CFD for Better Understanding of Wind Tunnel Tests: some examples

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Abstract

CFD requires validation for complicated flow problems involving complex physics such as turbulence. Wind tunnels are still the most commonly used validation tools for CFD including physical modelling although some limited use of reliable DNS data base for simple geometries is recently becoming possible. One can observe the trend that a higher and higher demand on the accuracy of the wind tunnel measurement as numerical simulation and CFD expand into more and more complicated flow regimes. This presentation gives a few examples to demonstrate how CFD may be used in a reversed way to help wind tunnel to meet the challenges posed by both better understanding of flow physics and CFD validations.

For supersonic flows around slender pointed bodies of a circular cross section, a bow shock form in an approximately conical shape around the geometry. At certain conditions for moderate incidences, a weak secondary wave was occasionally observed in the Schlieren images. This was initially attributed to the possible local geometrical roughness of the models or the wind tunnels. However the consistency of the position of the weak shock wave indicates the physical relevance of the phenomenon. Detailed CFD simulations were able to pinpoint the mechanism for the formation of this weak secondary shock and therefore enhance our understanding of the associated flow physics.

Criteria for incipient separation are important for control surface design at supersonic and hypersonic speeds. Empirical relations have been established based on extensive experimental tests for both laminar and turbulence flows. On the other hand, the incipient separation angle can be found by solving a non-linear problem for zero-skin friction as a function of the ramp angle based on the flow field simulation. With reliable numerical simulations for the laminar flows, we can demonstrate that, using a bi-section method, the incipient separation predicted is in good agreement with the empirical criterion. This example shows the usefulness of the CFD simulations in verifying and potentially extending the range of applicability of some wind tunnel based empirical relations. Furthermore, new *numerical* empirical relations may be derived for fast design and *real time* predictions based large credible CFD database.

The third example is the use of CFD for the study of wall interference. Wall interference correction is particularly important for transonic wind tunnel tests, where it is the most significant, necessitating the use of porous (perforated or slotted) wind tunnel walls to reduce the wall interference. This poses a significant problem in setting proper boundary conditions in the numerical simulation of the complete transonic wind tunnel problem. Ideally, the difference between the CFD simulation of the flow inside the tunnel and the CFD simulation in the free air can provide the required corrections to the wind tunnel measurement data so as to make it more useful for flight conditions. This is based on the arguable assumption that the CFD increment is much more accurate than the CFD raw data, such as the drag coefficient (almost always questionable due to grid resolution and turbulence modelling), while the measurement of these aerodynamic data are of higher accuracy (or higher believability?).