NAVAIR Airwake Modeling & More!

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HPC User Group Forum
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• Background
  – Why is airwake important?
  – JSHIP

• SAFEDI
  – Goal
  – Products
  – Airwake Predictions & Validation

• Highlights

• Way Ahead
• **Background**
  - Why is airwake important?
  - JSHIP

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

• **Highlights**

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

Effect of island

Deck spot 7

Edge vorticies

Periodic shedding from bow (burble)

Separation off bow
SAFEDI

Development of Airwake Databases

Time Accurate CFD Airwake Calculations on a US Navy LHA

US Navy – Air 4.3.2.1
S. Polsky & C.W.S. Bruner
Flow character changes dramatically with changing wind direction.

0° WOD

30° WOD

Edge vortices

Shedding off island
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

DDG-81

Airwake control device testing

Ultrasonic anemometer calibration

DD 963
Ship Motion

Ship Antenna Mast

Satisfying Navy needs since 1994
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**

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

\[ V_\infty \]

\[ V/V_\infty \]
Validation Efforts

**CFD Comparisons with WT**

- $000^\circ$ wind angle
- Vertical velocity component
  - Time-averaged
- Good agreement between CFD and WT

Wind Tunnel

CFD
Validation Efforts

**CFD Comparisons with WT**

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

![Wind Tunnel vs CFD comparison graphs](image-url)
Validation Efforts

**CFD Comparisons with WT**

- 350° wind angle
- Vertical velocity component
  - Time-averaged
- Good agreement between CFD and WT
Validation Efforts

**CFD Comparisons with WT**

- **340° wind angle**
- **Time-averaged velocity magnitude**
  - \( v, w \) velocity vectors
- **Good agreement between CFD and WT**
Validation Efforts

**CFD Comparisons with WT**

- 340° 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

[Image of DDG 81 with CFD simulation and wind tunnel model]
Airwake Control

Control Devices on DDG 81 (NATO AVT-102)

- Flow control devices on DDG-81

- CVG
- Forward facing Ramp/wedge
- Balloon
- Flap
- Blowing
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

Spot 2
Spot 7

Experimental CFD
Comparison with Full Scale Data
Power Spectral Density
Spot 7, Event 4, Anemometer 3

PSD $u$, knots$^2$

PSD $v$, knots$^2$

PSD $w$, knots$^2$

Experimental

CFD
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

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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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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

Vorticity at an instant in time

Approximate center of rotation
Antenna Mast Airwake

Novel Modeling Techniques

• CFD results using sub-grid scale bc’s

Validated against wind tunnel data taken in Pax Facility
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Background

SAFE-DI Tool

• **Airwake data perturbs aircraft simulation model**

• **Presence of aircraft does not affect airwake**
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

- GRID 1H
- GRID 2H
- GRID 3H
- GRID 4H
- GRID 5H

Wind Direction

**Hangar**

- 26.5 ft
- 23 ft
- 20 ft
- 10 ft
- 240 ft
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

<table>
<thead>
<tr>
<th>Hover Altitude (Skids AGL)</th>
<th>10 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>M=0.00755 (~7.4 knots)</td>
</tr>
<tr>
<td>Sideslip</td>
<td>303°</td>
</tr>
<tr>
<td>Temperature</td>
<td>533° R (73° F)</td>
</tr>
</tbody>
</table>

*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
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


