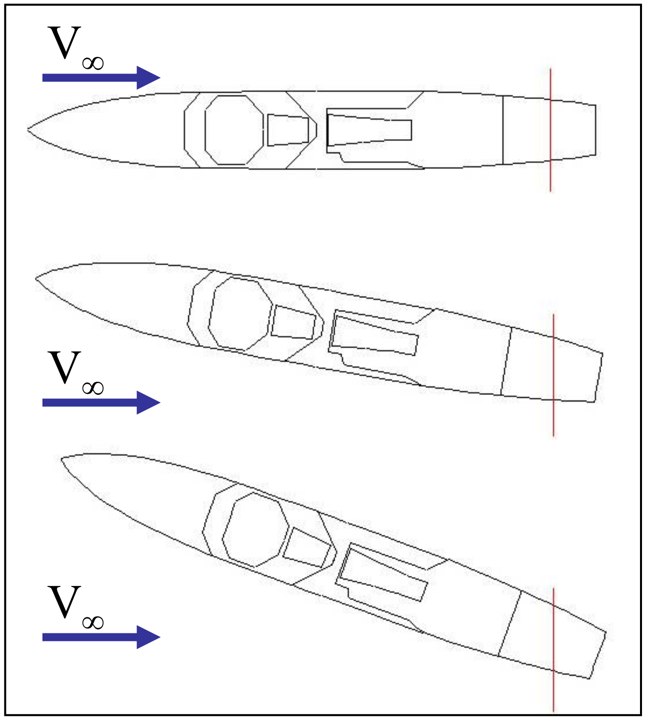


Validation Efforts

Wind Tunnel Experiment

- **Compared 3 wind angles**
  - **000°, 350°, 340°**
  - **75 fps**
- **3-component velocity data**
  - **Steady and unsteady**
- **Data plane at flight deck centerline**

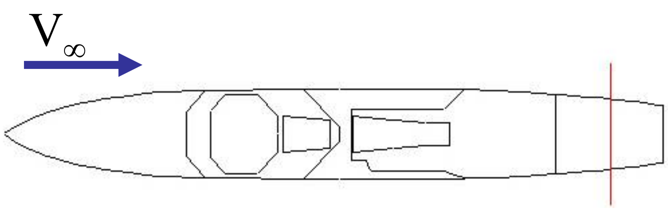


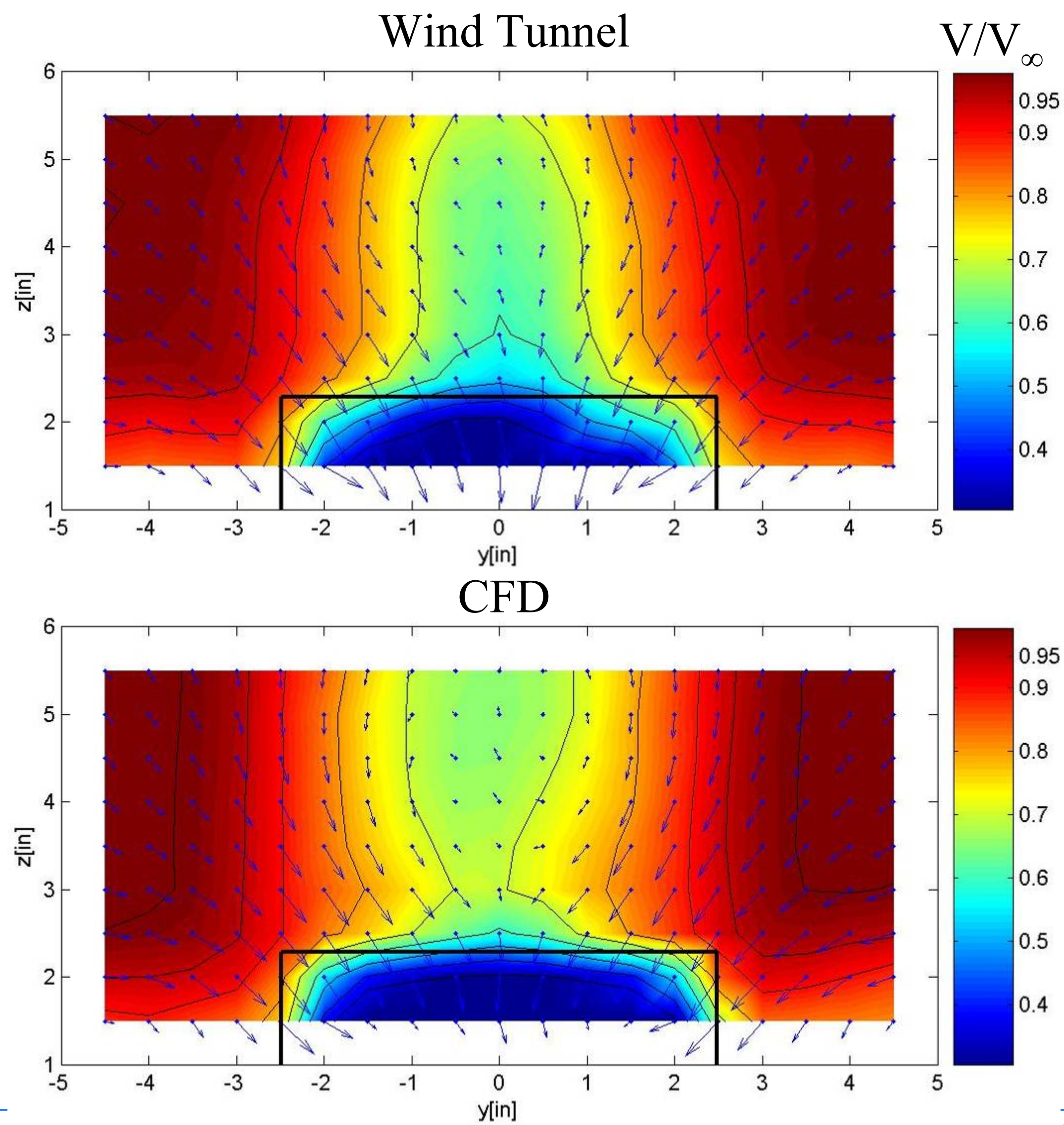


Validation Efforts

CFD Comparisons with WT

- **000º wind angle**
- **Time-averaged velocity magnitude**
  - **v,w velocity vectors**
- **Good agreement between CFD and WT**

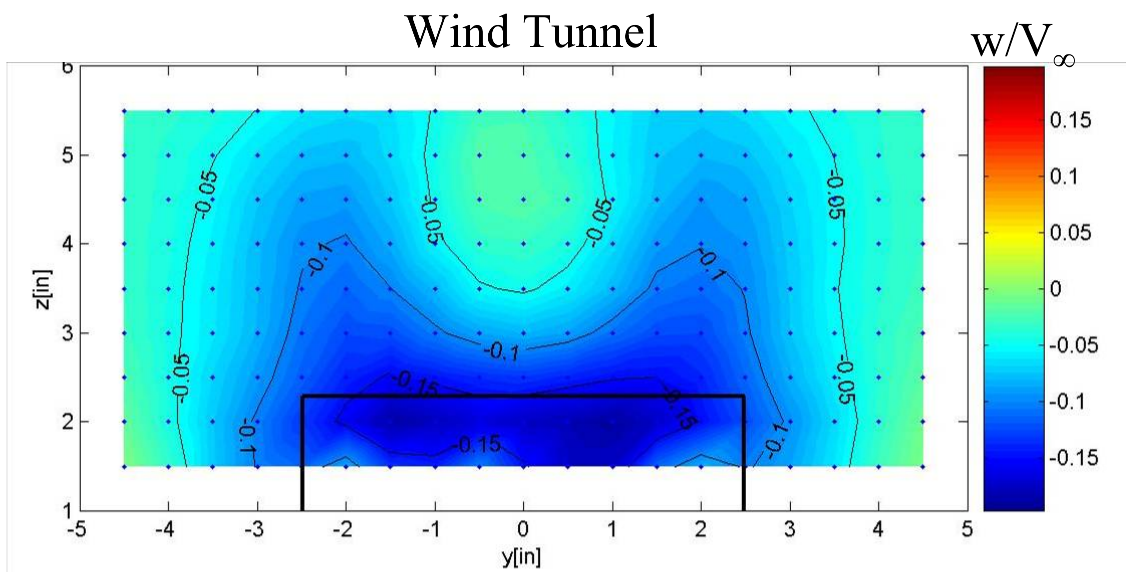


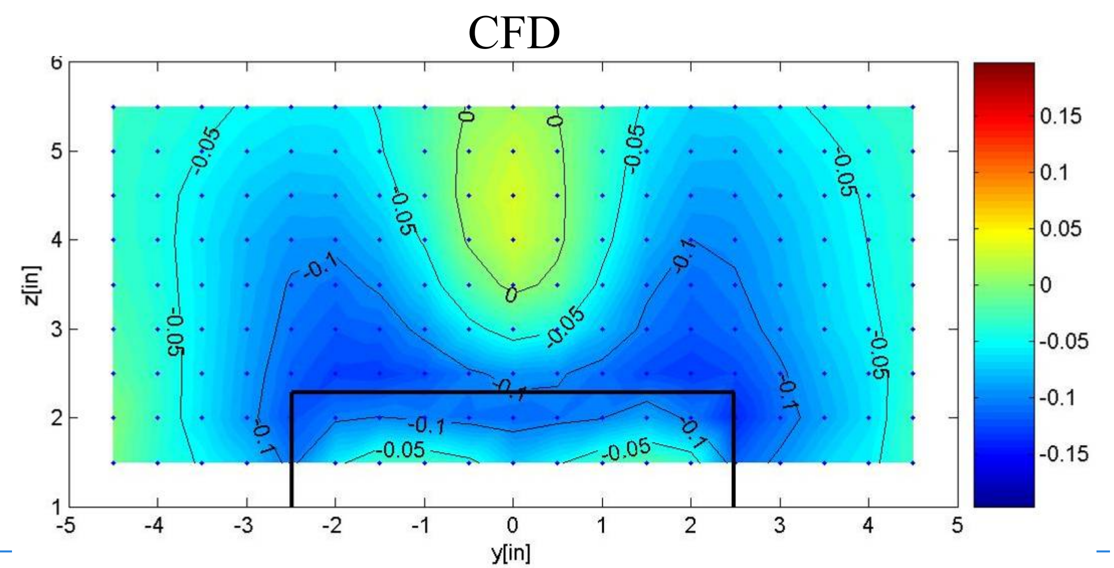


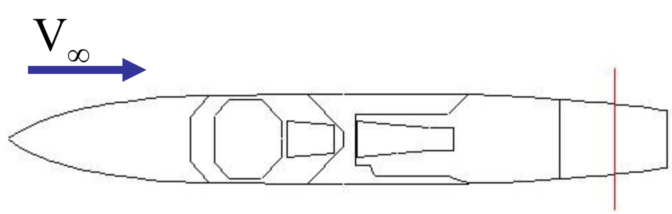
Validation Efforts

CFD Comparisons with WT

- **000º wind angle**
- **Vertical velocity component**
  - **Time-averaged**
- **Good agreement between CFD and WT**



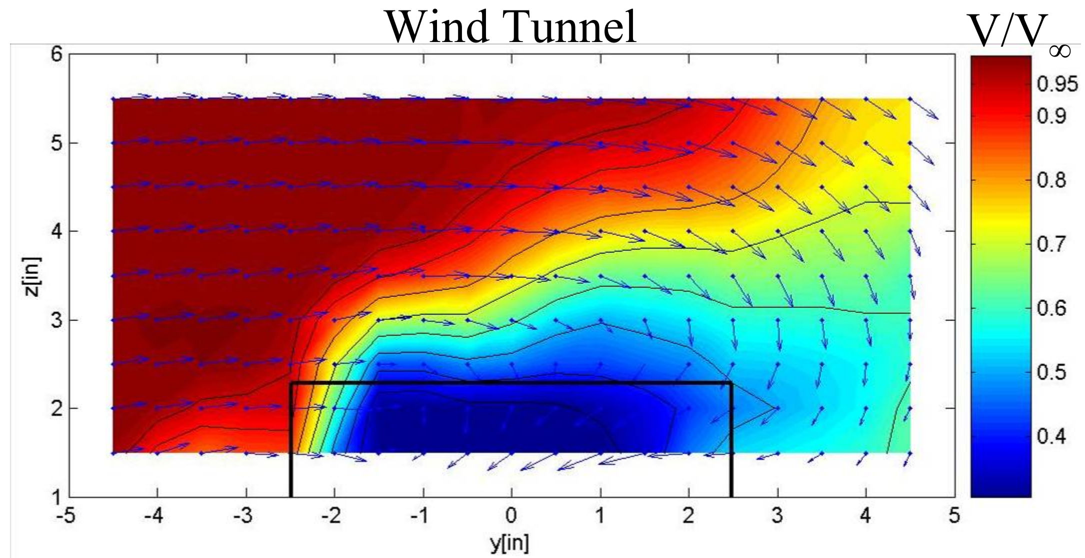


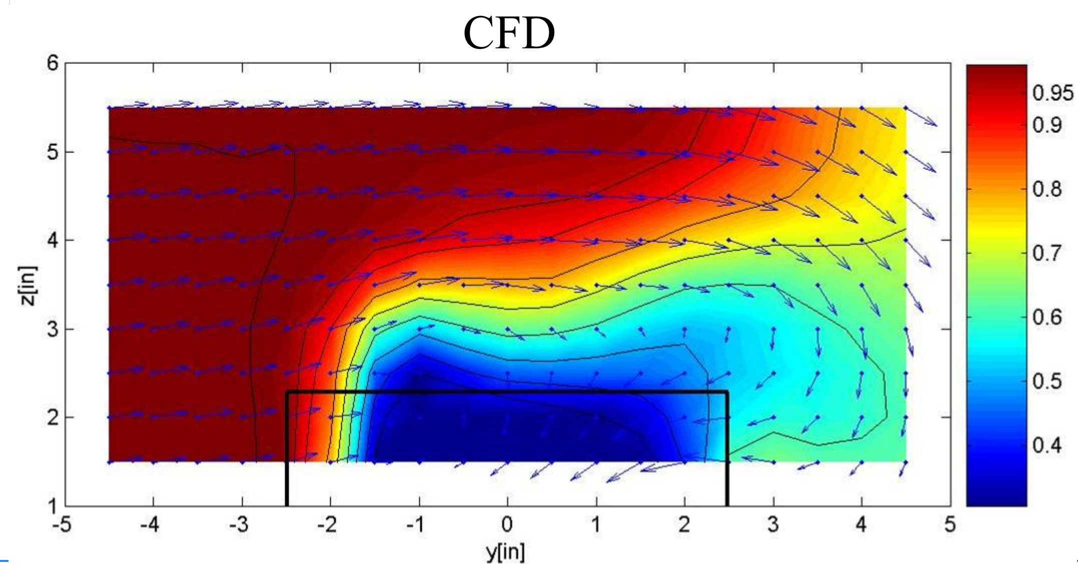


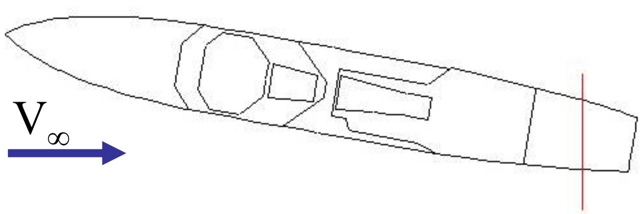
Validation Efforts

CFD Comparisons with WT

- **350º wind angle**
- **Time-averaged velocity magnitude**
  - **v,w velocity vectors**
- **Good agreement between CFD and WT**







Validation Efforts

CFD Comparisons with WT

- **350º wind angle**
- **Vertical velocity component**
  - **Time-averaged**
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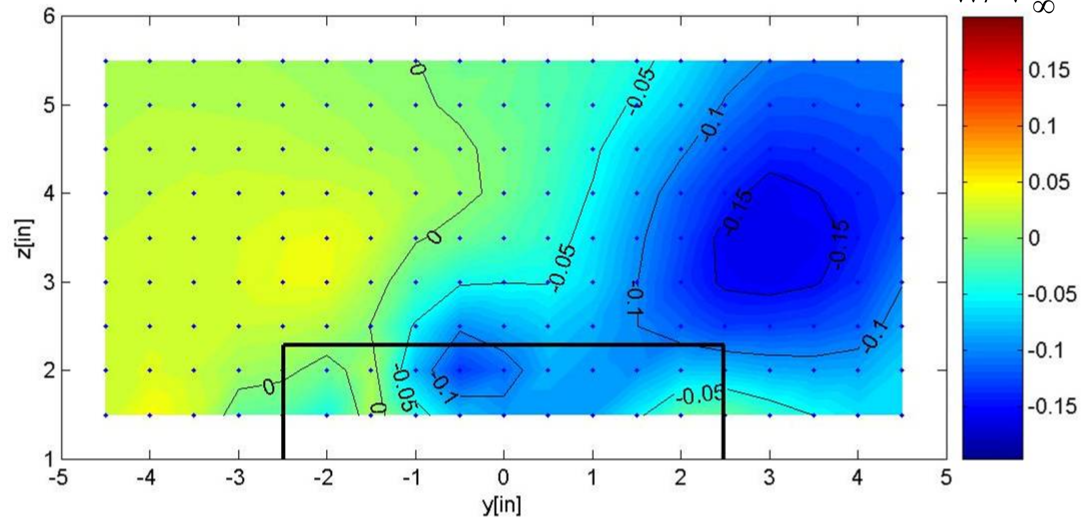
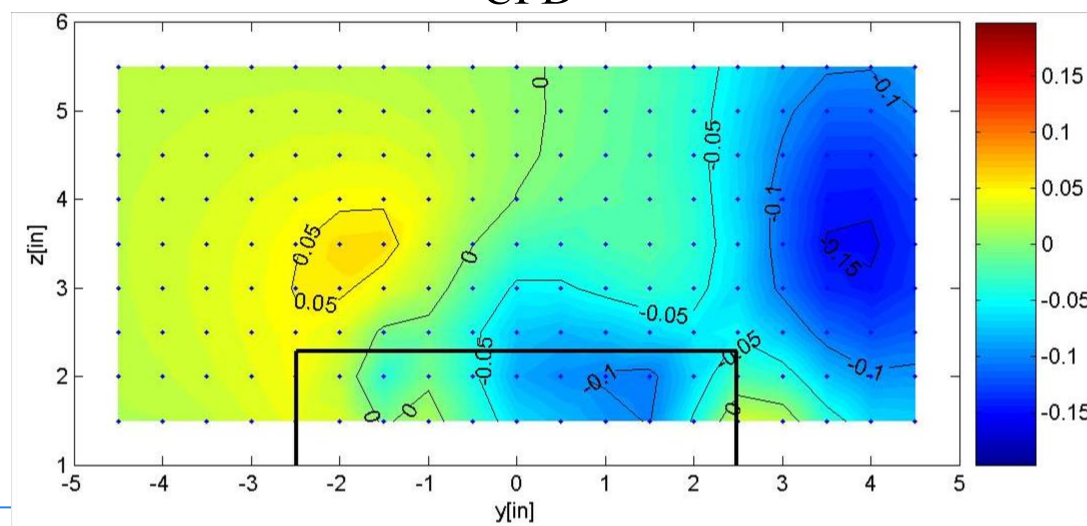
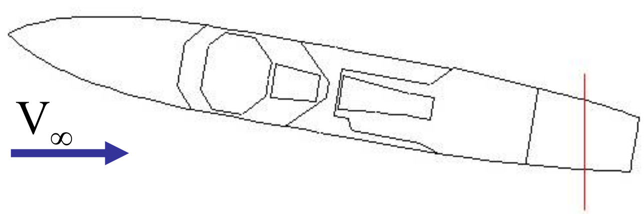
Wind Tunnel

w/V∞



CFD

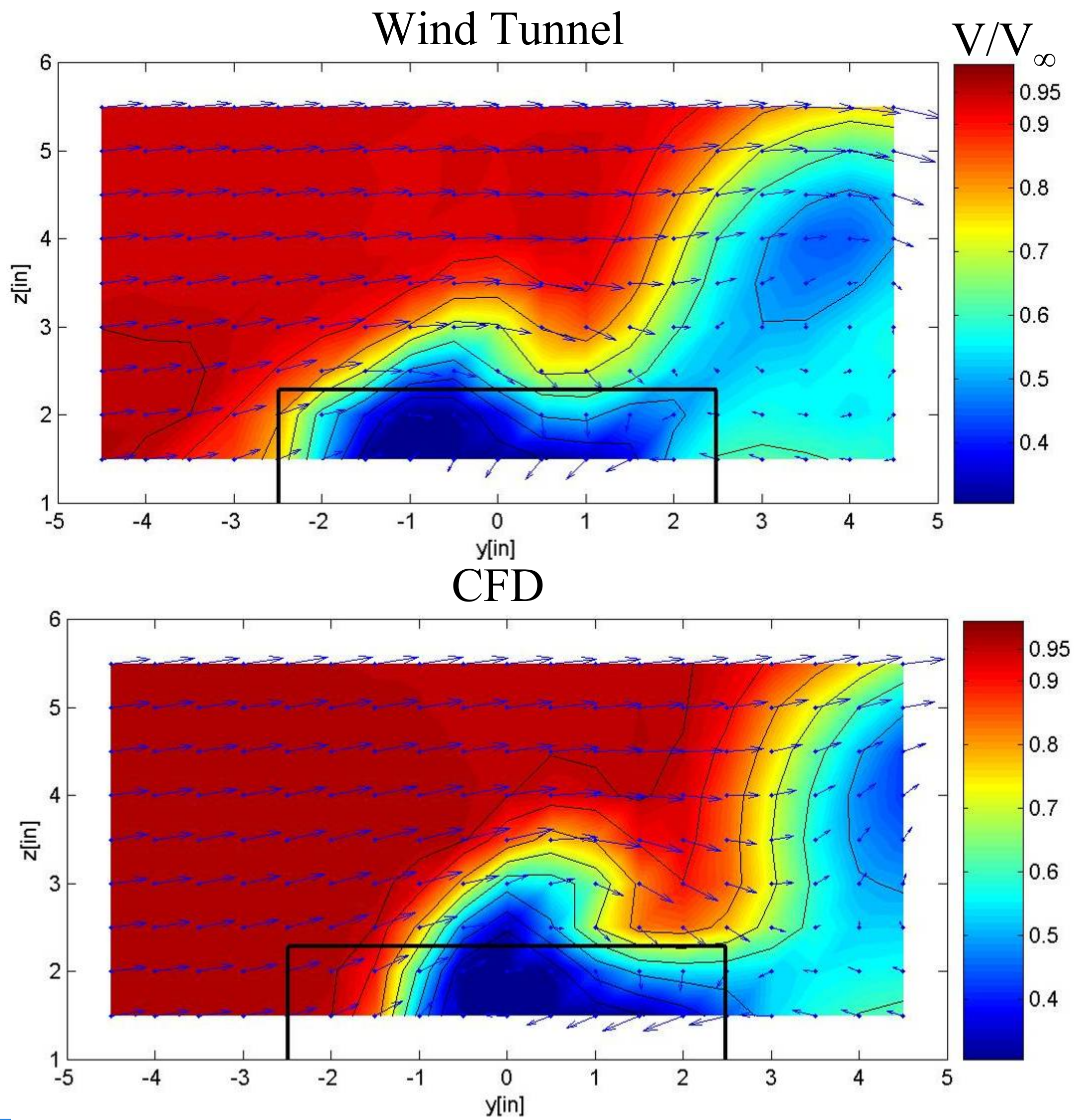


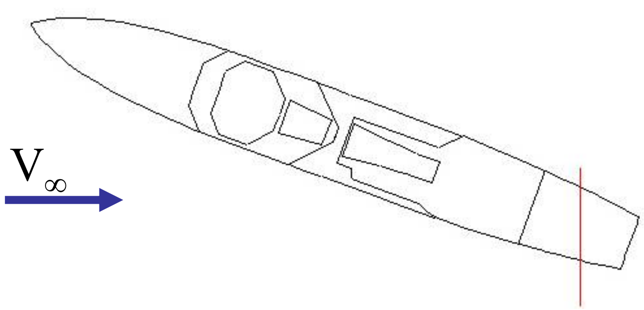


Validation Efforts

CFD Comparisons with WT

- **340º wind angle**
- **Time-averaged velocity magnitude**
  - **v,w velocity vectors**
- **Good agreement between CFD and WT**

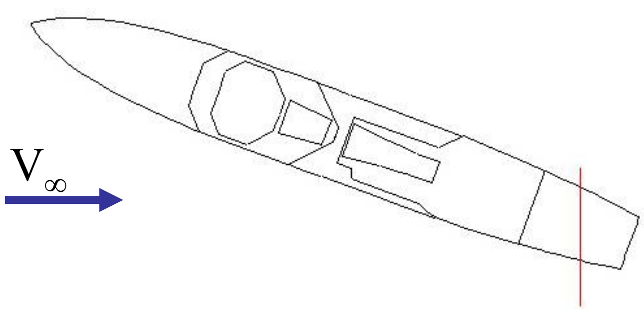


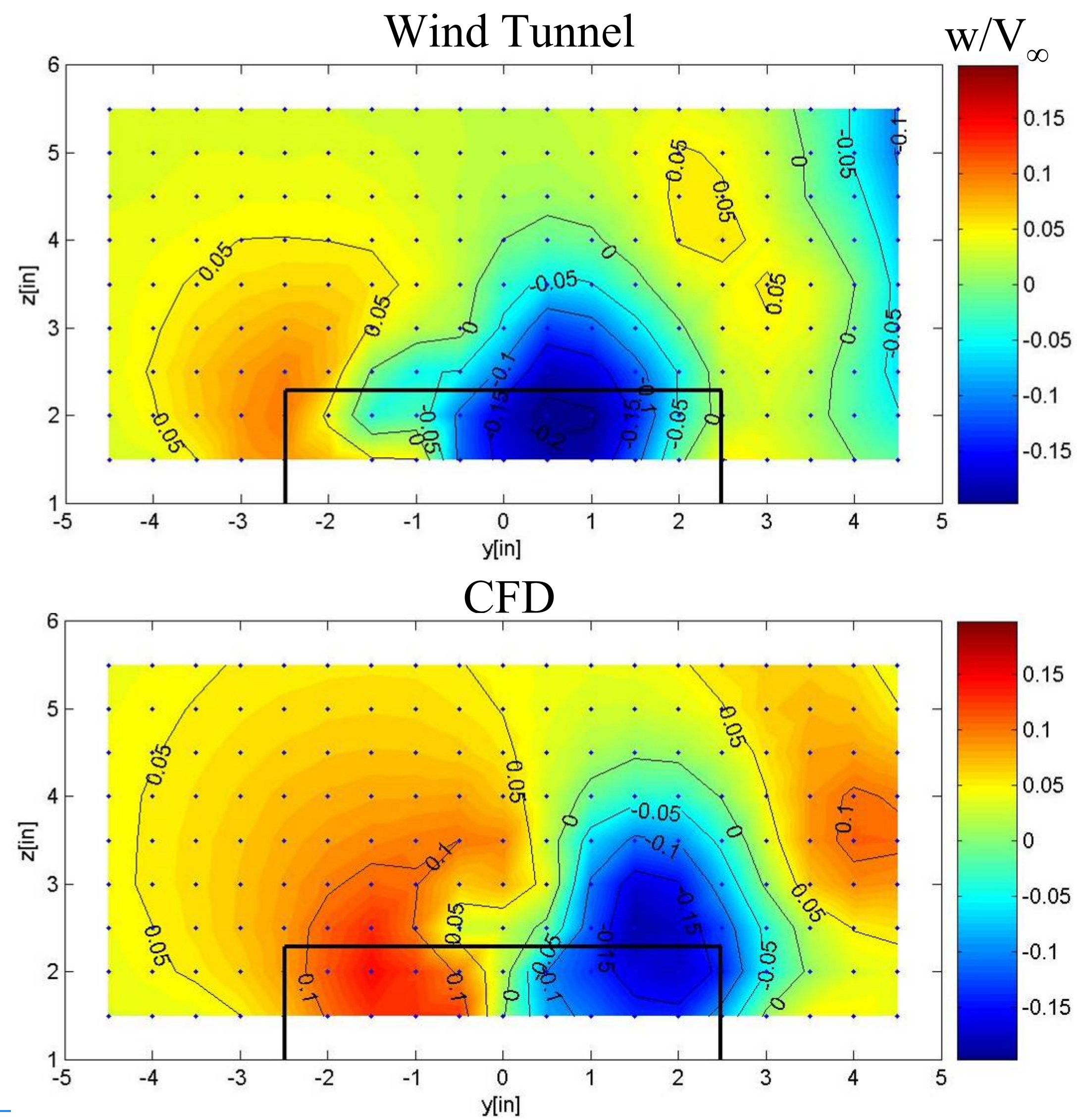


Validation Efforts

CFD Comparisons with WT

- **340º wind angle**
- **Vertical velocity component**
  - **Time-averaged**
- **Good agreement between CFD and WT**

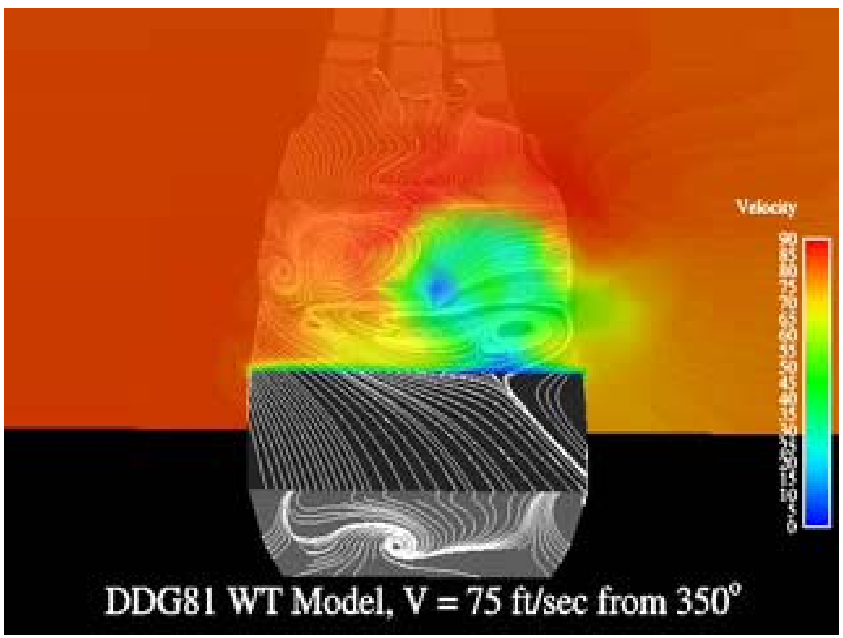


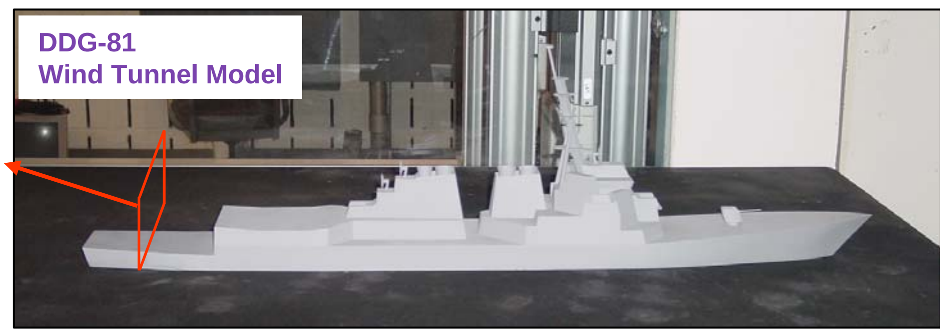


DDG 81

CFD, Autopilot & Piloted Simulations

- **CFD Airwake predictions at 5 WOD azimuths**
- **Offline & piloted simulations at Pax MFS**
  - **Flight simulation data will be compared to flight test data for validation**
- **CFD airwake data validated against Pax wind tunnel data**



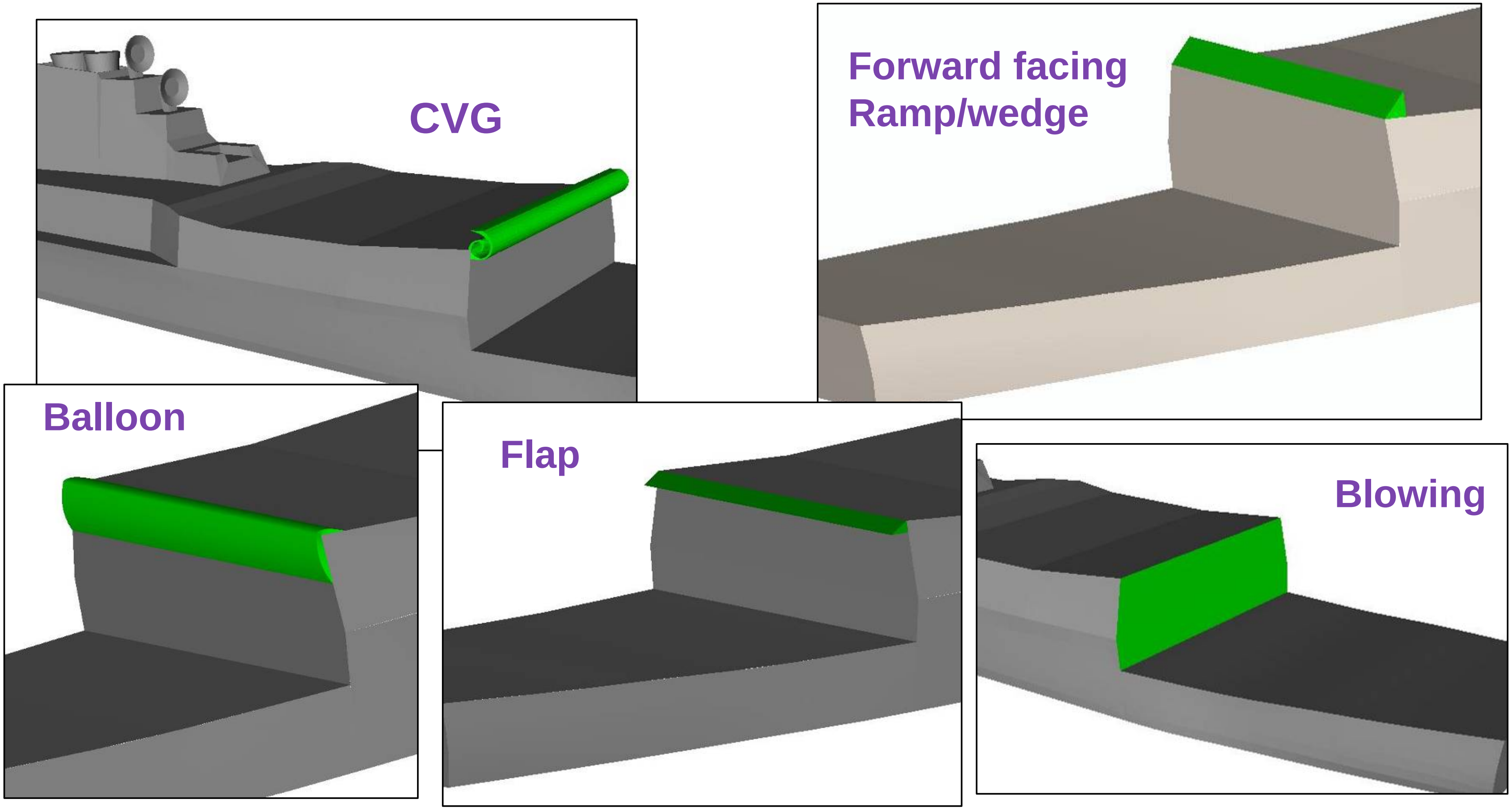


- **Animation of CFD**
- **Velocity plane through hover location**
- **Surface oil flow**

Airwake Control

Control Devices on DDG 81 (NATO AVT-102)

- **Flow control devices on DDG-81**



CFD Validation

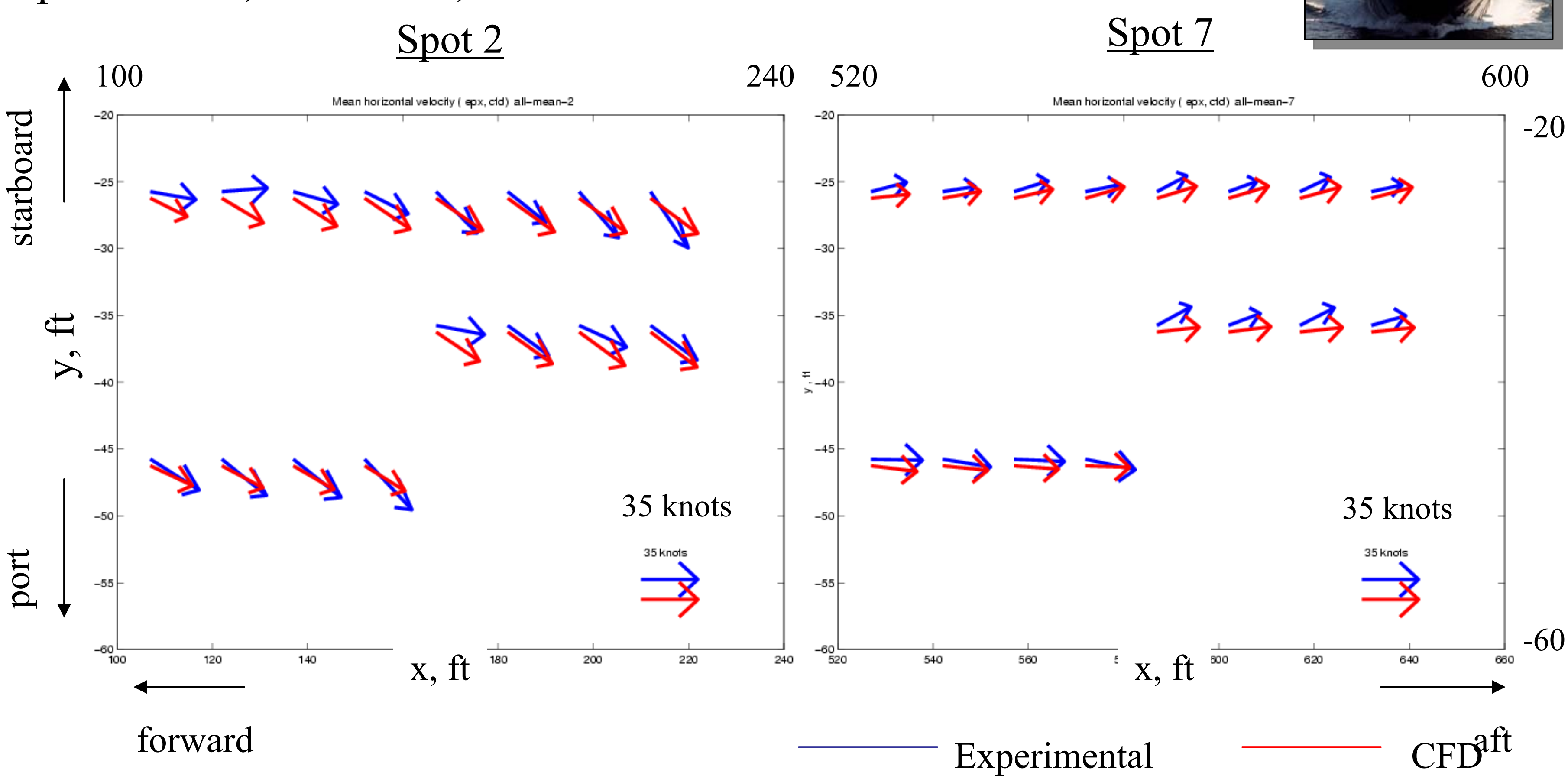
NAVAIR Pax River Assets: Full Scale

- **Ultrasonic Anemometers**
  - High frequency, 3 component velocity data
  - 17 probes
  - Boom rig, pole stand mountings

Comparison with Full Scale Data

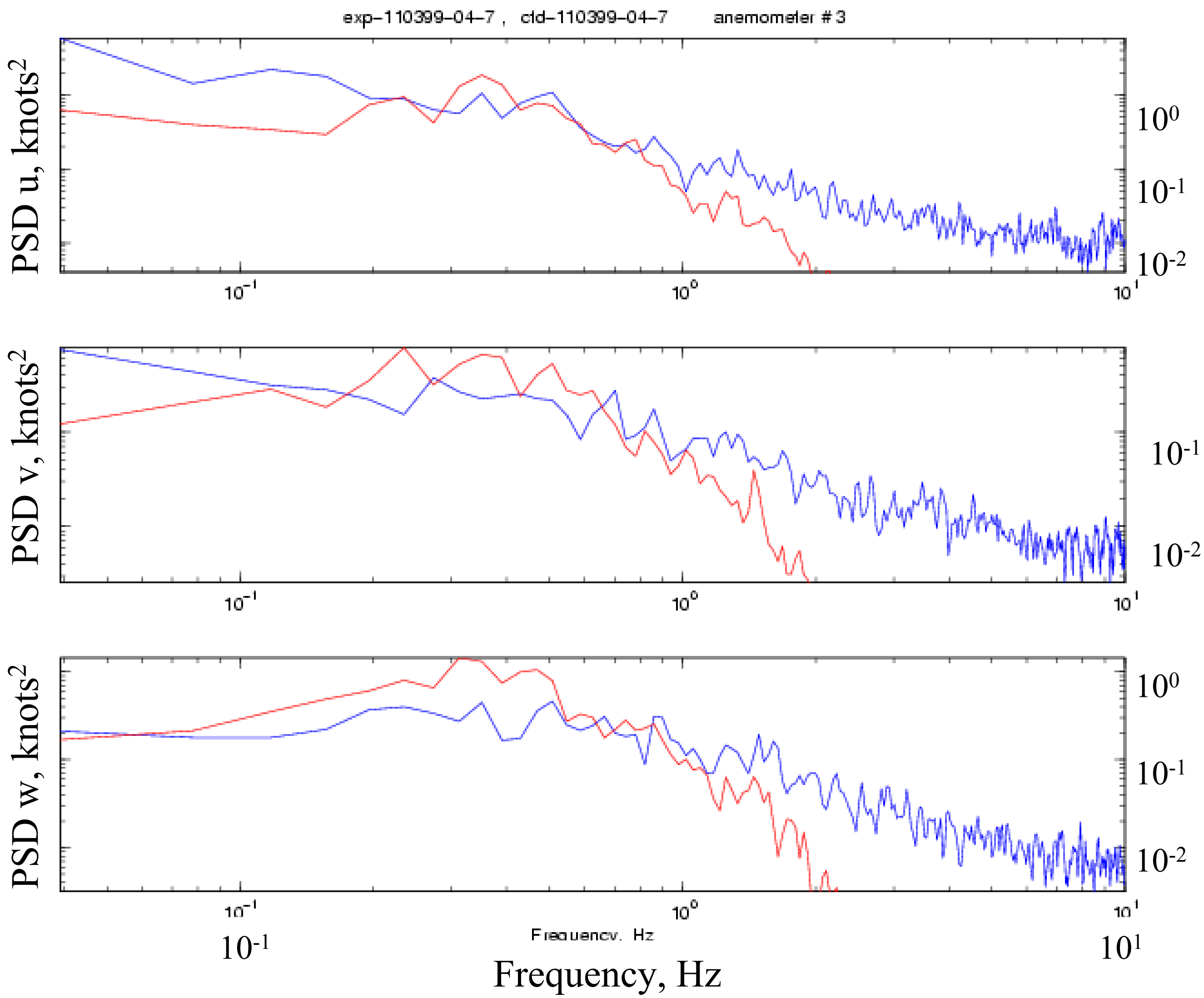
Mean Horizontal Wind Speed

Spot 2 and 7, All events, All anemometers



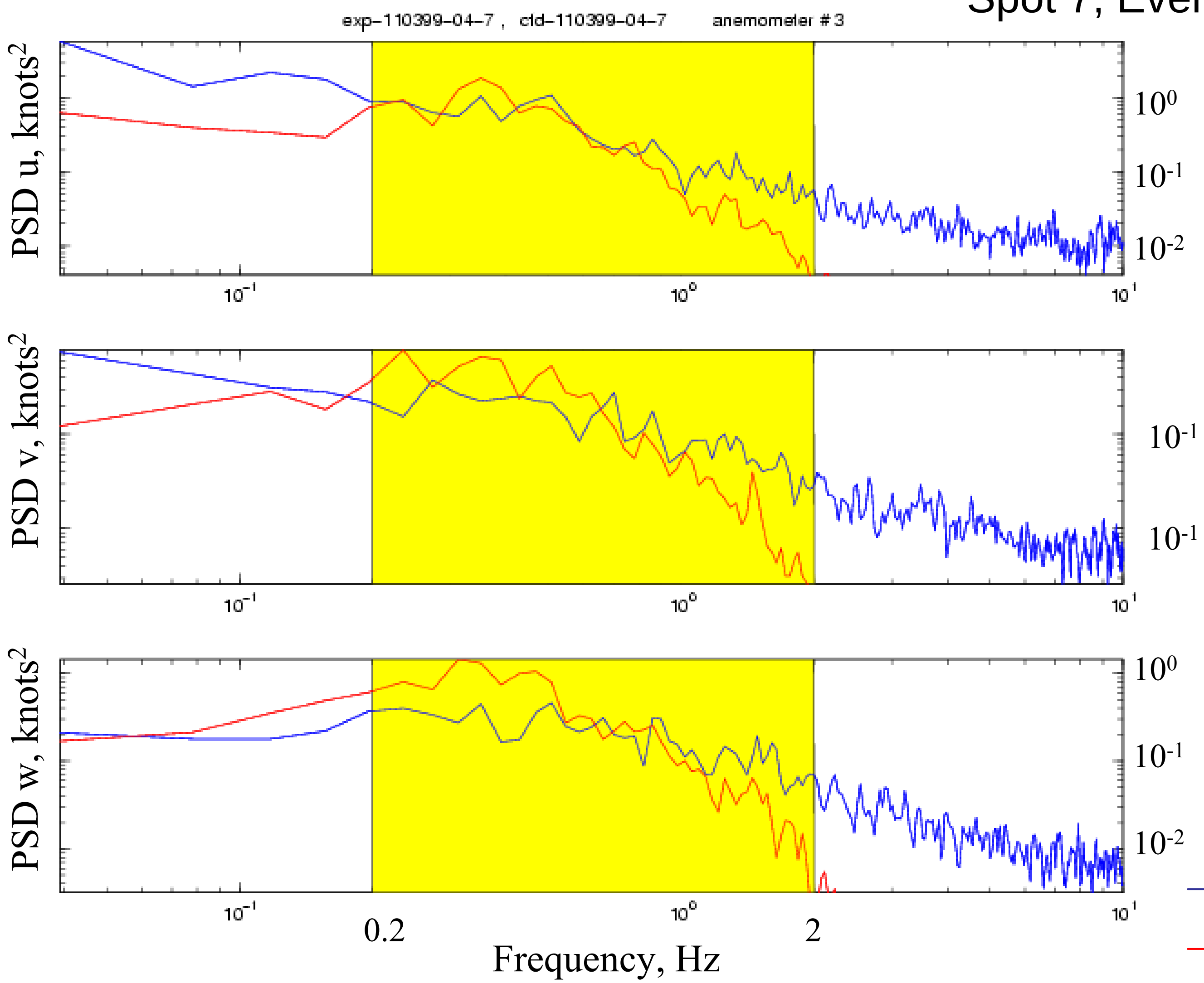
Power Spectral Density

Spot 7, Event 4, Anemometer 3



Power Spectral Density showing Band 0.2Hz to 2.0Hz

Spot 7, Event 4, Anemometer 3



St. dev. in range 0.2-2Hz
3.38
3.31

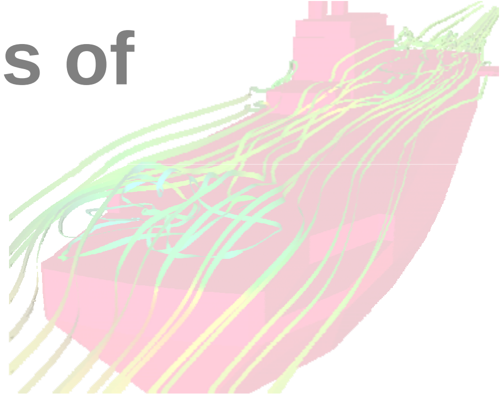
St. dev. in range 0.2-2Hz
2.21
2.45

St. dev. in range 0.2-2Hz
2.78
3.38

Experimental
CFD

SAFEDI Products

1) Accurate predictions of ship airwake

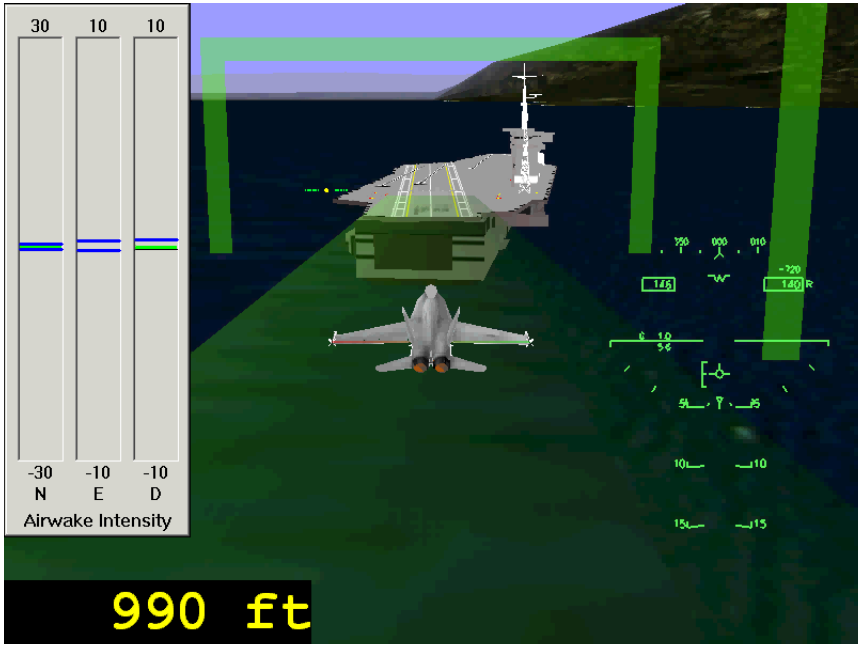


2) **Analytical tool for offline airwake evaluation**

3) Manned flight simulation with validated airwakes

PC-Based Airwake Evaluation

- "Fly" Aircraft models through CFD airwakes
  - F18, EA6B, UH60
- Examine hundreds of approaches in non-real time mode
- Provide information on airwake trouble spots
  - Aircraft control surface activity
  - ACLS activity
- Validation problematic



SAFEDI Products

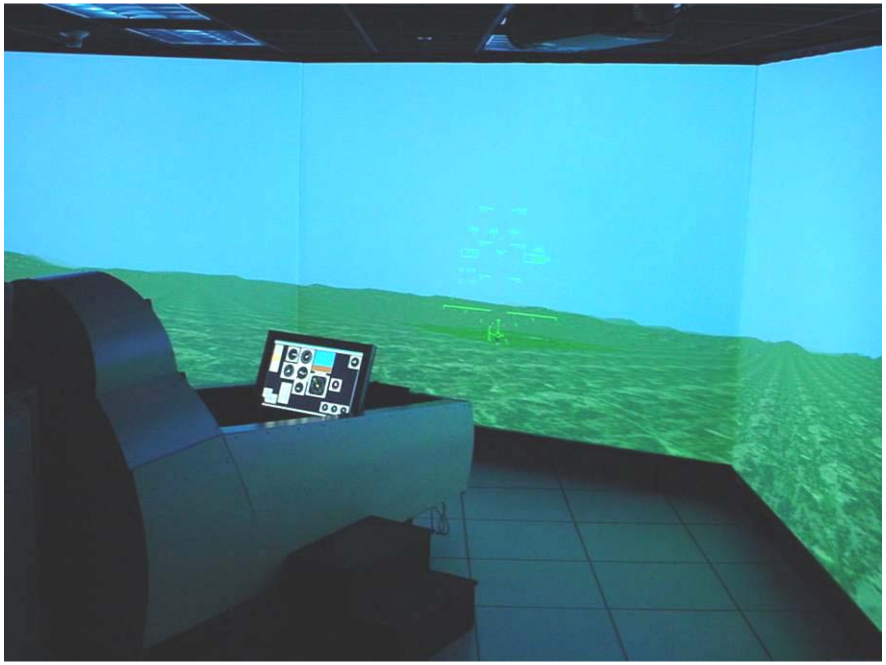
1) Accurate predictions of ship airwake

2) Analytical tool for offline airwake evaluation

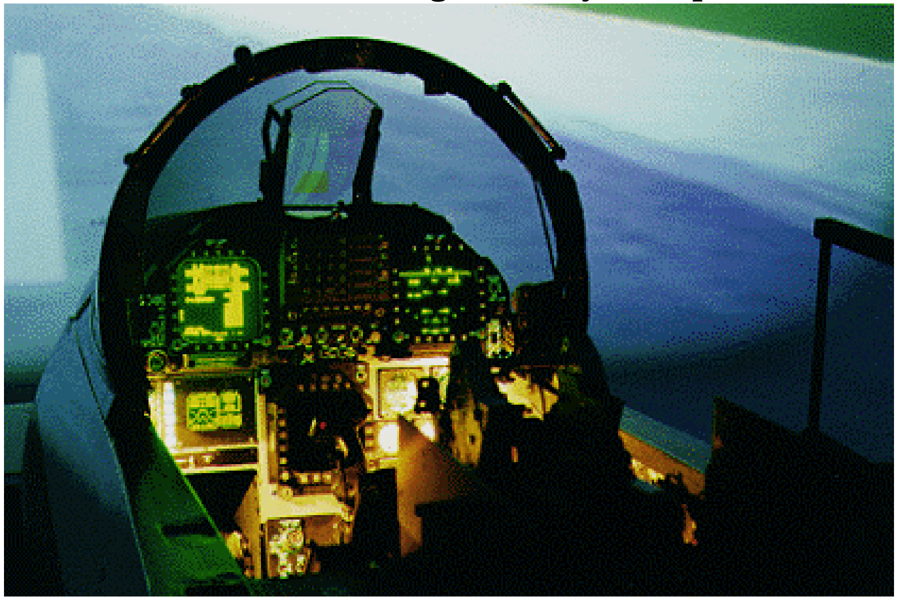
3) Manned flight simulation with validated airwakes

Manned Flight Simulation

- **Rapid integration in manned flight environment**
  - NAVAIR flight dynamics lab
  - Easily transitioned to high fidelity MFS
  - Retains analysis of PC-based tool



F/A-18 C/D High Fidelity Cockpit



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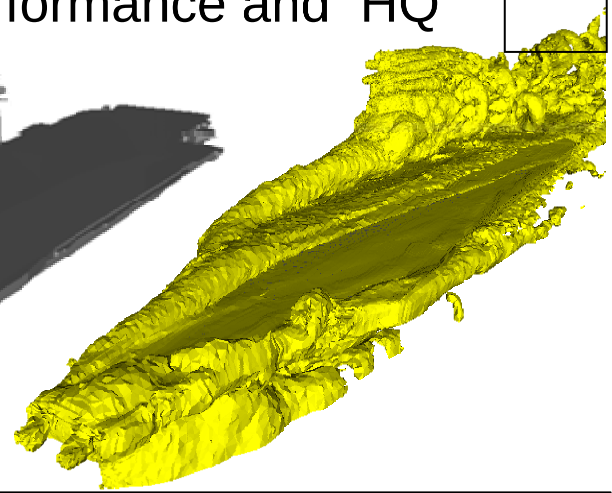
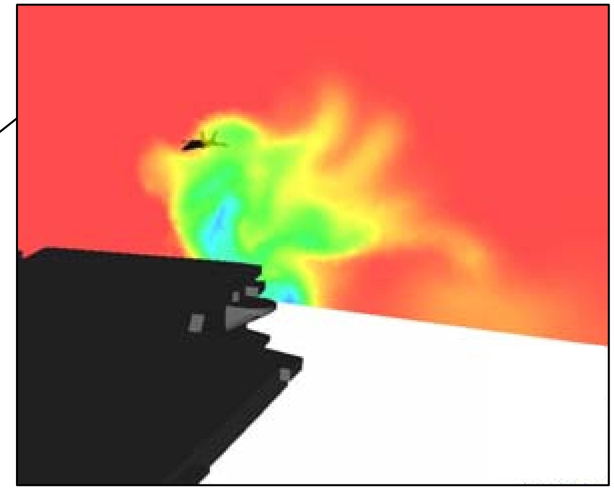
NAVAIR

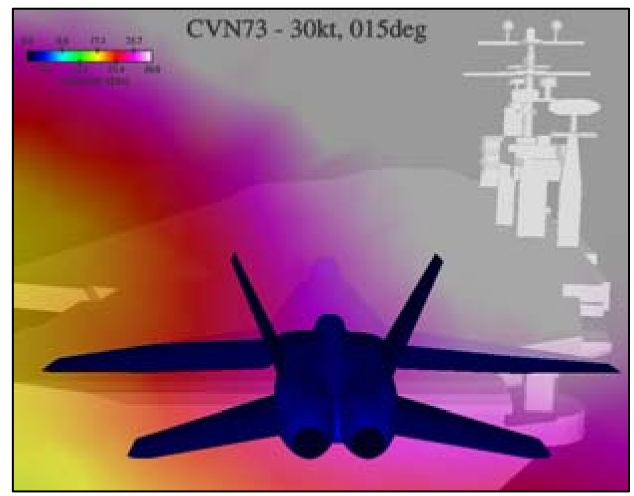
CVN Calculations

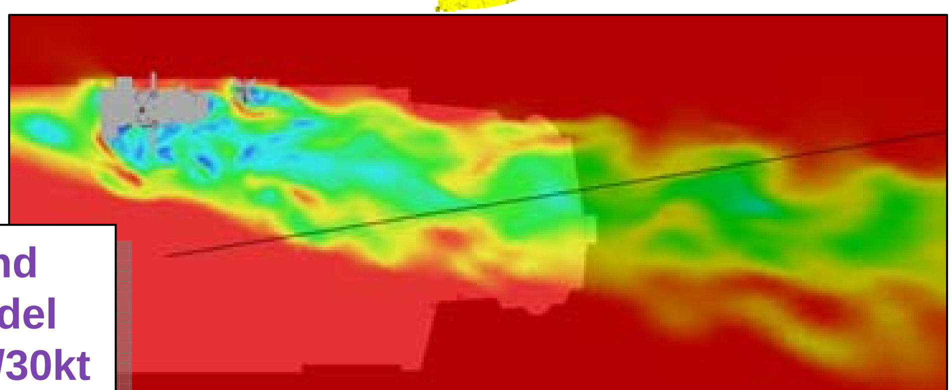
CFD Prediction: ‘Full Scale’ CVN 73

- **Predict airwake for CVNs**
  - Aerodynamic effect of deck and island geometry
  - Fixed wing aero performance and HQ investigations
  - Validation for CVN-21





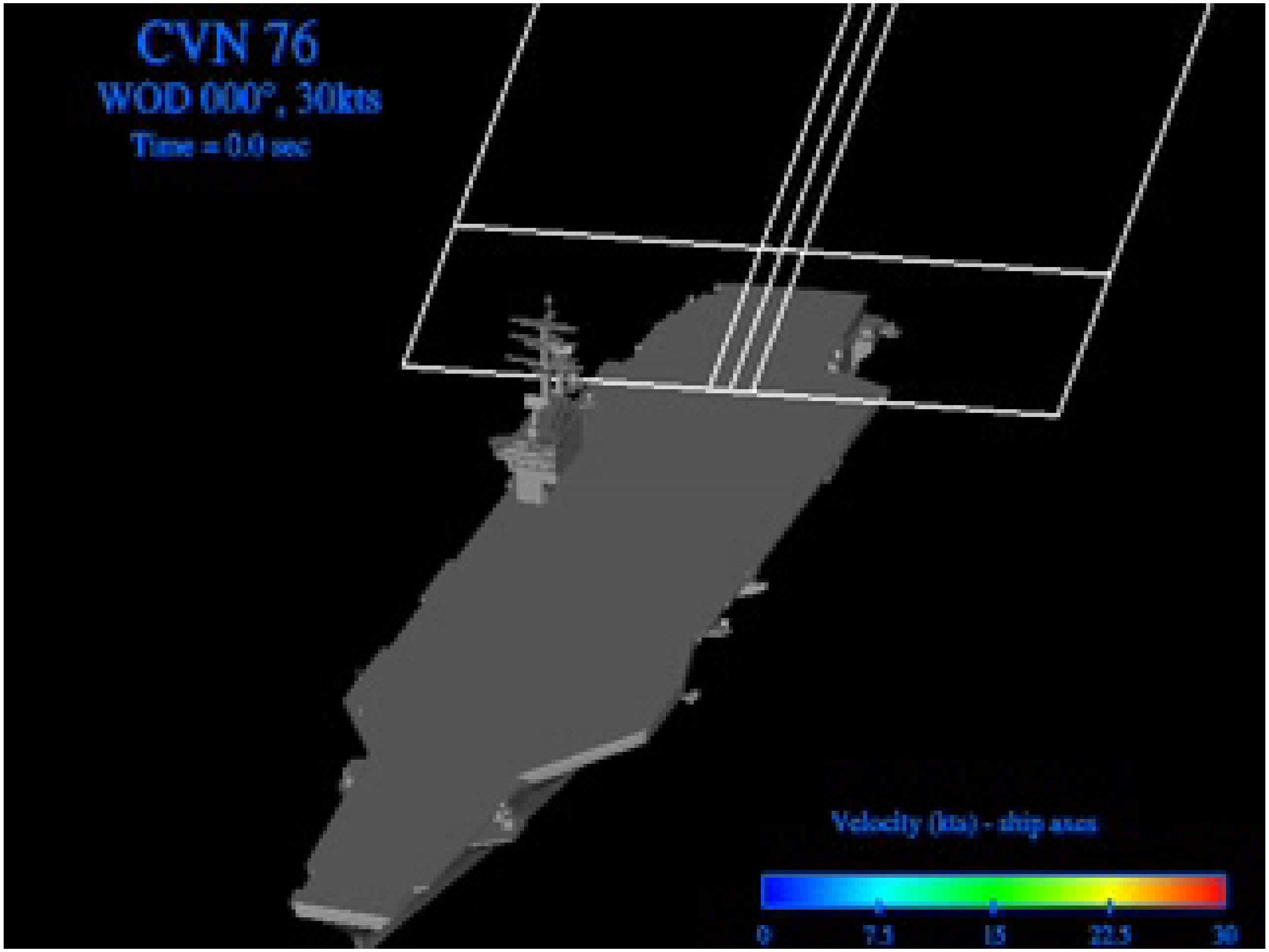




- **Scaled wind tunnel model**
- **WOD: 015/30kt**

CVN Calculations

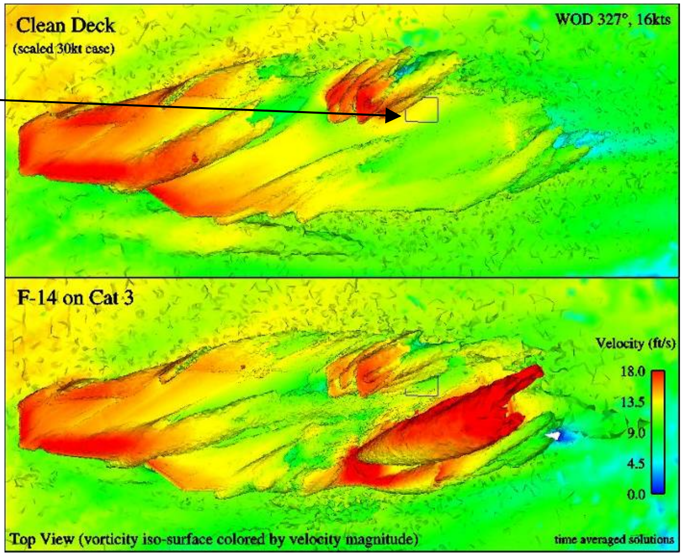
CVN 76 Animation

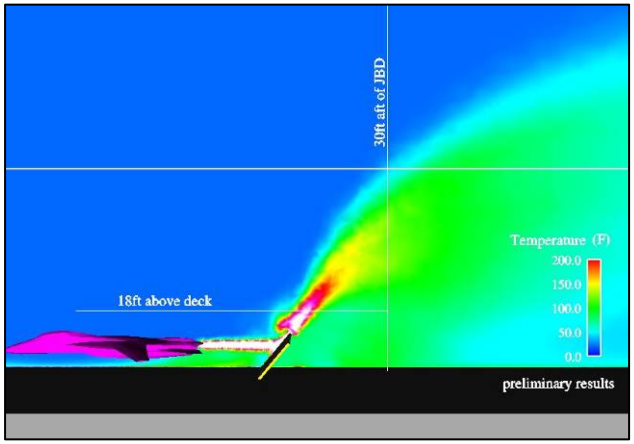


Interoperability

F-14 / Catapult Wake for H-60

- **Concerned about jet influence on helos operating on Elevator 3**
- **Test article not available for "real life" testing**
- **CFD used as tool in flight clearance process**
- **The Abraham Lincoln Carrier Strike Group currently operating providing humanitarian aid to tsunami victims**



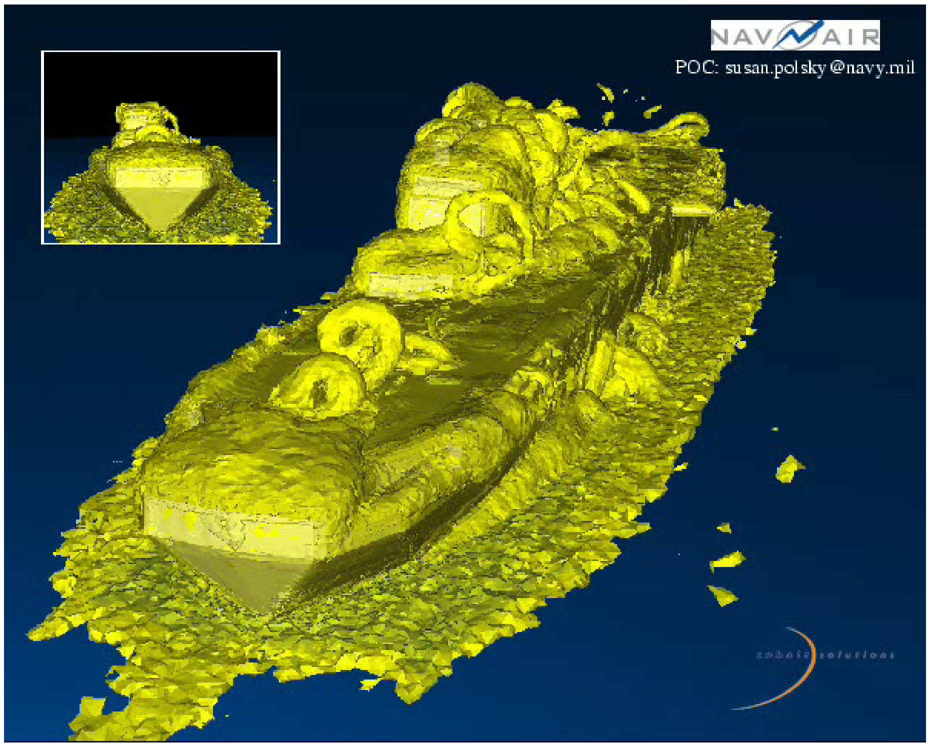


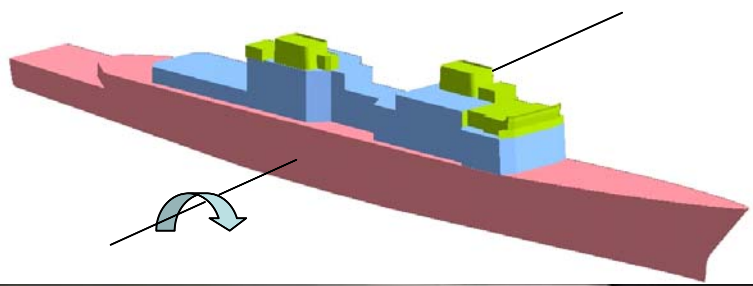
- **Helped out Hawkeye/F-18 air-to-air refueling team**
- **Argument was made that E 2 can taxi behind F-18 on cat so should not have problem flying behind it**
- **Demonstrated that JBD was doing its job**

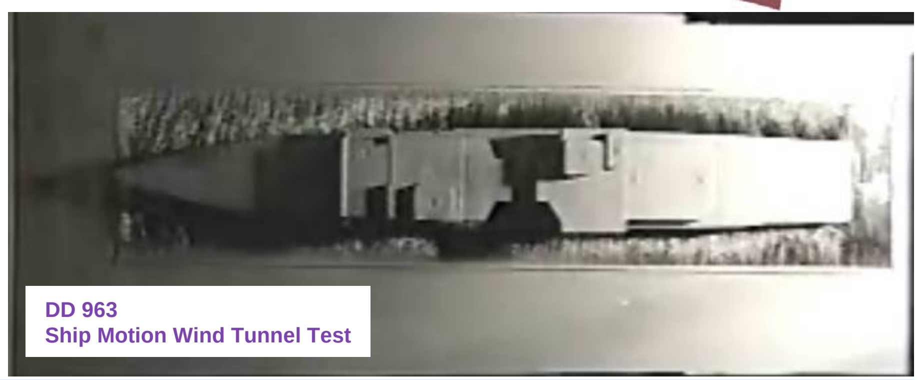
Ship Motion

LHA and DD 963

- **Developed 6 dof ship motion CFD capability**
- **Ship motion wind tunnel test conducted Jun/Jul 04**
  - **DD 963, 1 dof (pitch), Pax River (4' x 3')**
- **LHA high sea state CFD test case**





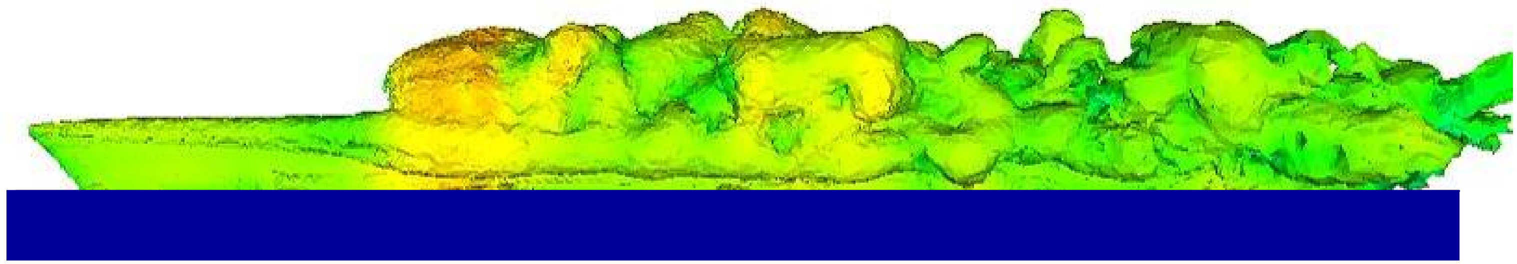


Ship Motion

DD 963 Static Pitch Cases

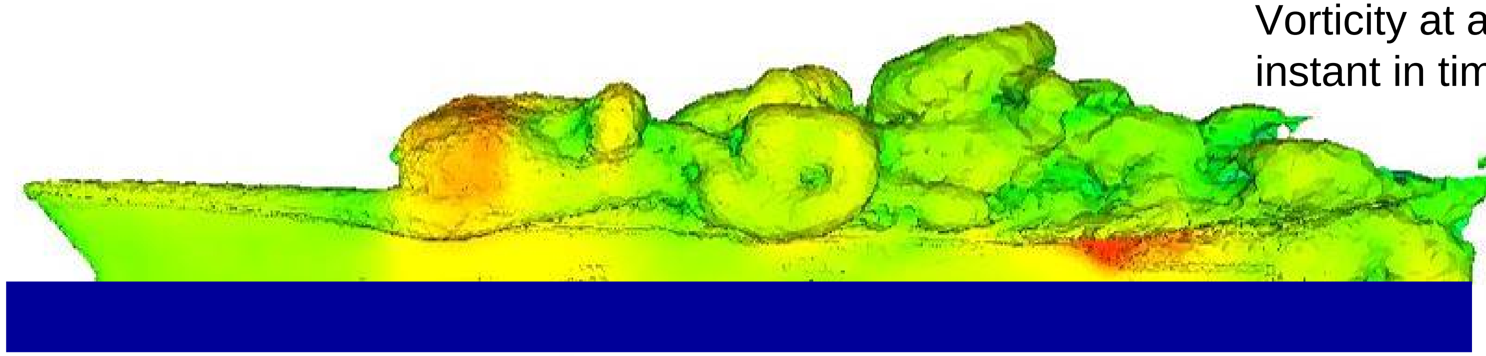
- **Static pitch: +2°, 0°, -2°**
  - **DD 963**
  - **Full scale (hull different than WT test article)**
  - **Also doing a motion case**

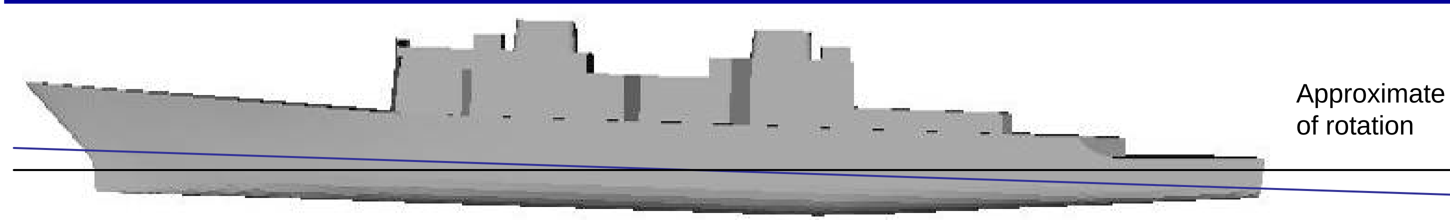
0°



Vorticity at an instant in time

+2°

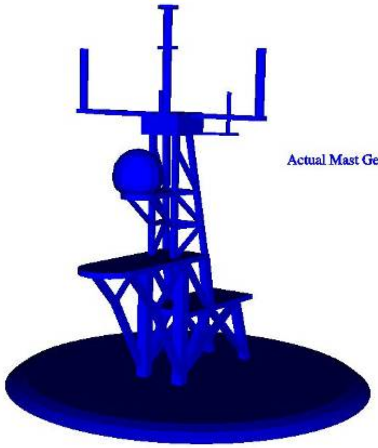


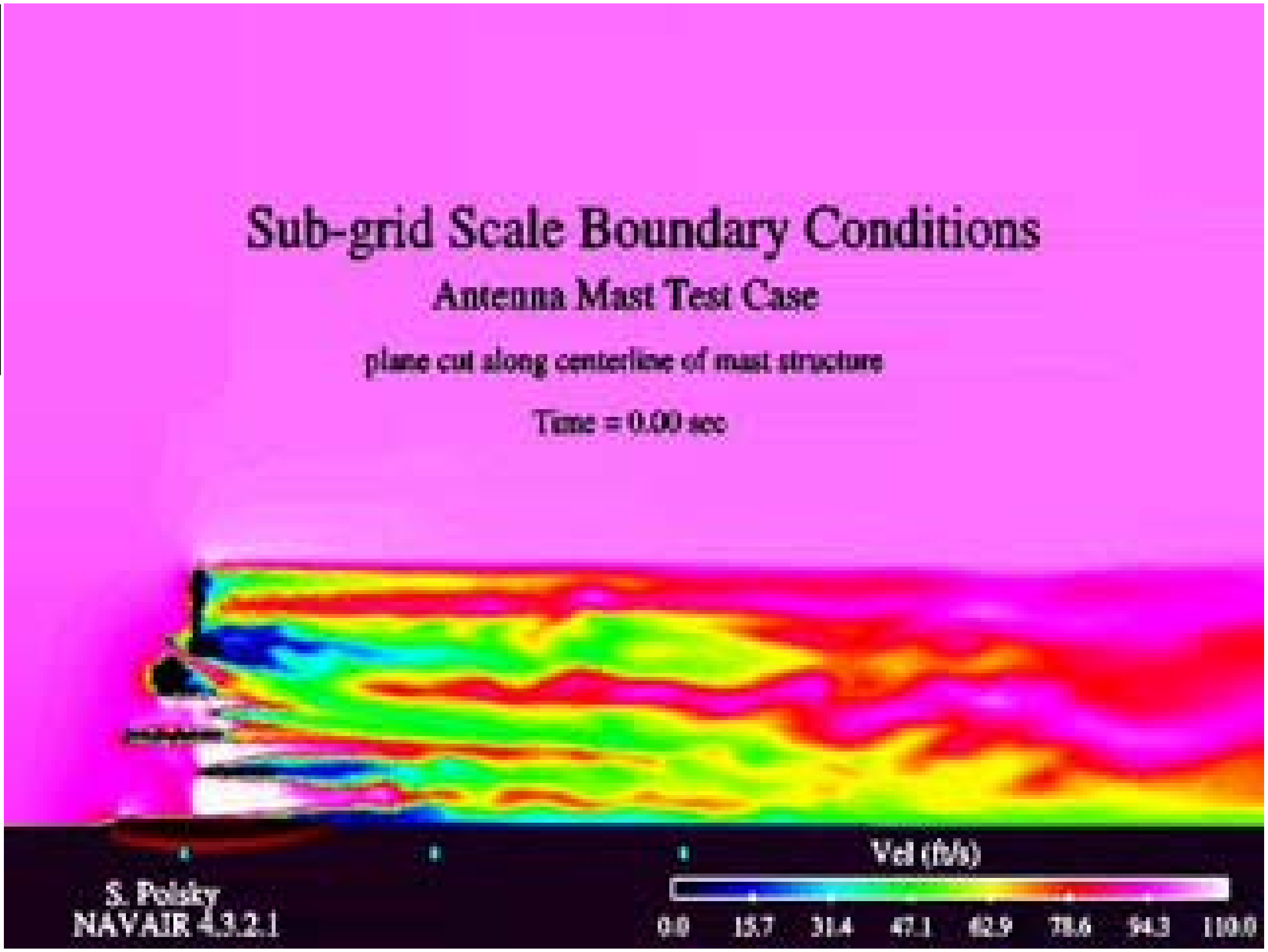


Antenna Mast Airwake

Novel Modeling Techniques

- **CFD results using sub-grid scale bc's**





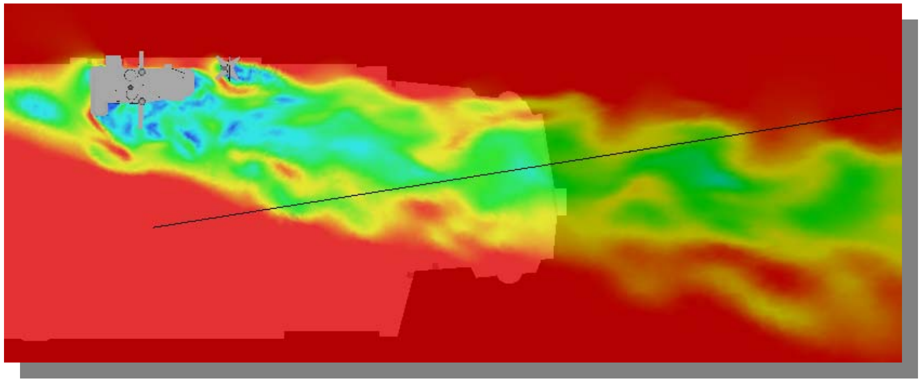
- Background
  - Why is airwake important?
  - JSHIP
- SAFEDI
  - Goal
  - Products
  - Airwake Predictions & Validation
- Highlights
- **Way Ahead**

NAVAIR

Background

SAFE-DI Tool

- ***Airwake data perturbs aircraft simulation model***



Airwake Turbulence Data

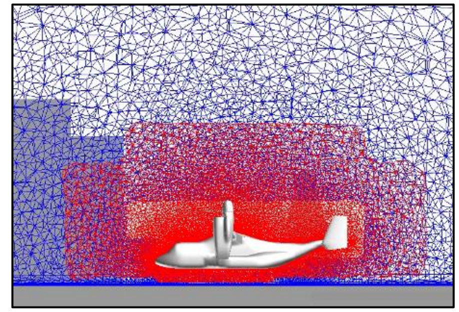
- ***Presence of aircraft <u>does not</u> affect airwake***

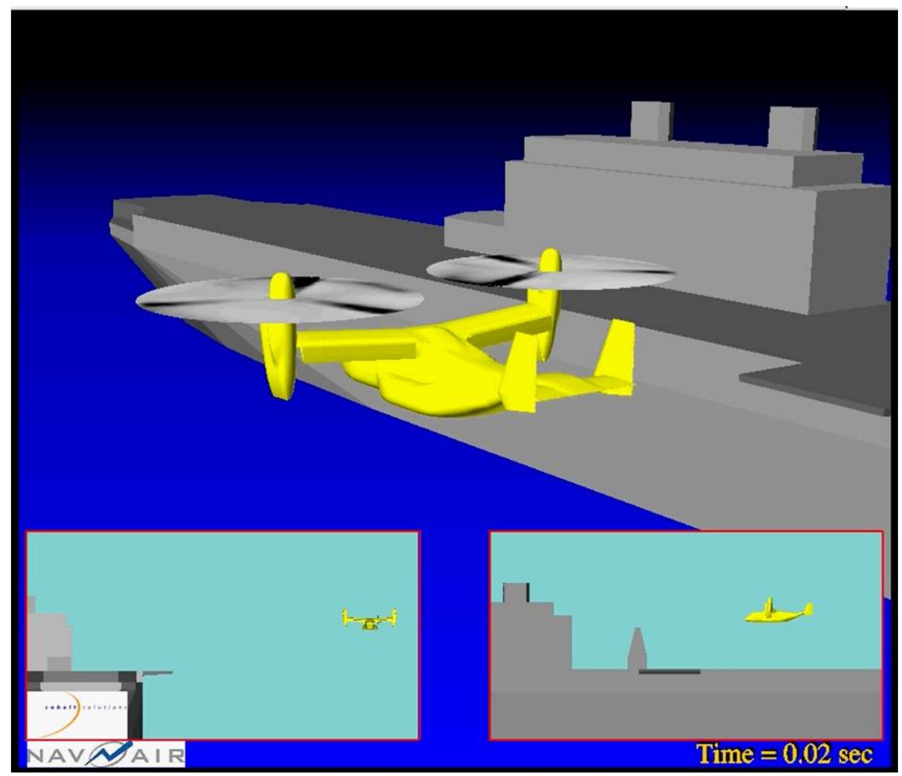
Aircraft Flight Simulation Model

Fully Coupled CFD Analysis

V-22 Dynamic Approach to LHA

- **Approach**
  - *Cobalt*
  - Unstructured/overset
  - Actuator disk with blade tracking
    - Fixed thrust target
  - Fixed approach path
  - WOD conditions simulate actual test event
- **Results**
  - Simulation completed through entire approach
    - Decent to 10 ft above deck

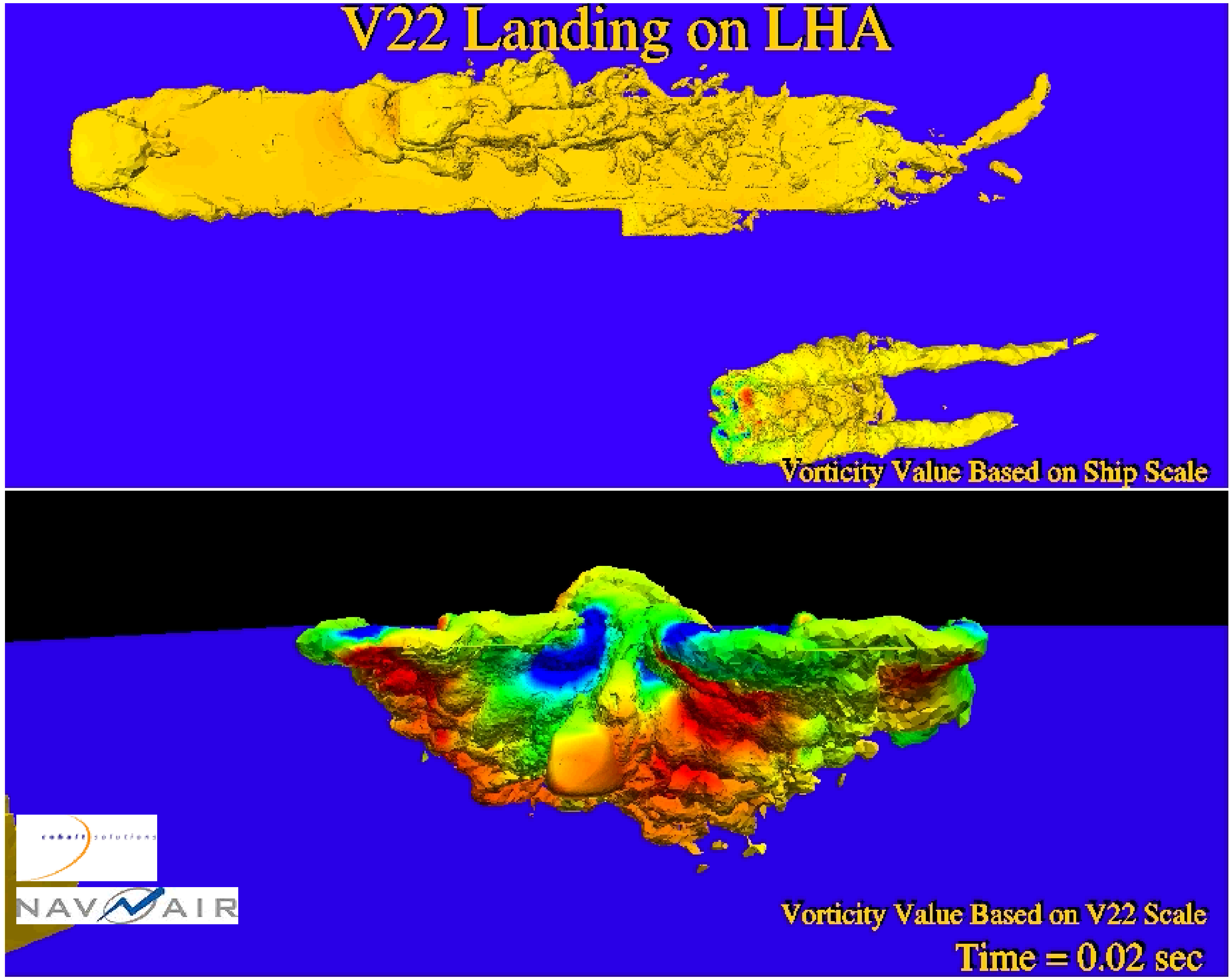




Fully Coupled CFD Analysis

V-22 Dynamic Approach to LHA

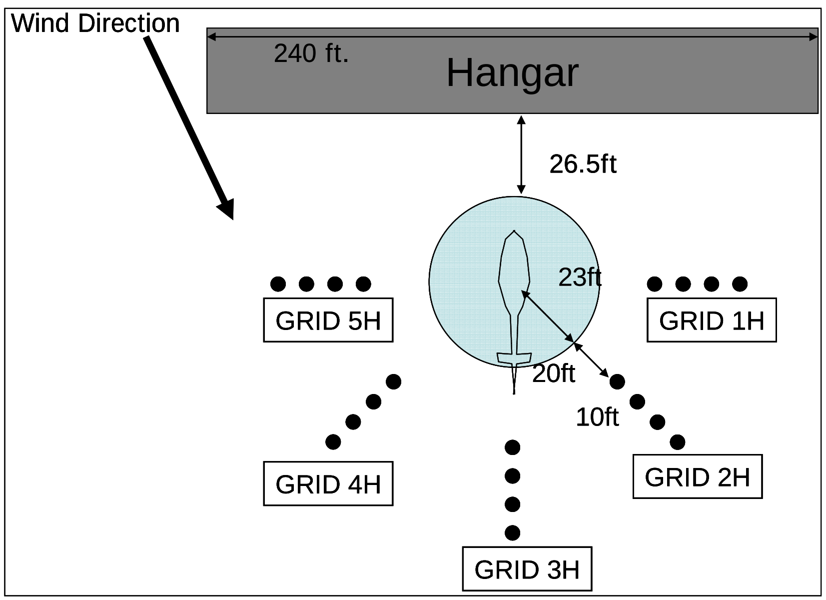
- **Results**
  - **Hole cutting technique proved robust even near ship deck**
  - **Outwash from tandem rotors affect large portion of the flight deck**



Validation Efforts

Coupled Airwake Modeling

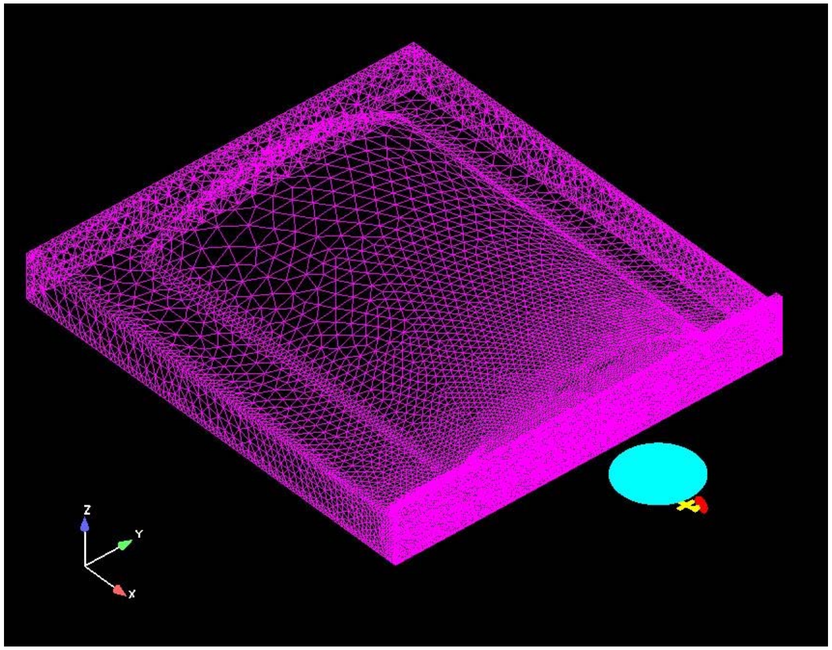
- **Joint NRC/NAVAIR test**
  - **Bell 412 hovering in front of land-based hangar**
- **Collect time history outwash data with 7 ultrasonic anemometers**
  - **3 freestream anemometers**



Validation Efforts

Coupled Airwake Modeling

- **CFD Approach**
  - Modeled hangar, aircraft fuselage, main and tail rotors (actuator disks)
  - Performed grid density study
  - Performed limited turbulence model study
  - Atmospheric boundary layer effect currently under investigation



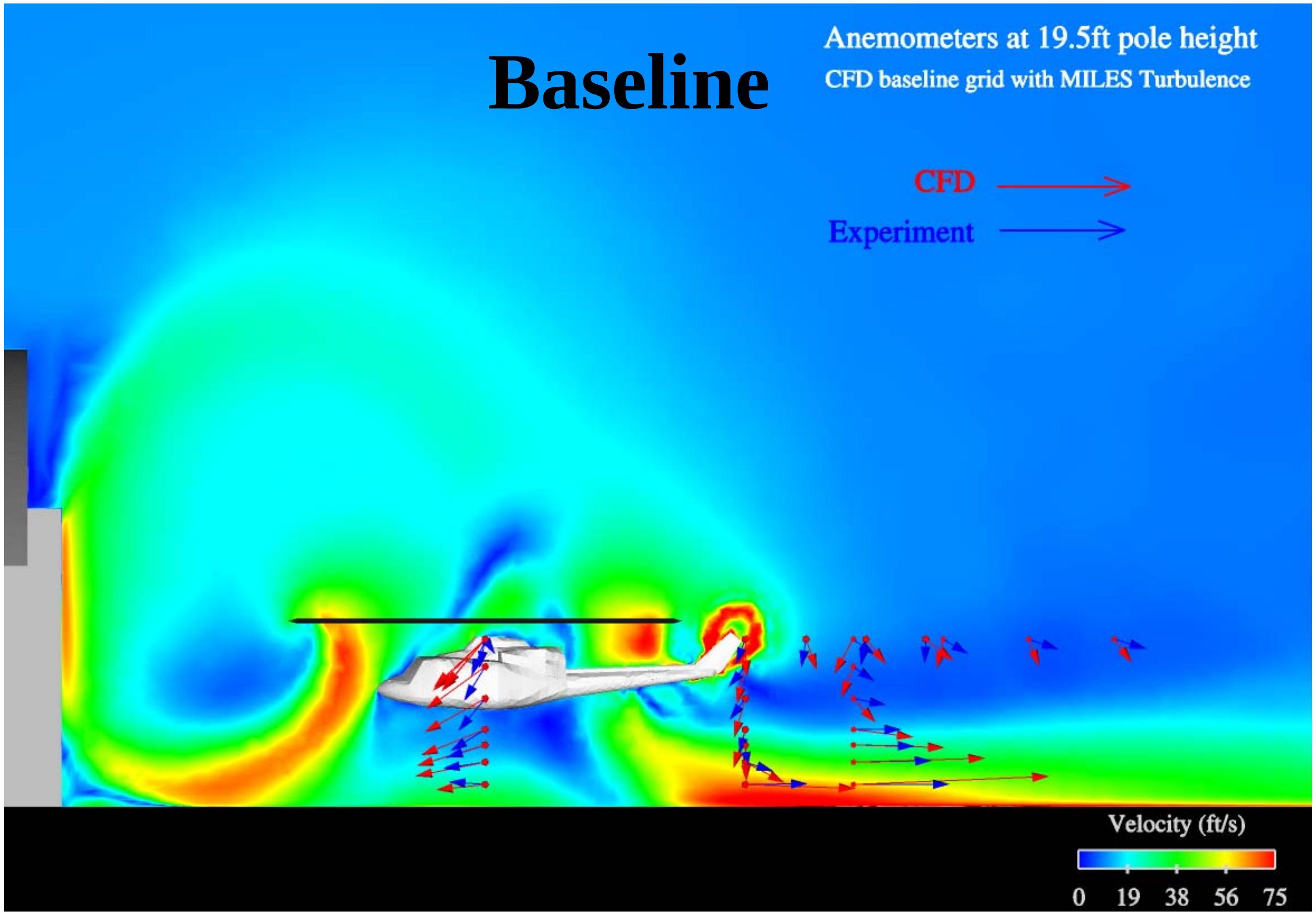
Hover Altitude (Skids AGL)	**10 ft**
Wind Speed	**M=.00755 (~7.4 knots)**
Sideslip	**303°**
Temperature	**533° R (73° F)**

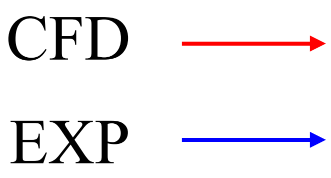
** Significant portions of this work were conducted by Air Force Cadet Daniel Rowland through the HPCMO summer internship program. Lt. Rowland was mentored by Maj. Jim Forsythe during his internship.*

Validation Efforts

Coupled Airwake Modeling

- **Results**
  - **Generally favorable; CFD tends to over predict outwash velocity**

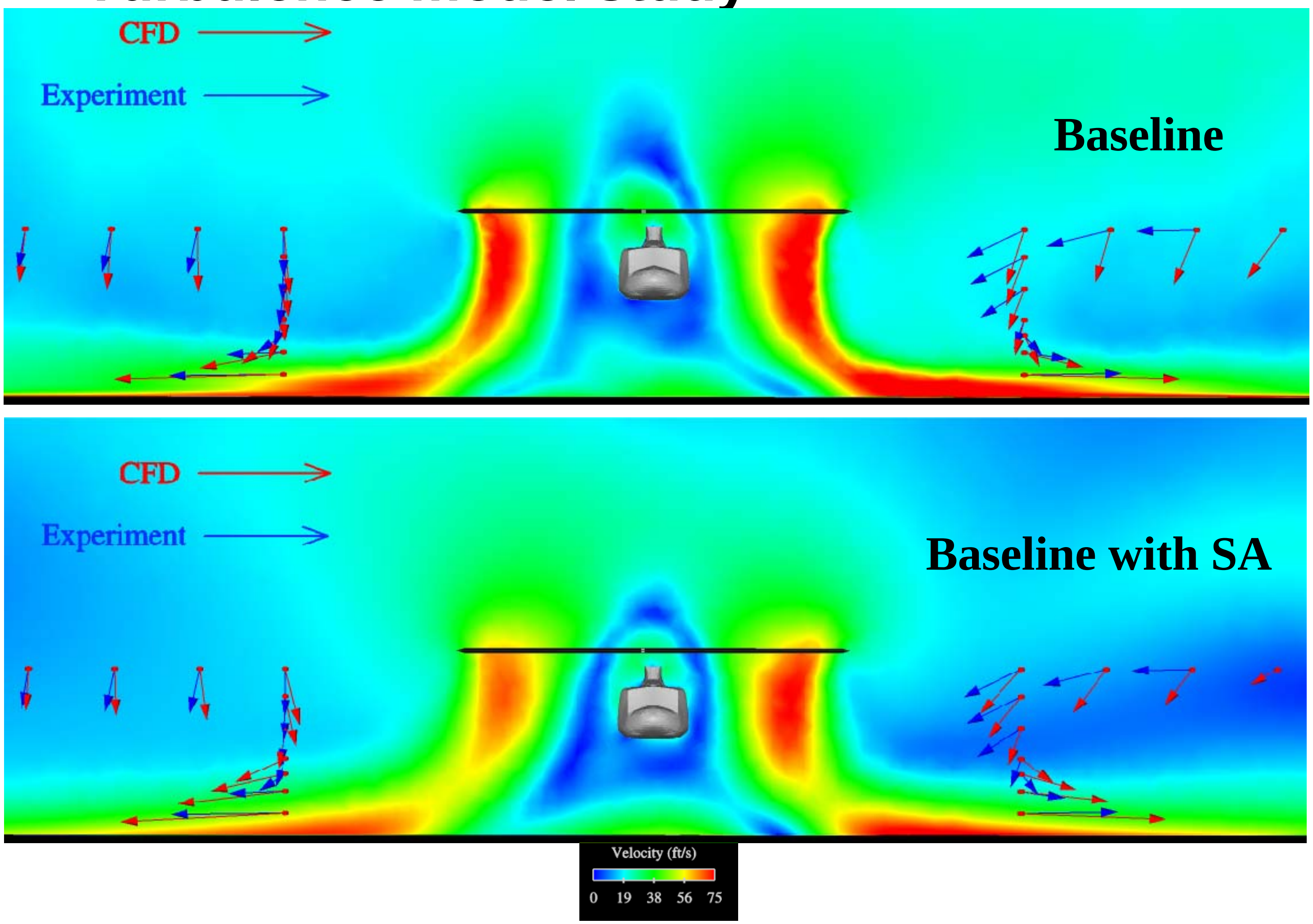




Validation Efforts

Coupled Airwake Modeling

- **Turbulence model study**



- **Comparisons with experimental data generally good**
- **SA compares better for port side anemometers**
  - **Effect of prevailing winds modeled more accurately**
- **The baseline case compares better on starboard side anemometers**

CFD →

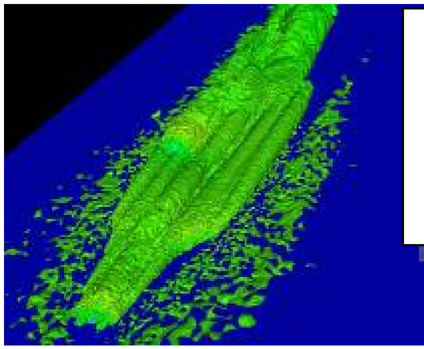
EXP →

The Way Ahead

- **Concentrating on coupled ship/aircraft aero**
  - Rotorcraft
  - Fixed-wing
- **Looking at novel approaches to bring coupling effects into real-time simulations**
  - Airwake “warping”
- **Continuing to build airwake databases**
  - LHA, LHD, CVN, CVN-21, T-AKE, DDG, DDX, LCS, LHA(R)
- **Continuing to improve SAFEDI Tool**
  - Examining airwake integration methods
  - Human pilot modeling

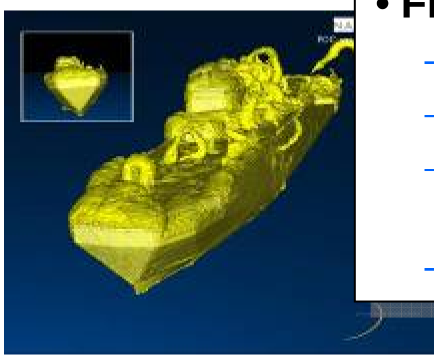
Summary

Airwake Accomplishments



- **Airwake Models**
  - –LHA, LHD, LHA(R)
  - –CVN-73, CVN-76, CVN-21
  - –DDG-81, DD(X)

- **Validation**
  - –Full scale data
    - LHA, CVN-76
  - –Wind tunnel data
    - LHA, CVN-73 & 76, DDG-81
    - Antenna mast, ship motion



- **Fidelity Enhancement**
  - –Time step & grid dependency
  - –Atmospheric boundary layer
  - –Geometric fidelity
    - Sub-grid Scale BC
  - –Ship motion effect

- **Offline airwake evaluation tool**
  - –H-60 on DD(X)
  - –H-60 on LHA & LHA(R)
  - –F/A-18 on CVN
  - –V-22 on LHA

- **Manned simulation**
  - –H-60 on LHA (JSHIP)
  - –H-60 on DDG (FY04)
  - –EA-6B on CVN
  - –F/A-18 on CVN

- **8 peer reviewed publications**
- **2 Grand Challenge Projects**

Questions?

Published Work

1. Polsky, S.A., Imber, R.D., Czerwiec, R.M. and Ghee, T.A., *A Computational and Experimental Determination of the Air Flow Around the Landing Deck of a US Navy Destroyer (DDG): Part II*, AIAA Paper 2007-4484, presented at AIAA Applied Aerodynamics Conference, Miami, FL, Jun. 2007.
2. *Woodson, S. H. and Ghee, T. A., "A Computational and Experimental Determination of the Air Flow Around the Landing Deck of a US Navy Destroyer (DDG)", AIAA-2005-4958, June 2005.*
3. Polsky, S.A. and Naylor, S.M., *CVN Airwake Modeling and Integration: Initial Steps in the Creation and Implementation of a Virtual Burble for F-18 Carrier Landing Simulations*, AIAA Paper 2005-6298, presented at AIAA Modeling and Simulation Technologies Conference, San Francisco, CA, Aug. 2005.
4. Polsky, S.A. and Ghee, T.A., *Application and Verification of Sub-Grid Scale Boundary Conditions for the Prediction of Antenna Wake Flowfields*, AIAA Paper 2004-4841, presented at AIAA Applied Aerodynamics Conference, Providence, RI, Aug. 2004.
5. Czerwiec, R.M. and Polsky, S.A., *LHA Airwake Wind Tunnel and CFD Comparison with and without Bow Flap*, AIAA Paper 2004-4832, presented at AIAA Applied Aerodynamics Conference, Providence, RI, Aug. 2004.
6. Polsky, S.A., *CFD Prediction of Airwake Flowfields for Ship Experiencing Beam Winds*, AIAA Paper 2003-3657, presented at 21st AIAA Applied Aerodynamics Conference, Orlando, FL June 2003.
7. Polsky, S.A. *Computational Study of Unsteady Ship Wake*. Presented at the AIAA Aerospace Sciences Meeting (2002-1022), Reno, Nevada,14-17 January 2002.
8. Advani, S.K., and Wilkinson, C.H. *Dynamic Interface Modelling and Simulation – A Unique Challenge.* Presented at the RAeS Symposium, 'The Challenge of Realistic Rotorcraft Simulation', 7 - 8 November 2001, London, UK.
9. Bunnell, J.W. *An Integrated Time-Varying Airwake in a UH-60 Black Hawk Shipboard Landing Simulation*. Presented at the AIAA Modeling and Simulation Technologies Conference, Montreal, August 2001.
10. Wilkinson, C.H., Roscoe. M.F. & VanderVliet G.M. *Determining Fidelity Standards for the Shipboard Launch and Recovery Task.* Presented at the AIAA Modeling and Simulation Technologies Conference, Montreal, August 2001.
11. Roscoe, M.F., VanderVliet, G.M. & Wilkinson, C.H. *The Use of ADS-33D Useable Cue Environment Techniques For Defining Minimum Visual Fidelity Requirements*. Presented at the AIAA Modeling and Simulation Technologies Conference, Montreal, August 2001.
12. VanderVliet, G.M., Wilkinson, C.H. & Roscoe. M.F. *Verification, Validation and Accreditation of a Flight Simulator: The JSHIP Experience.* Presented at the AIAA Modeling and Simulation Technologies Conference, Montreal, August 2001.
13. Polsky, S.A. & Bruner, C.W.S. *A Computational Study of Unsteady Ship Airwake* Presented at NATO RTO Applied Vehicle Technology Panel Symposium on Advanced Flow Management, Loen, Norway, May 2001.
14. Wilkinson, C.H., VanderVliet, G.M. & Roscoe. M.F. *Modeling and Simulation of the Ship-Helicopter Environment.* Presented at the AIAA Modeling and Simulation Technologies Conference, Denver, August 2000.
15. Polsky, S.A., & Bruner, C.W.S. *Time-Accurate Computational Simulations of an LHA Ship Airwake.* Presented at the 18th AIAA Applied Aerodynamics Conference, Denver, Colorado, 14-17 August 2000.