Chapter 37 – CONCLUSIONS AND RECOMMENDATIONS

by

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37.1 SUMMARY

This chapter provides a brief wrap-up of the task group report and focuses on the overall conclusions and recommendations for future work for the CAWAPI and VFE-2 facets beyond the task group. The overall conclusion is that the Technology Readiness Level (TRL) of CFD solvers has been improved in predicting the flow-physics of vortex-dominated flows during the work of the task group, by having flight and wind-tunnel data available for comparison. Moreover, like all good scientific studies, this task group has identified flight conditions on the F-16XL airplane or wind-tunnel test conditions for a specific leading-edge radius on the 65° delta-wing model where the TRL still needs to be increased.

37.2 INTRODUCTION

From the preceding chapters, as well as the TAP and TOR, each facet of this task group dealt with questions that needed answers. For the CAWAPI facet, it was how well did CFD, in particular unstructured grid solvers, predict the flight data. For the VFE-2 facet, there were at least two questions: one dealt with could new experiment data be generated beyond that published to provide additional, fundamental insight into the flow around the 65° delta wing, especially with a medium radius rounded leading-edge; and the second dealt with how well could these measured data sets be predicted. Some of these answers appear in the lesson learned chapters [37-1] to [37-4] of this report and the results are summarized here.

37.3 CONCLUSIONS

37.3.1 CAWAPI Facet

As reported in [37-5], the F-16XL-1 aircraft had been successfully modelled in a structured grid solver. However, for the CAWAPI study, there was a need to use an improved geometrical description and to satisfy the needs of both the structured and unstructured grid communities with a common surface-grid. This was accomplished and reported in [37-6]. The solutions generated by the unstructured grid solvers are reported in [37-7] to [37-14] and join those generated with the structured grid solvers reported in [37-15] to [37-17]. The basic message here is that complex aircraft, having many of the surface details modelled, can be successfully computed over a range of vortex-flow-dominated fight conditions with both unstructured and structured grid solvers. Moreover, the Technology Readiness Level (TRL) has been increased and best practices identified for the solvers employed in this study. One surprise occurred at the transonic flight condition, low α, where none of the CFD solvers predict well the C_ps over the middle third of the inboard wing or on the outer panel, yet there was good C_p agreement across the wing among all the solvers. Thus, we still have the unanswered question: Why should this be so?

37.3.2 VFE-2 Facet

Within Second International Vortex Flow Experiment (VFE-2) the original experimental NASA data base has been considerably enlarged. Four new wind tunnel models were fabricated and 15 new wind tunnel experiments were coordinated among four countries. A focus was established on two of the leading edges (sharp and medium bluntness) from the NASA experiments, and significant details of the vortical flow have been measured. The experimental campaigns confirmed the multiple-vortex structure of blunt leading edge vortex separation, and considerably more details of this flow are now available through the use of the Pressure Sensitive Paint (PSP) technique. Detailed flow field measurements by Particle Image Velocimetry (PIV) provided new insight into the vortical structure, and surface and off-body fluctuating measurements by Hot-Wire Anemometry (HWA) showed the turbulent structure of these flows.

Within VFE-2, the available CFD codes have been applied to the vortical flow around the relatively simple delta wing configuration with sharp and rounded leading edges. Numerical calculations have been carried out on structured and unstructured grids. The CFD codes have been validated using the experimental data, and the numerical results have been used as guidelines for the set-up of the wind tunnel experiments. Moreover in the final RTO-phase of VFE-2 the numerical results played an important role in the understanding of the flow physics, since the lack of experimental details in some flow regions could be replaced by numerical results. Therefore the present state of knowledge is the outcome of a proper combination of experiments and numerics.

The status of knowledge achieved by the VFE-2 facet of the RTO AVT-113 Task Group is described and many results documented in [37-4]. However, some problems have not been solved completely, some have not yet been addressed, and others were outside the scope of the present Task Group. Therefore new experiments will be carried out worldwide in a new open phase of VFE-2. The configuration under consideration is relatively simple and described analytically, and therefore new wind tunnel models can be built quite easily. Numerical calculations will go on as well to aid in the study.

37.4 RECOMMENDATIONS

37.4.1 CAWAPI Facet

The basic recommendation is to resolve the C_p predictive disagreement for the transonic, low α flight condition. Another item of note is whether acceptable vortical-flow dominated flow-physics results can be generated with simplifications of the complex aircraft geometry. Both of these items are subject to further study.

37.4.2 VFE-2 Facet

At the end of the RTO-phase of VFE-2 the scientific program is not terminated. As with VFE-1, the scientific work will continue in the next decade. Recommendations for future experimental investigations are:

- New measurements on the boundary layer status laminar/turbulent for the VFE-2 configuration with sharp and rounded leading edges.
- Experimental investigations on the mutual interference between the terminating and the cross flow shocks in transonic fully developed vortical flow with vortex breakdown for the VFE-2 configuration with sharp and medium radius rounded leading edges.
- New measurements on the partly separated vortical flow in order to check the final view of the flow structure as described in Figure 35-30 [37-4].

For the numerical side the recommendations are:

- New calculations related to the fully developed vortical flow without vortex breakdown for the VFE-2 configuration with sharp and medium radius rounded leading edges in incompressible flow and at very low Reynolds numbers in order to check the suitability of the various turbulence models.
- Prediction of the laminar/turbulent transition in fully developed vortical flows without vortex breakdown, starting with the sharp edged VFE-2 configuration.
- Further validation of the CFD codes for partly separated vortical flow at $\alpha = 13°$. The vortical flow field in the vicinity of the onset point of the outer primary vortex should be analysed in detail in order to check the validity of the schematic view presented in Figure 35-30 [37-4].

The RTO-phase of the Second International Vortex Flow Experiment (VFE-2) has been concluded and is documented in the present Final Report. An open phase of VFE-2 begins in 2008 and the scientific community is invited to join this project and to start new investigations.

37.5 REFERENCES

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