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Wavy Trailing-Edge Flatback Aerodynamics using a GPU-Accelerated Navier–Stokes Solver

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Abstract

Flatback airfoils have been regarded as structurally robust designs for inboard sections of large wind turbine blades. However, these airfoils suffer from a large aerodynamic base drag arising from its blunt trailing edge. A wave-like modification along the span of the blade has been proposed to help alleviate the drag losses while maintaining the aerodynamic efficiency. A 3D RANS-based CFD, augmented with GPUs was used for the present study. It was observed that the wavy trailing edge designs considerably reduced the drag on the airfoil compared to the baseline design while maintaining the lift produced.

Objectives

- Flatback airfoils by design, suffer from a large base drag caused by the growth of span-wise coherent vortices at the trailing edge. Therefore, the objective of the present work is to effectively breakdown these vortices to reduce the airfoil drag. This breakdown is achieved through the modification of the trailing edge in the spanwise direction.
- The computational efficiency is improved by implementing the RANS-LES methodology on Graphics Processing Units (GPUs).

GPU-Accelerated Navier–Stokes Solver

GPURANS3D flow solver:

•The 3D RANS GPU-accelerated finite volume method Navier–Stokes solver (GPURANS3D) was developed at the University of Maryland.

•GPU framework written using NVIDIA CUDA-C.

GPU computation:

•GPUs, by way of design, are highly parallel, multi-threaded, many-core processor with a large computational power and memory bandwidth. Therefore, they lend themselves readily to the high cost of CFD computations. According to recent benchmark tests with the RANS-LES solver, computations on a GPU are more than 50 times faster when compared to a single core CPU.

•In this research, the NVIDIA Tesla K20m GPU cards located at the Deepthought II cluster in UMD were used. These cards feature 2,496 processor cores with 706 MHz clock speed and 5GB board memory, ideal for the present work.

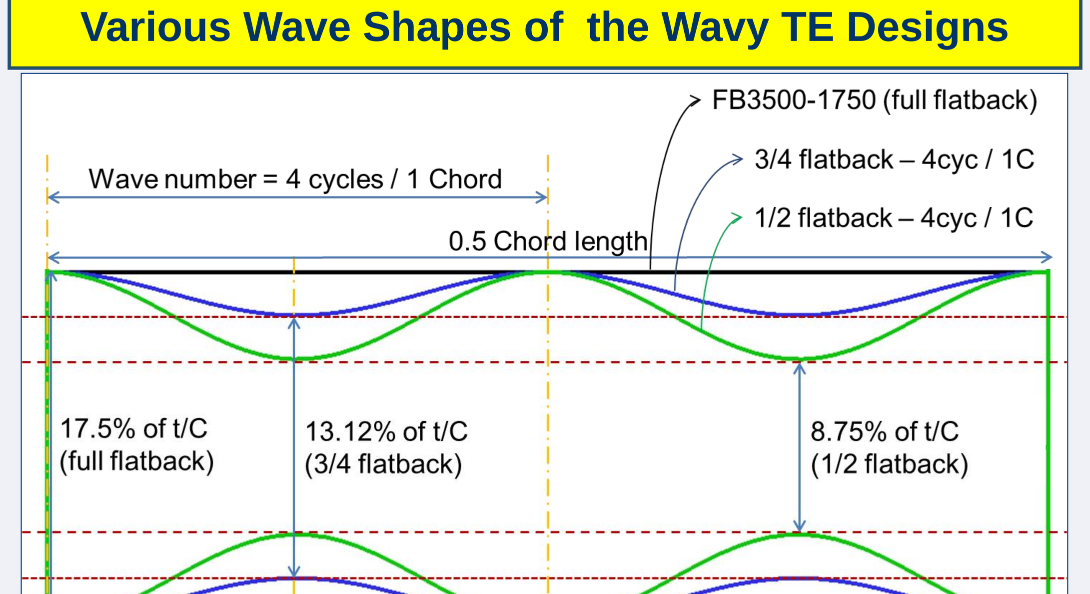
Wavy Trailing Edge Flatback Design

The proposed wavy trailing edge airfoils are designed by span-wise modifications of the original trailing edge thickness. All wavy trailing edge designs proposed in the current work have been modified based on the FB3500 flatback airfoil series. The local span-wise thickness of each trailing edge design is calculated by the following trigonometric variation:

$$\Delta y = y_{max} - y_{min}$$

$$\text{local thickness} = \frac{\Delta y}{2}\left[\cos\left(\frac{\omega * 2\pi x}{l}\right) + 1\right] + y_{min}$$

Various Wave Shapes of the Wavy TE Designs



Numerical Methods

- GPU-RANS3D employs a three-dimensional curvilinear structured grid with a compressible time-accurate RANS-LES solver.
- A γ-$Re_{\theta t}$ transition model with the SA turbulence model is used to predict the point of laminar-turbulent transition on the surface of the airfoil.
- A Delayed Detached Eddy Simulation (DDES) model is used to capture both the attached regions of the boundary layer and the large eddies contained in the well separated regions of the boundary layer flow.

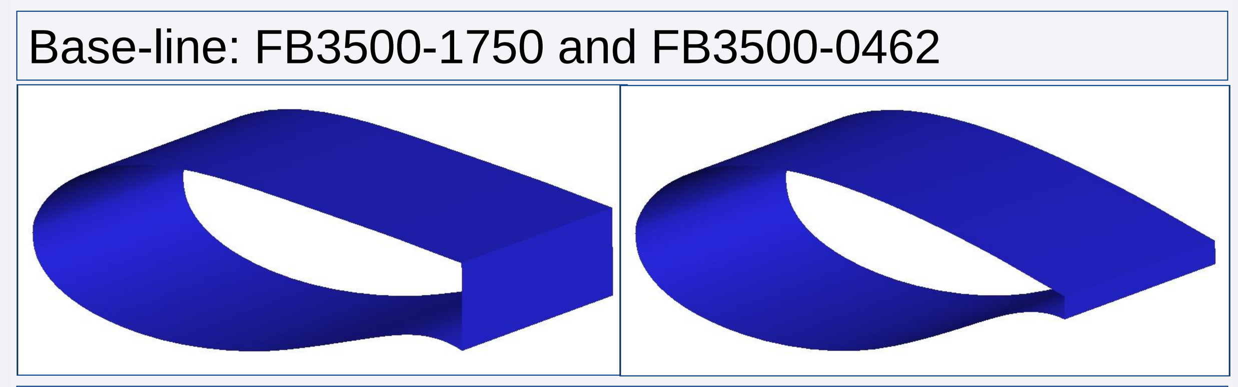
Three-dimensional Flow Simulation

Free-stream: Re = 666,000, M = 0.3, AoA 8° –20°

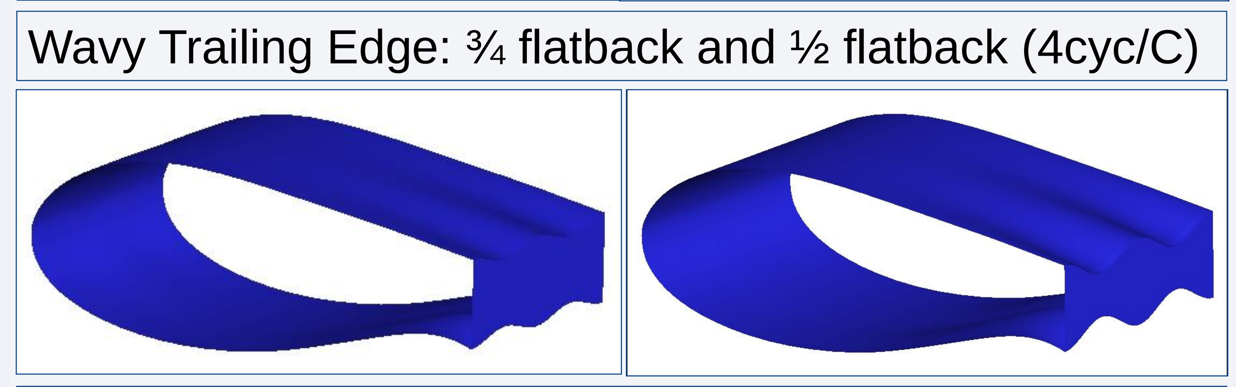
•Base-line (full flatback and sharp trailing edge with an unmodified plain trailing edge) validated with reasonable comparison to experimental data.

•Wavy trailing edge (3/4 flatback and 1/2 flatback with 4 waves per chord along the span) examined.

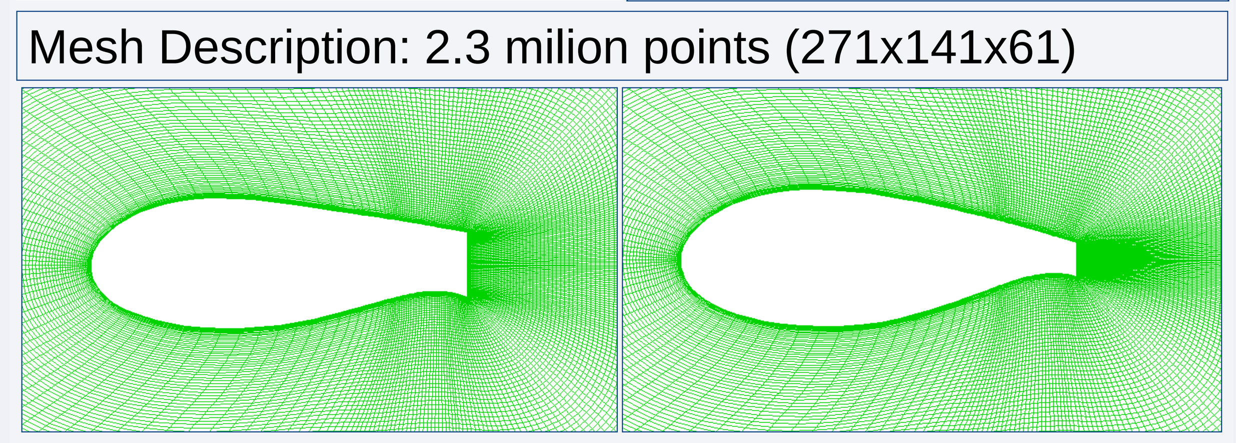
Base-line: FB3500-1750 and FB3500-0462



Wavy Trailing Edge: ¾ flatback and ½ flatback (4cyc/C)

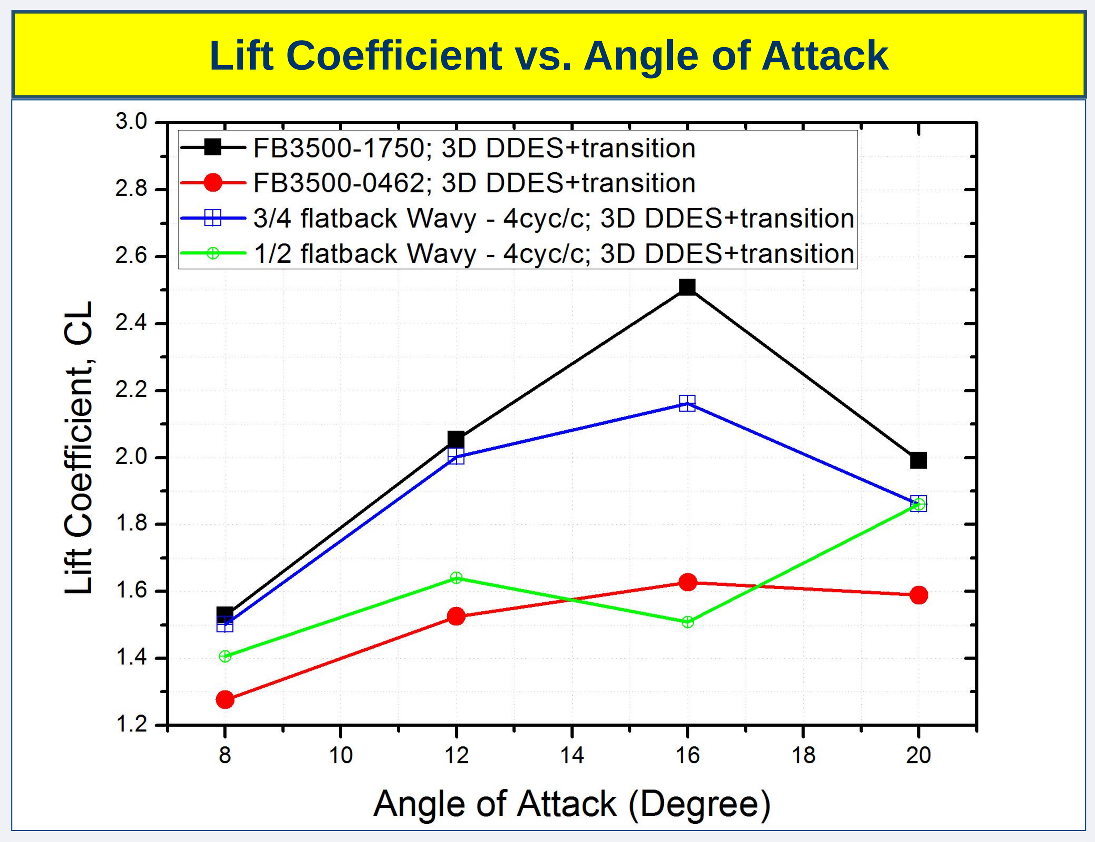


Mesh Description: 2.3 milion points (271x141x61)

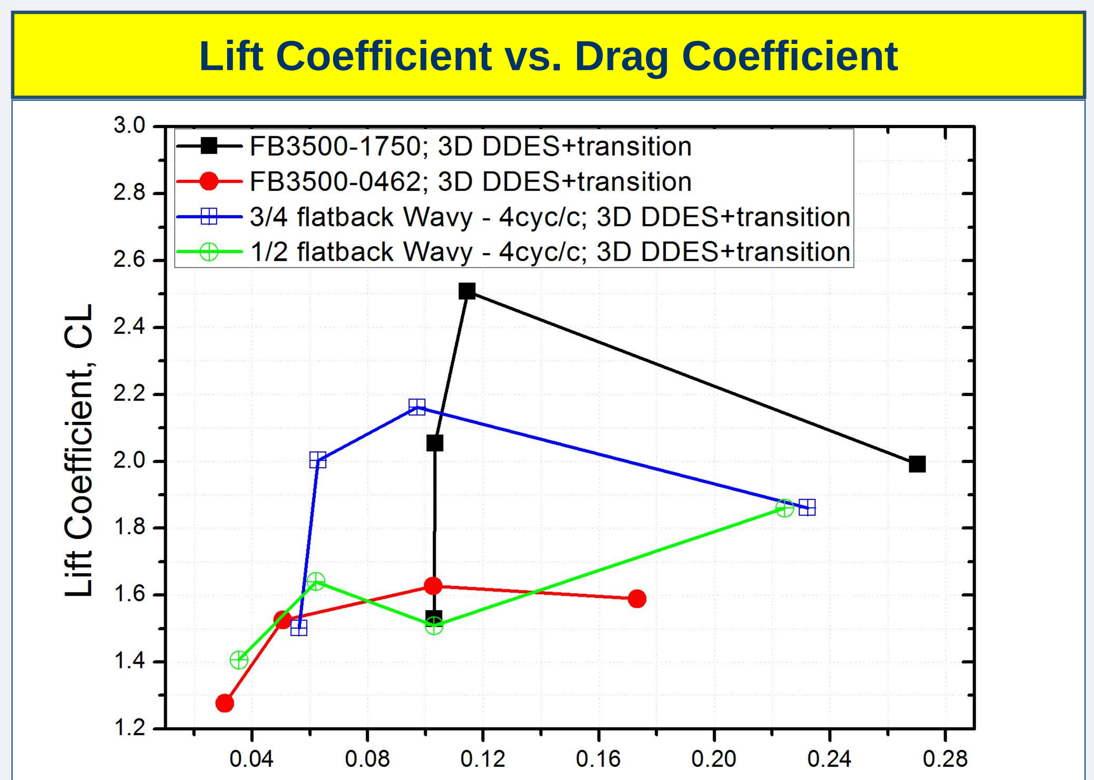


Results

Lift Coefficient vs. Angle of Attack



Lift Coefficient vs. Drag Coefficient

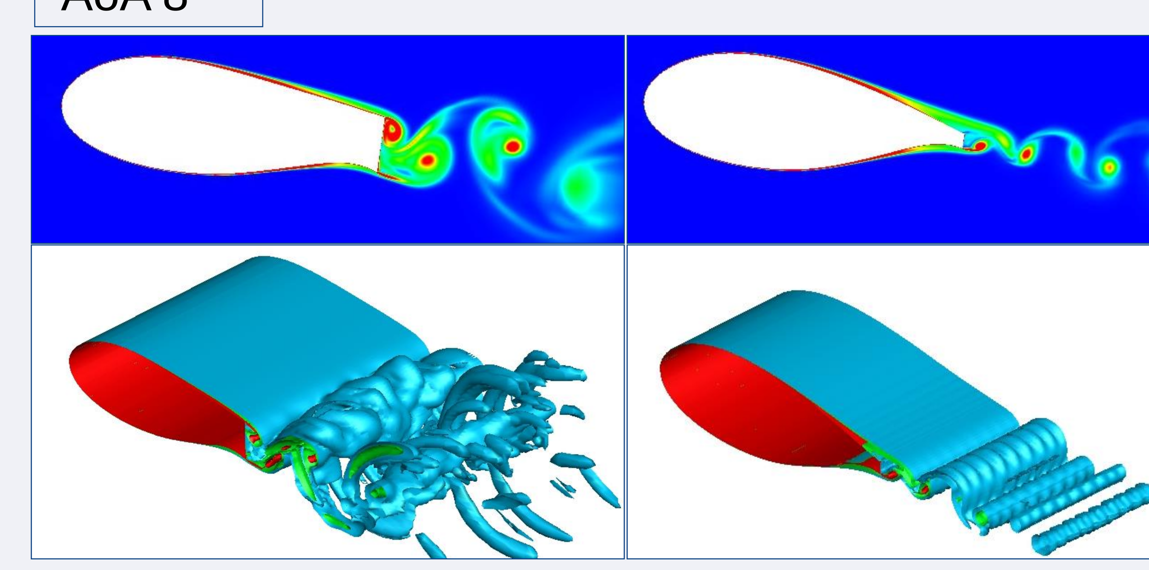


Results (Continue)

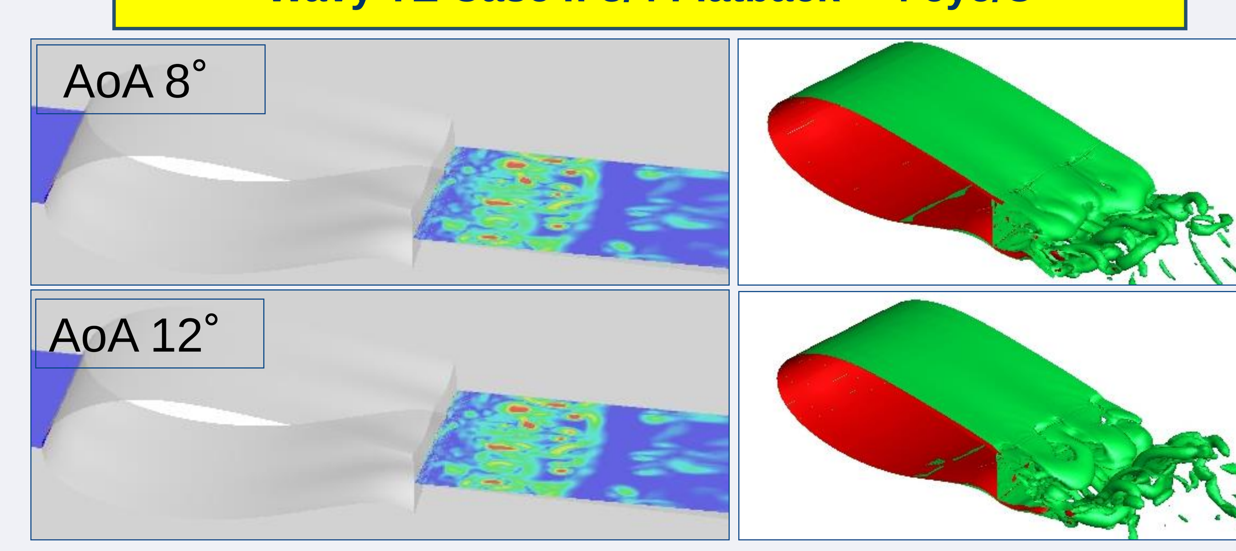
- For the 3/4 flatback wavy trailing edge at moderate angles of attack, a maximum of 40% reduction in aerodynamic drag was observed, while maintaining the lift of plain full flatback airfoil.
- While the 1/2 flatback wavy trailing edge performed better than the plain flatback airfoils at moderate angles of attack, the observed aerodynamic performance were deficient when compared to the 3/4 flatback wavy airfoils.
- The stream-wise vortices generated by the wavy trailing edge airfoils were successful in breaking up the coherent span-wise trailing edge vortices.

Baseline Cases: Full Flatback

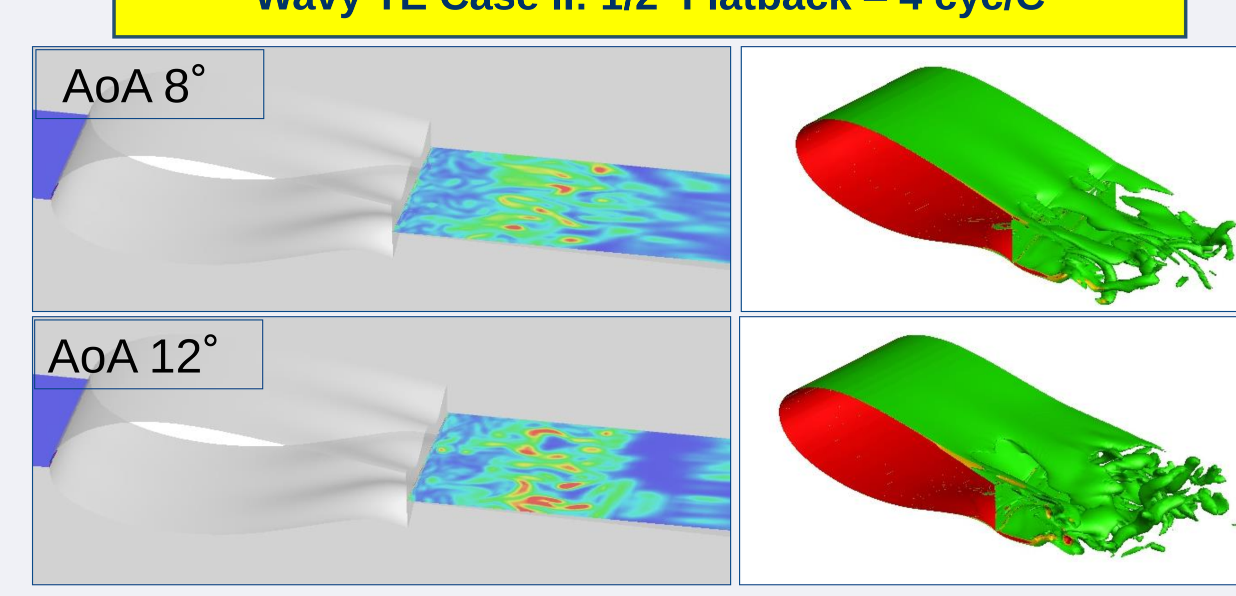
AoA 8°



Wavy TE Case I: 3/4 Flatback – 4 cyc/C



Wavy TE Case II: 1/2 Flatback – 4 cyc/C



Conclusions

- The *proposed wavy trailing edge design* was shown to be an *effective drag reduction modification to the flatback airfoils*.
- Amongst the tested airfoils, the *3/4 flatback wavy trailing edge airfoil was the most aerodynamically efficient*.
- The *GPU computation* environment *expedites* the *computational process by about 50 times when compared to a single core CPU*.

References

1. **S. Thomas, J. D. Baeder,** "Modeling the Two-Phase Flowfield Beneath a Hovering Rotor on Graphic Processing Units using a FVM-RANS Hybrid Methodology," 21th AIAA CFD Conference, Jun. 2013, San Diego, CA.
2. **S. Yang, J. D. Baeder,** "*Aerodynamic Drag and Aeroacoustic Noise Mitigation of Flatback Airfoil with Spanwise Wavy Trailing Edge,*" 33th Wind Energy Symposium, AIAA Scitech 2015, Kissimmee, FL, Jan 2015.
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4. **S. Medida, J. D. Baeder,** "*Application of the Correlation-based γ-$Re_{\theta t}$ Transition Model to the Spalart—Allmaras Turbulence Model*", 20th AIAA CFD Conference, Jun. 2011, Honolulu, HI.

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