SU2-Related Activities at NIA

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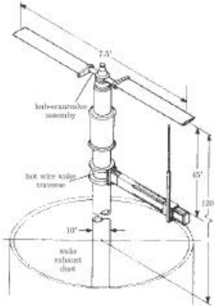
SU2
The Open-Source CFD Code

15TH ANNIVERSARY

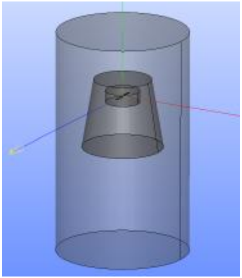
Scientific Computing
Technische Universität Kaiserslautern

NASA

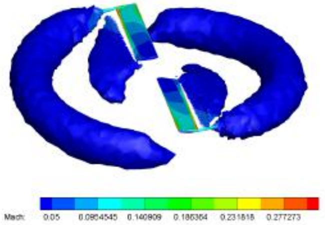
Rotor/Propeller Noise Prediction and Minimization



Caradonna-Tung Rotor Model



Multi-Zone Mesh for SU2



Iso-surface of Q-Criterion

Highlights

- NASA-funded project to predict and reduce rotor/propeller noise using SU2
- CFD: SU2-URANS solver with rotating mesh
- CAA: SU2-FWH solver for non-stationary source
- Design sensitivities: discrete adjoint
- Hierachy of configurations: isolated prop → prop-wing → prop-prop
- First case: 2-Bladed Caradonna-Tung Rotor in hover for aerodynamic validation

Partners

TU Kaiserslautern

- Beckett Y. Zhou

NASA Langley

- Leonard V. Lopes

ODU

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- Andy Moy
- Oktay Baysal

NIA

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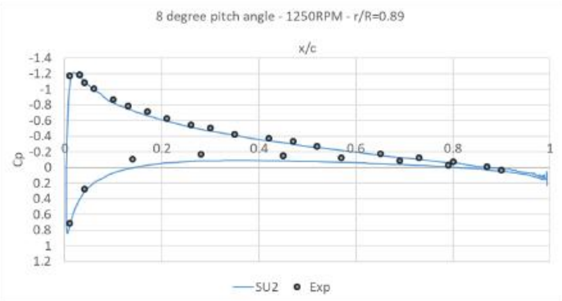
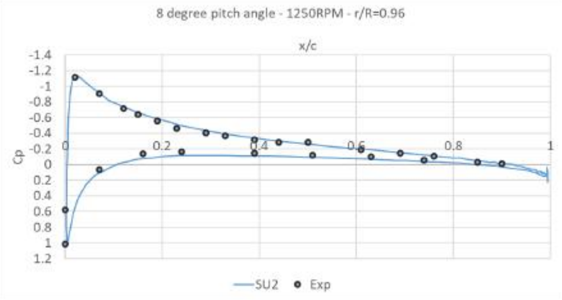
Rotor/Propeller Noise Prediction and Minimization


8 degree pitch angle - 1250RPM - r/R=0.89


8 degree pitch angle - 1250RPM - r/R=0.96

Highlights

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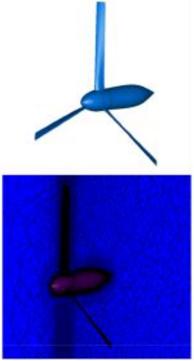
Rotor/Propeller Noise Prediction and Minimization

XV15 Tilt-Rotor Test Model



XV15 Tilt-Rotor Mesh

NASA X57 Maxwell Distributed Propulsion Aircraft

Highlights

- Current effort:
  - XV15 tilt-rotor in *forward flight*
  - Extension of existing FWH solver to moving-source formulation
  - Coupled CFD-CAA adjoint solver with rotating mesh
- Target configuration: NASA X57 Maxwell Distributed Propulsion Aircraft
  - Noise is a main design show-stopper
  - Significant prop-wing interaction noise

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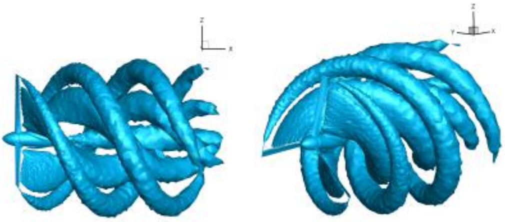
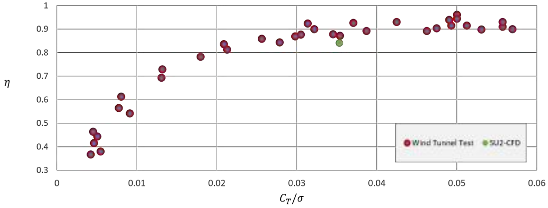
Rotor/Propeller Noise Prediction and Minimization





Comparison with Wind Tunnel Data

Highlights

- Current effort:
    - XV15 tilt-rotor in *forward flight*
    - Extension of existing FWH solver to moving-source formulation
    - Coupled CFD-CAA adjoint solver with rotating mesh
- Target configuration: NASA X57 Maxwell Distributed Propulsion Aircraft
    - Noise is a main design show-stopper
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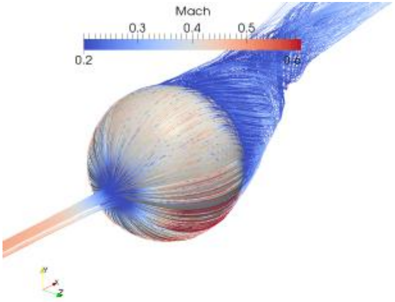
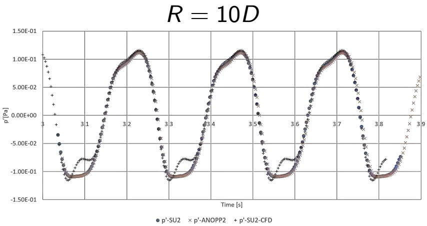
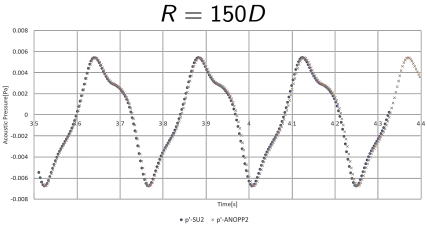
Extension to 3D Moving-Source FWH

- Fixed-source FWH extended to full F1A formulation of Farassat
- Test case: translating sphere ($M_\infty = 0.5$)
- URANS-FWH result validated against static CFD pressure and NASA-ANOPP2



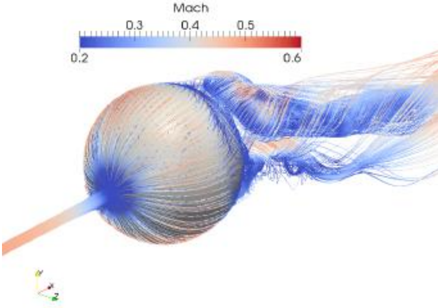

$R = 10D$

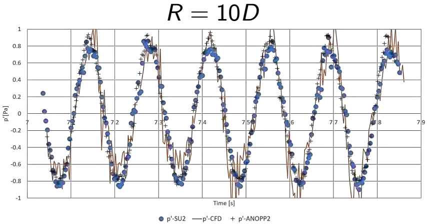

$R = 150D$

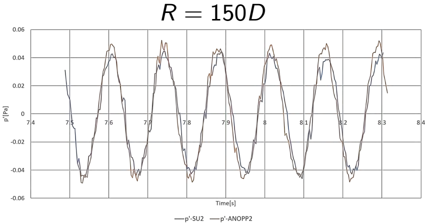
*On-Going Work: **Omur Icke**, Andy Moy, Beckett Y. Zhou, Oktay Baysal, Leonard V. Lopes and Boris Diskin

Extension to 3D Moving-Source FWH

- Fixed-source FWH extended to full F1A formulation of Farassat
- Test case: rotating and translating sphere ($M_\infty = 0.5$, RPM=812 about $\hat{x}$)
- URANS-FWH result validated against static CFD pressure and NASA-ANOPP2







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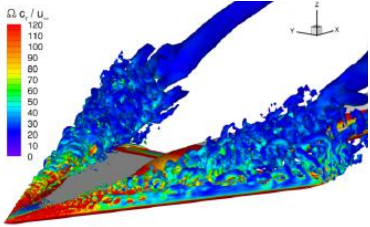
Mesh Generation and Simulation of Vortex Breakdown Over a Delta Wing

TUM Wind Tunnel Model



Source: J. Kok, NLR

NLR XLES Simulation

Highlights

- Exploratory effort in coupling grid generation/adaptation tool of ODU/NASA with SU2
- 65° sweep delta wing undergoing vortex breakdown
- Extensive measurement and simulation data from several EU projects (ATAAC, Go4Hybrid, etc)
- Turbulent flow field: new SU2-DDES-SLA solver

Partners

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- Beckett Y. Zhou

NASA Langley

- Mike Park

ODU

- Christos Tsolakis
- Juliette Pardue
- Nikos Chrisochoides
- Andrey Chernikov

NIA

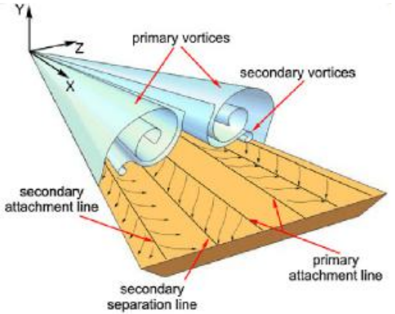
- Boris Diskin

Cross-Validation Contribution

- J. Kok (NLR)

Turbulent Flow Over a Delta Wing

- Delta wings are commonly employed in fighter and supersonic aircraft
- 'Vortex lift' contributes significantly to lift generation at low speeds
- Shear layer separates from leading edge and rolls up into primary vortex
- Vortex core corresponds to reduced static pressure over wing suction side resulting in increased lift
- At high *Re*, shear layer becomes unstable and turbulent vortex is formed



Vortex Breakdown

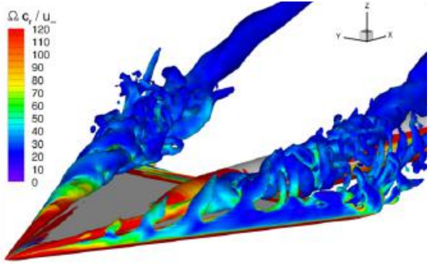
- At a sufficiently high angle of attack, primary vortex breaks down (high axial velocity in core drops to zero)
- Suction effect is lost → drastic reduction of lift
- Impingement on airframe → challenges in flight control and structural fatigue
- Onset of vortex breakdown often asymmetric → triggers instability about the roll axis

Important predict the strength and location of vortex breakdown as well as the flow conditions at which breakdown occurs

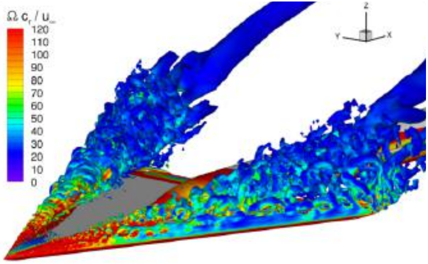
Vortex Breakdown Over a Delta Wing

The 'Grey Area' Problem of DDES

- Symptom: Unphysically slow development of the Kelvin-Helmholtz instability in free shear layer and delay of transition to 3D turbulence
- Reason 1: Excess modeled eddy viscosity convected from attached flow region treated by RANS into the separated LES region
- Reason 2: Excessive production of subgrid viscosity on strongly anisotropic grids
- In case of delta wing:
    - Shear layer remains stable over first half of the wing
    - Resolved turbulence absent over large portion of the wing
    - Leads to vortex breakdown further upstream compared to measurements

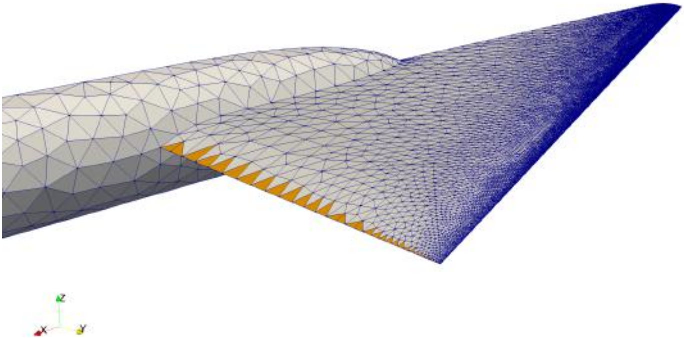


Source: J. Kok, NLR



Source: J. Kok, NLR

Boundary Layer Region Mesh Generation



- A viscous mesh generator[1] was used to generate an anisotropic mesh for the boundary layer region.
- Input: Surface of the delta wing.
- Extrusion-based approach is used where vertices are inserted along normals based on a geometric growth function.
- The surface is analyzed to determine which edges are highly convex.

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[1] J. Pardue and A. Chernikov. Three-Dimensional Prism-Dominant Mesh Generation for Viscous Flows Around Surface Slope Discontinuities. AIAA Paper 2018–3722, 2018

Inviscid Region Mesh Generation

- CDT3D [2] was used to generate an isotropic mesh for the inviscid region.
- Input: External surface of the viscous region mesh and bounding box of the configuration.
- The surface of viscous region mesh was kept fixed to ensure conformity when merging the two meshes.
- The rest of the surface mesh was adapted as needed.
- Refinement zones used to control mesh spacing in the region of interest.
- Finally, the inviscid and viscous meshes were merged along the common surface and passed to SU2.

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[2] F. Drakopoulos, C. Tsolakis, and N. Chrisochoides, "Fine-grained speculative topological transformation scheme for local reconnection methods," AIAA Journal, 2019, (In press).

Inviscid Region Mesh Generation

- The refinement zone consists of simple solids. A pyramid and two hexahedra.

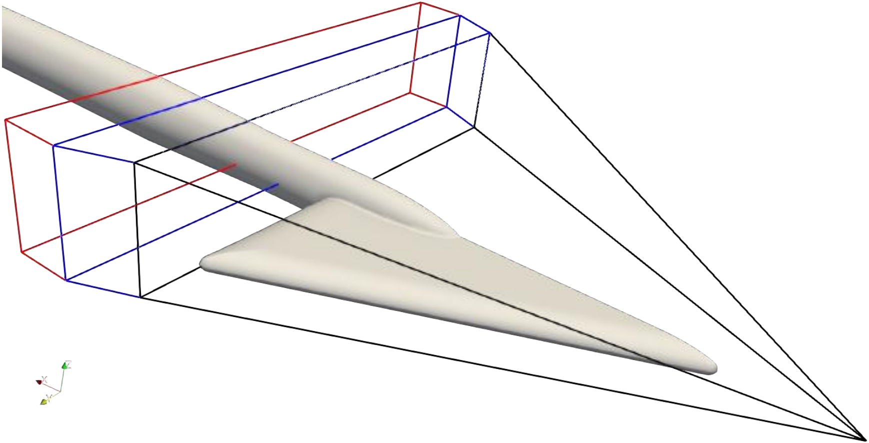


Figure: Refinement zone around the viscous mesh

Inviscid Region Mesh Generation

- Point spacing is initialized by the edge size on the boundary of the viscous mesh and is limited within the refinement zone.

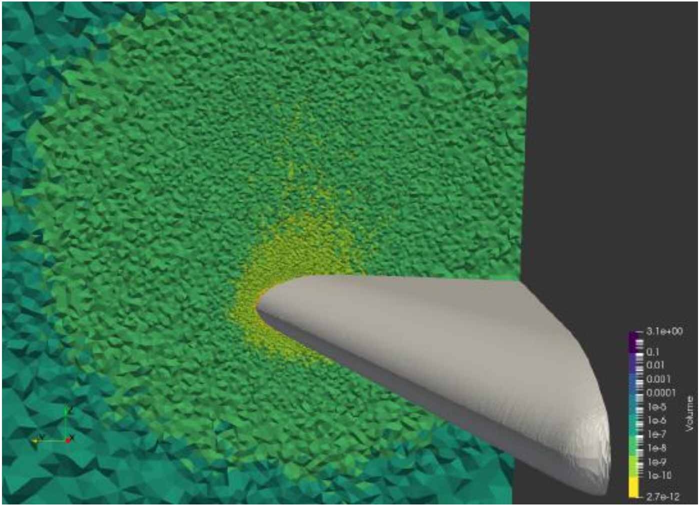


Figure: Cross section along X axis

Inviscid Region Mesh Generation

- Outside of the refinement zone the spacing is increased gradually based on the distance from the refinement zone.

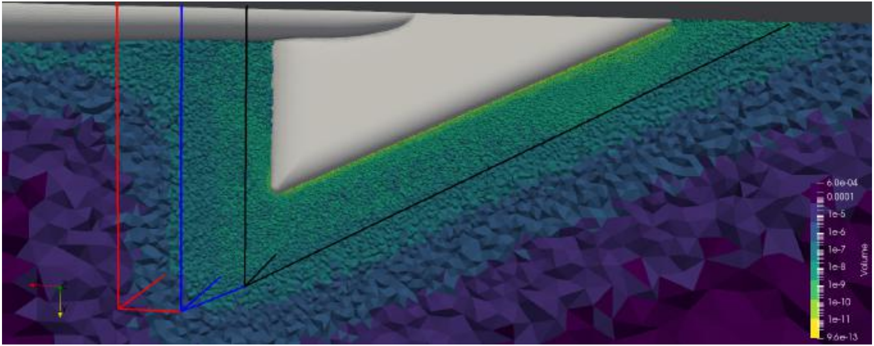
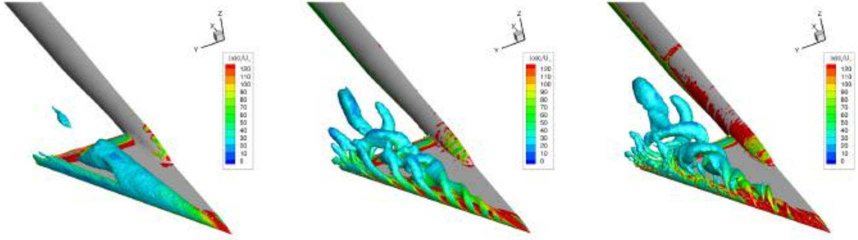


Figure: Cross section along Z axis

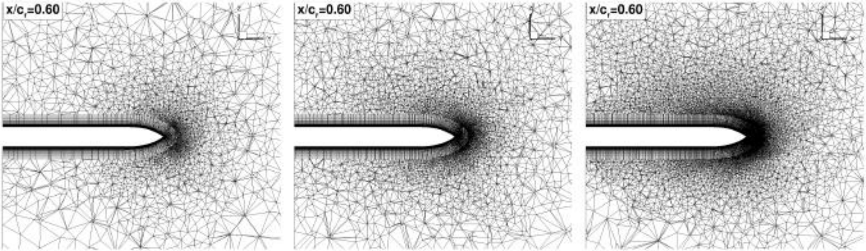
Instantaneous Vortical Structures



Coarse Mesh Medium Mesh Fine Mesh

- Isosurface of Q-criterion colored by vorticity magnitude
- Coarse mesh appears to be too dissipative to resolve even the largest flow features
- Medium mesh: shear layer roll-up and large helical structures over the suction side clearly visible
- Fine mesh: resolves more smaller turbulent structures but large structures remain in the vortex core region over the wing (K-H instability still delayed)

Volume Meshes (Streamwise Cross-Sections)



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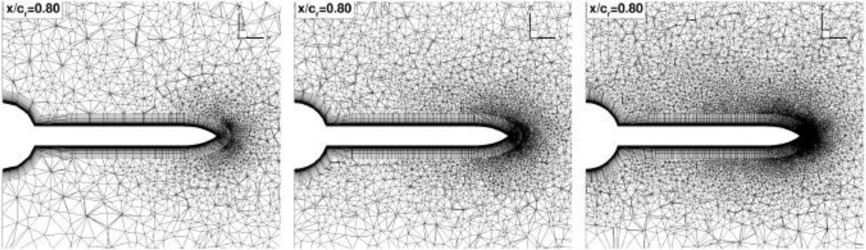
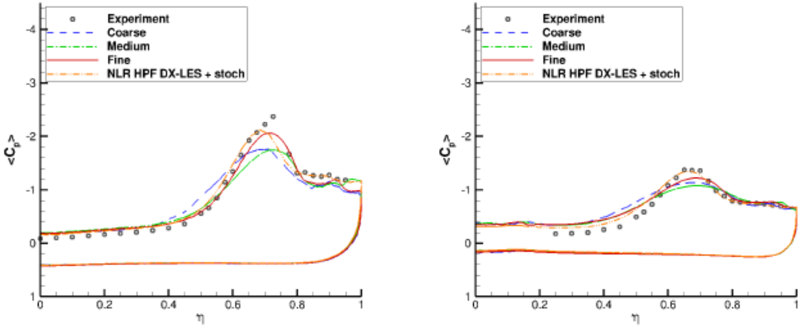


Time-Averaged Pressure Coefficient (Around Vortex Breakdown)

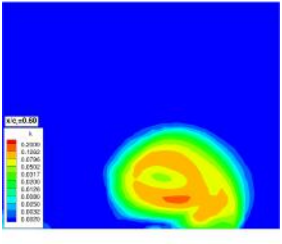


$x/c_r = 0.60$

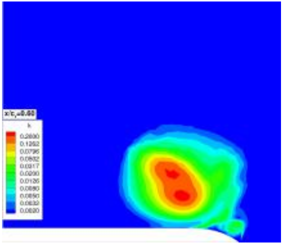
$x/c_r = 0.80$

- Additional numerical result using XLES with Stochastic Backscattering shared by J. Kok, NLR
- Vortex breakdown observed in experiment between $x/c_r = 0.60$ and $x/c_r = 0.80$
- Before and after vortex breakdown, fine mesh result is in good agreement with experiment and NLR result

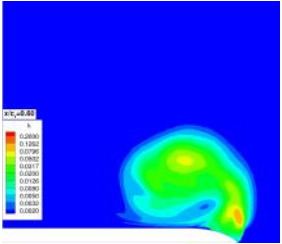
Measured vs. Resolved Turbulence Kinetic Energy ($x/c_r = 0.60$)



Experiment (HWA)



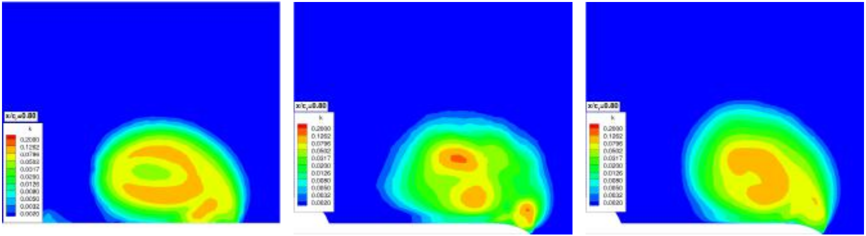
Medium Mesh



Fine Mesh

- Shortly before ‘known’ vortex breakdown location ($x/c_r = 0.60$), medium mesh significantly over-predicts TKE level → likely due to existing, premature vortex breakdown at that location
- Post vortex breakdown ($x/c_r = 0.80$): fine mesh TKE in good agreement with measurement both in terms of peak level and topology

Measured vs. Resolved Turbulence Kinetic Energy ($x/c_r = 0.80$)



Experiment (HWA) Medium Mesh Fine Mesh

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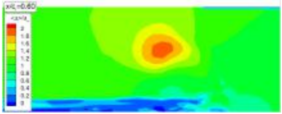
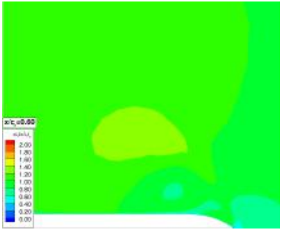
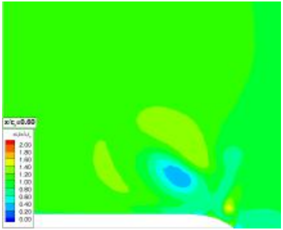
Time-Averaged Streamwise Velocity ($x/c_r = 0.60$)



Experiment (PIV)



Coarse Mesh



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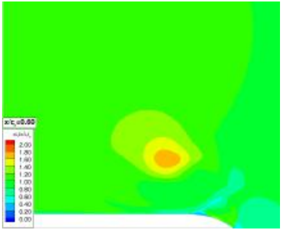
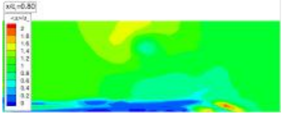


Fine Mesh

- Vortex breakdown at $x/c_r = 0.60$ for both coarse and medium meshes (near-zero axial velocity in vortex core), in contrary to PIV measurement
- Vortex breakdown location of fine mesh roughly agrees with measurement

Time-Averaged Streamwise Velocity ($x/c_r = 0.80$)



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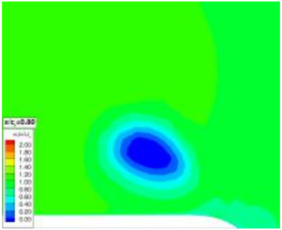

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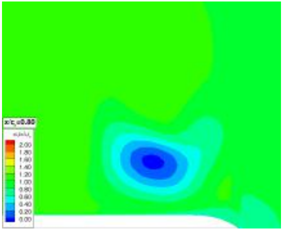

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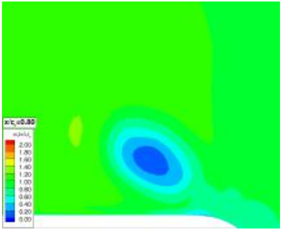

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Thank you for your attention

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