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Not Your Father's Hybrid Code: Advancements in CFD-Based Hybrid Methods for a New Millennium

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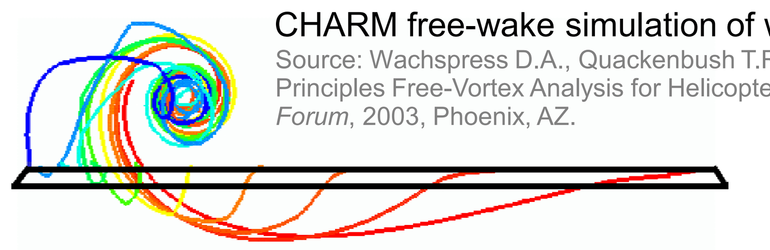
Introduction

WHY use a hybrid code?

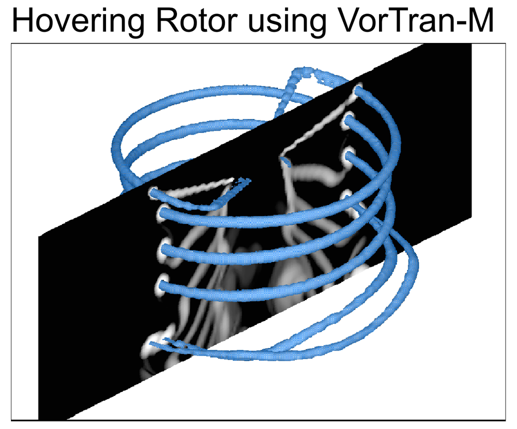
- Preserve vortical wake over long ages using alternate Eulerian or Lagrangean methods
- Capture flow features accurately in the near-field using unstructured CFD

Previous work



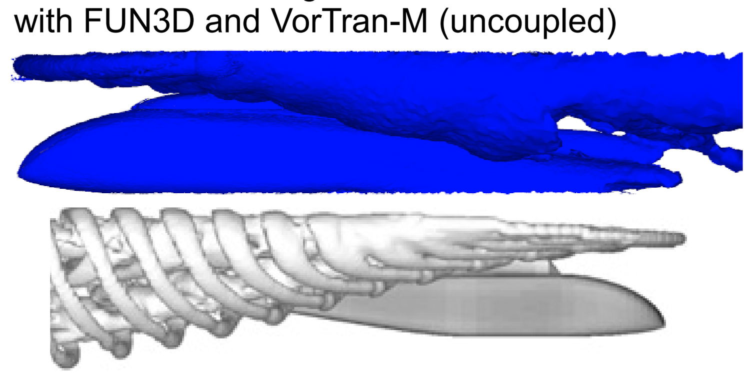
CHARM free-wake simulation of wingtip vortex roll-up
Source: Wachspress D.A., Quackenbush T.R. and A.H. Boschitsch, "First-Principles Free-Vortex Analysis for Helicopters and Tiltrotors", *59th Annual AHS Forum*, 2003, Phoenix, AZ.

Hovering Rotor using VorTran-M



Source: Komerath, N. and M.J. Smith, "Rotorcraft Wake Modeling: Past, Present and Future." *35th European Rotorcraft Forum*, 2009, Hamburg, Germany.

ROBIN rotor-fuselage interactions with FUN3D and VorTran-M (uncoupled)



Source (top): Smith M.J., Shenoy R., Kenyon A.R., and R.E. Brown, "Vorticity-Transport and Unstructured RANS Investigation of Rotor-Fuselage Interactions." *35th European Rotorcraft Forum*, 2009, Hamburg, Germany.
Source (bottom): Kenyon, R. and R.E. Brown, "Wake Dynamics and Rotor-Fuselage Aerodynamic Interactions." *Journal of the American Helicopter Society*, 54.1, 2009.

Coupling Methodology

WHAT are we doing differently?

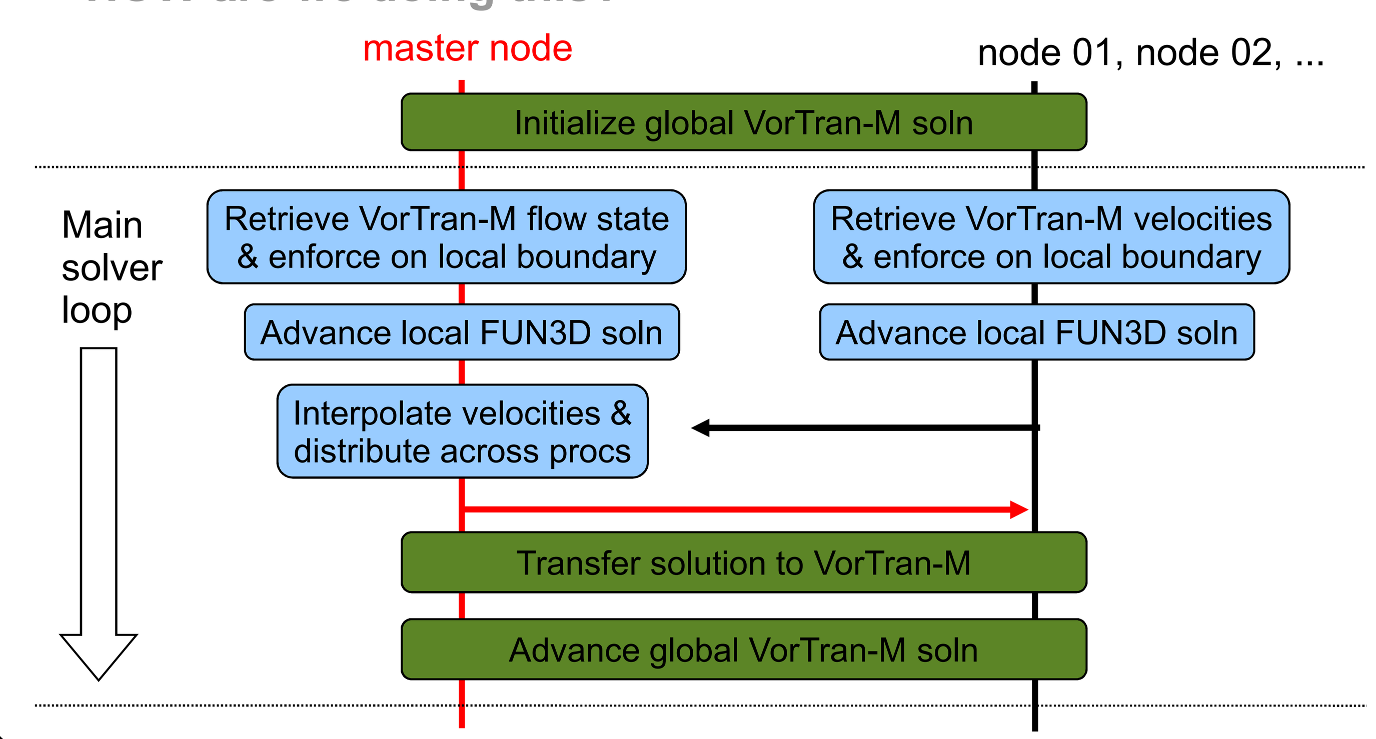
- Use **FUN3D** solver
  - 3D Unstructured Navier-Stokes solver
  - Handles overset dynamic meshes
  - Has been coupled with CSD solvers (DYMORE, CAMRAD II) for aeroelastic analyses
- Evolve vortical wake using CDI's **VorTran-M** code
  - Solves the Vorticity Transport equations, assuming incompressible, inviscid flow in wake
  - Vorticity is a conserved quantity, allowing preservation of wake over long ages

Transport equation: $$\frac{\partial}{\partial t}\omega + \boldsymbol{u}\cdot\nabla\omega - \omega\cdot\nabla\boldsymbol{u} = S$$

Vorticity source: $$S = -\frac{\mathrm{d}}{\mathrm{d}t}\omega_b + \boldsymbol{u}_b\nabla\cdot\omega_b$$

- Added parallelized interface for coupling with VorTran-M
- Coupling with CDI's **CHARM** free-vortex wake code accomplished in similar manner, with the CHARM wake solution advanced on the master node and then broadcast to all other nodes

HOW are we doing this?



Solution in a Non-Rotating Frame

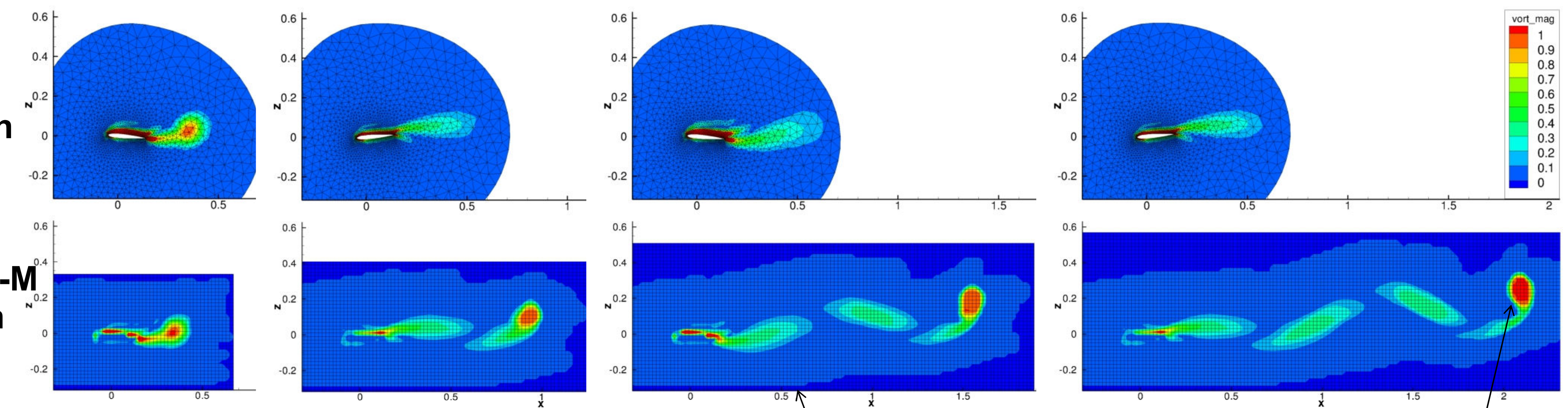
Static wing at 8º angle of attack

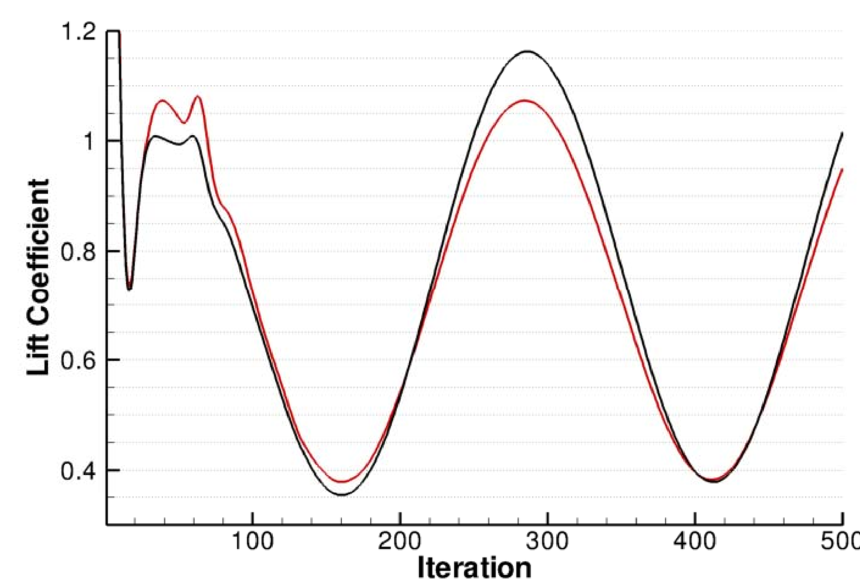
Background grid	VorTran-M wake coupling	C_L	Error* (%)
none	off	0.7732	7.9
farfield to 5c	off	0.7616	6.3
none	on	0.7326	2.2

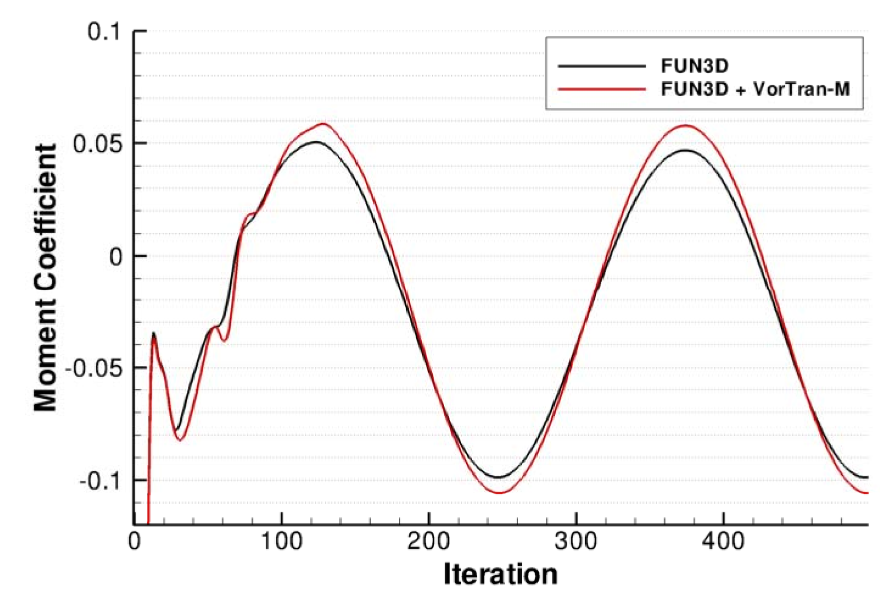
* in comparison with values from Abbott & von Doenhoff with correction for a finite wing:

$$a_{3D} = \frac{a_{2D}}{1 + (a_{2D}/\pi AR)}$$

Pitching wing at 8±5º ($k=\omega b/U_\infty=0.5$)

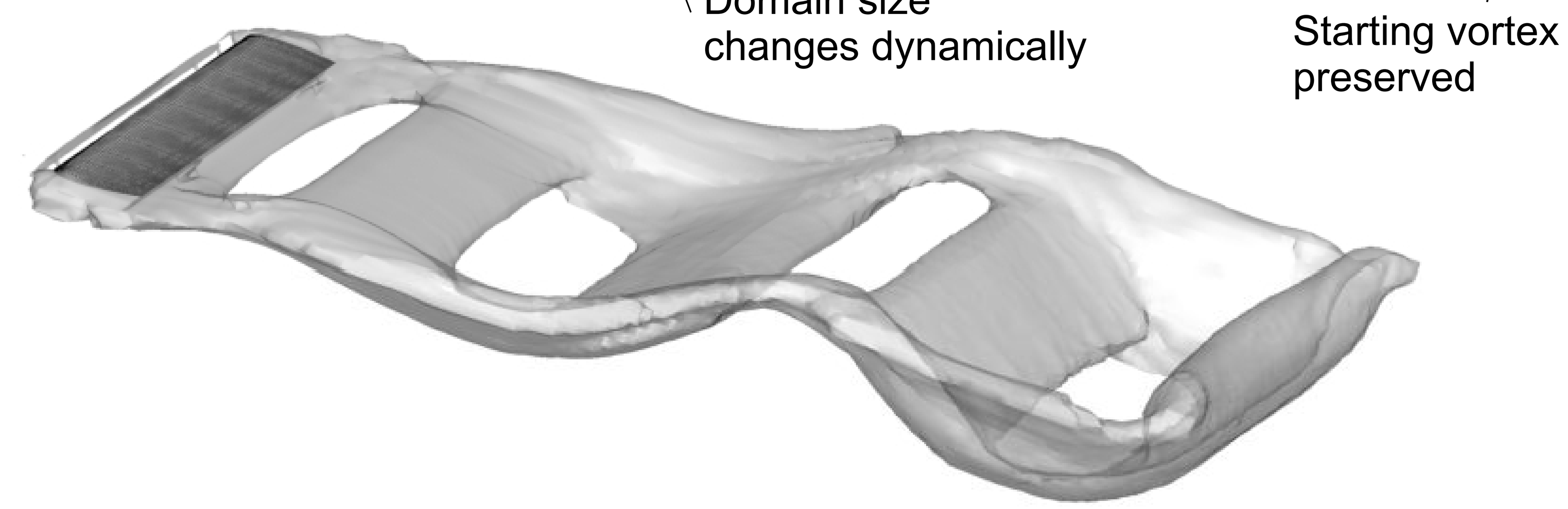






Domain size changes dynamically

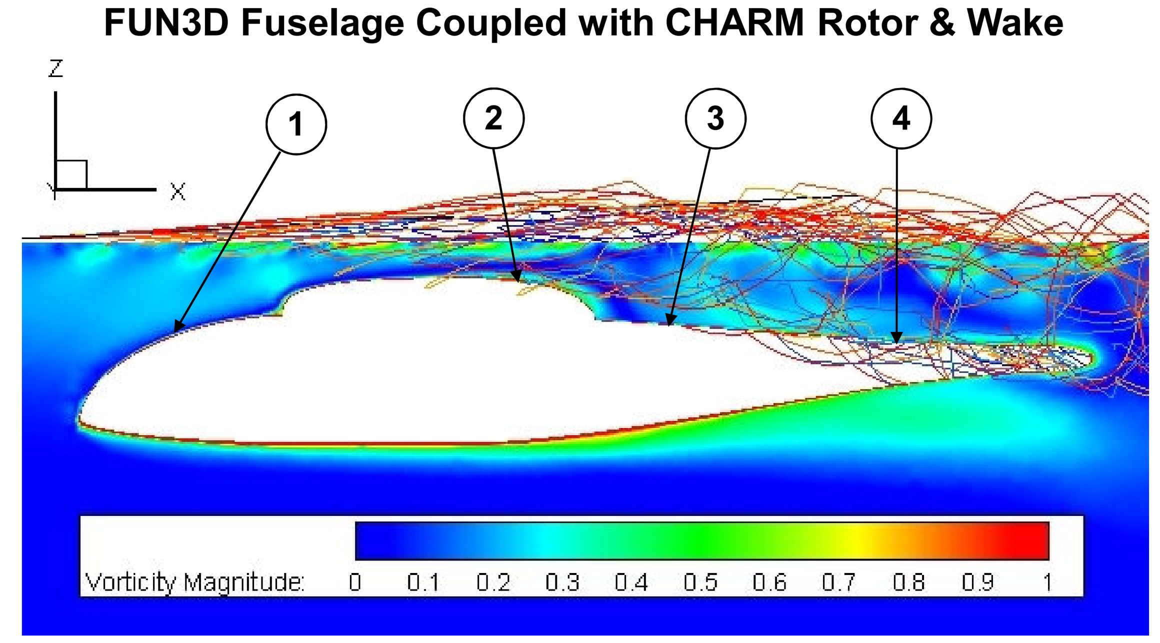
Starting vortex preserved



Solution in a Rotating Frame

Coupling with CHARM: Rotor-Fuselage Interactions

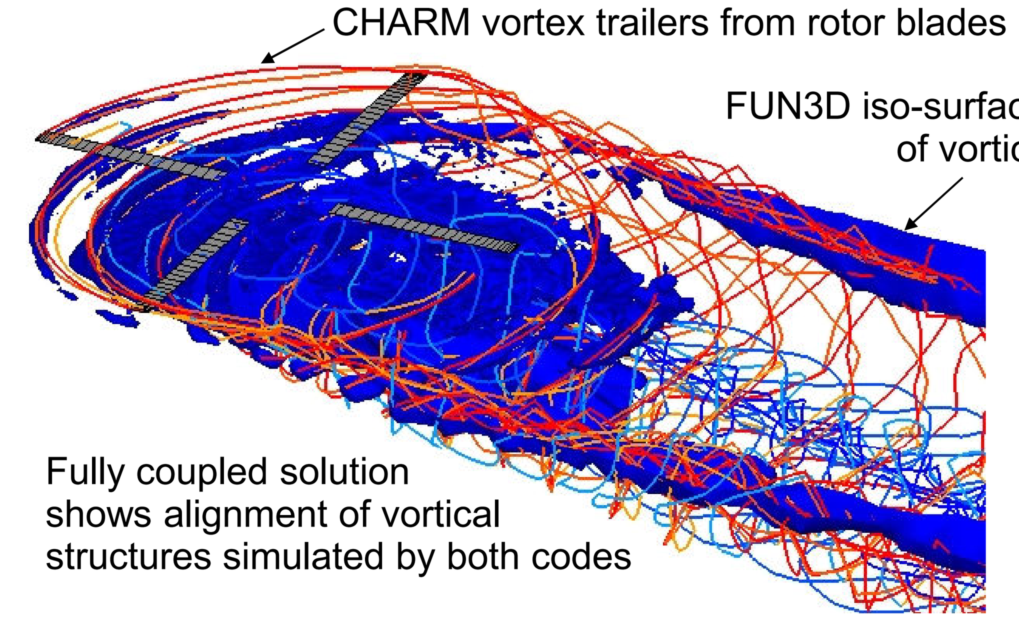
FUN3D Fuselage Coupled with CHARM Rotor & Wake



FUN3D Rotor Coupled with CHARM Fuselage & Wake

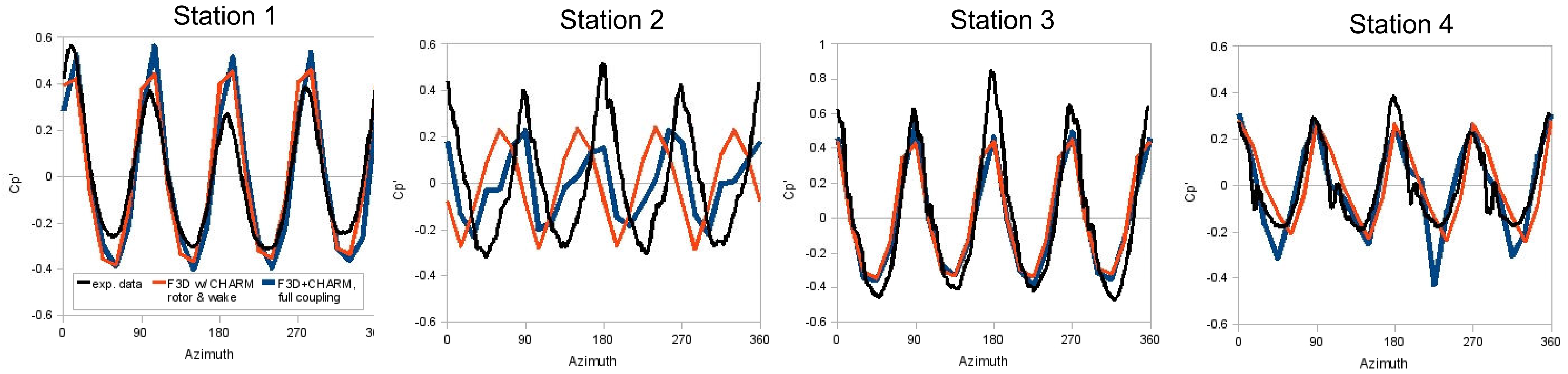
CHARM vortex trailers from rotor blades

FUN3D iso-surfaces of vorticity



Fully coupled solution shows alignment of vortical structures simulated by both codes

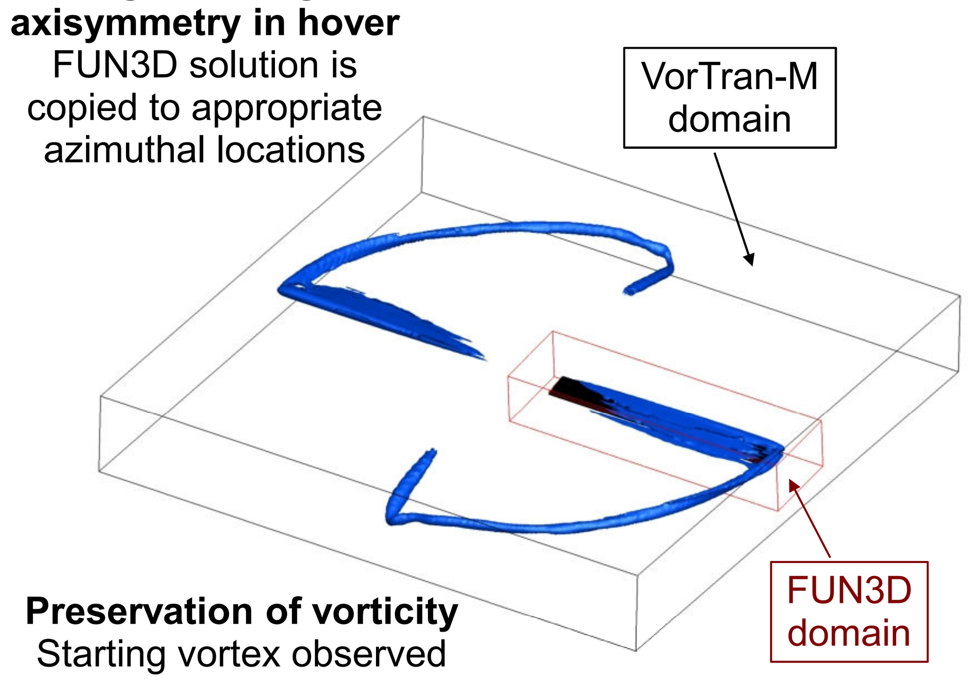
Unsteady Surface Pressures (at locations indicated above)



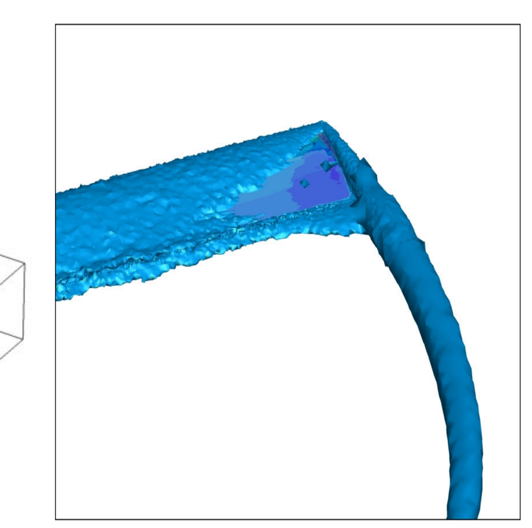
Current Work

- Parallelization of the VorTran-M code by CDI
- Continued investigation of rotary wings and validation of coupled results

Taking advantage of axisymmetry in hover
FUN3D solution is copied to appropriate azimuthal locations



Preservation of vorticity
Starting vortex observed



Combined solution
information passed smoothly

GT Advisor: **Prof. M. J. Smith**
CDI Collaborators: **Dr. G. Whitehouse and Mr. D. Wachspress**
Sponsor: NAVAIR