Fixing Poor Control Surface Performance on a Transonic Missile – A Case Study of Combining Cost-Effective Wind Tunnel Testing and CFD Analysis

CP Crosby and SG Gobey
Aerodynamics Department, Kentron
Centurion, South Africa

ABSTRACT

Initial small-scale (1:13) wind tunnel tests on a new transonic missile design with particularly challenging pitch control requirements revealed a lack of elevator effectiveness. Lacking a suitable CFD capability, the design of the closely coupled canards was improved through three iterations on this model scale, without determining the root cause of the problem. It was assumed that the problem was at least partly caused by sub-scale model profile inaccuracy and low Reynolds number, and the testing programme proceeded to a 30% scale version of the evolved design. At this point however, it became clear that the lack of elevator effectiveness was being caused by a fundamental characteristic of the flow, and was not an artifact of the small-scale wind tunnel test. CFD analysis was then undertaken in order to understand the flow characteristics.

Limited time and resources dictated that fully detailed and validated CFD would be unrealistic. It was accepted that grid-independent results would not be achievable, and much downstream detail was also omitted from the CFD model. The emphasis of the CFD study thus shifted towards a qualitative understanding of the most dominant fluid flow characteristics. It was assumed that lack of downstream geometric detail and grid-independence would not fundamentally change the nature of the calculated flow field. These assumptions proved to be valid, as CFD-Fastran (used with the k-ε turbulence model) predicted collapse of elevator effectiveness at incidence and deflection angles that were close to wind tunnel values. Inspection of the calculated flow fields revealed excessive flow separation partly caused by interference effects and nose upwash.

The canard design was then developed through five evolutions, evaluated only by inspection of the CFD-calculated flow fields, in order to reduce flow separation and adverse interference. By the fifth evolution the design featured much more leading edge sweepback, and also a large boundary layer fence. CFD flow fields indicated that major flow separation had been delayed to sufficiently large incidence and deflection angles. Integration of the aerodynamic forces also indicated that the angles at which elevator effectiveness collapsed had been increased sufficiently.

Considerations of time-scale, model cost and transonic wind tunnel unavailability resulted in these modifications being tested in a low-speed wind tunnel, using control surfaces with much simplified profiles. These cheap tests indicated that the design had been greatly improved and that the boundary layer fence was hurting rather than helping. There was considerable scepticism about the validity of these "rough" tests. However, CFD simulations (performed at these tunnel conditions) reproduced the trends seen in these tests, and also confirmed the negative effect of the boundary layer fence. Subsequent CFD simulation of the design with the fence at transonic tunnel conditions confirmed that it had indeed been a blind development alley.

The modified design, using accurate profiles, was then tested in the transonic wind tunnel and confirmed that the control effectiveness collapse had indeed been delayed to sufficiently large incidence and deflection angles. The following lessons were learnt from this study:

1. Inexpensive, small-scale wind tunnel tests can give misleading results, but CFD should be used to determine the cause of unexpected results before jumping to conclusions
2. CFD simulations do not always need to be performed to high levels of geometric detail and grid refinement in order to capture the most important characteristics of a complex flow field
3. Qualitative inspection of CFD flow fields should be taken seriously, as it is an invaluable aid to understanding complex flows encountered in the real world. Development without this understanding is mostly a shot in the dark.
4. Given the "safety-net" of a very detailed and accurate wind-tunnel test to be performed later in a project, much time and money can be saved by performing some earlier CFD work and wind-tunnel tests at much lower levels of detail and refinement. This allows more designs to be evaluated under more conditions for the same cost.
5. The aerodynamic designer, wind-tunnel test engineer and CFD analyst need to discuss the relevant fluid flow phenomena, aerodynamic characteristics and design decisions on a daily basis.
6. When using CFD, it is entirely possible to pursue blind development alleys by over-concentrating on a single characteristic of the flow. However, even inexpensive "crude" wind tunnel testing can easily rectify this, by virtue of its ability to quickly compare candidate designs at a variety of flow conditions.