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STUDY OF MODEL DEFORMATION AND STING INTERFERENCE TO THE AERODYNAMIC ESTIMATIONS OF THE CAE-AVM MODEL

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Abstract

Major observations of the wind tunnel model deformation and sting interference to the aerodynamic performance estimation at high subsonic Mach number are discussed in this paper, based on the numerical and wind tunnel investigation of the CAE-AVM configuration (Chinese Aeronautical Establishment - Aerodynamics Validation Model). This dual purpose model was designed via numerical tools and tested in the wind tunnel both for the verification of the aerodynamic performance of the high subsonic design and for the validation of CAE AVICFD software. In order to reduce the deformation of the wind tunnel test model, the wing was re-designed at a reduced Mach number 0.85 to increase the wing relative thickness. Special wind tunnel test techniques and model fabrication, such as the simultaneous measurements including transition detection and wing deformation are effective for CFD validation purpose. The experimental measurements at DNW-HST verified the aerodynamic design and test strategy of the CAE-AVM. CFD analysis with both deformed wings and sting before and after the wind tunnel test is found necessary for CFD-wind tunnel comparisons during the test, and for the CFD-wind tunnel correlation studies.

1 Introduction

Future sustainable aviation brings further challenges to innovative technologies in aeronautics and air transportation. In the fields of aerodynamics for commercial aircraft, study is continued for increasing the aerodynamic efficiency ML/D. Besides the long term effort on improving the lift to drag ratio L/D, recent study focuses on increasing the flight Mach number M. Modern wide body airliners and business jets could fly at M=0.85 and higher with extended long haul capacities.

With this background, Chinese Aeronautical Establishment (CAE) conducted a conceptual design study of a greener business jet at cruise Mach number 0.87. The aerodynamic design was completed with a multi-block structured solver of CAE in-house Aviation CFD code AVICFD-Y [1]. For the un-structured version AVICFD-X under development, it was found necessary to collect sufficient experimental data with this model to build a database for the validation of the AVICFD software [2]. Therefore it was decided to combine the wind tunnel verification of the greener business jet with the CFD validation database. The test configuration of this dual purpose model is named CAE-AVM (Chinese Aeronautical Establishment – Aerodynamics Validation Model).

In order to reduce the wing deformation of the wind tunnel test model of CAE-AVM for CFD validation, the wing was re-designed at a smaller Mach number to increase the relative thickness by around 1%. Design optimization with CFD tools was also followed to improve the flow details observed when Reynolds number (Re) reduced from flight value to wind tunnel value with the 1:22 model ratio. The specific consideration and test procedures for the data base of CFD validation purpose are discussed. CFD analysis of the model alone and the model with deformed wings and the sting of the support system, before and after the wind tunnel test provided very satisfied comparison with the experimental data from the DNW-HST wind tunnel.

2 Design and Wind Tunnel Verification of CAE-AVM

2.1 Conceptual Study of a Greener Long Haul Business Jet and the CAE-AVM Design

The conceptual design of the greener business jet is targeting M=0.87, range 11000 to 13000 km. The aircraft length is 33m and wing span 33.5m with high speed wing tips. While combining this design with the CFD validation database, the wing was re-designed at M=0.85 and the configuration was named CAE-AVM as discussed above. In order to increase the size of the wind tunnel test model, the wing tips are not included. The configuration of CAE-AVM is shown in Fig.1.

Fig. 1. Aerodynamic configuration of CAE-AVM

2.2 Design methods and software

CAE in-house code AVICFD-Y is the major tool for the flow and aerodynamic performance analysis，which is a RANS solver based on multi-block structured mesh. During the progress of Designing, the mesh sizes of 15 to 30 million nodes and SST turbulent are adapted.

The airfoil[3] named NPU-SP6 is used as the baseline profile for the wing design. For the design of M=0.87 wing, Both inverse method [4] and numerical optimization [5] are applied . Fig. 2 shows the FFD approach for the wing design optimization.

During the re-design of the M=0.85 wing, inverse method was used only for a fast convergence [6].

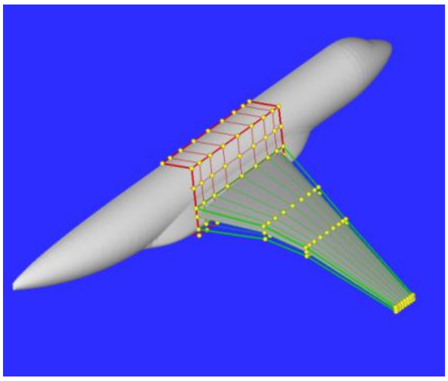

Fig. 2. FFD approach

2.3 Optimization at Wind Tunnel Reynolds Number

CFD analysis of the CAE-AVM at wind tunnel test Reynolds number Re=4.7 million, based on the mean aerodynamic chord of the 1:22 model, was conducted and the aerodynamic performance found acceptable. some typical flow phenomena happened at Wind Tunnel Reynolds Number, such as small trailing edge separation of the wing and supersonic flow area between engine nacelle and fuselage, design optimization was performed to eliminate the un-expected. Fig. 3 shows the trailing edge separation disappear at Wind Tunnel Reynolds Number.

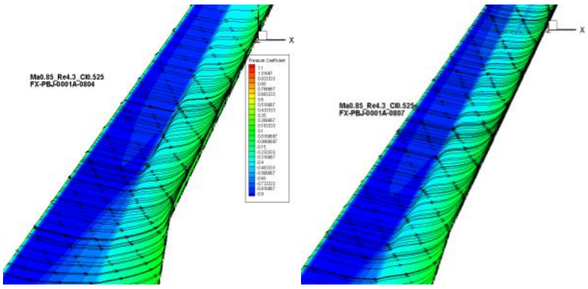

Fig. 3. Removal of the trailing edge separation

2.4 Wind Tunnel Test of CAE-AVM

The wind tunnel model was fabricated by the National Aerospace Centre of the Netherlands (NLR) [7] with a 1:22 full size. Fig. 4 shows the wind tunnel test model of CAE-AVM. The wind tunnel test was accomplished in the German-Dutch Wind-tunnel DNW-HST [8], including measurements of the forces, moments, pressure distributions, transition detection by infrared camera and wing deformation with Stereo Pattern Recognition technique SPR, all in parallel. Fig. 5 shows the model installation and test instrumentation.

Fig. 4. Wind tunnel test model of CAE-AVM

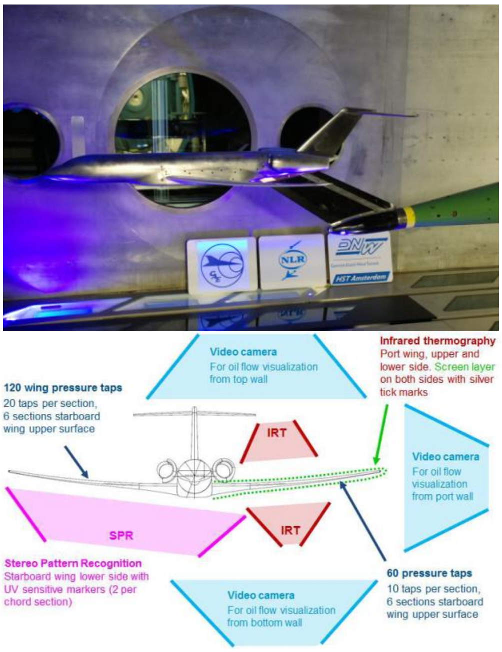

Fig. 5. Test instrumentation of CAE-AVM in DNW-HST

3 CFD Study and Wind Tunnel Verification of CAE-AVM

3.1 CFD Estimation preparation

Two configurations are prepared, one named CAE-AVM including aircraft designed shape, another named CAE-AVM-DZ including aircraft with deformed wings and Z sting. Two sets of structured mesh are generated, one for designed geometry CAE-AVM (Fig. 6) and the other for test geometry CAE-AVM-DZ (Fig. 7), which is the designed geometry with deformed wing and Z sting.

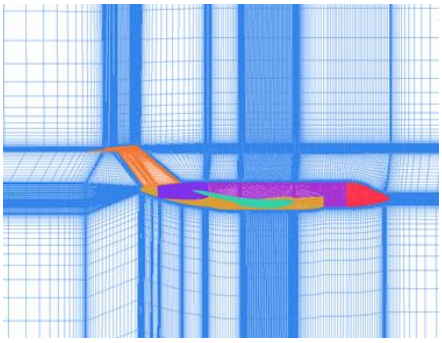

Fig. 6. CFD mesh of CAE-AVM

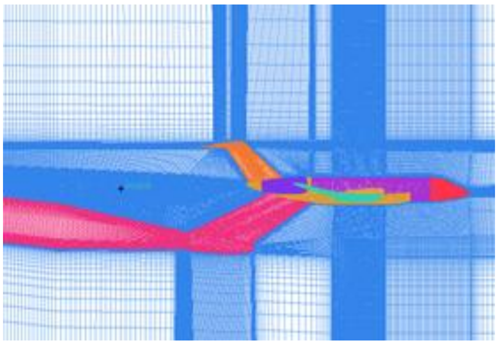

Fig. 7. CFD mesh of CAE-AVM-DZ

3.2 Comparison of the Numerical and Experimental Results

Fig. 8 illustrates the comparison of CFD results of AVM-DZ with measured data near design condition, in mid- and out-board span sections, the coincidence is excellent.

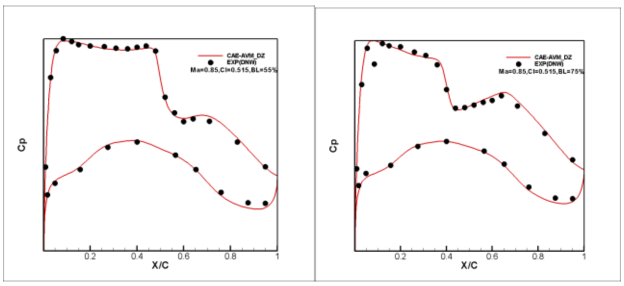

Fig. 8. Comparison of Cp at 55% and 75% semi-span sections

4 Wing Deformation Effect and Sting Interference to the Aerodynamic Performance

4.1 Comparisons of CFD and Wind Tunnel results

Detailed CFD analysis was conducted for both CAE-AVM geometry and CAE-AVM-DZ. Fig.9 shows the Cp distribution of both CAE-AVM and CAE-AVM-DZ at the 0.55% semi-span wing section. It is observed that the wing deformation and sting interference will weak the shocks on the upper surface of the wing and shift the shock wave forward, meanwhile reduce the sectional lift.

Fig.10 shows the comparison of lift curve of both CAE-AVM and CAE-AVM-DZ at M=0.85, it could be seen that while the wing deformation and sting (AVM-DZ shape) are included in the CFD, the coincidence to the test data is much improved. Fig. 11 is the same comparison for drag coefficients CD, the drag values of AVM-DZ are 30 counts less than AVM shape and are more close to the test data around flight angle of attack from 0 to 3.5 degrees. Similar results could be identified for pitching moment.

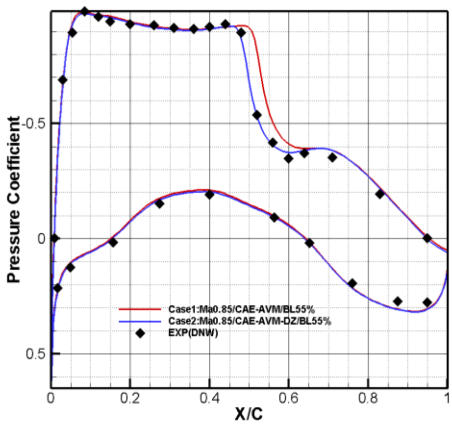

Fig.9. Cp distribution of both CAE-AVM and CAE-AVM-DZ at the 0.55% half-span wing section

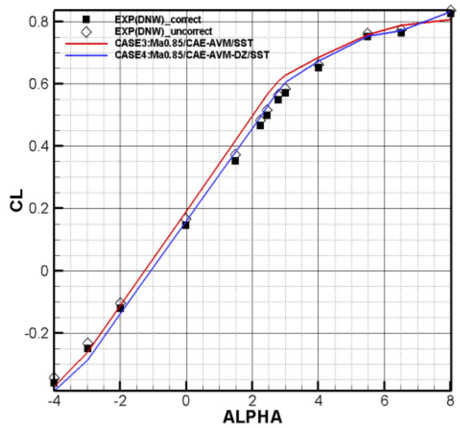

Fig.10. Comparison of lift curve of both CAE-AVM and CAE-AVM-DZ at M=0.85

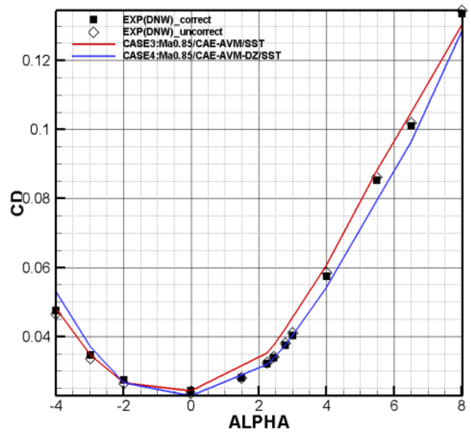

Fig.11. Comparison of drag coefficient of both CAE-AVM and CAE-AVM-DZ at M=0.85

Interference breakdown is also studied with CFD tool for wing deformation and Z sting separately. It is observed that the wing deformation alone will reduce the section lift of the outboard wing, while the Z sting intends to shift the shock wave forward at the upper side of the wing.

4.2 Observations from the Comparisons

The general observations from the above correlation study include but not limited to:

- CFD with both wing deformation and string will significantly improve the coincidence with the uncorrected wind tunnel data, especially Cp
- CFD with both wing deformation and string before the wind tunnel test will improve efficiency of the data interpretation during wind tunnel testing
- CFD with and without wing deformation and sting (AVM and AVM-DZ) will

significantly improve the efficiency and understanding of the CFD validation with wind tunnel test data Well applied CFD with wing deformation and/or sting system may be used for test data corrections, wing loads corrections and play other roles in CFD-wind tunnel correction studies.

5 Conclusions

The aerodynamics design of the dual purpose research model CAE-AVM has been accomplished. The CFD tools, inverse design method and numerical optimization approach have been reasonably applied. Considerations for CFD validation require well balance of the aerodynamic performance and wing thickness, together with detailed flow optimization at wind tunnel test Reynolds number. Special wind tunnel test strategy and model fabrication are also necessary for CFD validation database, including the simultaneous measurements of the forces, moments, pressure distributions, transition detection and wing deformation. CFD analysis with both wing deformation and sting is found essential for CFD-wind tunnel comparisons of large aspect ratio wings at Mach number around 0.85. General observations of the interferences from the model deformation and sting at transonic speed are summarized.

Acknowledgment

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