Aerodynamic Aircraft Model Calibration

Calibration of Menter-SST turbulence model for industrial flow applications

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In Short

- implementing and testing vortex correction extensions to the Menter-SST model
- calibrating with deterministic optimization and uncertainty quantification
- validation of model to industrial flow applications

Numerical modeling of fluid flow plays an important role in the design and development of aircraft. The effectiveness of the flow prediction capabilities of a flow solver depends on the underlying turbulence model. One of the widely used turbulence models is the Menter-SST two-equation turbulence model[1]. This model is relatively robust and requires less computational resources for the simulation. The main drawback with the Menter-SST eddy viscocity model lies in the reproduction of some complex flow phenomenons such as vortical flows. It has been observed that the model can not capture the effects of the system rotation and streamline curvature effects, and performs weakly for wake flows. To offer a solution for the problem, an extension of the two-equation model with correction terms for special flows was suggested[1,2]. The extended model has to be calibrated before it can be applied to practical flow problems. The framework of the project LUFOV2-790-024 "Virtual Aircraft Model - Aerodynamic Calibration" deals with the calibration and validation of the extended model. Calibrations are to be done based on deterministic optimization and uncertainty quantification using Bayesian updates. The main objective of this project is to exploit the potentials of different correction methods for a two-equation model (Menter-SST) of turbulence. Therefore, three correction methods are investigated within this project: the vortex correction method, the wake flow correction method and the pressure gradient correction method.

During the intial phase of the project, the existing vorticity correction implementation in DLR TAU-code was validated using 3D delta wing test cases. Delta wings offer the ideal test case scenario as they produce vortical flow and also due to the availability of extensive experimental and numerical results from VFE (Vortex Flow Experiment). Vortical lift[3] is well known on highly swept wings with low aspect ratio. Delta wings are a standard example for this and these wings have different types of leading edge profiles and planforms. Due to the high pressure differences along the leading edge, vortical sheets are created along the suction side which produce a component of lift called vortical lift. Generally, a larger primary vortex is created along with a smaller secondary vortex. Sharp leading edges and rounded leading edge profiles are of importance in this project. Vortical flows from delta-shaped wings are typical for low-speed flight of supersonic aircraft. However, vortical flows are also present on subsonic transport aircraft, for example on strake of the empennage, on nacelle strakes, and they are shed from the lateral edges of high-lift devices. A double delta wing and a low aspect ratio wing with a leading edge slat were also studied, encompassing complex vortical flow problems. The sensitivities are evaluated related to the geometry and vortex interactions that take place in the case of double delta wings. It is a challenging task with a turbulence model to effectively predict the exact point and modes of separation.

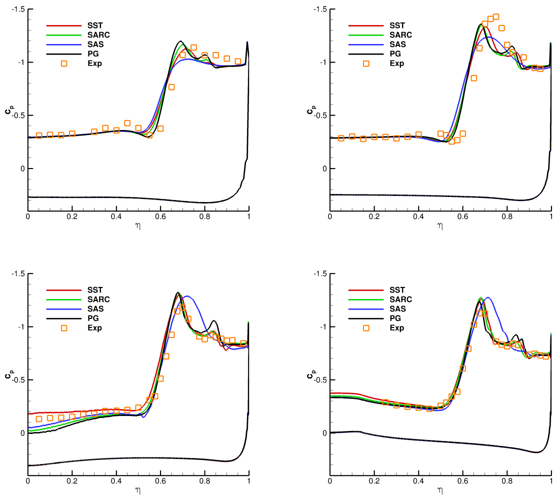

***Figure 1:** Spanwise surface pressure distributions of a sharp leading edge delta wing at transonic flow condition*

The wake flow correction (Scale Adaptive Simulation term) and the pressure gradient (PG) correction methods were implemented and a series of tests have been conducted. Initially all the extended models were tested for a Zero Pressure Gradient Flat Plate, to ensure that the extended models do not adversely influence the good predicting capabilities of Menter-SST model for near wall flows. A series of 2D computations such as Backward Facing Step(BFS), axisymmetric transonic bump and subsonic tail-plane research airfoil HGR-01 were performed for several types of flow conditions. These tests served to investigate the implementations and the results for different test cases were consistent with the modifications done to the length scale of the turbulence model.

It was known from the axisymmetric transonic bump case that the SAS model was very sensitive to high mach numbers. Therefore the delta wing (VFE-2) with the sharp leading edge was tested under transonic condition (0.8 Mach), Reynolds number of 2 million and at 13.3 degrees angle of attack as shown in figure 1. The models exhibited consistent behaviours as was seen in the previous test cases. SAS model predicts only one primary vortex whereas all the other models shows the presence of both primary and secondary vortices. A gradual increase in the intensity of the suction peak along the streamwise direction is exhibited by the SAS model in comparison to the other models. Similar behaviour is seen by the models for the other two angles of attack investigated. In the case of Ericsson double delta wing test case, the comparison was made under subsonic flow condition (0.5 Mach). As the angle of attack increases, after the onset of vortical flow, both SAS and PG models are highly sensitive due to the vortex interactions on top of the wing. Reduced intensities in the vortex suction peaks were observed.

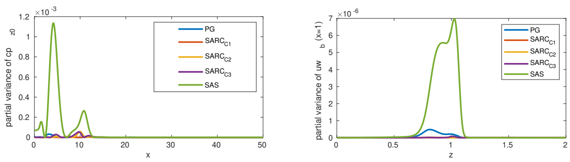

Figure 2: *BFS: Sobol partial variances[4]*

All the test cases were analysed individually with the original model and other three extensions of interest. The models are in the calibration process simultaneously through successive Bayesian updates. SARC model extension has three parameters to be calibrated whereas SAS and PG extension have one each of their own. Backward Facing Step is the first test case which was selected for the calibration process, to gain knowledge about the sensitivity and apply it to further complicated cases progressively. Initially a sensitivity study for each of the extension was done individually by varying the parameters in a range of zero to one and half times of its original value. This domain is set as a bound for the five dimensional parameter spacing and the sets of parameters are generated using different sampling techniques (Quasi Monte Carlo, Latin Hypercube and Sparse)[4]. It has to be noted that during the calibration process, the SST model is treated as an extended single model with all three correction methods (SARC, SAS and PG). Simulations were performed for the parameter sets and data such as coefficient of pressure and wall skin friction, velocity and reynolds stresses were given as input to the Uncertainity Quantification software. Experimental data for the same flow properties comprise the reference data. Two different representations (Generalized Polynomial Chaos and Normalized Radial Basis Functions) were chosen for the surrogate models. A few data sets from the paramter sets were used to train the model while the others were used to validate the model. A GPC based Sobol sensitivity analysis was performed which shows the response from the extended turbulence model parameters at different instances for different flow properties. The partial variances of the responses from the first iteration are shown in the figure 2. Based on the knowledge gained from the first iteration of calibration, an informative second iteration is currently being performed. A new refined parameter set (10 times smaller interval than the first iteration) is generated concentrated around the area of interest and CFD simulations are being performed. This process would be done for three more test cases and finally the calibrated parameters would be validated for all the test cases.

WWW

https://www.tu-braunschweig.de/ism

More Information

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Project Partners

Airbus; DLR; TU Braunschweig: Institute of Fluid Mechanics, Institute of Scientific Computing; TU München: Institute of Aerodynamics and Fluid Mechanics, Institute of Lightweight Structures; University of Stuttgart: Institute for Aerodynamics and Gas Dynamics

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