A PRELIMINARY CFD INVESTIGATION ON REAR FUSELAGE SUPPORT CORRECTION

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Abstract

Wind tunnel (WT) and computational fluid dynamics (CFD) have long been regarded as two indispensable tools in modern aircraft research and design.

In this paper, CFD, serving as a complementary tool for WT, is emphasized. A few preliminary applications of CFD on WT support interference research performed in the authors' institute are introduced. Though there is still a long way to go, CFD here has demonstrated its superiority in quantification and visualization, clarifying and validating some understanding and practices in WT support interference corrections.

1 Introduction

Wind tunnel (WT), computational fluid dynamics (CFD) and together with flight test (FT) constitute three pillars for modern aircraft design [1]. With advances of CFD techniques and their increasing use in aeronautical industry, the number of WT tests for developing a new aircraft has been dramatically decreased over the last few decades. However, design engineers are still prone to believe in and rely on WT results to make critical decisions. In most cases, WT and CFD now complement with each other in supporting design of a new aircraft [2]. The current paper here will demonstrate several results from a preliminary CFD investigation on rear fuselage support system, which is often used in high-speed wind tunnel tests.

An essential step for scaling WT results to free flight condition is interference correction, including mainly corrections on wind tunnel wall and support system effects. During a wind tunnel test, a certain kind of support system must be used to maintain aircraft model in the test section. In the meantime, the support system will create some flow distortions around the test model, leading to the so-called aerodynamic interferences, which in certain cases have a strong effect on measurement data.

With certain combinations of the test model and the support system, special interference measurements on these combined configurations are also conducted right after completing routine tests, through which corresponding interferences are separated and derived. Nearly all wind tunnels have developed their own bookkeeping procedures to determine and correct support interferences.

From an airframer's perspective, existing support interference corrections have some drawbacks. They are wind tunnel dependent; they are relying on some empirical assumptions and experiences; and they are in a certain extent difficult to validate. Thanks to the availability of modern CFD software, simulations can be performed to compare, validate WT support interference corrections and used for control or minimizing interference effects through design optimization on support configuration before WT. Another unique feature for implementation of CFD here is that it can visualize the flow field and provide detail flow information due to occurrence of support interferences.

In this paper, several simplifications both on physical and numerical models are made for limitation on details at that time and essence of problems under research. On one hand, the WT wall interference has not been considered, and only the rear support sting with part of double-roll boom is modeled due to available geometry information. On the other hand, RANS simulations are performed on unstructured tetra meshes with ANSYS CFX software package. No prism layers are generated to further refine the near-wall region because variations in surface pressure are supposed to be dominated in current research. Owning to the simplifications and limitations here, No quantitative conclusions and decisive judgments can be made before further improvement on prediction and validation is conducted with CFD results. Perhaps in future a better validated CFD prediction together with WT results can help to make engineering decisions.

In the following sections, two main effects are considered and investigated, dorsal sting interference effects and horizontal tail plane (HTP) deflection angle effect. Longitudinal force coefficients are calculated respectively and compared correspondingly to account for the support interference effects.

2 Effect of dorsal sting

For a high-speed aerodynamic wind tunnel test, a sting penetrating the rear part of fuselage is often used to support the aircraft model in the test section. The interfering flow effect due to the presence of the rear sting on the model is what we called sting interference, which will be inherently part of final measurement results. To get the aerodynamic characteristics of the scaling aircraft in free flight condition, sting interferences must be corrected. An ideal way to do this is that the pure sting effect can be measured directly and then separated from the test results, but it is not exactly what is actually done during practical wind tunnel tests.

A two-step method is implemented to get the rear sting interferences during high speed wind tunnel tests. The first step is to test the scaling aircraft model with a dorsal sting fixing on the forward part of fuselage at corresponding test conditions. At the second step, a dummy rear sting placing at the same location with the real rear sting used in former routine tests is then added in order to create a similar flow disturbance. It is believed that subtracting step 1 result from step 2 result will produce the force coefficient increment due to rear sting interference. The resulting interference will then be applied accordingly to correct the routine test results.

Theoretically speaking, the corrected interference from the two-step methodology can't be purely regarded as the rear sting interference effect, because extra interferences caused by the dorsal sting may not be totally eliminated through the subtraction process. To minimize the potential secondary interferences, during wind tunnel test it is assumed that the interactional interference between the dorsal sting and the dummy rear sting can be ignored, and the installation of dorsal sting will lead to minimum additional change on local flow.

The above assumptions are seldom checked and validated at pre-test phase. Here in this section CFD will be used to clarify those common practices.

The nomenclature for configurations used in CFD simulation is first introduced here. WBT stands for aircraft configuration with wing, body (fuselage) and tails (including both vertical tail plane and horizontal tail plane). WBTS stands for configuration with wing, body, tail and rear sting support. WBTD stands for configuration with wing, body, tail and dorsal sting. WBTSD stands for configuration with wing, body, tail, rear sting support and dorsal sting.

Fig. 1. WBT configuration and WBTS configuration

Fig. 2. WBTD configuration and WBTSD configuration

Assuming that the real rear sting interference can be got by subtracting WBT results from WBTS results (Fig. 1.), the nominal rear sting interferences will be obtained by reproducing the WT two-step correction procedure through CFD, subtracting WBTD results from WBTSD results (Fig. 2.). Respective increment in longitudinal force coefficients will be accordingly compared as following. (Fig. 3. - Fig. 5.)

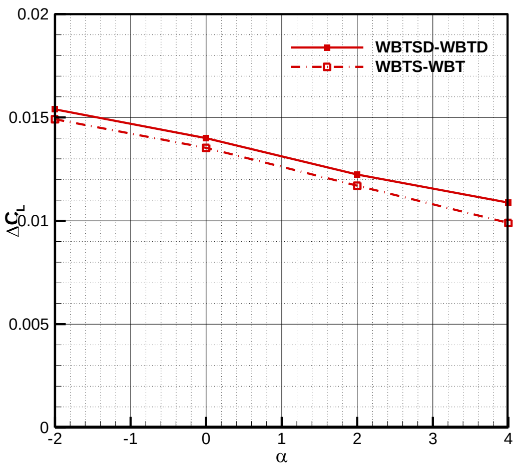

Fig. 3. Real and nominal rear sting interference correction on lift coefficients

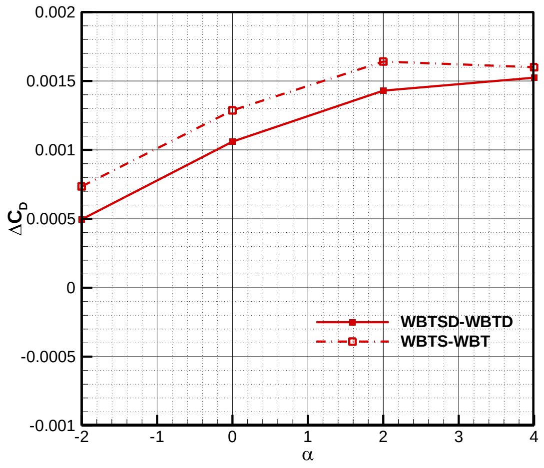

Fig. 4. Real and nominal rear sting interference correction on drag coefficients

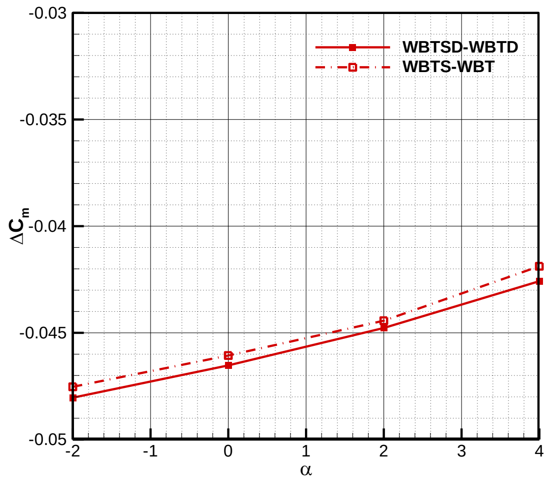

Fig. 5. Real and nominal rear sting interference correction on pitching moment coefficients

The objective of CFD here is not to seek the absolute quantity but the incremental quantity. Though lacking of enough previous validation and verification, CFD results here can still in a certain extent reflect the relative trends and help to understand sting interference effect in pre-test phase. Compared to the lift coefficient and pitching moment coefficient, it can be seen that corrected value for drag coefficient will be affected more by rear sting interference correction method used during WT. If the real correction and nominal correction are both applied to the uncorrected results from the routine test, the nominal correction will tend to lead to a right shift in the drag polar (Fig. 6.), which means that the two-step methodology with the aid of a dorsal sting will probably over-predict the drag level.

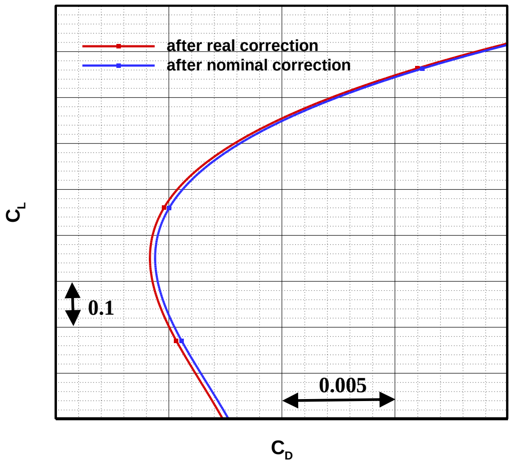

Fig. 6. Drag polar after real correction and nominal correction

Using CFD, the rear sting interference effect on drag can be further decomposed onto different parts of the aircraft model, which can't be easily realized during WT. Fig. 7 shows how rear sting interferences with drag on aircraft level is distributed among each parts.

	Forward-fuselage	Aft-fuselage	Wing	VTP	HTP	aircraft
Real correction	0.3	1.9	-2.3	2.4	10.5	12.8
Nominal correction	-0.2	-0.1	-2.1	2.5	10.5	10.6

Fig. 7. Rear sting interference effect on drag on different part of aircraft

After comparing the results between real correction and nominal correction, it can be seen that the difference on aft-fuselage contributes the most of deviation between nominal correction and real correction. It can be inferred that the dorsal sting and the dummy rear sting in WBTSD configuration will have some additional interactions mainly at the aft-fuselage region, which leads to the over-prediction of the drag level when implementing the two-step correction methodology.

To be more illustrative, several calculated flow field contours are visualized and compared to demonstrate the flow distortion created by the presence of dorsal sting (Fig. 8. and Fig. 9.). Further simulation and detail analysis can be expected to uncover the flow physics and optimize the installation of the support sting.

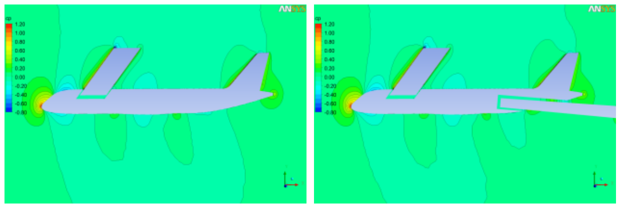

Fig. 8. Comparison of the pressure coefficient on the symmetry plane

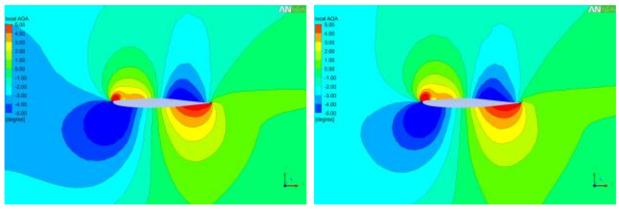

Fig. 9. Comparison of the local angle of attack on a cross-section plane of HTP

3 Effect of HTP deflection

There is another common practice in sting interference correction during wind tunnel tests. For HTP efficiency test, a series of configurations with different HTP deflection are tested together with the baseline configuration, the configuration with no HTP deflection. However, corresponding interference measurements are only performed once on the baseline configuration. All other test configurations with different HTP deflection will then be corrected with the same quantity got from baseline. The validity of current practice during wind tunnel tests still needs additional consideration. CFD here is used again to help understand and clarify this problem.

Real rear sting interferences for configurations with -3 degree HTP deflection are obtained through subtraction between WBTS and WBT also with -3 degree HTP deflection. Nominal rear sting interferences are got from subtracting WBTD from WBTSD with no HTP deflection as what is done in wind tunnel tests. Real and nominal corrections on longitudinal force coefficients are both shown below (Fig. 10. - Fig. 12.). Evident difference between real and nominal correction at the same angle of attack can be seen.

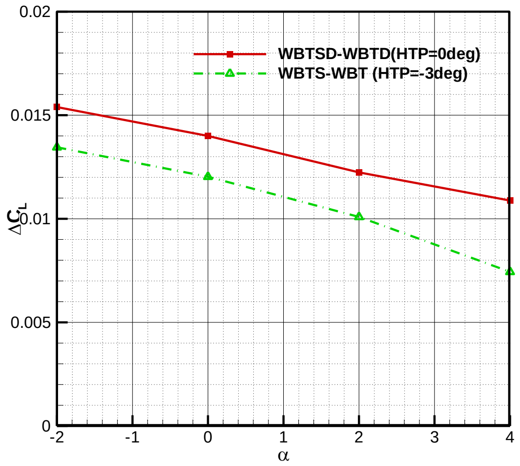

Fig. 10. Nominal and real correction on lift coefficients for configurations with-3 degree HTP deflection

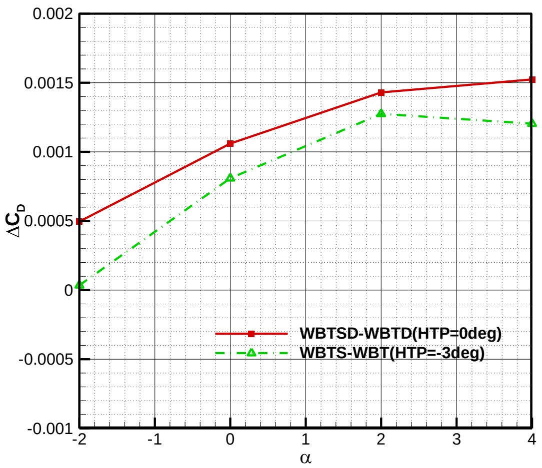

Fig. 11. Nominal and real correction on drag coefficients for configurations with -3 degree HTP deflection

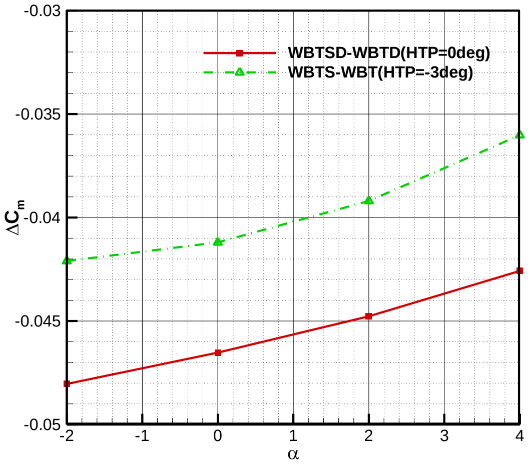

Fig. 12. Nominal and real correction on pitching moment for configurations with -3 degree HTP deflection

After applying the real and nominal interference both on uncorrected results, no much difference are found on pitching moment versus lift relationship. For drag polar, there exists a left shift (Fig. 13.), which means nominal correction for configuration with -3 degree HTP deflection will accordingly lead to an under-prediction of the drag level.

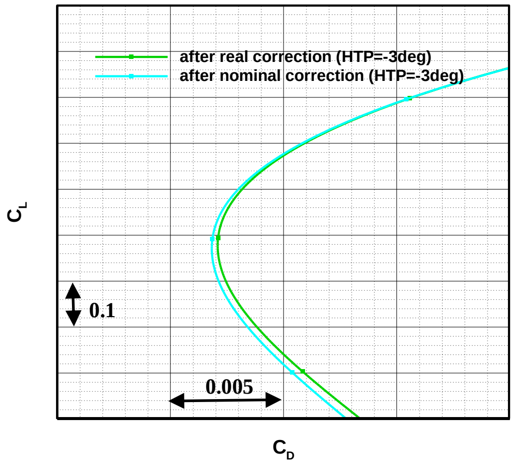

Fig. 13. Drag polar after real correction and nominal correction for configurations with -3 degree HTP deflection

4 Conclusion

In this paper, a preliminary CFD investigation on rear fuselage support correction is conducted. Two common practices for rear sting interference correction, which are often took for granted during high speed wind tunnel tests, are clarified and understood.

Both the dorsal sting and HTP deflection have little effect on pitching moment coefficient versus lift coefficient relationship. The presence of the dorsal sting in the two-step rear sting interference correction tend to over-predict the drag level, but the current rear sting interference correction on configurations with HTP deflection will under-predict the actual drag level.

Owning to the simplification of both the geometry and physical model, further validation and improvements must be done based on available results in future. For the moment, current research can be only regarded as a beneficial and worthwhile trial during pre-test phase.

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