Flap Gap Oscillatory Blowing on 2D and 2.5D Wing

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Abstract
Here we present preliminary results obtained in developing an active flow control system for high lift systems at advanced TRL level. The work is based on theoretical and experimental work performed in AVERT EU FP6 project where the oscillatory flap gap blowing system was designed and tested on a INCAS F15 2D wing model. Pressure data and global loads have been recorded for a complex evaluation of the basic flow control mechanism. In 2.5D test cases this work has been extended so that the proposed system may be selected as a mature technology in the JTI Clean Sky, Smart Fixed Wing Aircraft ITD. For this goal, new experimental setup was used and also updated electronics for the blowing system have been introduces. This was complemented by a new extension for the data acquisition system and visualization tools. Finally global correlations for basic lift increments have been compared with the reference 2D case and analysed with respect to the system efficiency.

INTRODUCTION

The overall objective of AVERT Project is to deliver upstream aerodynamics research that will enable breakthrough technology development and innovative aircraft configuration development leading to a step change in aircraft performance. The project objective is to be achieved through the evaluation of selected types of sensor, actuator and control systems, the assessment of these devices against baseline aircraft configurations and the evaluation of the most promising technologies in a medium/large scale wind tunnel test.

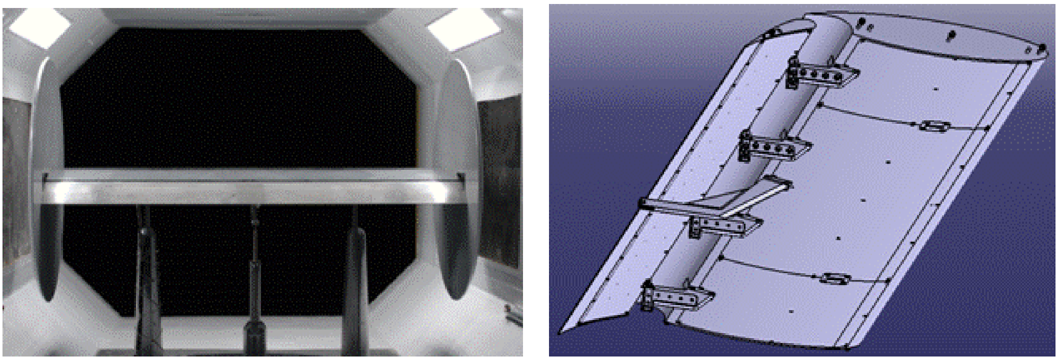

Figure 1 – AVERT F15 model with end plates (basic 2D setup)

The considered flow control technologies are focussed on low-speed applications, mainly investigations with AFC for standard (e.g. DLR F15) and non-standard (e.g. ONERA DND A310) high-lift configurations. Several technologies are investigated and developed

through both numerical simulations and experiments in wind tunnel. INCAS activities are related to separation control by flap gap oscillatory blowing on a high lift configuration.
A high-lift, 2-D model geometry suitable for the application of oscillatory blowing in the flap gap has been selected from previous investigations (DLR F15 model) and manufactured from new at INCAS (Figure 1). A number of test cases with different slot and blowing parameters have been investigated numerically for wind tunnel conditions by DLR. From the numerical results, recommendations for the model design were given (blowing angle and slot widths).
A new F15 model has been designed and manufactured for wind tunnel testing at INCAS subsonic wind tunnel. This model was designed so that 19 TU Berlin actuators could be integrated in a 2m span model and tested in a wide range of blowing conditions for the F15 proposed geometry (Figure 2).
TU Berlin has designed and manufactured dedicated actuators suitable for flap integration and flap gap oscillatory blowing experimental investigation on a high lift configuration in INCAS facility.

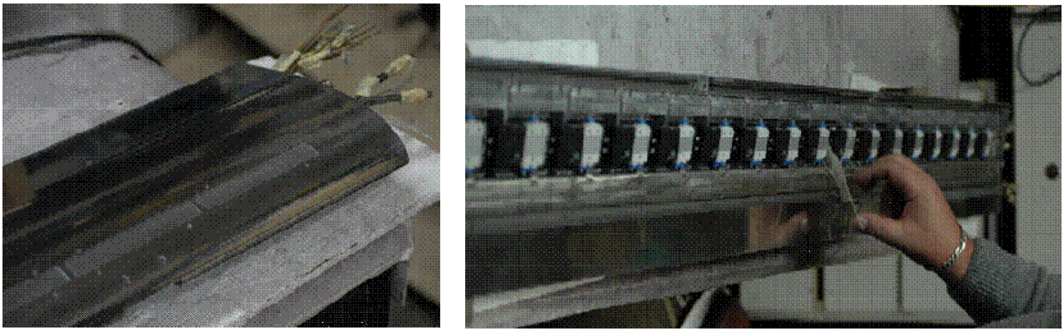

Figure 2 – Flap setup (external view) and actuators integration

Wind tunnel tests results for the selected test cases have been compared and validated against numerical results and existing experiments (with previous existing WT results at DLR for the F15 high-lift airfoil).

EXPERIMENTAL SETUP

The experiments in the Subsonic Wind Tunnel at INCAS have been conducted so that we could benefit from the medium size of the facility and to enable large model validation.

1. The maximum wind tunnel test room is of 2.5m width & 2 m height; the maximum permissible span of the model is aprox. 2.0m, in order to make room for end plates and to enable popper distance to the side walls of the test section.
2. In order to achieve a high Reynolds number in the range of 3 million (for wt speed close to 90 m/s), the basic chord length was selected as 600 mm. However, the basic experiments were performed at Reynolds 2 million.

3. The global span of the model is 2.050 m, with a chord length of 600 mm (basic configuration – cruise). This gives a global aspect ratio of 2.0/0.6 = 3.333 for cruise configuration and lower for HL configurations.

4. The model was made from aluminums alloy (main wing) and stainless steel (movable flap) in order to enable low deformations under heavy loads. End plates are in wood, with metallic insertions for flap mechanism external support, if requested.

5. The HL system will be movable with:

- Continuous XZ positions in 2 degrees of freedom translation system;
- Continuous hinge rotation from 0 to 60 deg.;

6. The flaps for testing are deflected at 40, 45 and 49 deg.(as imposed for AVERT tests), according to the CFD analysis performed by DLR.

7. The model is instrumented with pressure taps, readable through a scanning system.

8. Global loads are measured using a 6 component external balance, pyramidal type.

9. Flow visualization with laser-smoke and oil paint was used for separation identification.

10. System and wall corrections have been used in order to provide corrected data for equivalent free stream conditions.

The speed for tests was in the range close of 50 m/s for all tests. The speed is correlated with the Reynolds number (aprox. 2 million), so that several criteria are achieved:

- Reynolds similitude evaluation in the range of 2 to 3 million – Global Loads and main aerodynamic coefficients.
- Basic experiments considered for Reynolds number close to 2 million for comparison with DLR numerical data and previous experiments – Pressure distribution, global loads and main aerodynamic coefficients
- Pressure distribution for specific Reynolds number (2 million) in incidence range -10 to +15 deg.
- Global loads under maximum balance capacity (AoA limited so that maximum Lift is under 10.000 N)

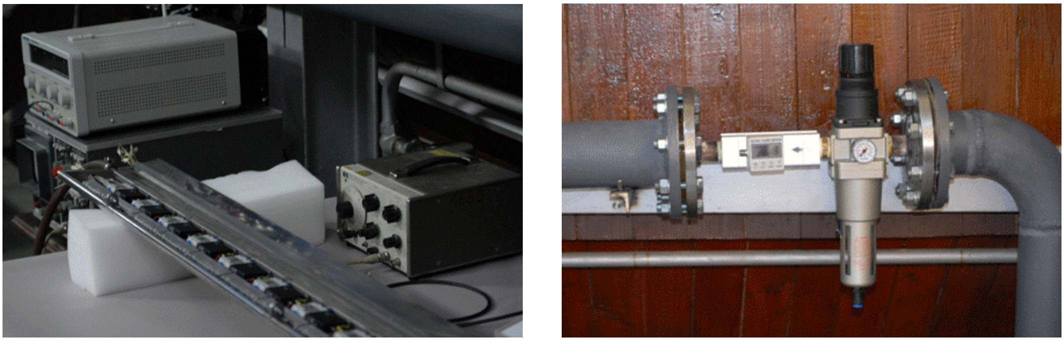

Figure 3 – AFC system control unit (including mass flow measurement system)

The active flow system (Figure 3) was designed so that the following parameters could be reached and continuously monitored during the tests:

- Blowing pressure in the range of 2 – 8 bar, from 25Hz to 250 Hz
- Continuous pressure monitoring and stabilisation in the blowing system
- Actuators could be operated individually and/or in arrays.
- Individual mass flow rate measurements and for global array

EXPERIMENTAL RESULTS

In the initial phase of the experiments, the following objectives have been addressed:

- Global model setup in the tunnel (flow angularity and yaw). This has been achieved based on data acquisition readings from balance (side force) and external reference pressure probes in the full range of AoA (-15 to +15 deg.) and free stream velocities (40 m/s to 80 m/s)
- 2D flow pattern evaluation (flow visualization and pressure readings). Oil patterns have been analysed on the main element and on the end plates in order to ensure typical 2D like flow.
- Reynolds number influence evaluation and assessment – global characteristics. For a number of free stream velocities (40 m/s to 80 m/s) global loads have been recorded and analysed in strong correlation with transition strips locations on the main element and/or on the flap.
- Transition on the main element of the F15 model. Several locations and sizes of the strips for transition fixing on the leading edge of the model have been investigated. Assessment involved also 3 different free stream velocities.
- Transition on the flap. Several locations and sizes of the strips for transition fixing on the leading edge of the model have been investigated. Assessment involved also 3 different free stream velocities.

At the same time, since reference data for basic flow was provided from DLR for the case of 40 deg. flap deflexion, data was prepared for analysis and comparison with this reference (pressure distribution on the main element and flap for various AoA).(Figure 4)

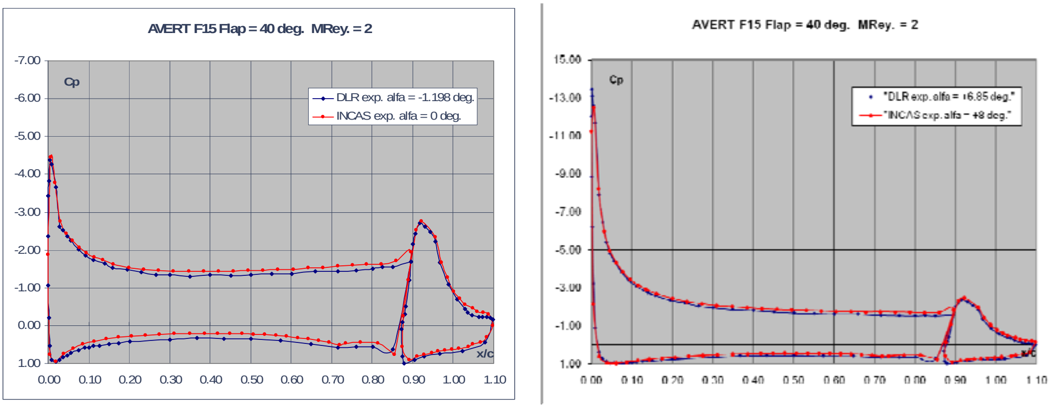

Figure 4 – Basic flow comparisons with DLR F15 data

In the second phase, the following objectives have been addressed :

- Global blowing system evaluation in the pressure range of 4 to 8 bar. This evaluation has been performed for frequencies in the range of 25 Hz to 250 Hz.
- Individual evaluation of the actuators – velocity profile evaluation
- Global evaluation of the actuators effect on the global loads – no flow
- Global evaluation of the actuators effect on the global loads – with flow

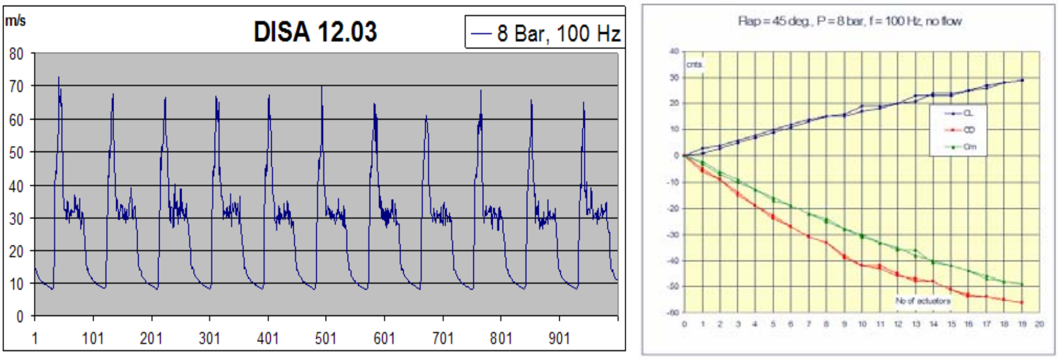

Figure 5 – Actuator velocity profile and global balance response

The results prove that (Figure 5):
- the balance is also sensitive to the individual increment of induced loads of individual actuators, with a linear response.
- low hysteresis with flow conditions
- no blockage in full operation conditions (8 bar, 19 actuators, 100 Hz)

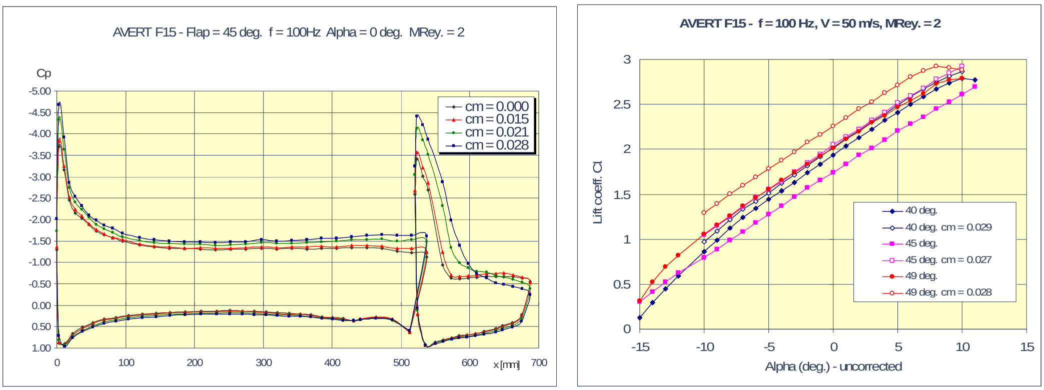

Figure 6 – AFC - pressure readings and global lift

In the third phase, the following objectives have been addressed :
- For the 3 flap positions, global blowing system evaluation in the pressure range of 4 to 8 bar. This evaluation has been performed for frequencies in the range of 25 Hz to 250 Hz (25/50 Hz increment, as needed)
- Pressure distributions have been recorded on the main component and on the flap
- Global loads have been recorded from balance readings (Figure 6).

Flow visualization have been produced in order to enable proper evaluation of the flow characteristics, mainly separation dynamics on the flap. Flow visualization techniques used are based on surface painting, using 2 different combinations of paints (TiOs and fluorescent paint).
Visualizations have been considered only for the upper side of the model, at various AoA. The visual field was prepared for a region of the model of aprox. 30% in span, with no pressure taps (located on the model from 60% to 90% spanwise). This area was also bounded with special tape with marks for surface coordinate starting from leading edge.
For active phases, laser visualizations have been performed (Figure 7).

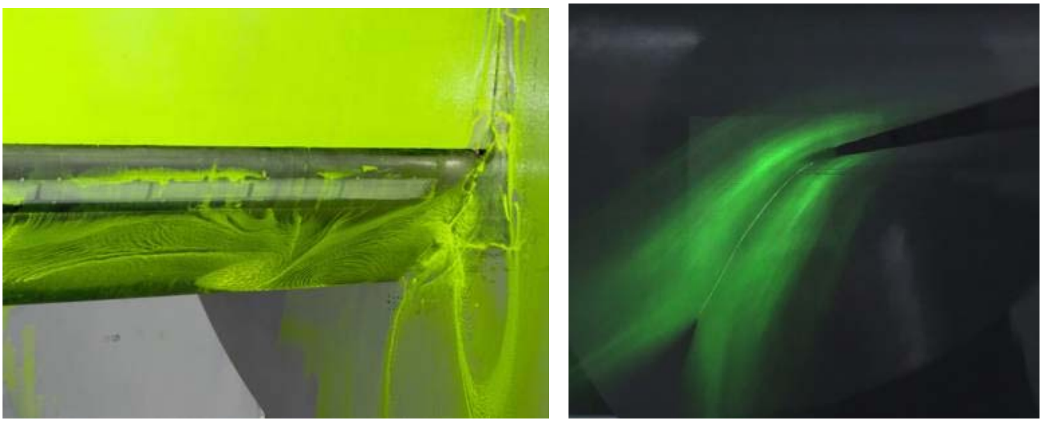

Figure 7 – AFC - flow visualizations (oil and laser)

SOME CONCLUSIONS

The major goal was to test the AFC in 2D and 2.5D configurations, using external data aquisition system (balance). This enabled proper evaluation of the characteristics. (Figure 8 and Figure 9)

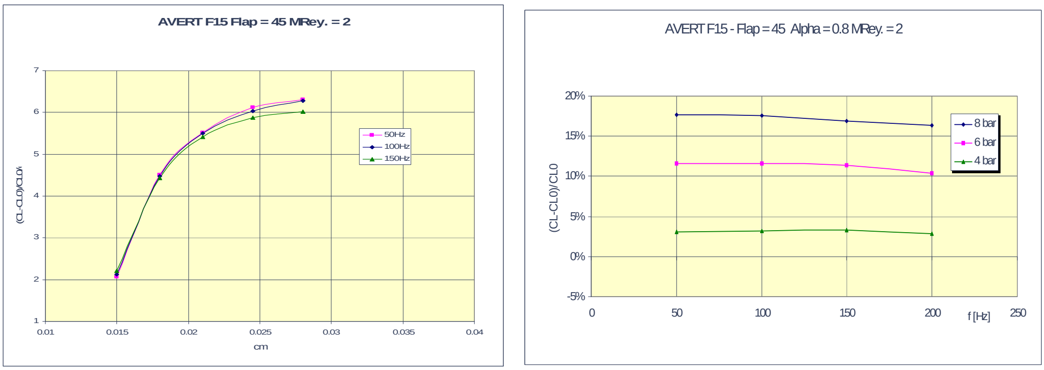

Figure 8 – AFC efficiency in 2D cases

We would like to emphasize that a suitable operation is close to 8 bar and f=100 Hz in 2D, with a potential lift increment of up to 18%. This needs more investigation on various flap settings.

In 2.5D we achieve consistent lift increments at similar operation conditions (Figure 9)

At the same time, as presented in Figure 8, the AFC system tested is close to the maximum efficiency. Therefore, one might expect that our experiments will also show the limitation of the oscillatory flap gap blowing system.

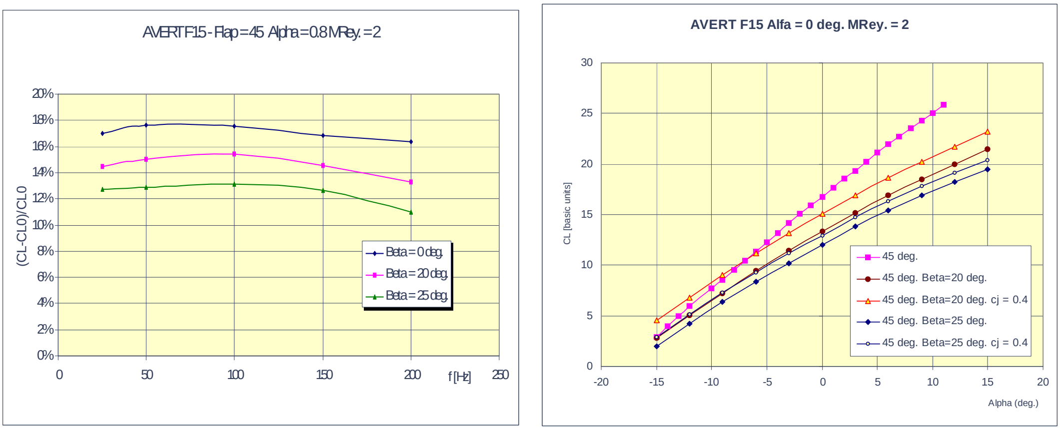

Figure 9 – AFC efficiency in 2.5D cases

Based on the experimental data, we conclude that the active flow control system based on the flap gap oscillatory blowing has reached a TRL level of 4. This enables the possibility to export the system to a higher evaluation process in order to be implemented in JTI Clean Sky.

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