Chapter 1 – OBJECTIVES AND OVERVIEW

by

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1.1 SUMMARY

The RTO Task Group AVT-113 "Understanding and Modeling Vortical Flows to Improve the Technology Readiness Level for Military Aircraft" was established in April 2003. Two facets of the group, "Cranked Arrow Wing Aerodynamic Project International (CAWAPI)" and "Vortex Flow Experiment-2 (VFE-2)", worked closely together. However, because of the different requirements of each part, the CAWAPI facet concluded its work earlier (December 2006) than the VFE-2 facet (December 2007). In this first chapter of the Final Report of the Task Group an overview on its work is given, and the objectives for the Task Group are described.

1.2 INTRODUCTION

This task group was established to look at two particular problems highlighted at the RTO AVT-072 ***Symposium on Advanced Flow Management: Part A – Vortex Flows and High Angle of Attack for Military Vehicles*** in 2001 [1-1],[1-2]. These problems had in common a need to revisit leading-edge vortical flows with a view toward understanding and modeling them so that critical flow features could be measured; thereby, providing an improved basis for CFD prediction. The later is tied in with increasing the technology readiness level (TRL) of the CFD solvers for this type of flow. To that end, published flight-test and wind-tunnel model data were examined on configurations that generate significant amounts of vortical flows, along with data collected from new wind-tunnel model tests.

Surface flow measurements on the F-16XL-1 aircraft at a variety of Mach numbers and angles of attack/sideslip comprise the flight-test data set. This airplane, shown in Figure 1-1, has a cranked leading edge with 70°/50° sweep angles and a cropped tip. The CFD studies for this aircraft were performed under the name of **Cranked Arrow Wing Aerodynamics Project International** (**CAWAPI**), and it is one facet of AVT-113.

Figure 1-1: The F-16XL Aircraft in Flight with Tuft and Video Targets on the Left Wing.

Wind-tunnel surface-pressure test results for an analytically defined 65° delta wing-sting combination at a variety of Mach and Reynolds numbers are available at two model scales and form the basic experimental data sets. Both models were tested at NASA Langley Research Center, one in the National Transonic Facility (NTF) [1-3] (see Figure 1-2) and the other in the Low Turbulence Pressure Tunnel (LTPT) [1-4]. Also, both models were designed/fabricated to accommodate four different full-span leading-edge pieces, each of which produced a model bluntness change. These experimental data sets were expanded by task group members using the LTPT and new models in a variety of international wind-tunnels to provide additional data details that will facilitate and enhance comparisons with CFD codes. The results of the experimental and computational studies for this configuration were performed under the name of **Vortex Flow Experiment-2** (**VFE-2**) and it is the other facet of AVT-113.

Figure 1-2: The 65° Delta Wing-Sting Combination in the NASA NTF.

1.3 OVERVIEW AND OBJECTIVES DISCUSSION

1.3.1 CAWAPI Facet

1.3.1.1 Overview

This facet resulted from a cancelled effort by the NASA High Speed Research Program to generate high lift/drag in the terminal environment using a modified F-16XL cranked wing aircraft and to understand its flow physics. The planned modifications primarily included flying with a calibrated engine and adding full-span leading-edge flaps to enhance the lift/drag during take-off and landing at flight conditions compatible with those of the proposed High Speed Civil Transport. When this project was cancelled, the aircraft modifications were not made and the flight restrictions on speed and angle of attack not implemented. Alternate funding was provided by NASA Langley and Dryden to continue the characterization of the **basic aircraft** flow physics in a project named **Cranked Arrow Wing Aerodynamics Project** (**CAWAP**). Some preliminary flights were performed at Langley but the bulk of the flights were conducted at Dryden in a joint effort and included both subsonic, transonic and low supersonic flight speeds using an uncalibrated engine at a

variety of angles of attack, up to ~20°, and sideslip angles of 0° & ±5°. The published results of the **CAWAP** flight test are contained in [1-5] and summarized in [1-1]. During exploratory team meetings of AVT ET-026, set up to advise the AVT on the need for subsequent vortical flow activity beyond the AVT-072 Symposium, the proposals contained in [1-1] and [1-2] were merged into one which emphasized the military nature of aircraft vortical flows. This lead to the establishment of AVT-113 and the results obtained during its tenure are the subject of this report. With several nations interested in performing computations of this aircraft in order to validate the flow physics modeling in their codes, **CAWAP** was expanded to **CAWAPI**.

As the F-16XL geometry is subject to ITAR restrictions, means of facilitating the sharing of this data lead to international agreements and the need to establish a Virtual Laboratory, as discussed in Chapter 2. EADS-M of Germany, KTH/FOI of Sweden, University of Glasgow/Liverpool University of Great Britain, TUSAS/TAI of Turkey, VUB of Belgium and the NLR of The Netherlands joined this aircraft computational effort from Europe. In the USA, there was a corresponding response from the USAFA at Colorado Springs, Lockheed Martin Aeronautics Company at Ft.Worth, Boeing-St.Louis, University of Tennessee/Chattanooga-SimCenter, University of Wyoming at Laramie, and NASA Langley. However, due to non-technical issues, not all were able to sustain their interest to the conclusion of this facet.

1.3.1.2 Objectives

The objectives of this effort are straightforward in that the flight data is to be used to help establish best computational practice for the use of each participant's code. (See Chapter 3 for a discussion.) In particular, this is to occur by computing results for selected flight conditions that contain significant interest and/or flight data using common grids, one for the structured solvers and one for the unstructured solvers (See Chapter 4 for a geometry and grid discussion). A total of seven flight conditions (FC) were chosen, five at a nominal $\beta = 0°$ for a variety of Mach numbers and α's, and two at subsonic speeds at β of ~±5°. The intent was to have as the only variables the solver and its turbulence model for each solver class at each FC; however, it turned out that some solvers required the grid to be tailored for its own particular use, so the results are not as clean as hoped. (See Chapters 5 to 15 for the details.)

The most numerous comparisons available are those made with surface pressures and flows (tufts), but there are limited comparisons of boundary layer and skin friction data at some FCs. No force or moment flight data exists to compare with CFD predictions but code-to-code comparisons are possible for these quantities and are summarized in Chapter 16.

1.3.2 VFE-2 Facet

1.3.2.1 Overview

This facet resulted from the comprehensive review on vortical flows given in [1-2]. In this paper, it was pointed out that current numerical methods for the calculation of vortical flows are available which use the RANS equations with various turbulence models. However, not enough detailed measurements exist of vortical flow fields to properly validate these numerical methods for the large number of available turbulence models.

Therefore, new measurements were proposed in [1-2] to meet the demands for a proper validation of the numerical methods. Following a similar program of VFE-1 in the 1980's, the new experiments were now performed under the name **Vortex Flow Experiment-2 (VFE-2)**. The NASA delta wing (See Figure 1-2) was proposed in [1-2] as a suitable configuration for the additional tests. This configuration has a simple geometry,

which is given analytically for wing and sting support and thus can easily be reproduced elsewhere in order to build new wind-tunnel models. In addition, the configuration comprises four different leading edge shapes, one sharp edged and three rounded ones, having different leading edge radii. Within the framework of VFE-2 new experiments on this configuration should add to the existing data sets ([1-3],[1-4]), with the main emphasis being to obtain flow field data for comparison with CFD results.

A wind-tunnel model that was 75% the size of the NTF model was tested in the NASA/LTPT tunnel and the results made available by NASA for facet members' use. In addition, they shipped this model – designated model (1) – to Europe for testing by means of pressure sensitive paint (PSP) and particle image velocimetry (PIV) at the DLR in the Transonic Wind-Tunnel Goettingen, Germany, and by force balance and PIV at ONERA Lille, France. A new wind-tunnel model (2) was built at the Technical University Munich, Germany, in order to perform surface oil-flow investigations, pressure distribution measurements as well as flow field surveys by means of the PIV and the hot-wire techniques. The same wind-tunnel model has also been tested by the DLR in the cryogenic wind tunnel KKK at Cologne, Germany, using the temperature sensitive paint (TSP) technique for laminar/turbulent transition detection. Another wind-tunnel model (3) has been built and tested through unsteady balance, pressure distribution and flow field studies at University of Glasgow, GBR. Two other new wind-tunnel models (4 and 5) have been built by ONERA Lille, France, in order to carry out balance measurements, and these two models were shipped to Turkey in order to investigate the laminar/ turbulent transition at TUBITAK-SAGE, Ankara.

From its very beginning numerical investigations were an important part of the VFE-2. The purpose for calculations of the flow field around the simple delta wing configuration was threefold:

1) Validation of the available codes;
2) Tuning of new experimental setups by means of CFD results; and
3) Synergistic effects through the possibility of test runs on a simple configuration prior to expensive calculations for a complete aircraft, such as in the CAWAPI facet.

1.3.2.2 Objectives

For the chosen configuration pressure distribution measurements as well as normal force and pitching moment data were already available from NASA for wide ranges of Mach number and Reynolds number. The new experiments should complete these measurements by adding drag data, and the main emphasis was to obtain flow field data, mainly by PIV and hot-wire techniques. For delta wings the status of the boundary layers underneath the vortex system is poorly known, and a more detailed knowledge about this matter would be very useful either for the validation of related prediction methods or for the adaptation of numerical calculations to the experimental status. Therefore attempts have been made to determine the laminar and the turbulent regions on the upper surface of the wing.

Before VFE-2, most experimental investigations on delta wings have been for sharp leading edges with the flow separation fixed to the leading edge. Therefore, the new experiments were aimed mainly at an understanding of the vortex formation for the wing with a rounded leading edge, and the experimental and numerical results were to be compared with the well known sharp leading edge case. Most of the new experiments were carried out at low speed, as the possibilities for tests at higher Mach numbers were limited.

Concerning the angle of attack, the configurations with sharp and rounded leading edges have been investigated at different regimes:

1) At low angles of attack for studies of the onset of vortex shedding on the configuration with rounded leading edge;
2) At moderate angles of attack with large primary vortices, but still without vortex breakdown; and
3) At large angles of attack with large primary vortices including vortex breakdown.

1.4 CONCLUDING REMARKS

In both facets of AVT-113 multiple numerical calculations were carried out. In the **CAWAPI** facet the flow around a complete aircraft configuration has been calculated. On structured as well as on unstructured grids, the computational expense with respect to grid size and CPU time was enormously large and the corresponding calculations were extremely expensive. On the other hand, the **VFE-2** configuration was relatively simple and the amount for numerical investigations was comparatively small. From this contrast resulted considerable synergistic effects within AVT-113. Prior to future expensive calculations for a full aircraft geometry, the codes and the various turbulence models could be checked using the much simpler VFE-2 configuration. Some members were active in both facets of AVT-113, and the discussions within the task group during its semi-annual meetings on the experiences of the members supported the anticipated synergistic effects.

1.5 REFERENCES

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