Vortex boundary layer interaction

Scale resolving simulation of a strake vortex interaction with a turbulent boundary layer

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In Short

- vortex dynamics
- vortex boundary layer interaction
- wall-modelled Large Eddy simulation
- DLR TAU-code
- modal analysis

The use of strake vortices for high-lift applications is well established with aircraft design. The generic vortices dominate the complex vortex system originating at the suspended flaps around the engine pylon. For this, the strake vortex originates at a strake on the engine nacelle and flows around the suction side of the high-lift airfoil. This is also depicted in fig. 1, which shows a real life example taken of a strake vortex on an A340, by Frank Starmer [4]. Previous

***Figure 1:** Strake vortex on a A340 during lift off; picture taken by Starmer*

studies have shown a significant vortex movement for a strake vortex generated by an isolated delta wing. The generic vortex resembles a strake vortex in strength and size [2].

Previous studies have shown the potential of hybrid RANS-LES simulations to accurately display such vortices with an efficient scale resolving simulation approach [1]. Within a preliminary study on the HLRN, two of the hybrid RANS-LES approaches, which differ by the interface position of the synthetic turbulence generator, were continued, in order to generate a database for a modal analysis. Figure 2 and fig. 3 show the iso-contours of the Q-criterion

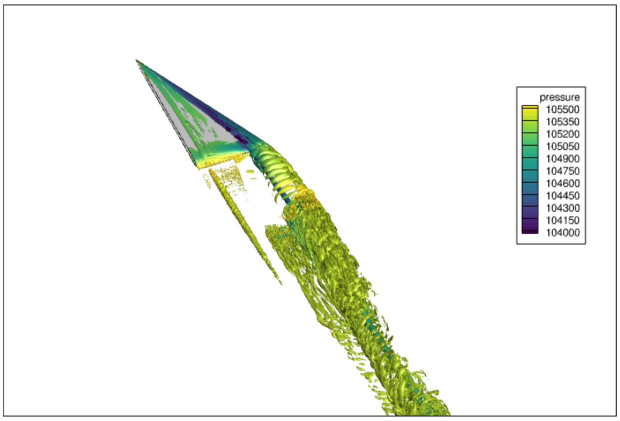

***Figure 2:** Iso-contours of the Q-criterion filled with the according pressure values; STG applied to the wake*

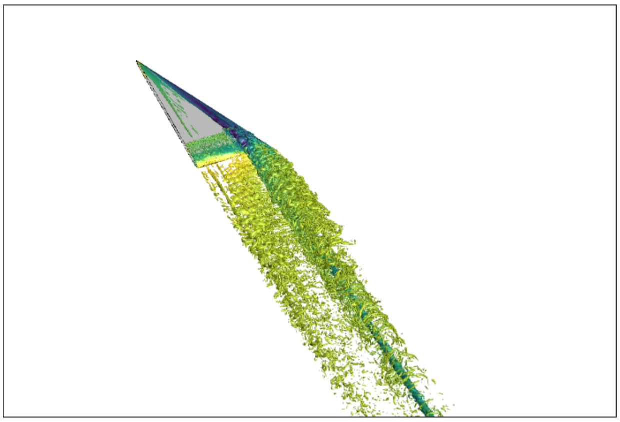

***Figure 3:** Iso-contours of the Q-criterion filled with the according pressure values; STG applied to the surface of the delta wing*

for the STG applied in the wake of the vortex generator and applied on the surface of the delta wing, respectively. The simulations were run for 11 convective time units and data was sampled at a sampling frequency of $f_s \approx 10$ kHz. A proper orthogonal decomposition reveals the dominating modes of the meandering motion and the results, shown on fig. 4 for both cases resemble the results found in experimental studies of the same case, as well results found in literature. The leading POD modes are commonly associated with an underlying coherent meandering motion [3]. Both positions of the synthetic turbulence generator are suitable to display the vortex characteristics and both spatial POD modees strongly resembles each other. However, the hybrid RANS-LES, which uses a STG in the wake of the vortex generator, consistently return a lower energy content of the individual modes, as well a a lower amplitude for the results of the dynamic mode

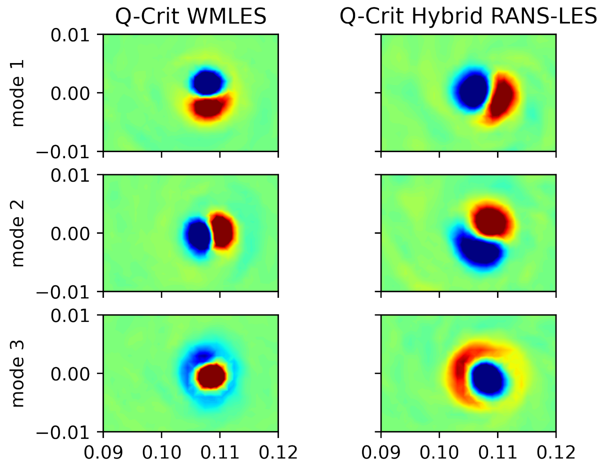

Figure 4: *Leading proper orthogonal modes for both hybrid RANS-LES approaches*

decomposition. The results for the DMD are shown within the full proposal.

The goal of this proposes project is to analyze a more realistic strake vortex application. For this, a combined simulation of the strake vortex generator, namely a sharp-edged delta wing configuration with a sweep angle of $65deg$ and an angle of attack of $8deg$, and a two-element high-lift airfoil is planned. The generated streamwise vortex will follow along the suction side of the airfoil, in a similar manner as depicted in fig. 1. A detailed grid convergence study is planned to generate the grids. The convergence study is based on three grid, each with a refinement of about 40%. In total three hybrid RANS-LES are planned to study the vortex boundary interaction. For each of the simulations a URANS start solution is necessary. Therefor, as a first step the URANS simulations are computed. Both, RANS and URANS are based on the Reynolds stress model $SSG-LRR-\omega$. The URANS solutions are then used as an input for the hybrid RANS-LES with will be run for an initiation phase of 8 CTU and a sampling phase of 12 CTU.

The first two hybrid RANS-LES will be based on the two interface positions, that were already used in the preliminary studies. The goal of this project phase is to analyze the possibility of both approaches to accurately display the vortex characteristics, the boundary layer interaction and the boundary layer detachment. The results will therefor also be compared to experimental Stereo-PIV results. Furthermore, the vortex dynamics will be evaluated in a similar manner as for the isolated delta wing test case. Within this evaluation process,the suitability of both interface positions of the STG to accurately display the vortex meandering on the suction side of the airfoil is of interest. A best practice method for the simulation of the vortex interaction with a turbulent boundary layer will be formulated and the interface position will be used for further studies.

The second focus of the project lies on the effect of the boundary layer interaction on the vortex dynamics. For this, a third hybrid RANS-LES is set up. The delta wing is moved downwards, further towards the pressure side of the airfoil, in order for the vortex to flow closer to the suction side. This will results in a stronger boundary layer interaction. The new grids are again evaluated by means of a grid convergence study. A modal analysis of these last results will be compared to results from the first two hybrid RANS-LES. This will allow for a conclusion on the influence of the turbulent boundary layer of the airfoil on the underlying vortex dynamics. The results will be compared to experimental results for the same configuration.

WWW

http://www.tu-braunschweig.de/ISM

More Information

[1] D.G. François, S. Probst, T. Knopp, C. Grabe, T. Landa, R. Radespiel, *JOURNAL OF AIRCRAFT* (2021-06). doi:10.2514/1.c036273

[2] T. Landa, L. Klug, R. Radespiel, S. Probst, T. Knopp *AIAA JOURNAL* (2020-07). doi:10.2514/1.j058650

[3] C. Del Pino, J.M. Lopez-Alonso, L. Parras,R. Fernandez-Feria *The Aeronautical Journal* (2011). doi:10.1017/S0001924000005686

[4] Frank Starmer 2010https://frank.itlab.us/photo_essays/wrapper.php?apr_01_2010_sq22.html

Project Partners

Deutsches Zentrum für Luft- und Raumfahrt Göttingen, Insitut für Aerodynamik und Strömungstechnik, Abteilung $C^2A^2S^2E$

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