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

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Presented by:
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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
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

Components:
- NSU3D
- FUN3D
- mStrand
- OVERFLOW
- kCFD
- SAMRAI
- SAMCart
- CART
- Near-body solver
- PUNDIT
- Domain connectivity
- SAMCart
- Off-body solver
- Python-based Infrastructure
  - Shared grid and solution data
  - CSD Flight Dyn
  - COVIZ Run-time Flow viz
  - MELODI Mesh Motion Fluid/structure
  - RCAS
  - CAMRAD
  - Paraview

Existing (v1-v5)
New (v6-v7)
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

Leffell et al
AIAA-2016-0066

Global implicit LU-SGS formulation

j=k=l=1

“Lower surfaces”
Communicate these three planes during forward sweep

“Upper surfaces”
Communicate these three planes during backward sweep

j=jmax
k=kmax
l=lmax

More details
• 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
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
  - $M_{\text{tip}}=0.625$, $Re_{\text{Tip}}=2.1M$

- **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
### Implicit Off-body Accuracy

**Explicit RK3 Euler**

<table>
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<th>15 revs</th>
<th>Thrust $C_T/\sigma$</th>
<th>Power $C_Q/\sigma$</th>
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</table>

**Implicit BDF2 Euler**

**Implicit BDF2 DES**

**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
**Strands**

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

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

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**Complex geometries**

**Automatic strand mesh generation**

**MOSS**

**quads**

**Tris (at tip)**
mStrand Solver

- Accuracy commensurate with best solutions we obtain with NSU3D

![Graphs showing comparison between mStrand and NSU3D]

- Good computational performance

![Graphs showing computational performance]

More details: Lakshminarayan et al. AIAA-2016-1581
• **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
• **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

**More details**

*Jain et al*

*AIAA-2016-1581*
• **Utilizes AV-Core package**  
  *J. Forsythe*
  - Interchangeable with other Helios solvers
  - Utilizes Kestrel mesh manager, output manager, event-based execution

• **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)
• 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
• **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

*Roget et al*
*AIAA-2016-1057*
• **In-Situ co-visualization – particle traces**
  
  – Coviz introduced in Helios v4 (2013)
  
  – Generates “extracts” in fieldview and paraview formats during the simulation
  
  – Utilizes parallel HPC resources and avoids massive data transfers
  
  – Leverages visualization capabilities from Paraview
  
  – Particle traces added in v6
• **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**

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

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