HPCMP CREATE^{TM}-AV Kestrel Dual Mesh Computations on the ROBIN Fuselage

Jennifer Abras

NAVAIR Applied Aerodynamics and Store Separation Branch

Nathan Hariharan

HPCMP CREATE-AV

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Background

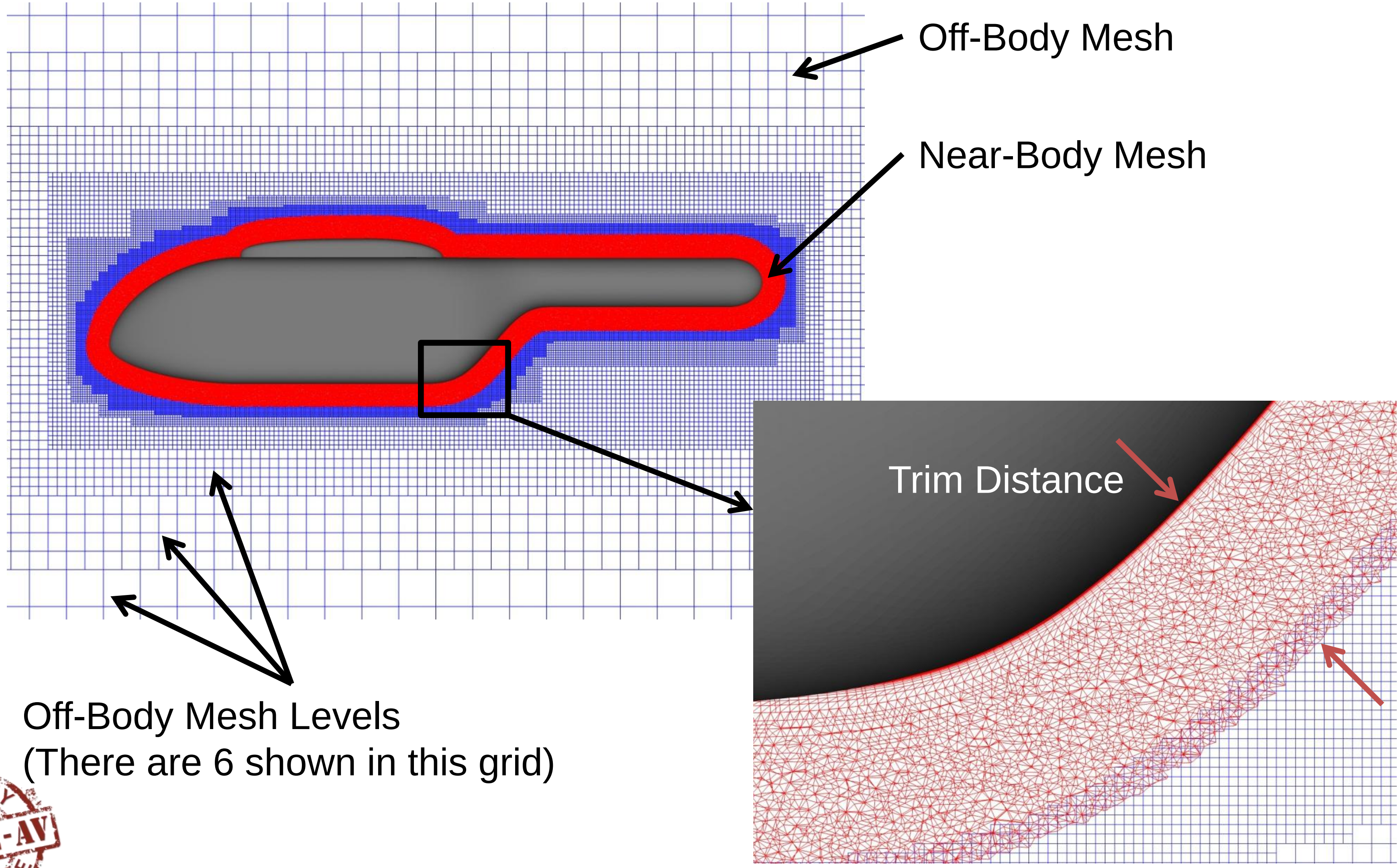
- **HPCMP CREATE™-AV**
  - Develops aircraft analysis software currently in use in Government, Industry, and Academia
- **CREATE™-AV KESTREL**
  - Multi-function code designed specifically for fixed wing aircraft analysis
- **KESTREL v5 features a dual mesh option**
  - KCFD computes the flow field close to the solid surfaces
    - Unstructured URANS solver
  - SAMKART computes the flow field away from the solid surfaces
    - Automatic grid setup and execution
    - Cartesian Euler solver (implicit or explicit time-integration)
    - GAMR adaptive mesh refinement
  - PUNDIT overset assembly
- **Why dual mesh?**
  - The Cartesian solver runs faster on a per node basis than the unstructured solver (i.e. for a given wall clock time you get a higher fidelity solution)

Kestrel v5 Credits

- **Kestrel Core Developers**
  – Scott Morton, Robert Nichols, Dave McDaniel, Tim Eymann, James Forsythe, Robert Starr, Steve Lamberson, Todd Tuckey, Patrick McNally, James Masters, Greg Denny, Travis Horine
- **Oversetting – PUNDIT, Off-body Cartesian System**
  – Jay Sitaraman, Andy Wissink
- **Integration, Inter-operability and Build Systems**
  – Stephen Adamec, Todd Tuckey, Brian Pittman, Jay Sitaraman
- **V&V, Quality Assurance & Support**
  – Theresa Shafer, Benjamin Hallissy, Chad Lillian, James Forsythe, David Hine, Jennifer Abras

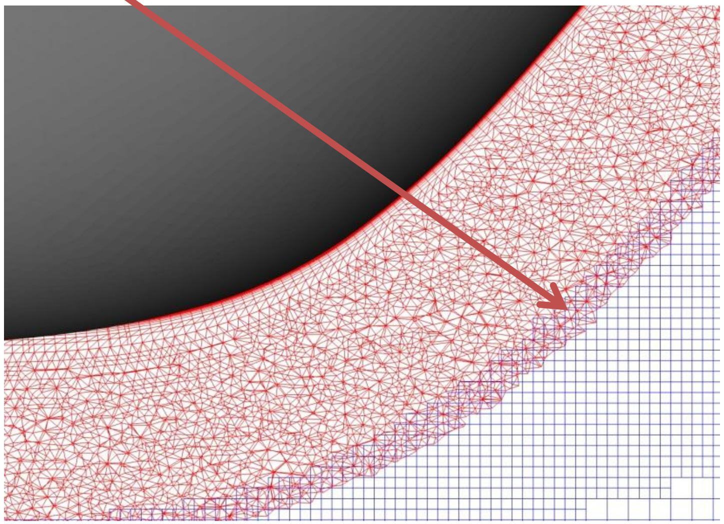
METHODOLOGY

Dual Mesh Assembly Terminology



Dual Mesh Construction

- **User provides the trimmed near-body mesh**
- **User inputs parameters that define the off-body mesh**
  - The Cartesian mesh is automatically constructed within KESTREL at runtime
  - The input parameters include at a minimum
    - Distance of the far field from the solid body
    - Number of grid levels
  - KESTREL will analyze the near-body fringe cell sizes and determine the finest cell size needed by the off-body mesh
  - Cartesian blocks are placed around the body in relation to the size of the near-body fringe
  - Remaining off-body grid levels are added
    - Each level is twice the size of the preceding level
  - PUNDIT performs the hole cutting



PUNDIT

- **Parallel UNsteady Domain Information Transfer features**
  - Implicit fringe determination
  - Implicit hole cutting
  - Minimum hole cutting using ray-tracing for solid bodies
  - Exact Inverse Map (EIM) donor search algorithm

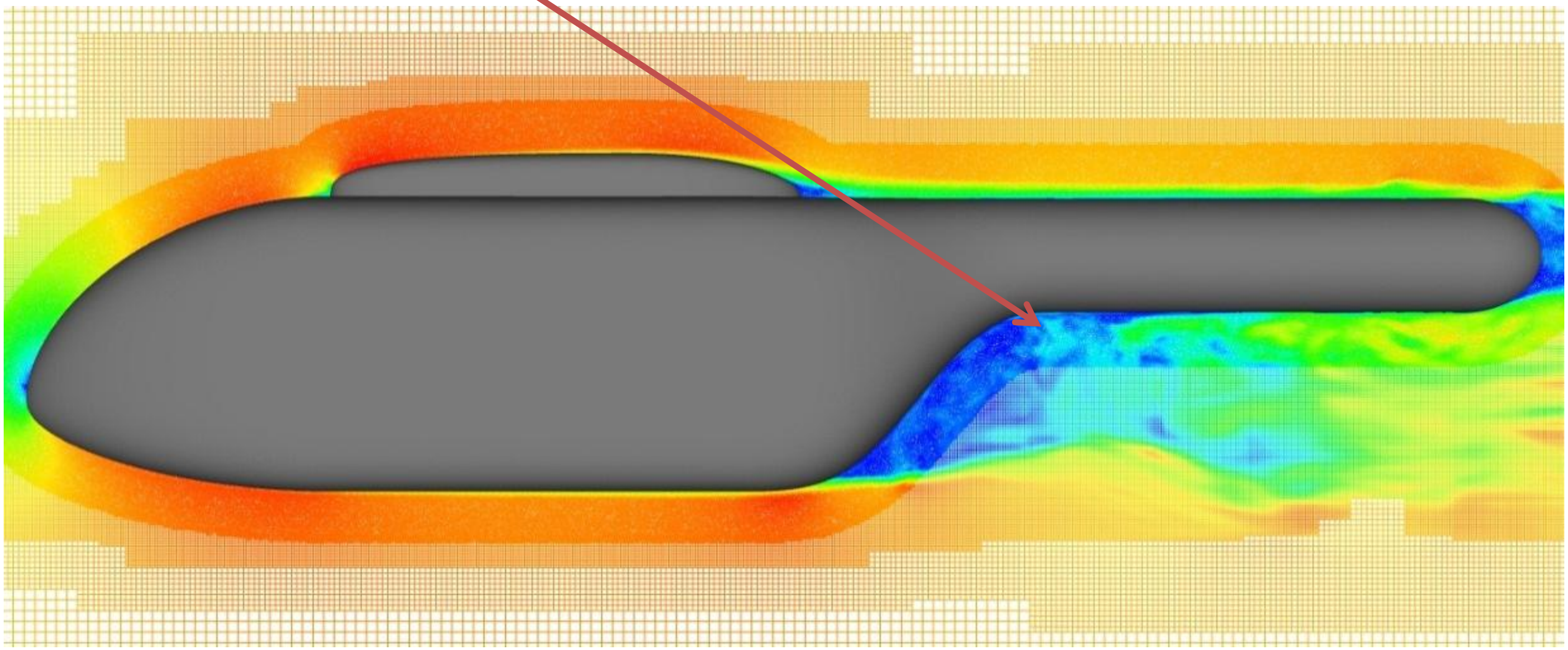
- **Controls overset computations both between multiple unstructured meshes and the Cartesian mesh**

Adaptive Mesh Refinement (AMR)

- **The off-body mesh density distribution is automatically adapted**
  - Adaption to the geometry
  - Adaption to flow features
- **GAMR (Guided Adaptive Mesh Refinement) is employed**
  - Applies a combination of scaled q-criterion feature-based adaptation and Richardson extrapolation error-based refinement
  - Automatically scaled, hence no guessing of scalar-values to adapt to
- **The user can limit how far from the body the adaptation is applied**

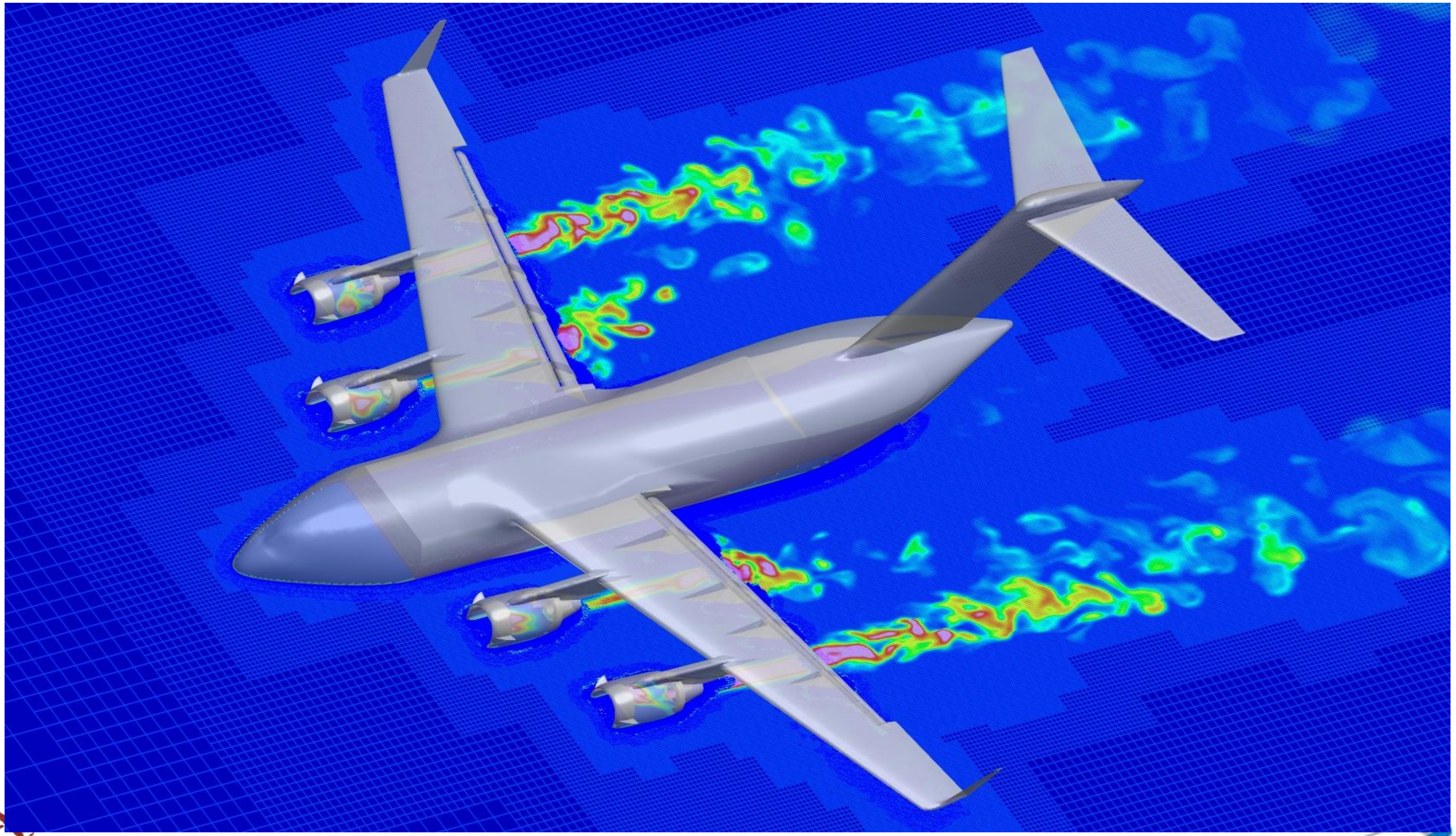
Adaptive Mesh Refinement (AMR)

- In case of ROBIN, the flow-AMR is expected to target the separated region



Adaptive Mesh Refinement (AMR)

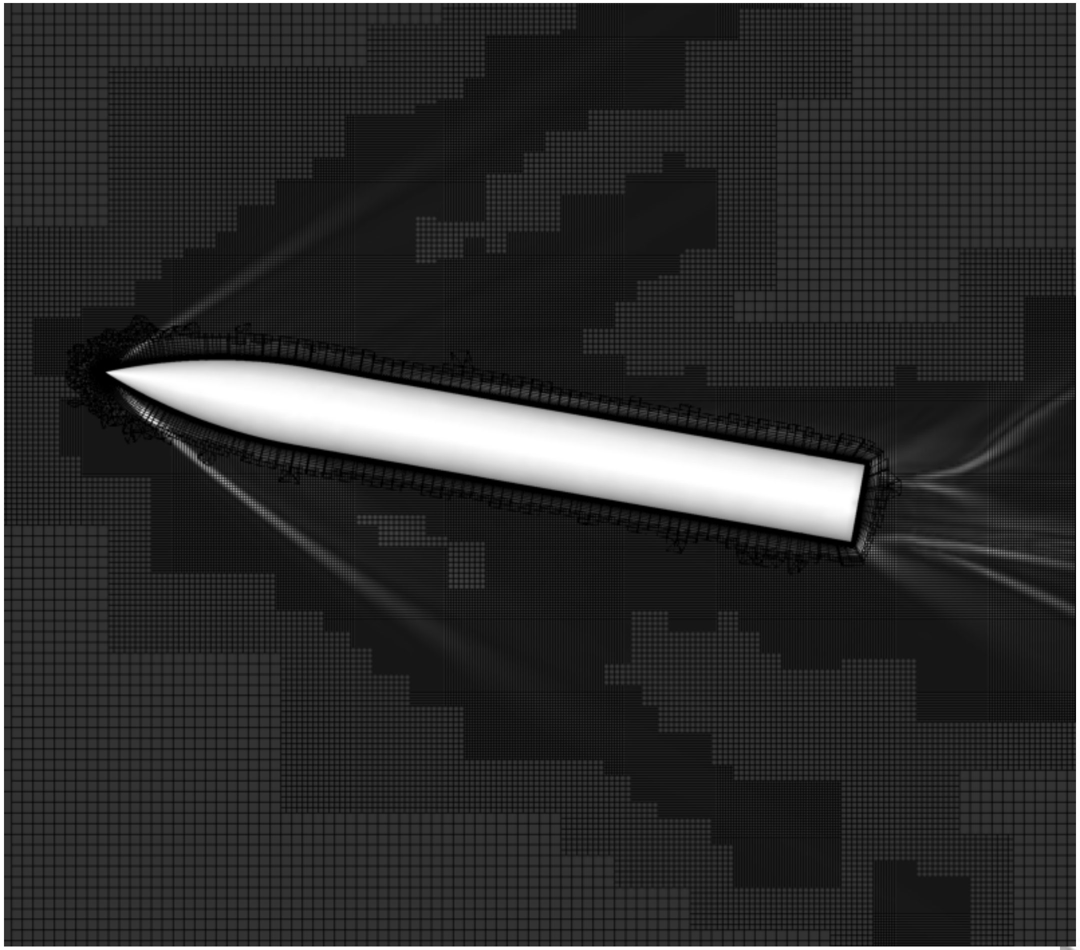
- **Off-body, GAMR adapt for other features – C-17 Engine exhaust shear layer**



(Kestrel v5, Dr. Tim Eymann, Eglin AFB)

Adaptive Mesh Refinement (AMR)

- **Off-body, GAMR adapt for other features – Supersonic Ogive @ 10 degrees**



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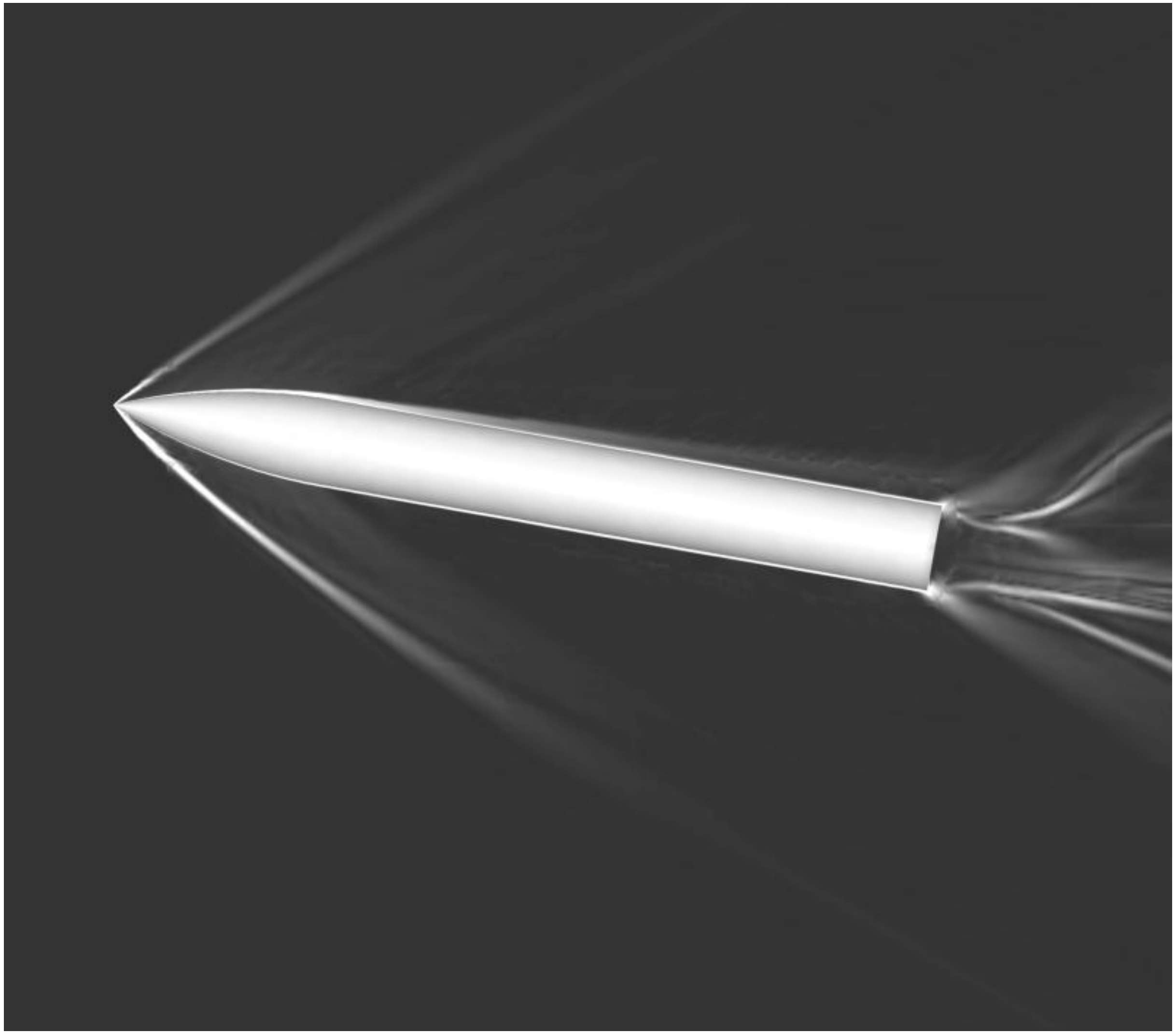
Adaptive Mesh Refinement (AMR)



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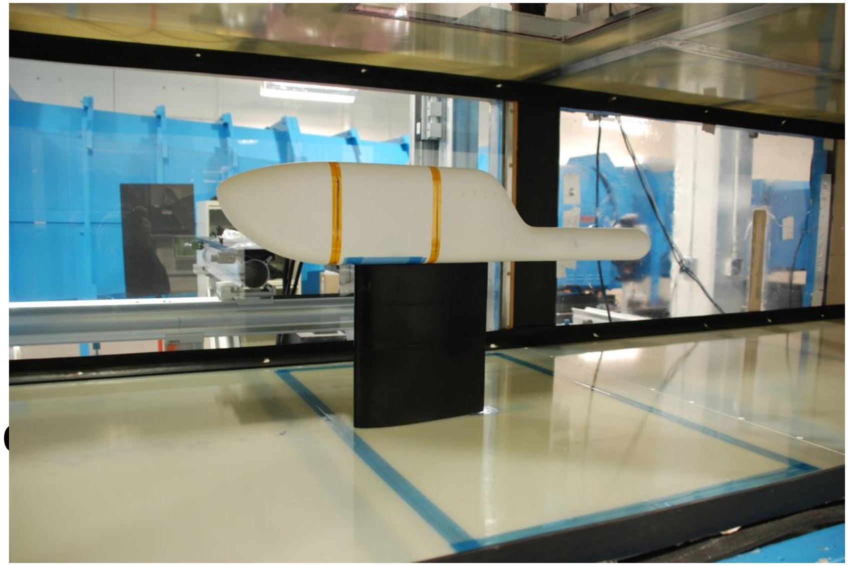
RESULTS

ROBIN Wind Tunnel Test

- **Mach number of 0.1 (about 34 m/s)**
- **Reynolds number (based on the fuselage length) of 1.6M**
- **Standard sea level conditions**
- **Angle of attack = 0°**
- **41 pressure taps along the centerline of the fuselage**
- **Mount shroud is constructed using an extruded NACA0018 airfoil section**



Schaeffler, N. W., Allan, B. G., Lienard, C., and Le Pape, A., “Progress Towards Fuselage Drag Reduction via Active Flow Control: A Combined CFD and Experimental Effort,” *36th European Rotorcraft Forum*, Paris, France, September 7-9, 2010.

QUALITY CREATE-AV ASSURANCE

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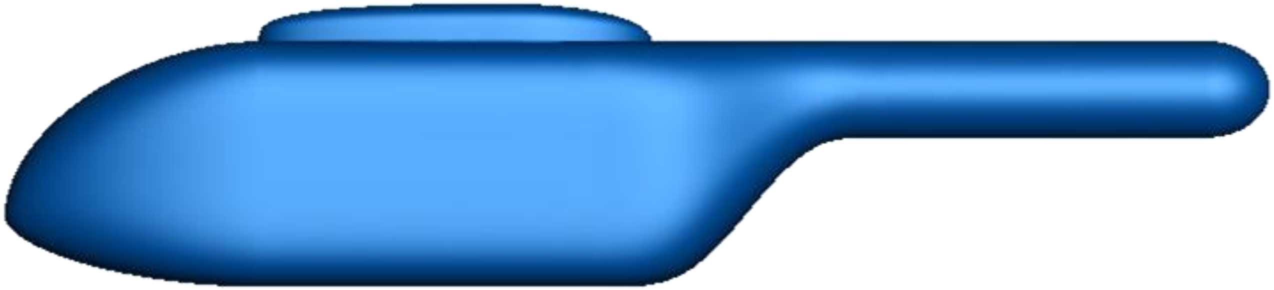
Unstructured Grids

- **Unstructured grid generation accomplished using Rhinoceros CAD software and TetrUSS grid generation software**
- **Boundary layer merging and near-body trim applied**

	Boundary Layer Cells	# of Cells	# of Nodes	Description
Grid 2	Prisms	14.0M	4.1M	Single mesh case
Grid 5	Prisms	15.5M	5.5M	0.05” cell size, for dual mesh use only

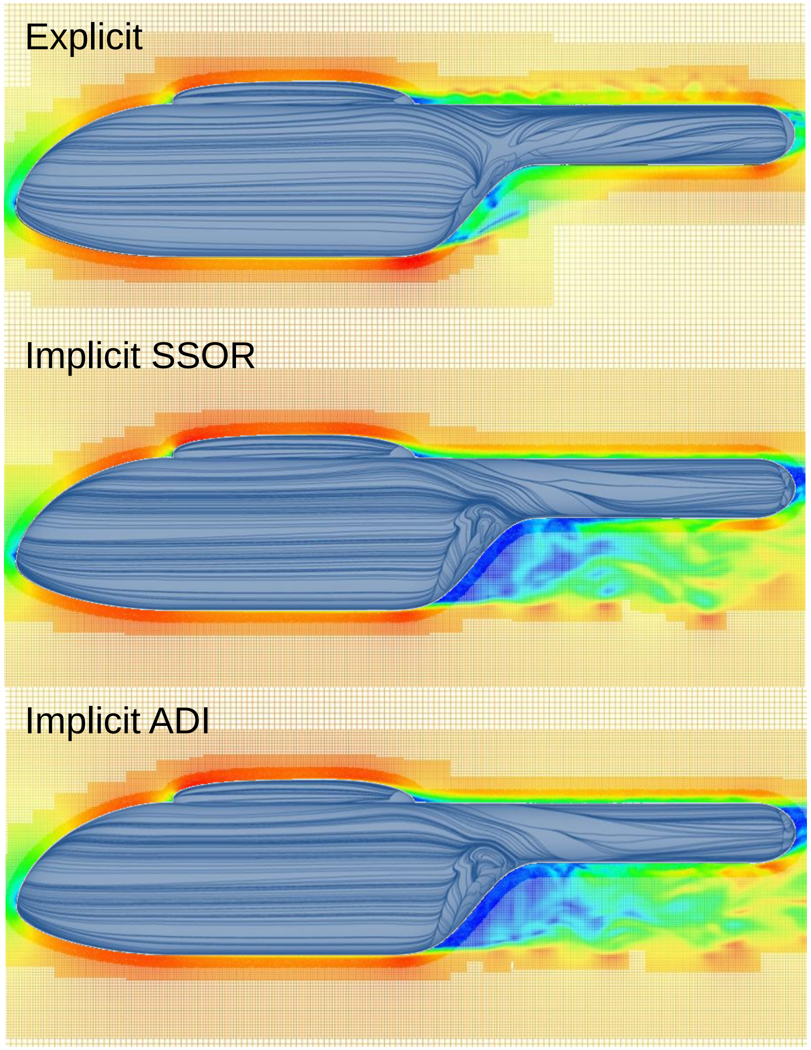


Explicit vs. Implicit Off-Body Solvers

- **Near-body solver employs same settings for all cases**
- **Three off-body temporal schemes are available**
  - Explicit Runge-Kutta (Third-order)
  - Alternating Direction Implicit (Second-order)
  - Symmetric Successive Over-relaxation (Second-order)
- **Each method exhibits different characteristics**
  - Explicit solver
    - Runs the fastest but converges the slowest (maximum stable time step = 5e-8 s)
  - Implicit SSOR
    - Runs the slowest but converges the fastest (time step = 1e-5 s)
  - Implicit ADI
    - Runs slower but converges faster than the explicit solver (time step = 1e-5 s)
- **Implicit within individual blocks for off-body**

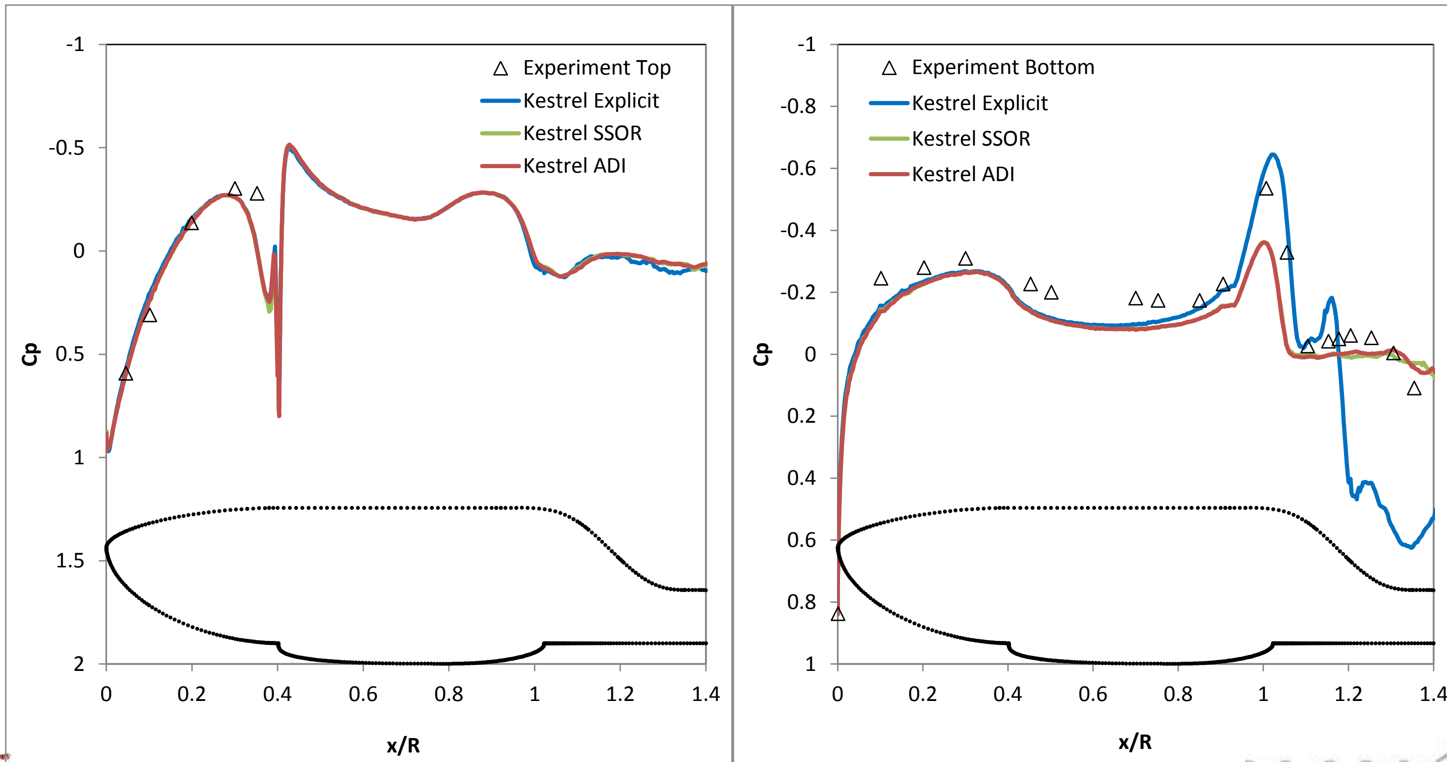
Velocity Contour Comparison

- **Near-body grid trim distance of 0.5”**
- **Differences are seen between all solvers**
  - Explicit scheme
    - Pylon shedding likely seen because of the very small time step
    - Aft separated flow is minimal
  - Implicit SSOR scheme
    - Produces more aft separated flow
  - Implicit ADI scheme
    - Produces more aft separated flow
    - Solution quality more sensitive to time step size



Centerline Pressure Comparison

- **Closer analysis confirms that the predictions in attached regions are about the same**
- **The aft separation region shows greater differences**
  - The explicit solution is not fully converged
  - The implicit solvers produce similar results



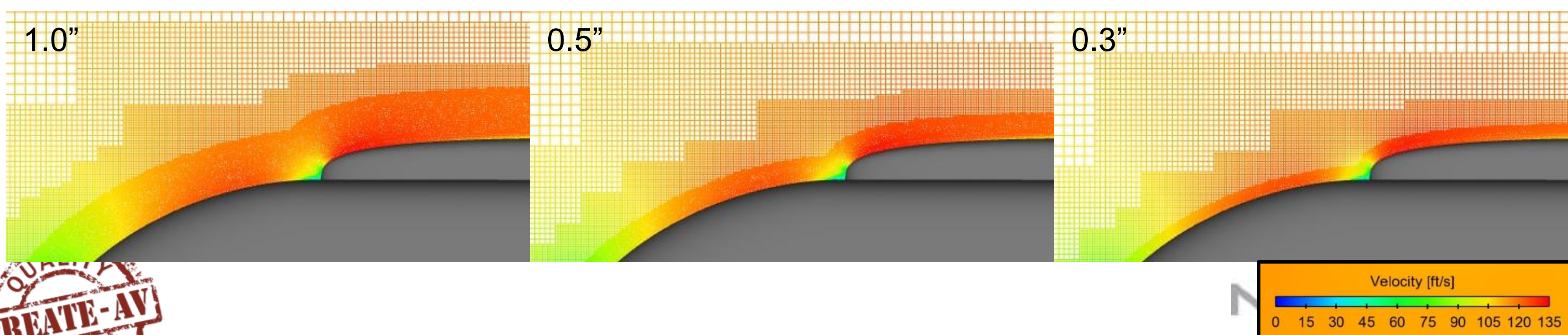
Computational Metrics

- **Implicit (SSOR) cases were run on HPCMP Pershing, explicit case run on HPCMP Riptide, all cases run on 256 processors**
- **Explicit solver runs the fastest, but takes two orders of magnitude more iterations to converge**
  - Results in a longer wall clock time to complete the case
- **Run time increases as trim distance increases**
  - Near-body solver runs slower than the off-body solver

Case Run	Grid (Trim)	Degrees of Freedom	Approximate Iterations to Converge	Time/proc/it/DoF [nanosec]	Estimated Run Time on 256 procs [days]
Dual Mesh Explicit	Grid-5 (0.5)	18.5M (cells near) 31.0M (nodes off)	~200K	1.97	5.74
Dual Mesh Implicit	Grid-5 (0.3)	14.6M (cells near) 46.2M (cells off)	~6K	9.49	1.02
Dual Mesh Implicit	Grid-5 (0.35)	15.4M (cells near) 45.5M (nodes off)	~6K	9.88	1.07
Dual Mesh Implicit	Grid-5 (0.5)	18.5M (cells near) 42.5M (nodes off)	~6K	10.09	1.09
Dual Mesh Implicit	Grid-5 (1.0)	29.3M (cells near) 35.2M (nodes off)	~6K	12.26	1.41

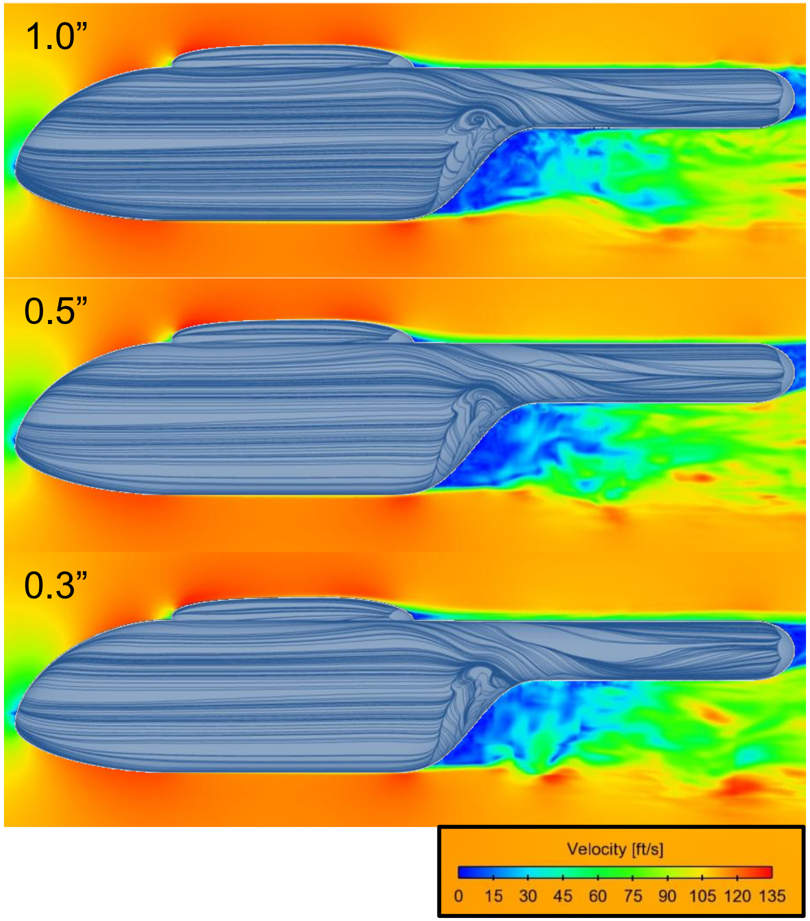
Trim Distance Study

- **Trim distances of 0.3”, 0.5”, and 1.0” are studied here**
  - Constant near-body mesh size of 0.05” for all trim distances
  - First level of the off-body mesh has the same constant cell size, but the placement varies
  - Differing solution methodology in each mesh will have a potential impact
  - All solutions are run using implicit SSOR in the off-body at a time step of 0.001 sec
- **To achieve the fastest run time the near-body mesh should be trimmed as much as possible**
  - Need to make sure that there is sufficient fringe area remaining
  - Need to make sure that the boundary layer computations are not impacted



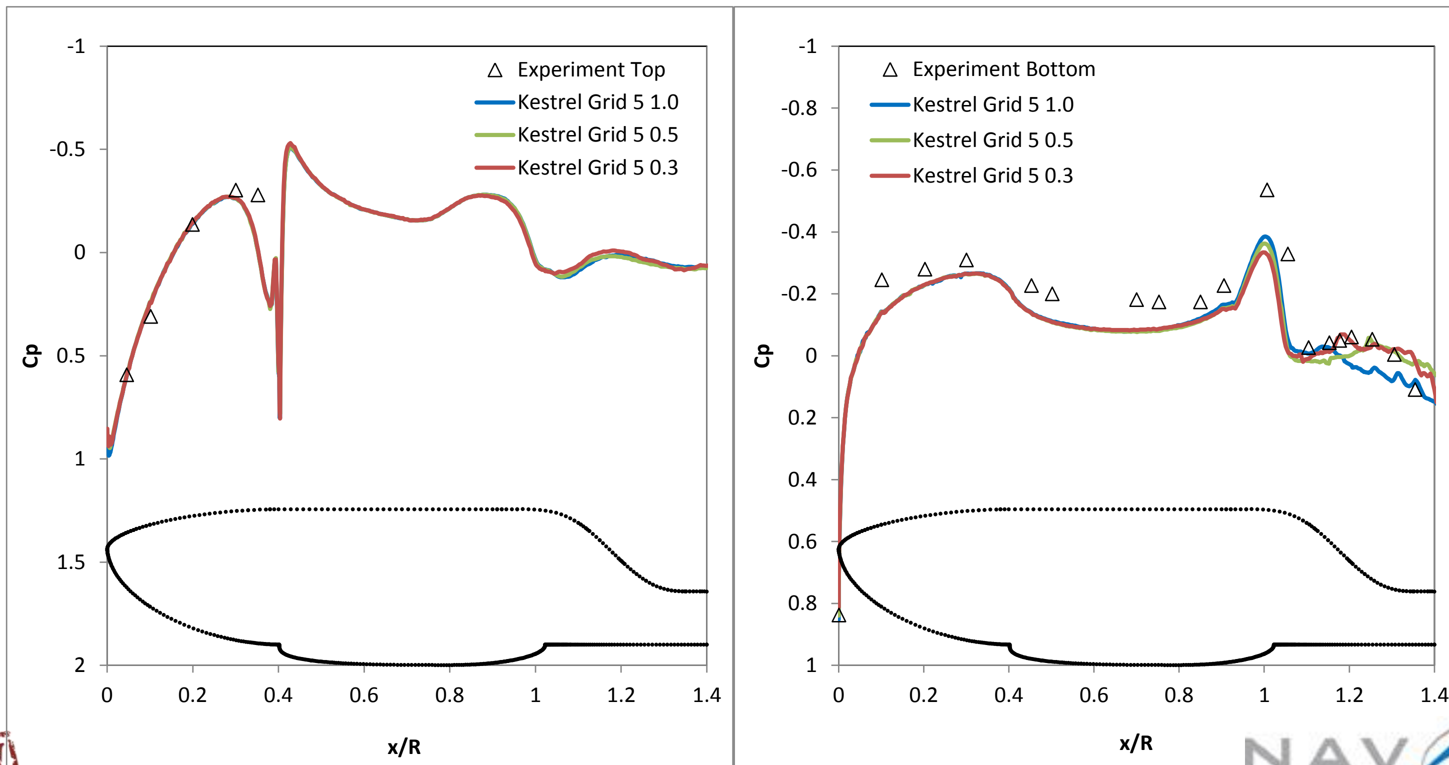
Velocity Contour Comparison

- All plots represent instantaneous velocity
- Closest trim distance has no apparent impact on the attached solution
- Separation point appears to be the same for all grids
- Separated region in the off-body mesh does appear to be influenced by the trim distance
- Centerline pressure analysis confirms these observations



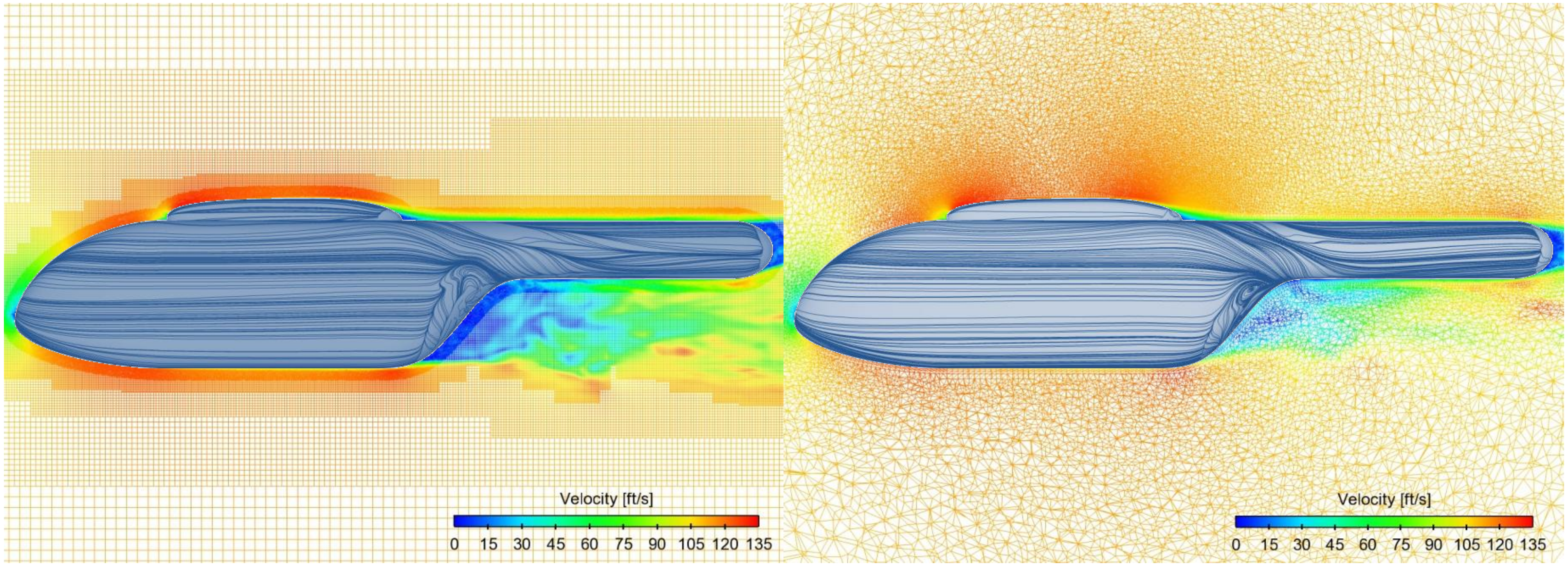
Centerline Pressure Comparison

- **Attached regions show no difference between trim distances**
- **Separated flow is influenced by the trim distance**
  - The closer trim distances more accurately follow the aft pressure contour
  - All miss aft peak (off-body is Euler)



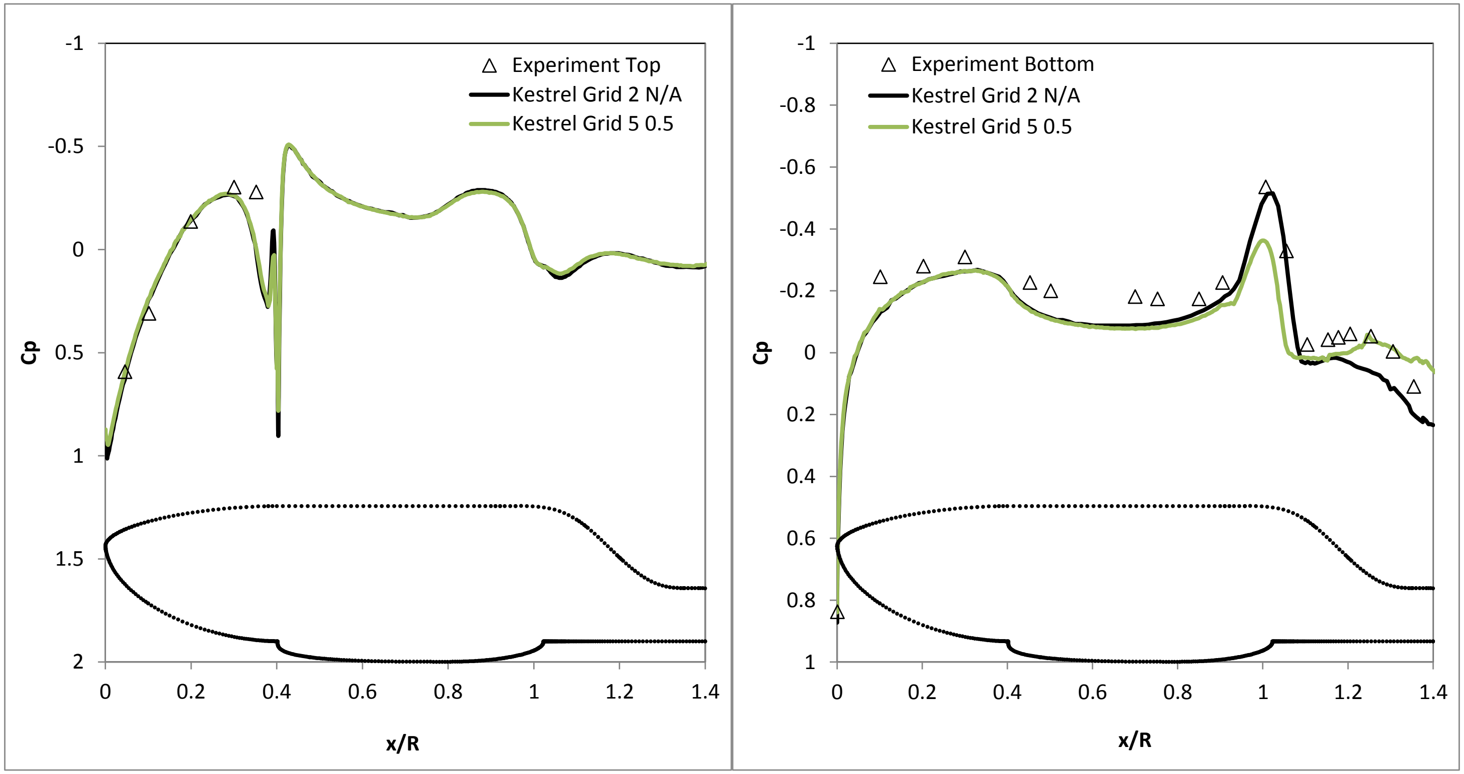
Dual Mesh vs. Single Mesh

- **Both cases run with the same kCFD inputs**
- **Attached regions are similar**
- **Separated region shows differences**
  - These are attributed to the coarser grid used in the single mesh case



Dual Mesh vs. Single Mesh

- **Attached regions show little difference**
- **Separated region shows difference in peak pressure**
  - Similar differences in earlier CREATE-AV Helios comparisons (SciTech, 2014)
  - Off-body is Euler



Drag Coefficient Comparisons

- **Drag coefficients show mixed results**
  - The viscous components are more consistent
  - The pressure component differences are a function of the separated flow region
- **CFD with and without the tunnel walls, current comparisons to without-wall free-air OVERFLOW computation**

Case	Pressure Drag	Viscous Drag	Total Drag	%Error
Experiment			0.145	
OVERFLOW (tunnel)	0.090	0.055	0.145	
OVERFLOW (free air)	0.058	0.056	0.114	
Single Mesh	0.063	0.056	0.119	4.3
Dual Mesh Explicit	0.071	0.059	0.130	14.2
Dual Mesh SSOR	0.049	0.054	0.103	9.3

- **Viscous off-body calculations – more at SciTech**

Conclusions

- **The dual mesh solver represents a significant leap in capability in the Kestrel code**
  - The off-body Cartesian solver provides improvements in efficiency as well as flowfield preservation
- **The implicit solver provides enhanced convergence characteristics over the explicit solver**
  - Block implici t currently for off-body
- **Problem setup can be tailored to provide the most efficient solution by eliminating as much of the near-body mesh as possible**
  - Adjusting the regions where the different solvers are applied does have an impact on the separation predictions
- **The predictions are insensitive to the methodology chosen in the attached regions**
- **The predictions are sensitive to the methodology in the separated regions**
  - Off-body viscous
  - Additional convergence studies

Acknowledgments

- **HPCMP CREATE™-AV Program**
- **Supercomputing resources provided by the HPCMP**
  - Maui High Performance Computing Center (MHPCC)
  - Army Research Lab (ARL)
- **NASTRAN ROBIN surface from Dr. Rajneesh Singh, ARL**
- **Wind Tunnel data and images and OVERFLOW results from reference 1**
  - Schaeffler, N. W., Allan, B. G., Lienard, C., and Le Pape, A., "Progress Towards Fuselage Drag Reduction via Active Flow Control: A Combined CFD and Experimental Effort," *36th European Rotorcraft Forum*, Paris, France, September 7-9, 2010.

QUESTIONS?