SU2-Related Activities at NIA

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**Rotor/Propeller Noise Prediction and Minimization**

**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
- Hierarchy of configurations: isolated prop → prop-wing → prop-prop
- First case: 2-Bladed Caradonna-Tung Rotor in hover for aerodynamic validation

**Partners**
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  - Beckett Y. Zhou
- **NASA Langley**
  - Leonard V. Lopes
- **ODU**
  - Omur Icke
  - Andy Moy
  - Oktay Baysal
- **NIA**
  - Boris Diskin
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**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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**Comparison with Wind Tunnel Data**
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

*On-Going Work: Omur Icke, Andy Moy, Beckett Y. Zhou, Oktay Baysal, Leonard V. Lopes and Boris Diskin
Extension to 3D Moving-Source FWH

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Mesh Generation and Simulation of Vortex Breakdown Over a Delta Wing

TUM Wind Tunnel Model

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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**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 $\rightarrow$ drastic reduction of lift.
- Impingement on airframe $\rightarrow$ challenges in flight control and structural fatigue.
- Onset of vortex breakdown often asymmetric $\rightarrow$ 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.
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
A viscous mesh generator\textsuperscript{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.

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

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

- 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)
Time-Averaged Pressure Coefficient (Around Vortex Breakdown)

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 ($x/c_r = 0.60$)

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

- 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
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Thank you for your attention