AIAA-2016-0563

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AMS Seminar Series
NASA Ames Research Center, Feb 23, 2016

Recent Advances in the CREATE™-AV Helios Rotorcraft Simulation Code

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

J. Sitaraman, Parallel Geom Algs LLC
B. Jayaraman, B. Roget, V. Lakshminarayan, J. Leffell, *STC Corp.*
M. Potsdam, R. Jain, *U.S. Army ADD - AFDD*
J. Forsythe, *NAVAIR*
A. Bauer, *Kitware Inc.*

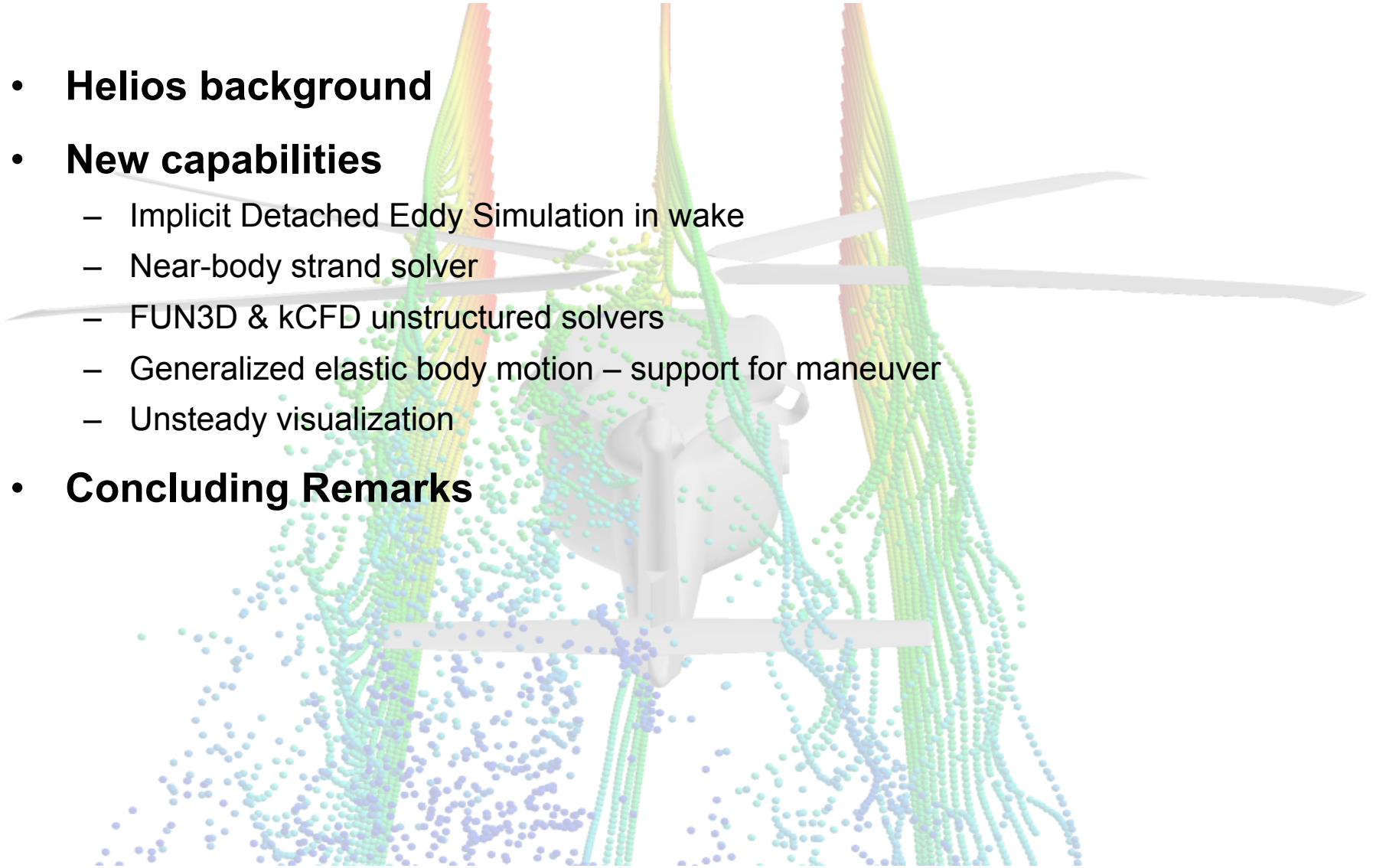
Presented by:

Andrew Wissink

Aerospace Engineer
Aviation Development Directorate - AFDD

Aviation and Missile Research, Development and Engineering Center
Moffett Field, CA

Presentation Outline

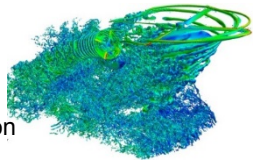


- **Helios background**
- **New capabilities**
  - Implicit Detached Eddy Simulation in wake
  - Near-body strand solver
  - FUN3D & kCFD unstructured solvers
  - Generalized elastic body motion – support for maneuver
  - Unsteady visualization
- **Concluding Remarks**

Helios code

- **Helios is the Rotary-wing product of the CREATE™-AV program**
  - Relative motion, complex geometry, multi-mesh
  - Targets govt rotary-wing acquisition programs

H-47 tandem simulation
Courtesy Boeing

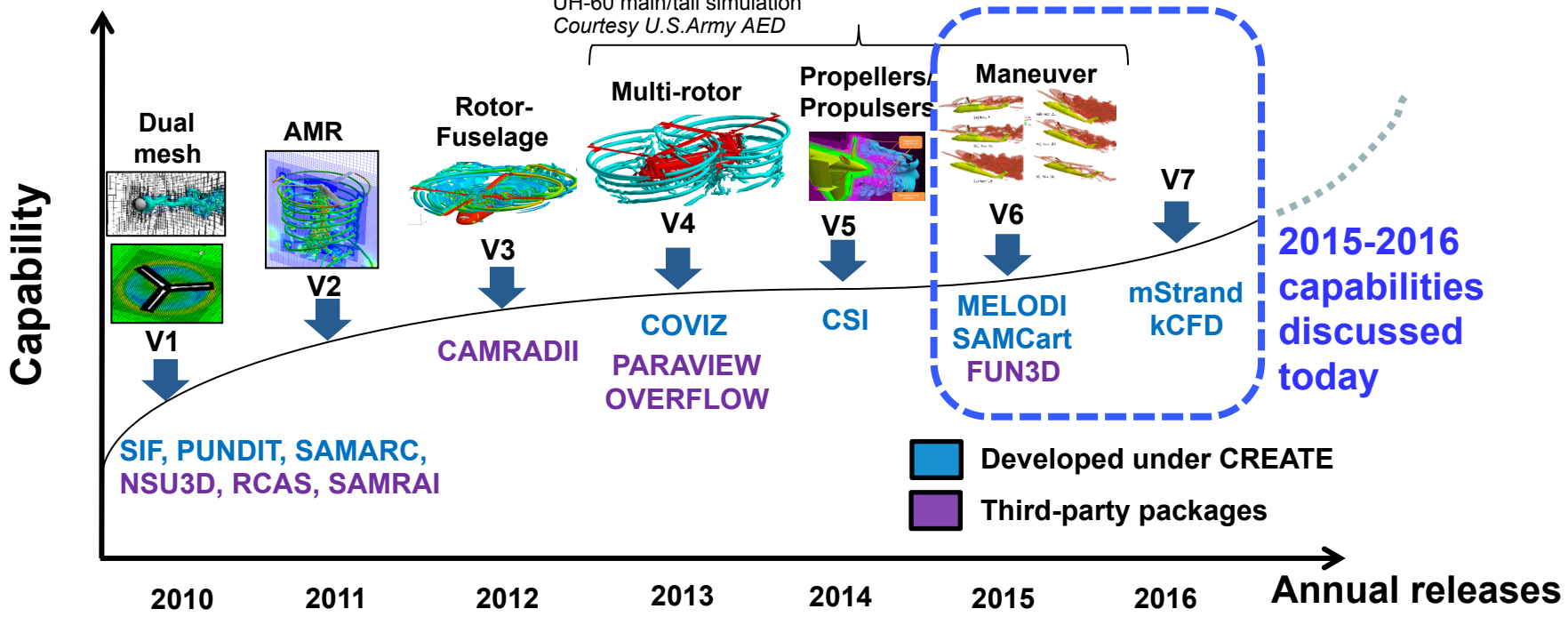


UH-60 main/tail simulation
Courtesy U.S.Army AED

JMR "Defiant"
Courtesy Boeing/Sikorsky

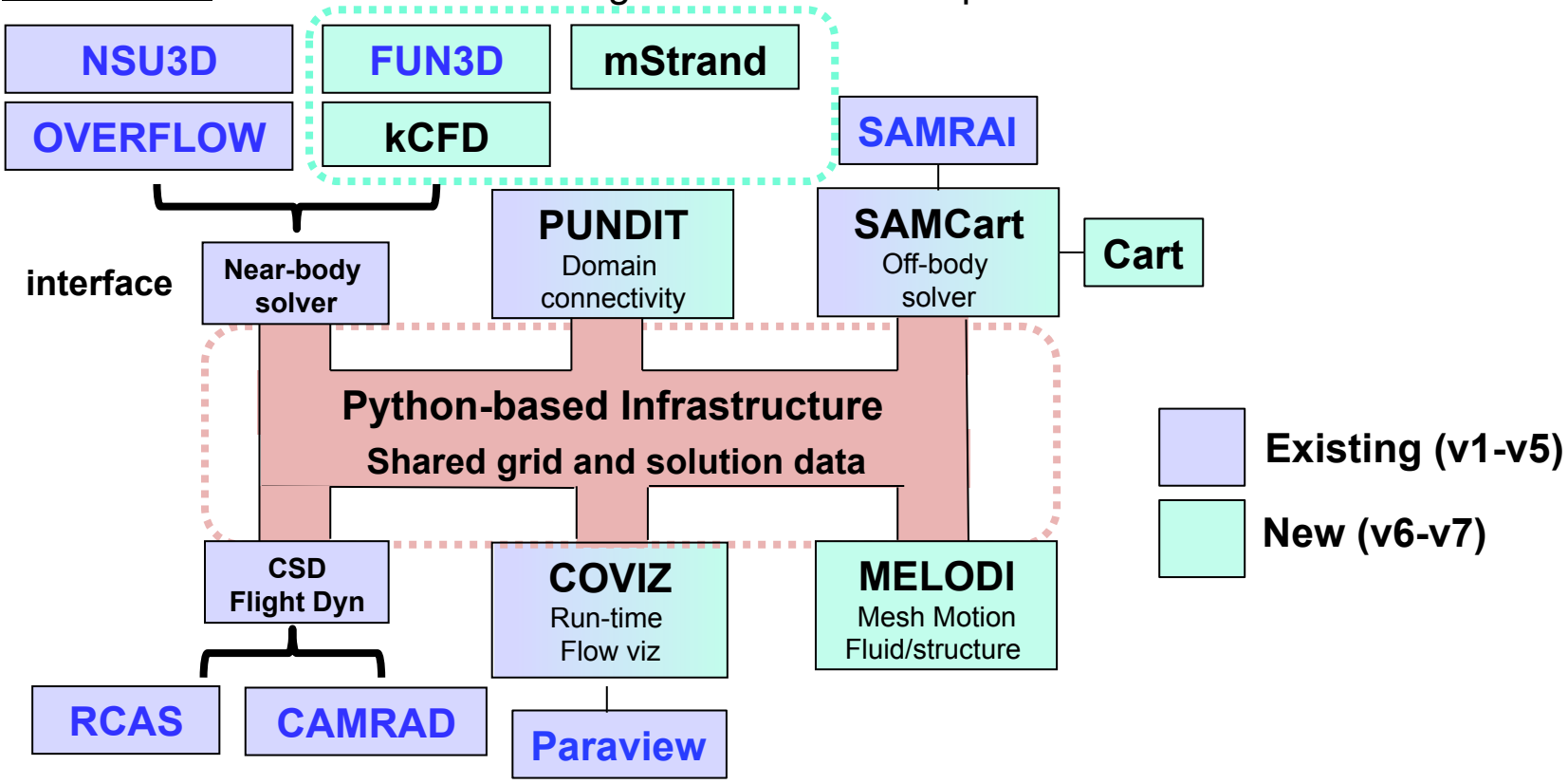
JMR "Valor"
Courtesy Bell Helicopter

Army programs using Helios



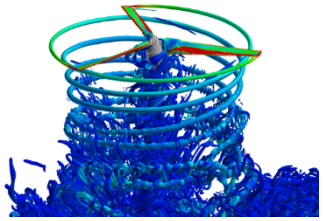
Components Recently Added to Helios

- **Developments to existing codes and addition of new codes**
- **Extensible infrastructure supports components developed under CREATE as well as those developed externally**
  - External codes have wide user base and trusted validation
  - New codes introduce advanced algorithms and concepts

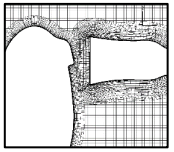


New Capabilities

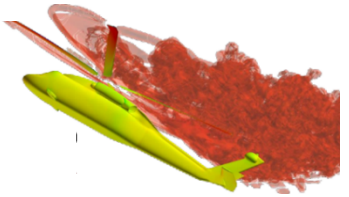
- **Implicit off-body solver with DES**
  - Leffell et al, AIAA-2016-0066, *Mon 9:00am*



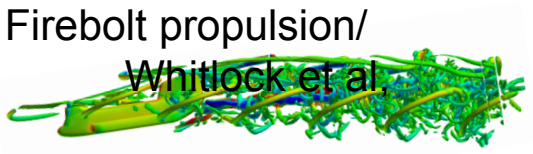
- **Near-body Strand solver**
  - Lakshminarayan et al, AIAA-2016-1581, *Thur 9:00am*



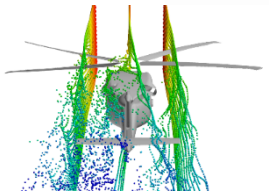
- **Support for complex generalized aeroelastic motions & maneuver**
  - Roget et al, AIAA-2016-1057, *Wed 12:00pm*



- **New unstructured near-body solver options**
  - **FUN3D**: New turbulence models, transition, near-body AMR, optimization
    Jain et al, AIAA-2016-1298, *Thur 2:30pm*
  - **kCFD**: Interfaces to CASTLE® flight dynamics model and Firebolt propulsion/ airframe integration model
    AIAA-2016-1928, *Thur 4:00pm*



- **New unsteady in-situ flow visualization**

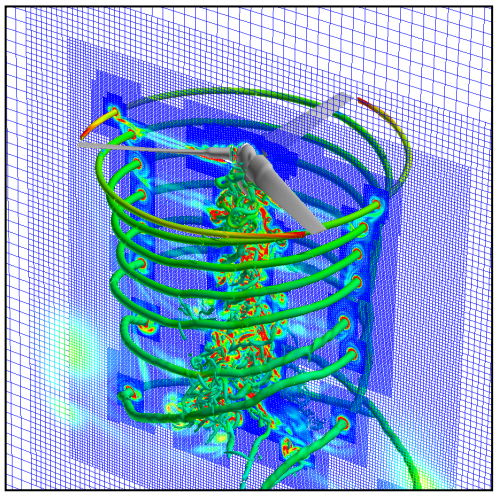


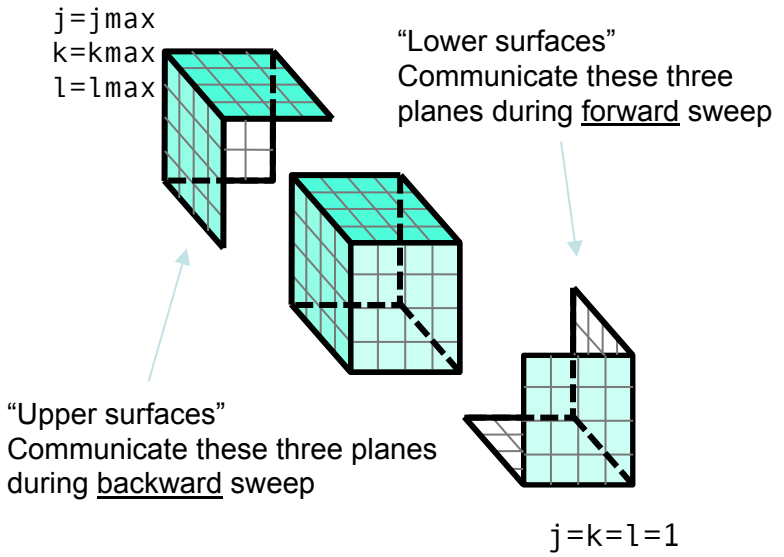
SAMCart off-body Solver

- **Replaced ARC3D (used in SAMARC) with new "Cart" solver**
- **Implicit solver added**
  - Explicit is fast and efficient but suffers from timestep restrictions
  - Implicit – local & global
    - LU-SGS
    - ADI – diagonally dominant variation
    - Gauss Seidel Line relaxation
  - Viscous w 4th-Order terms
  - SA & DES turb modeling
- **Global implicit scheme intended for running on large number of processors**

More details

Leffell et al
AIAA-2016-0066

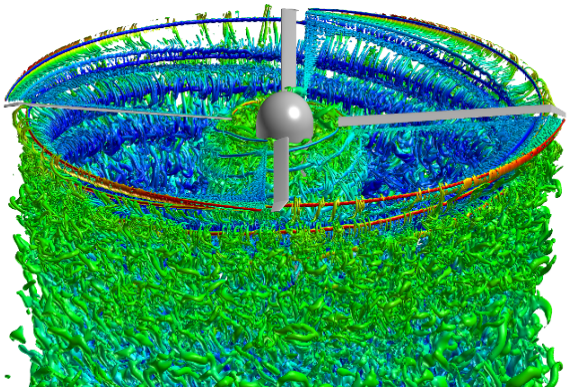




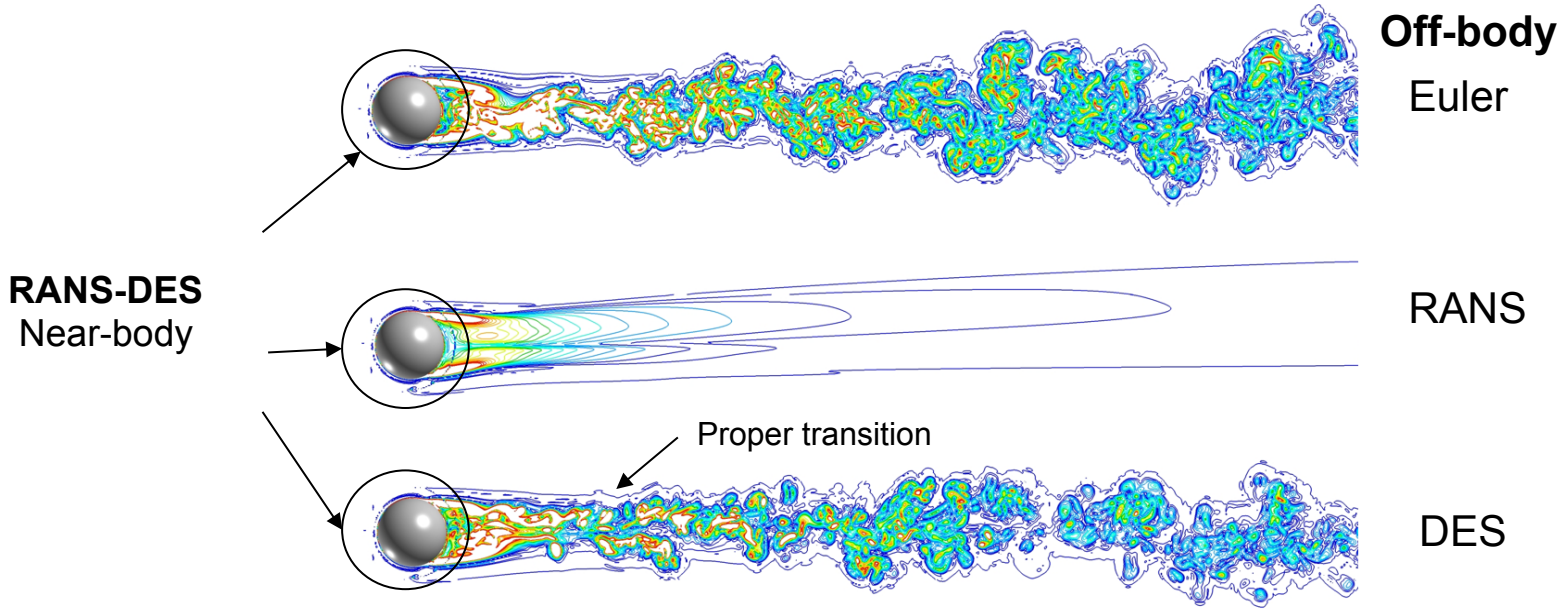
Global implicit LU-SGS formulation

Implicit DES Off-body

- **Detached Eddy Simulation**
  - RANS with SA turbulence model near the wall
  - LES everywhere else
  - Improved resolution of turbulent wake
- **DES enabled by implicit solver**
  - Helios v4-v5 SAMARC had explicit DES but stability issues prevented widespread use
  - Helios v6 implicit solver provides stability for DES with larger timesteps



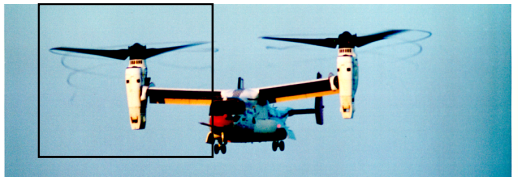
S76 Rotor – R. Jain



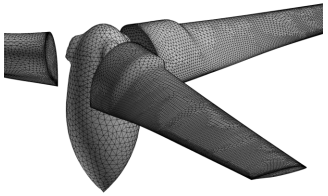
TRAM Rotor

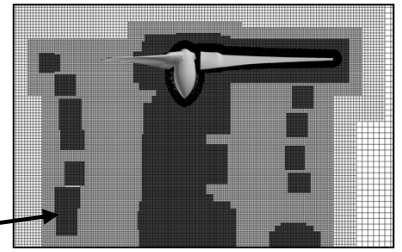
- **Tilt Rotor Aeroacoustics Model (TRAM)**
  - Quarter-scale model V-22 Osprey
  - Tested in DNW-LLF facility
  - Definitive dataset for CFD validation
- **Computational conditions**
  - Isolated hover
  - Rigid blade
  - 15 revs, 0.25 deg/timestep
  - M_{tip}=0.625, Re_{Tip}=2.1M
- **Unstructured/Cartesian grid**
  - Blade – 56K surf nodes surf, viscous
  - Centerbody – 1.4K surf nodes, inviscid
  - Rotor off-body – 0.05c finest level
  - Near body: 8M nodes
  - Off-body: 13M-315M nodes
  - 576 procs Cray XC30
  - Compute stats in paper

0.25-scale TRAM

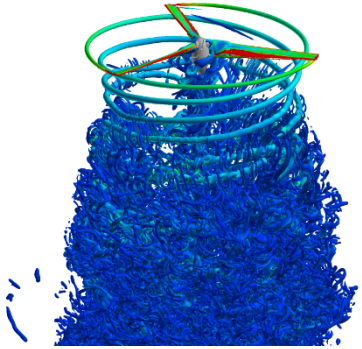


V-22 Osprey



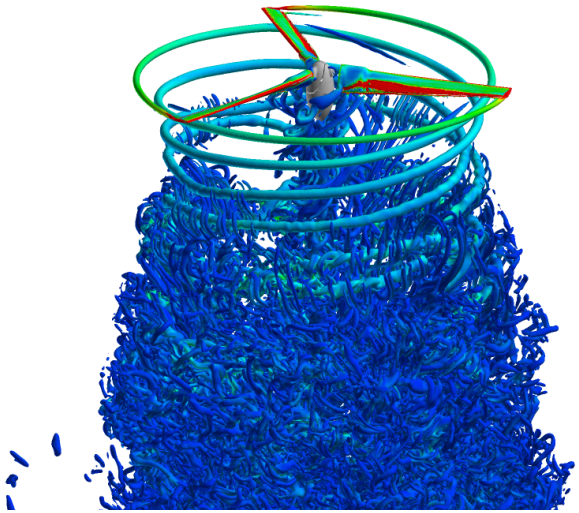


5% chord finest resolution

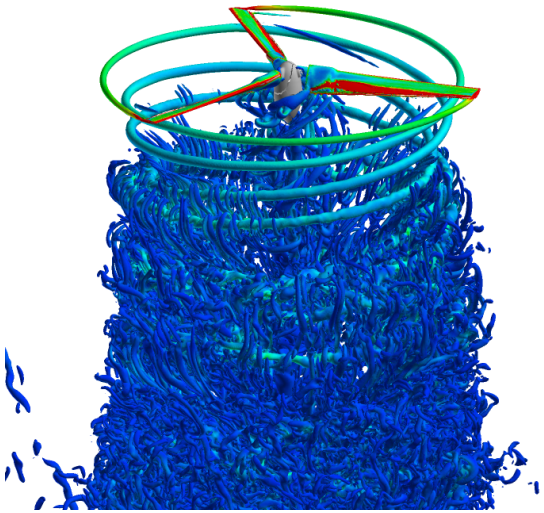


Implicit Off-body
Accuracy

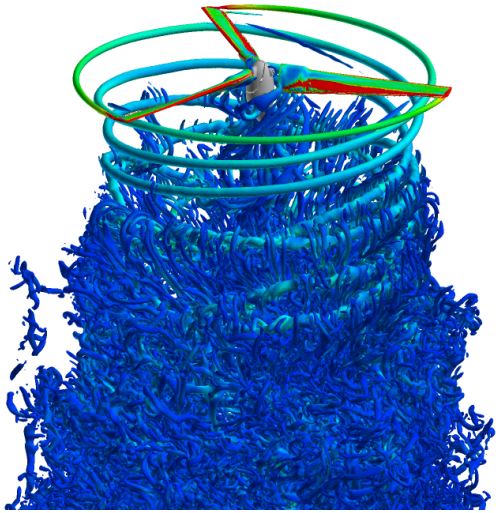
Explicit RK3 Euler



Implicit BDF2 Euler



Implicit BDF2 DES

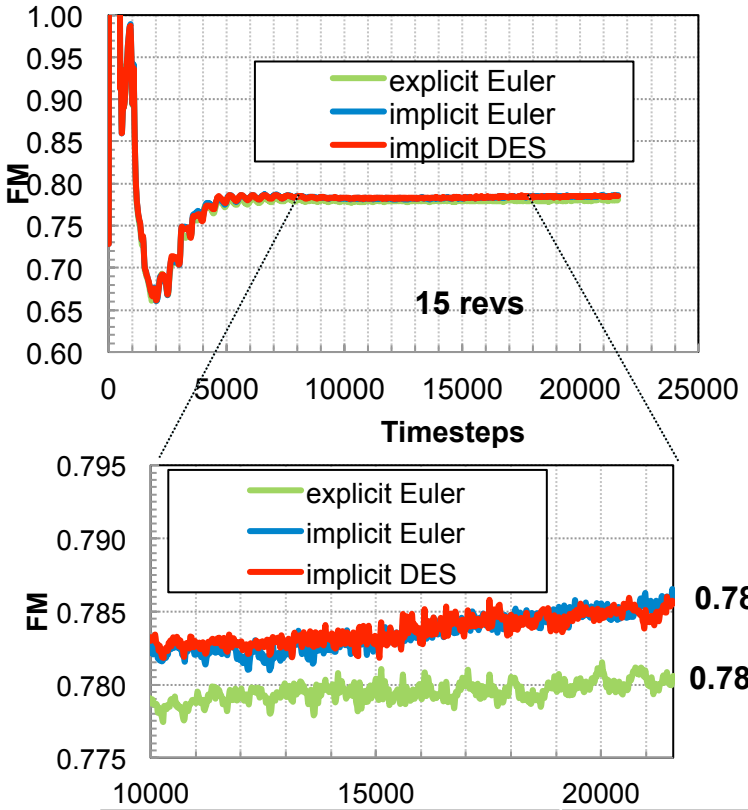


15 revs	Thrust C_T/σ	Power C_Q/σ	Figure of Merit	% Diff from Experiment
Experiment	*0.1495*	*0.01596*	***0.774***	--
Explicit RK3 Euler	0.1474	0.01662	**0.780**	**+0.6%**
Implicit BDF2 Euler	0.1488	0.01675	**0.785**	**+1.0%**
Implicit BDF2 DES	0.1488	0.01675	**0.785**	**+1.0%**

Biggest difference explicit vs implicit

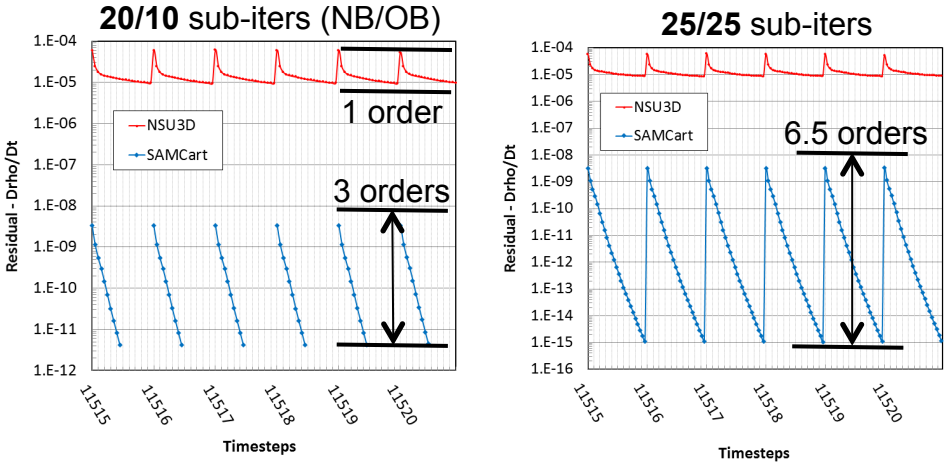
Nearly identical results

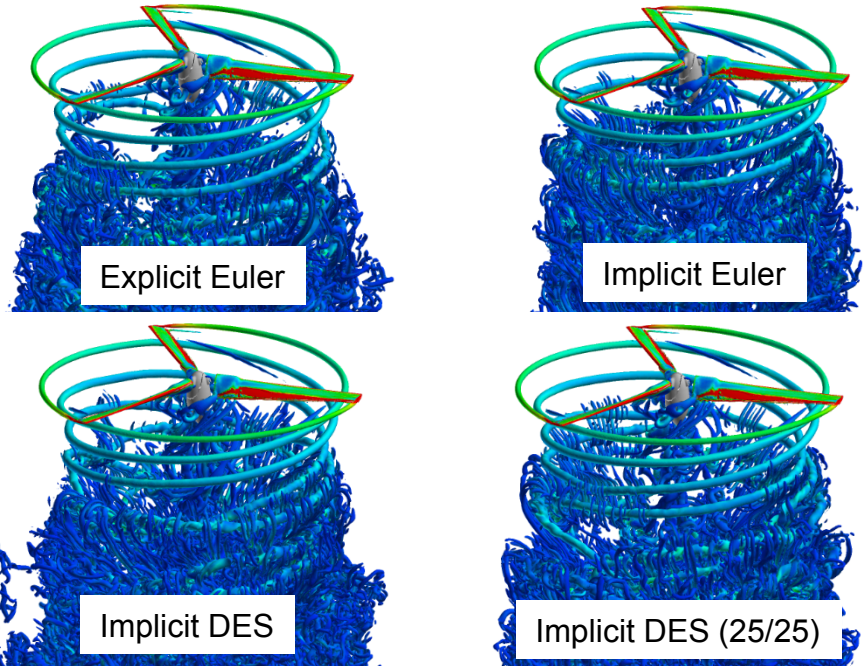
Implicit off-body
Convergence & Soln Time



Off-body solver	Time/step
Explicit Euler	16.5 sec
Implicit Euler	18.9 sec
Implicit DES	26.3 sec
Implicit DES (25/25)	55.5 sec

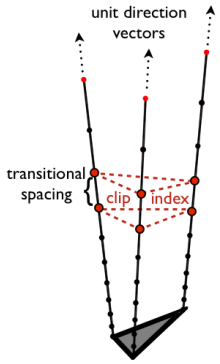
Implicit BDF2 Sub-iteration convergence





Strands

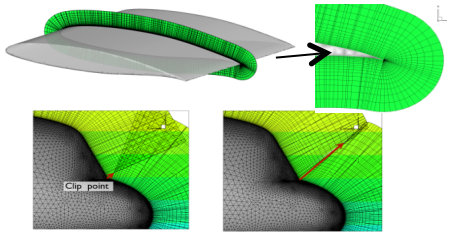
- **Overarching goal is <u>automated</u> near-body mesh generation**
  - Multi-strand generation from CAD
    R. Haimes
  - Fast parallel overset connectivity
    J. Sitaraman
  - High order strand solver



Strands

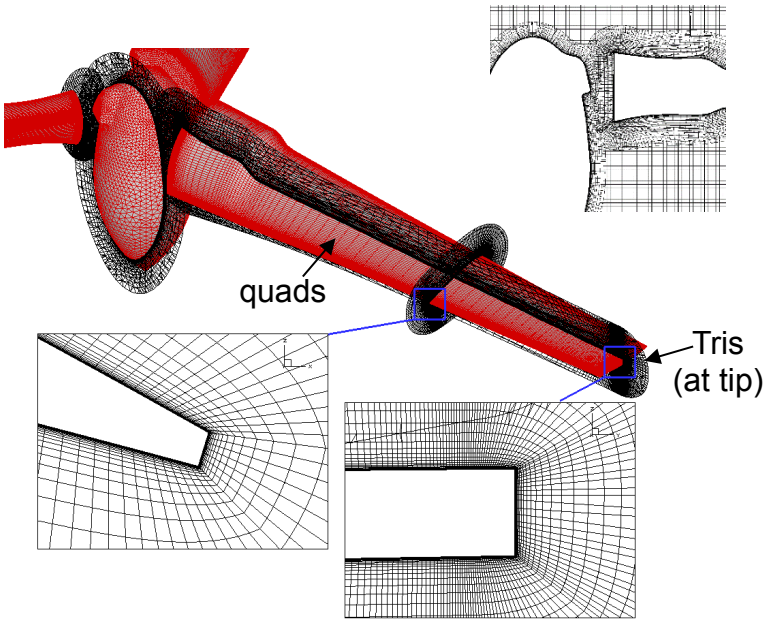
Complex geometries

Automatic strand mesh generation



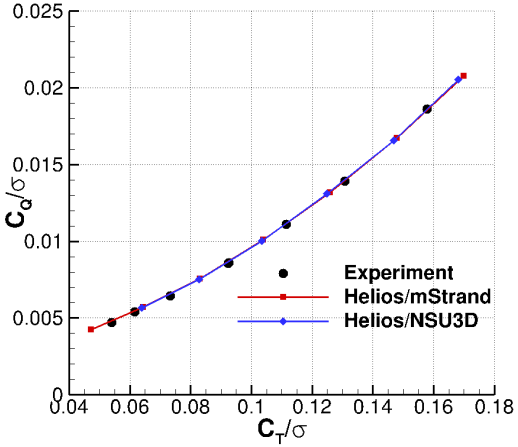
MOSS

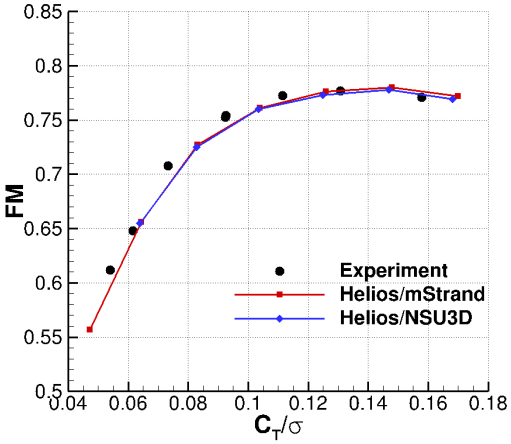
- **mStrand Solver**
  V. Lakshminarayan
  - 2nd Order FV gradient-based spatial discretization
  - 2nd Order BDF2 time integration w GMRES
  - Supports quad and tri surface elements
  - Spalart-Allmaras turbulence model
  - Supports multi-strand meshes generated by CREATE™ Capstone

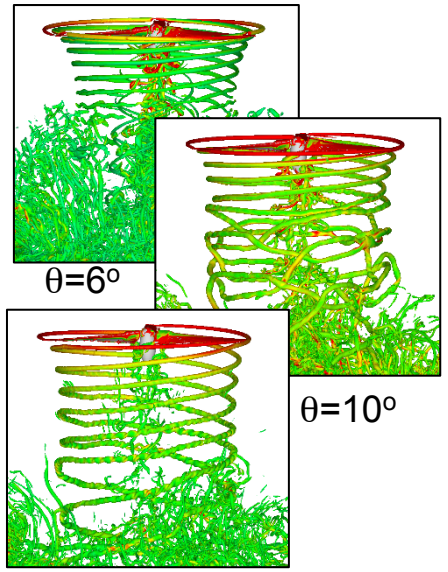


mStrand Solver

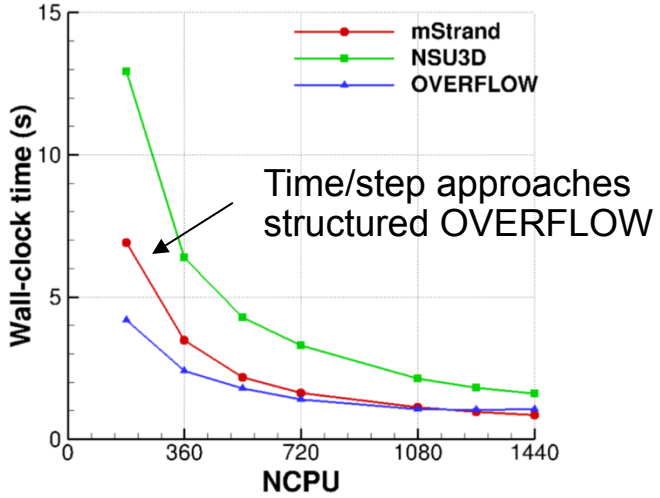
- **Accuracy commensurate with best solutions we obtain with NSU3D**

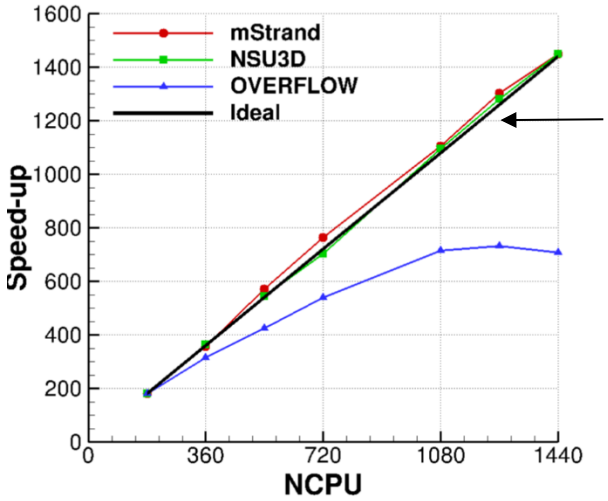






- **Good computational performance**





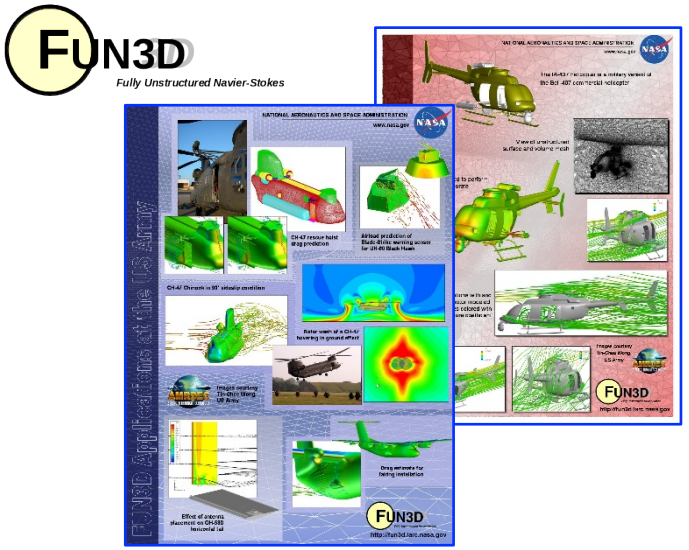
Scalability on par with unstructured NSU3D

More details

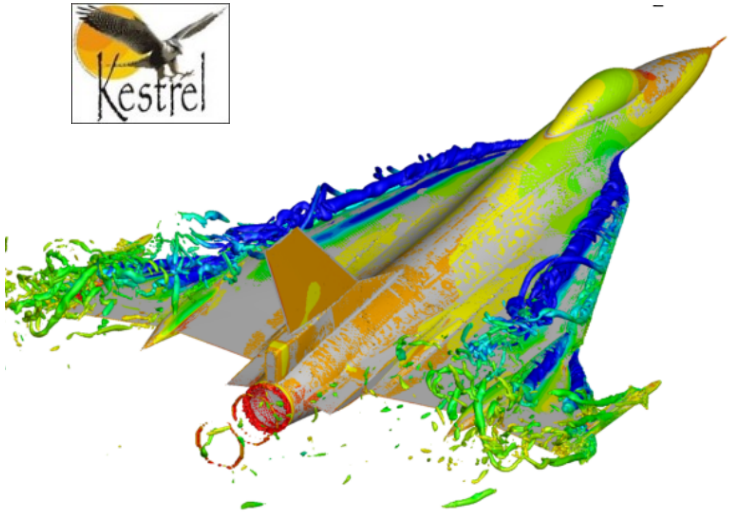
Lakshminarayan et al
AIAA-2016-1581

New Unstructured Solvers

- **FUN3D**
  - NASA's primary unstructured code, broad userbase in govt, industry, academia
  - Developed, maintained, and supported by NASA Langley since 1980s
  - Advanced turbulence and transition models
  - Near-body AMR
  - Adjoint-based optimization and error estimation
  - Multiple chemical species
- **kCFD**
  - Developed by CREATE™-AV Kestrel team
  - Large and growing userbase in DoD for fixed-wing and store separation problems
  - Interfaces to flight dynamics packages like CASTLE®
  - Firebolt airframe/propulsion engine integration model

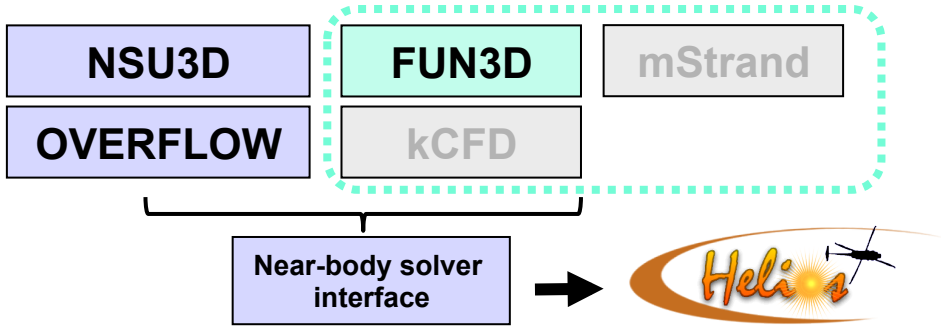


Courtesy: http://fun3d.larc.nasa.gov

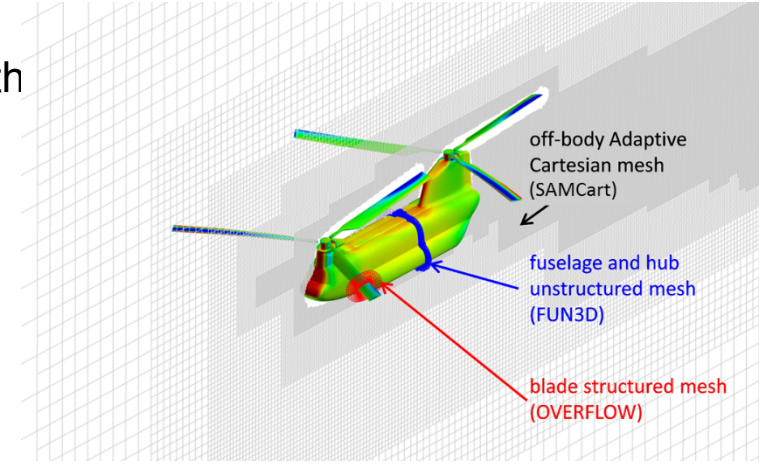


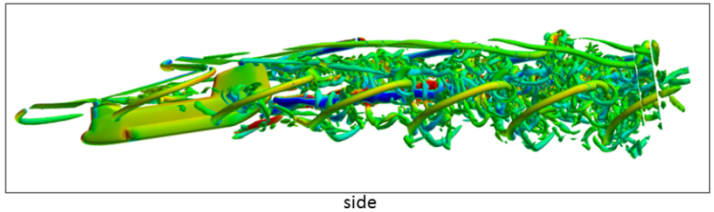
FUN3D

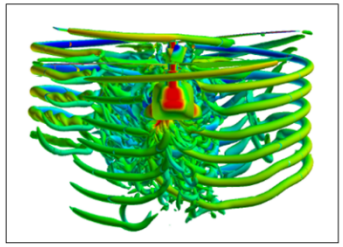
- **Uses Helios near-body solver interface**
  - Same interface used for NSU3D, OVERFLOW, mStrand

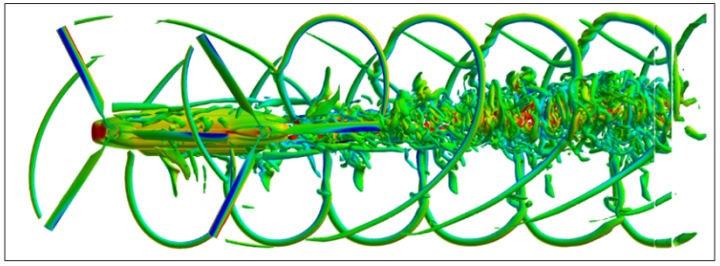


- **Demonstrated for tandem H-47**
  - Blades modeled with OVERFLOW, Fuselage with FUN3D, wake with SAMCart
  - Rotor structural dynamics modeled with RCAS
  - Steady free-flight trim




side


front

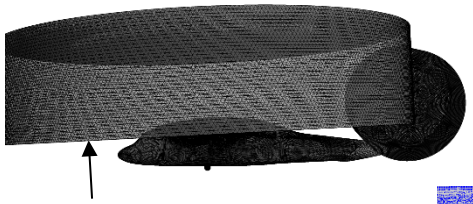

top

More details

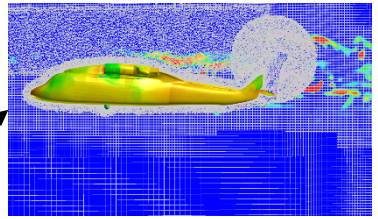
Jain et al
AIAA-2016-1581

kCFD

- **Utililizes AV-Core package**
  J. Forsythe
  - Interchangeable with other Helios solvers
  - Utilizes Kestrel mesh manager, output manager, event-based execution

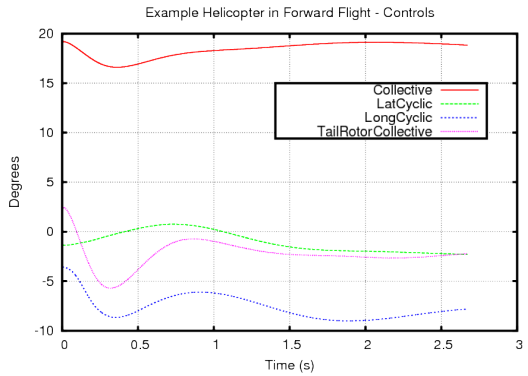


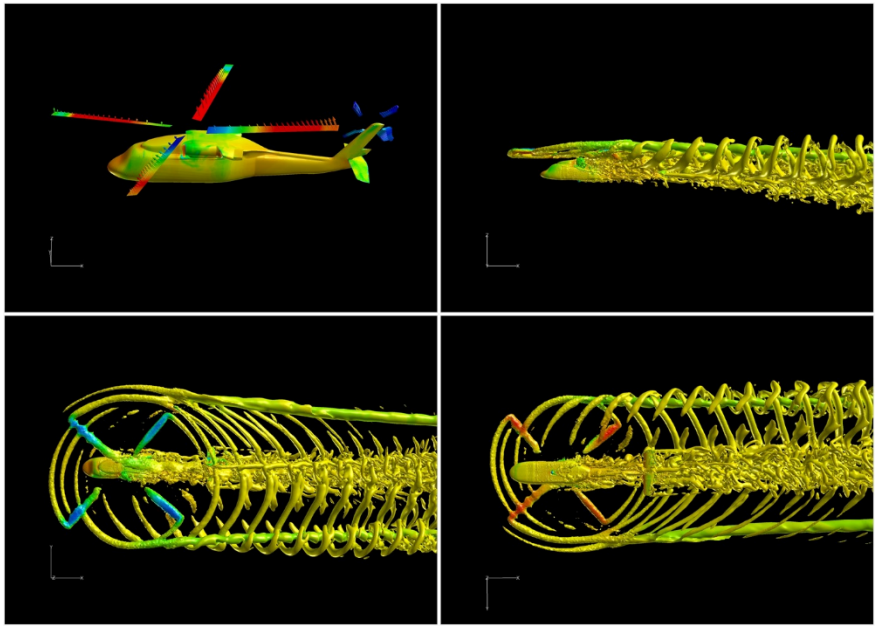
kCFD Near-body grid



SAMCart off-body

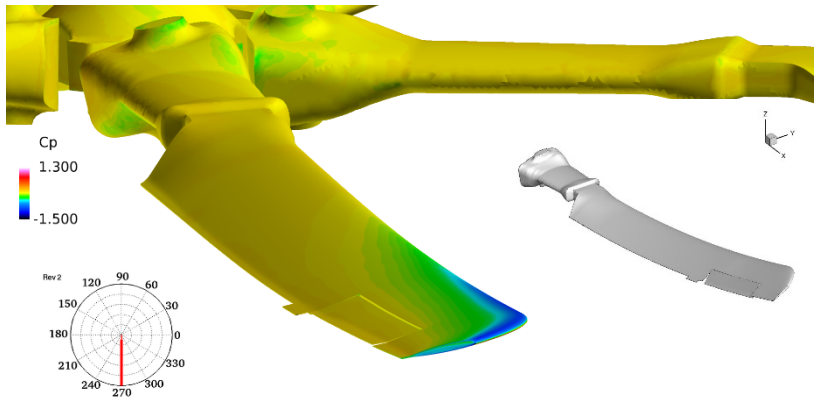
- **Demonstrated for Navy "Example Helicopter" (ExHel)**
  - Generic UH-60 like configuration
  - Flight dynamics managed by CASTLE®
  - Blades modeled by actuator line model (CastleCoupler, *AIAA-2015-0556*)



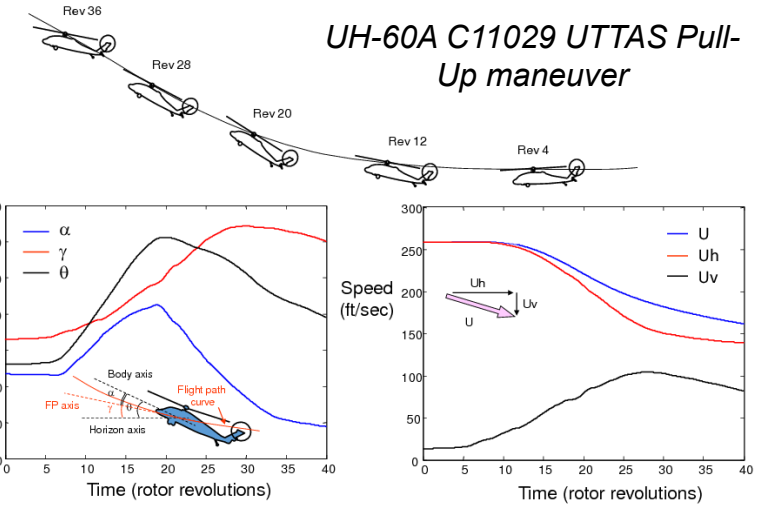


Melodi

- **Mesh Motion, Loading, and Deformation Interface (Melodi)**
  - Generalized hierarchical representation of bodies and frames supporting rigid-body and aeroelastic motion
  - Replaces the old mesh motion (mmm), flight/ fluid dynamics interface (ffdi), and fluid structure interface (fsi) in past versions
  - Supports multiple-connected rigid and elastic motions for rotors, wings, and fuselage

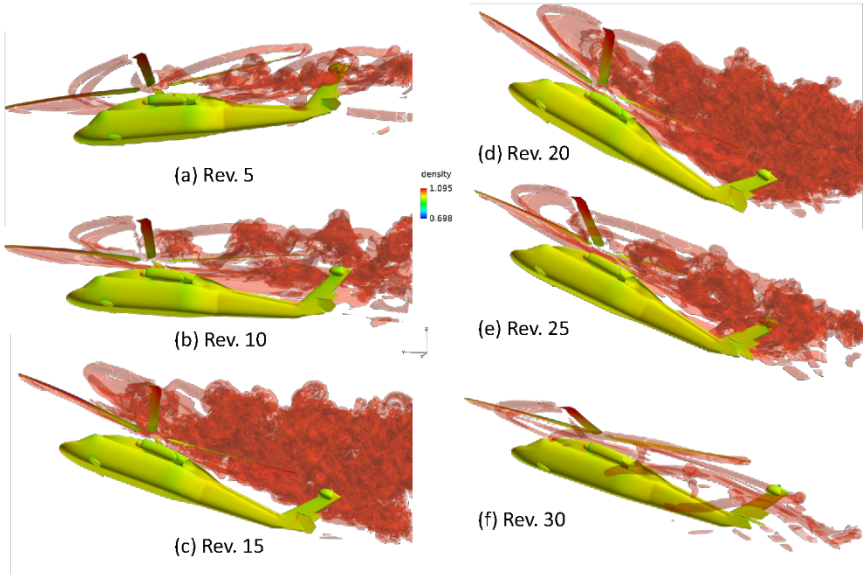


UH-60A C11029 UTTAS Pull-Up maneuver



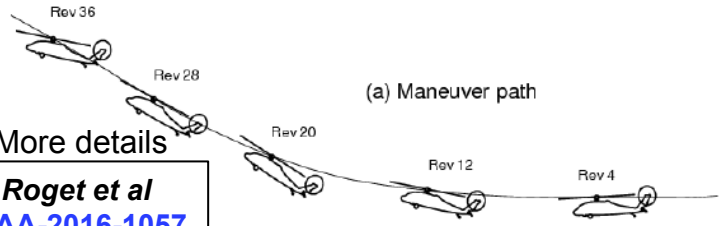
(b) Variation of aircraft angle of attack, pitch attitude, and flight path angle

(c) Variation of air velocity



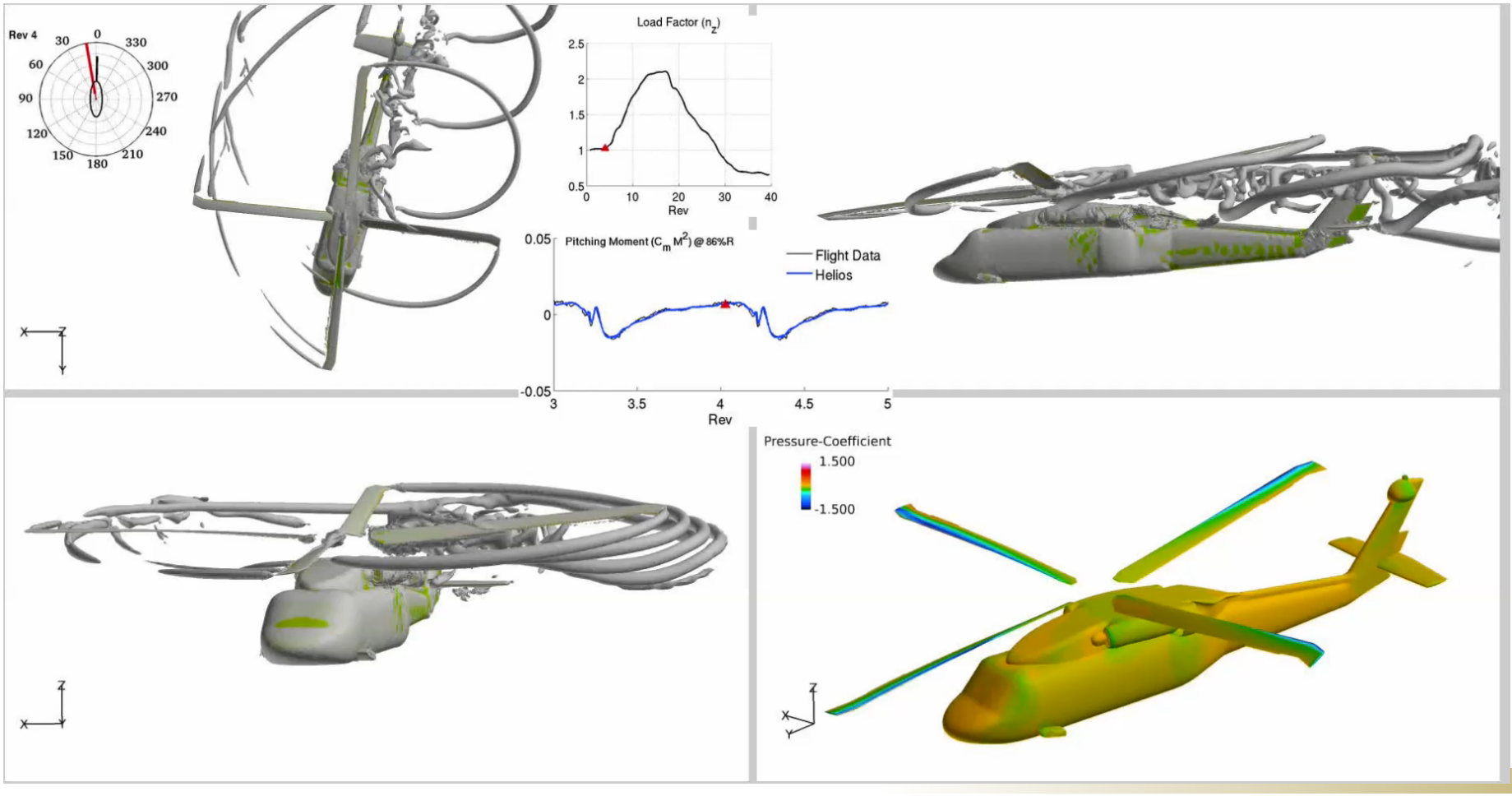
Maneuver

- **UH-60A C11029 UTTAS Pull-Up maneuver**
  - 40 revs, 9 sec (real-time)
  - Flight path angle 3 deg at start to 35 deg at end



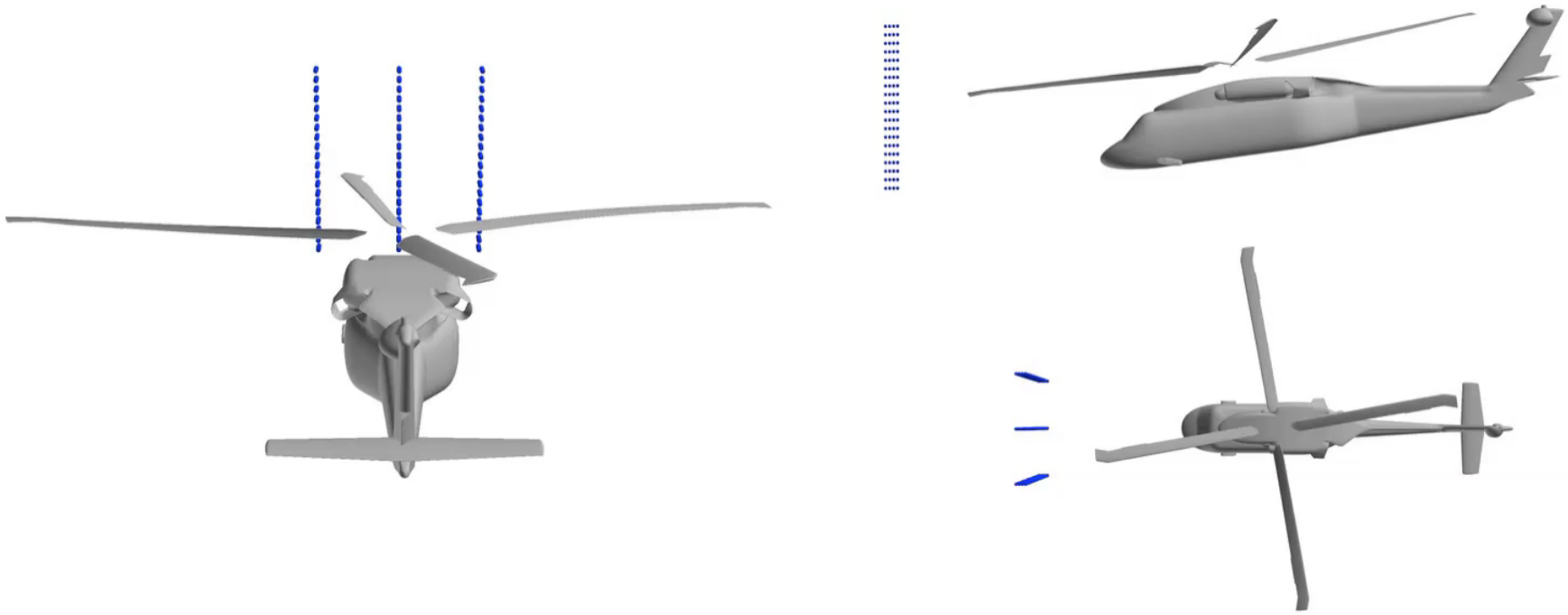
More details

Roget et al
AIAA-2016-1057



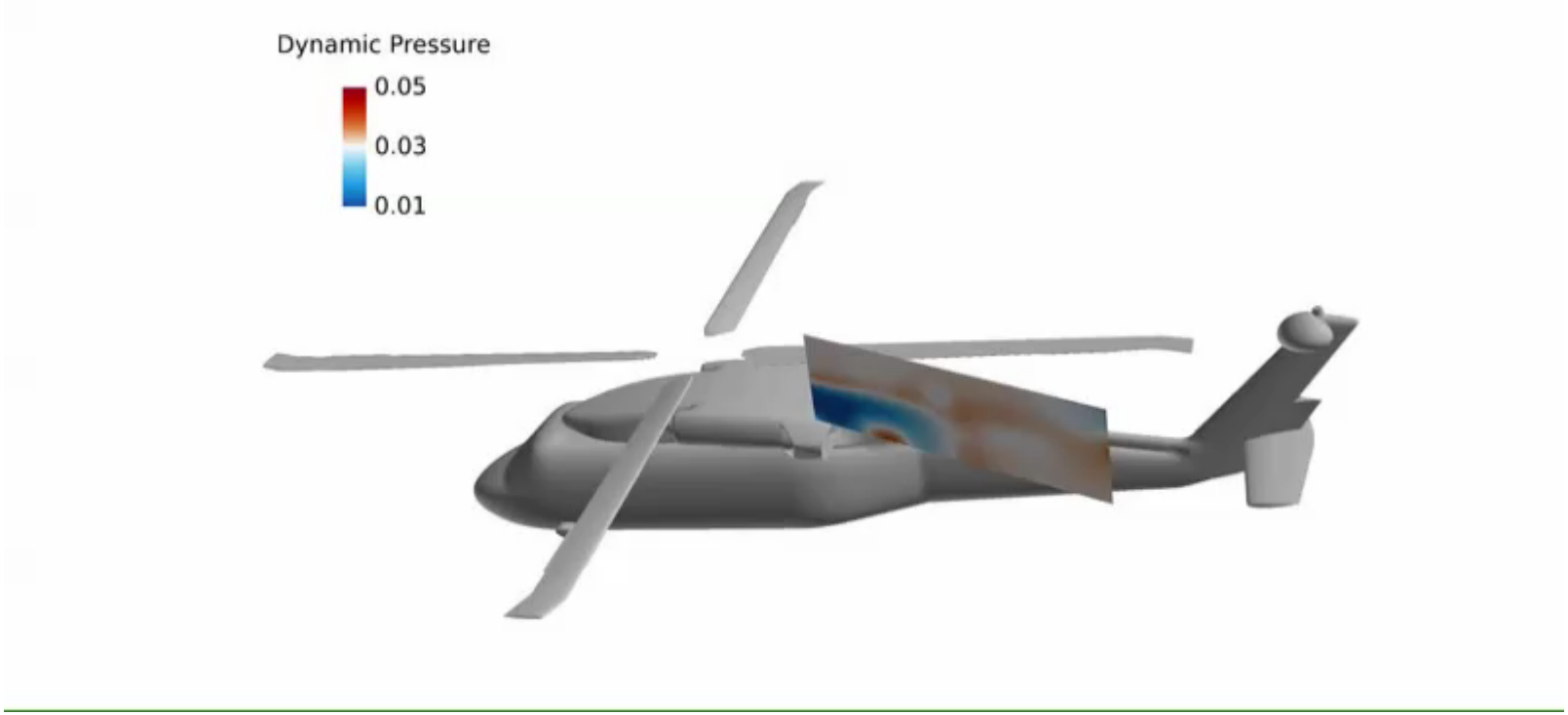
Unsteady Visualization

- **In-Situ co-visualization – particle traces**
  - Coviz introduced in Helios v4 (2013)
  - Generates “extracts” in fieldview and paraview formats during the simulation
  - Utililzes parallel HPC resources and avoids massive data transfers
  - Leverages visualization capabilities from Paraview
  - Particle traces added in v6



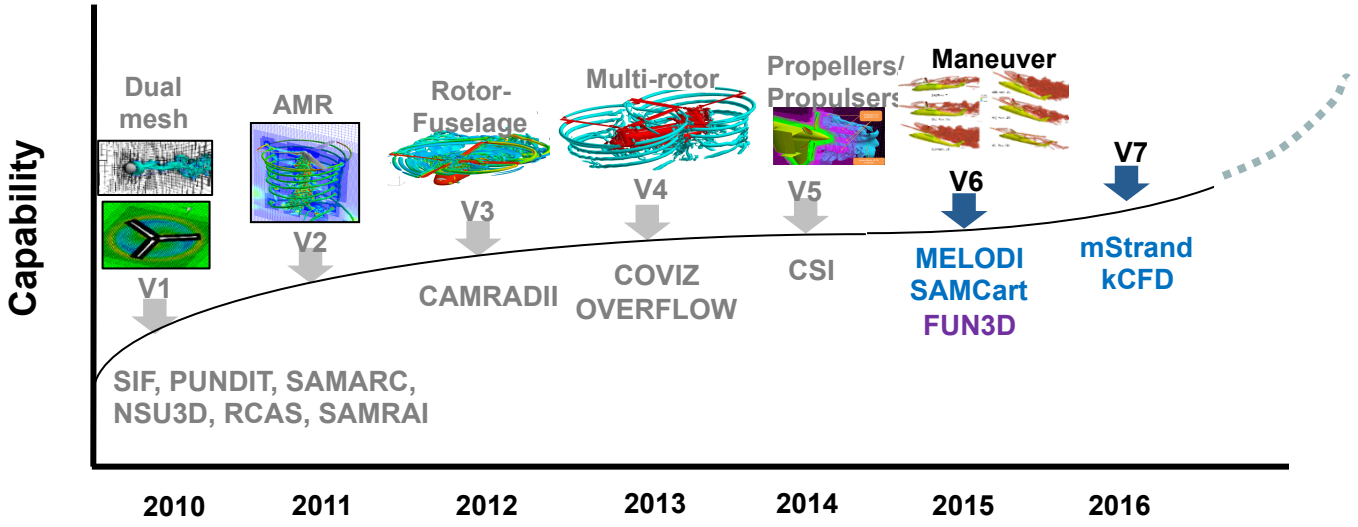
Unsteady Visualization Cont

- **Moving contour planes**
  - Size, location, and resolution of contour plane specified in input
  - Outputs quantities of interest (e.g. max velocity) on the plane to *.csv file for quantitative analysis



Concluding Remarks

- **Helios version 6 & 7 add a number of key new capabilities**
  - Improved turbulent modeling of wake (implicit DES off-body) – Hv6.0 *released*
  - Incorporation of FUN3D unstructured near-body solver – Hv6.1 *Spring 2016*
  - In-situ particle traces & moving planes – Hv6.1 *Spring 2016*
  - Support for maneuver – Hv6.1 *Spring 2016*
  - Automation and efficiency with new Strand near-body solver – Hv7.0 *Fall 2016*
  - Interfaces to CASTLE and Firebolt engine/airframe integration through kCFD – Hv7.0 *Fall 2016*
- **Advances enabled by extensible infrastructure**



Automated meshing
Unsteady transition
Multi-species flow
Engine/airframe
3D Structures
High order solvers
Design optimization
etc…

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