Evaluation of High Lift System with Oscillatory Blowing in 2.5D Configuration

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Abstract: *Following the successful results of the test campaign on 2D configuration of the oscillatory blowing system in the flap gap of the INCAS F15 wind tunnel model, extensive evaluation of the 2.5D effects have been initiated in order to enable solid understanding of the fluidic integrations mechanisms and to validate this technology at a higher TRL level. Initial experiments on 2D configuration were based on 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. 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. 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. Complex post-processing of the experimental data was mainly oriented towards system efficiency and TRL evaluation for this active technology.*

Key Words : wind tunnel testing, oscillatory blowing, high lift system

1. INTRODUCTION

As presented in a dedicated paper [1], the overall objective of AVERT project was to deliver upstream aerodynamics research that will enable breakthrough technology development and innovative aircraft configuration development leading to a step change in aircraft performance. Active flow control, based on oscillatory blowing in the flap gap, was consider as a promising technology able to deliver a new generation of high lift systems, as already introduced in specific investigations [2]. A set of wind tunnel test in AVERT project [3] demonstrated the potential of this technology, mainly with respect to current state of the art capabilities in fluidic actuators and global system design, as in Figure 1.

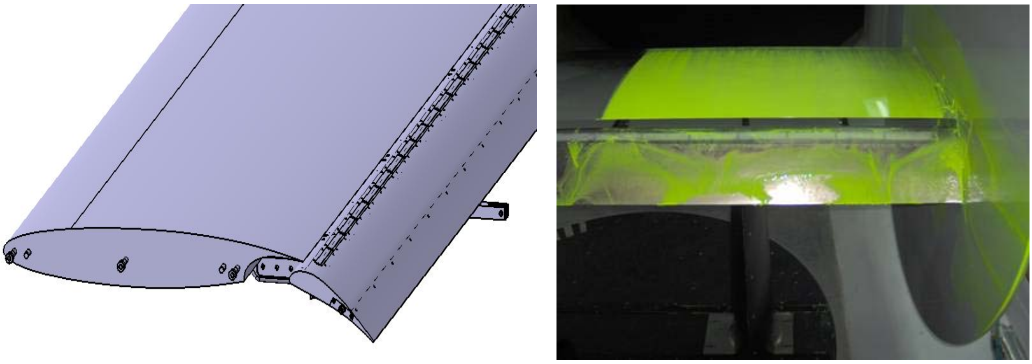

Figure 1 – INCAS F15 model with oscillatory blowing flap - global layout

The initial 2D wind tunnel test campaign was based on a high-lift, 2-D model geometry suitable for the application of oscillatory blowing in the flap gap, 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 previously investigated by DLR. Basic results from INCAS F15 model and DLR F15 model are in good agreement, as presented in Figure 2, where pressure distributions have been compared, including basic correction for angle of attack at INCAS (no correction at DLR). This good agreement was also a solid proof that the flow quality at INCAS Subsonic Wind Tunnel, and also the transition tripping performed were as requested by such a sensitive active flow control experiment.

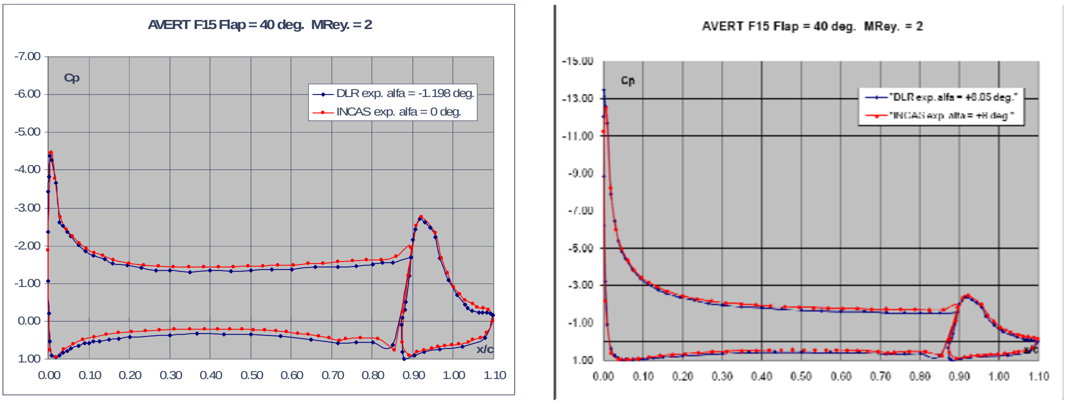

Figure 2 – Basic flow comparisons with DLR F15 data

Major findings with respect to 2D investigations were related to the fact that, for a particular high lift configuration, expressed by a flap angle-gap-overlap combination, oscillatory blowing has the potential to enhance lift significantly. This is valid only for un-optimized geometries, where the separation on the flap was significant, as in Figure 3. For optimized configurations the oscillatory blowing has limited effect, as in Figure 4. This effect has been fully investigated on the wind tunnel test campaign [4].

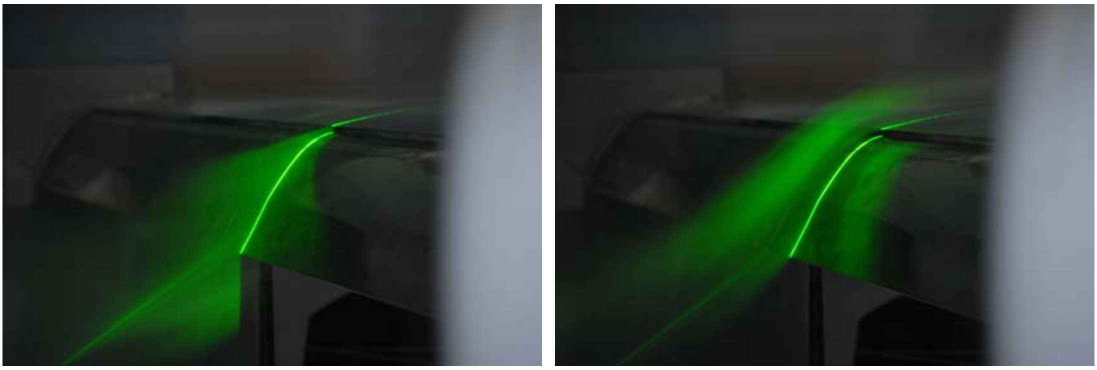

Figure 3 – INCAS F15 - 2D control for Flap at 49 deg., f = 100Hz

For the three flap settings considered, several blowing regimes have been used, in the range of 50 to 200 Hz, at a pressure from 4 to 8 bar. Global efficiency of the 2D system proved to have a maximum for actuation frequency at 100 Hz and at maximum momentum (e.g. at maximum pressure in the system). From the evaluation in Figure 4, the experiments were conducted so that the system was operating close to a maximum efficiency.

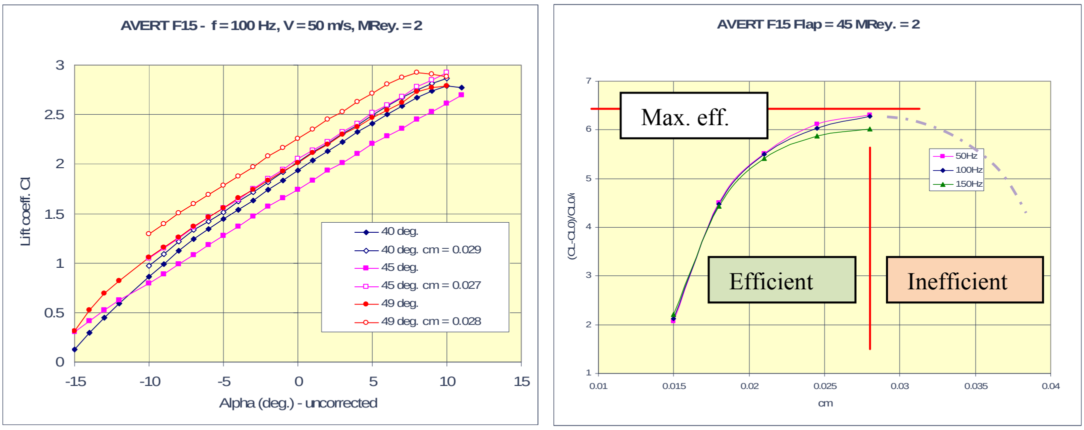

Figure 4 – Global efficiency for Oscillatory Blowing on 2D model

Findings in the first campaign were to be compared with results for a 2.5D test campaign at INCAS Subsonic Wind Tunnel. This new test campaign was intended to validate effects at several sweep angles, based on the information from pressure readings in the central area of the wind tunnel model.

2. THE MODEL FOR AFC

A new F15 model (INCAS F15) has been designed and manufactured for wind tunnel testing at INCAS subsonic wind tunnel [4]. 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 5). 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.

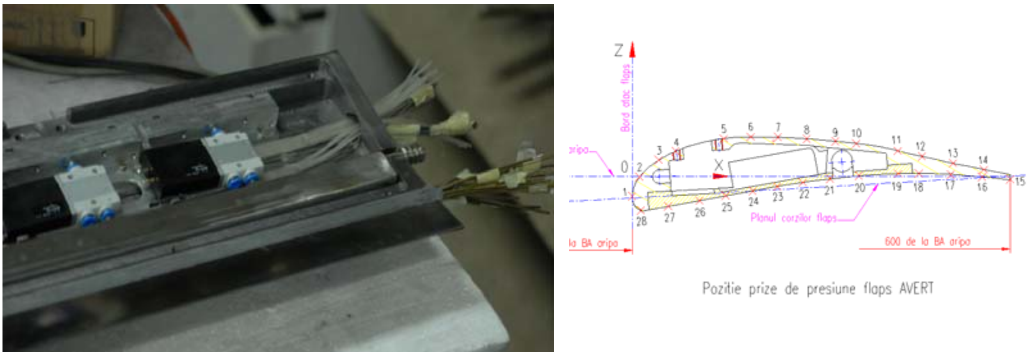

Figure 5 – Flap setup (external view) and actuators integration

At the same time, in order to meet the AQ requirements for wind tunnel testing at INCAS, the model design was subject to a number of dedicated validations, including structural analysis and global model setup compliance with natural frequency of the external balance system (Figure 6).

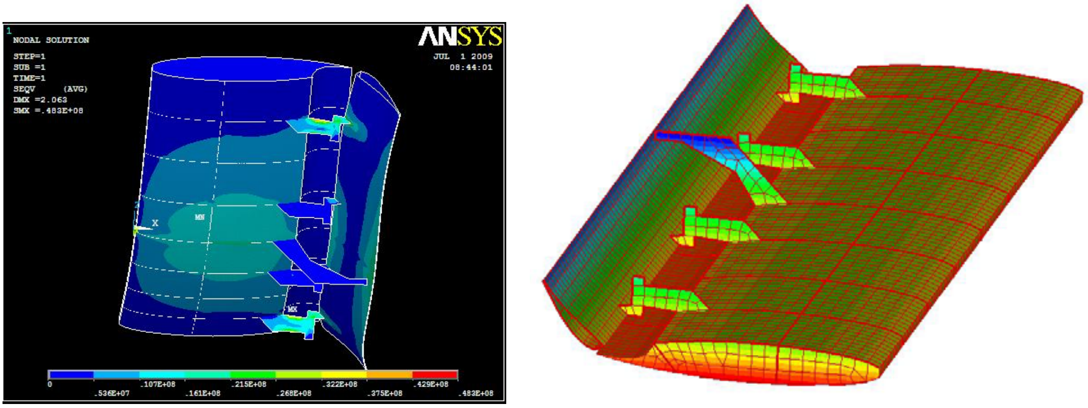

Figure 6 – INCAS F15 structural analysis

For 2.5D tests several changes have been imposed by the specific model installation in the wind tunnel. The major change was related to the removal of the end plates, so that sweep angles up to 30 degrees could be achieved with limited flow disruption. However, this decision had to be considered in the final validation of results, where only pressure in the middle section could be analyzed, and no global loads as for the 2D case.

3. THE 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.

a. 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 side edges and to enable popper distance to the side walls of the test section.

b. 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.

c. 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.

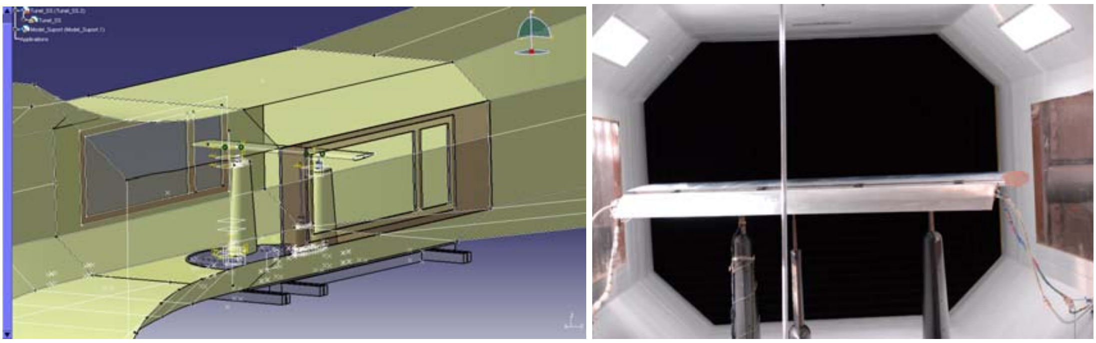

Figure 6 – INCAS F15 structural analysis

d. The model was made from aluminums alloy (main wing) and stainless steel (movable flap) in order to enable low deformations under heavy loads.

e. The HL system is movable with:

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

f. The flaps for testing are deflected at 40, 45 and 49 deg.(as imposed for AVERT tests), according to the CFD analysis performed in the design phase of the experiments [4].

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

h. Global loads are measured using a 6 component external balance, pyramidal type. However, for 2.5D experiments such data has limited relevance.

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

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

The air 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:

a. Reynolds similitude evaluation in the range of 2 to 3 million – Global Loads and main aerodynamic coefficients.

b. 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

c. Pressure distribution for specific Reynolds number (2 million) in incidence range -10 to +15 deg.

d. Global loads under maximum balance capacity (AoA limited so that maximum Lift is under 10.000 N)

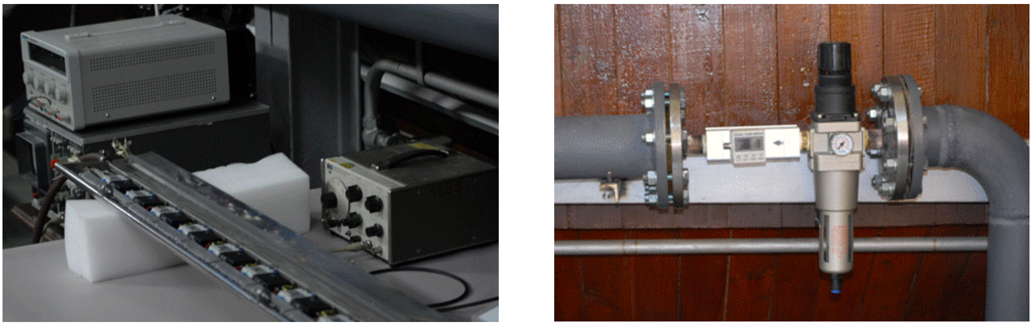

Figure 7 – AFC system control unit and mass flow measurement system

The active flow system (Figure 7) 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 stabilization in the blowing system
- Actuators could be operated individually and/or in arrays.
- Individual mass flow rate measurements and for global array

3. EXPERIMENTAL RESULTS

In the first 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 analyzed on the main element - central area - and on the side edges in order to ensure typical 2.5D 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 analyzed in strong correlation with transition strips locations on the main element and/or on the flap. However, this was not relevant since only middle section was in 2.5D flow, due to the decision of removing end plates at sweep angles.
- 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 [4] 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 2)

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

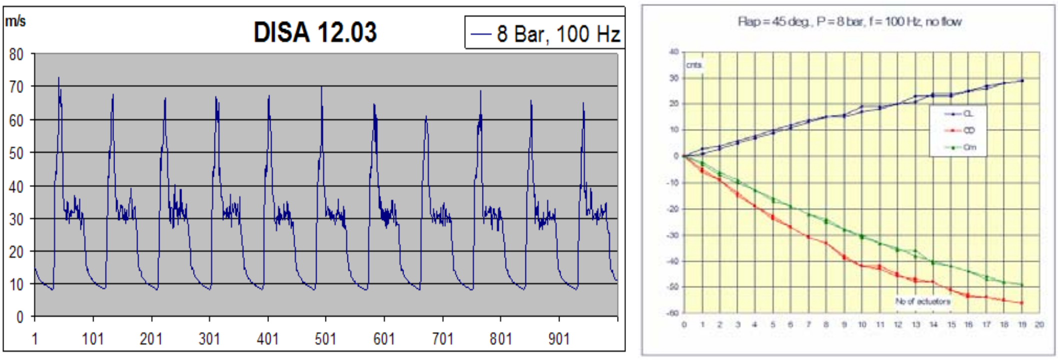

Figure 8 – Actuator velocity profile (hot wire measurements) and global balance response

The results prove that (Figure 8):

- 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)

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 (however, this has limited relevance for 2.5D flow case).

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 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. 20% in span, with no pressure taps (located on the model from 60% to 20% 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 3).

The main goal of the experimental campaign was to collect pressure data (Figure 9) for the sweep cases from 0 to 30 deg. at various blowing regimes for the AFC. Obviously, comparison with existing data from [4] at 2D case was intended, so that the AFC was controlled in order to have good comparison for active sequence. The most interesting cases were considered those where, from previous 2D investigation, the flow configuration was not optimized, showing clear detachment on the flap. This was mainly the case for 45 deg, flap deflexion presented in Figure 9.

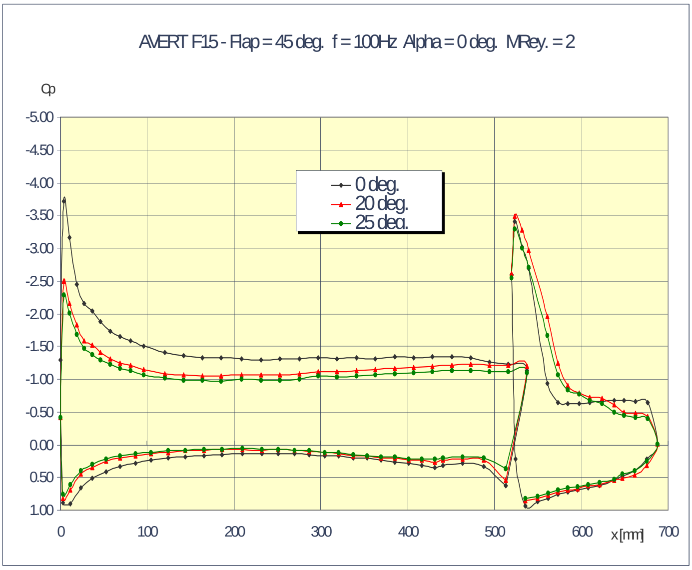

Figure 9 – 2.5D case - Pressure distributions

Since comparison with global loads was necessary, pressure distribution was integrated for all experiments and sectional lift was computed. This was used for cross-correlation with already existing data in 2D cases and also with some existing CFD data computed by INCAS. At the same time, efficiency of the AFC was computed for all experiments in a similar way as for the 2D cases in [4].

4. SOME CONCLUSIONS

The major goal of this test campaign was to test the AFC in 2.5D configurations (sweep angles up to 30 deg.), using external data acquisition system (pressure measurements and external pyramidal balance). This enabled proper evaluation of the characteristics. (Figure 9 and Figure 11).

A particular interest was related to the un-optimized flow configurations, where the benefit of AFC was expected to be higher. For example, in the configuration with 45 flap deflexion, at 25 sweep angle, the flow is not fully attached on the flap, as observed in CFD analysis (Figure 10) and flow visualizations (Figure 3).

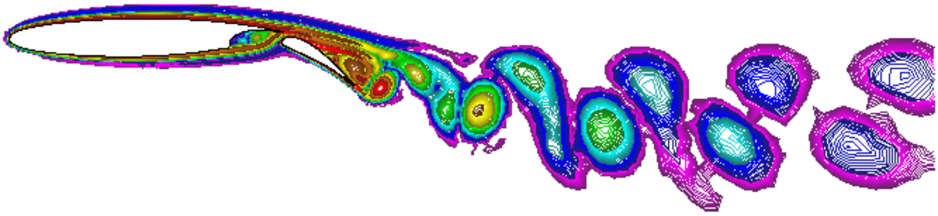

Figure 10 – 2.5D case Flap 45 deg. - CFD analysis (izo-vorticity)

Global sectional characteristics for the AFC have been post-processed and compared with basic values for the 2D case (Figure 11). We would like to emphasize that a suitable operation is close to 8 bar and f=100 Hz in 2.5D as for 2D, with a potential lift increment from 18% decreasing to 13% with the sweep angle (Figure 12). This needs more investigation on various flap settings.

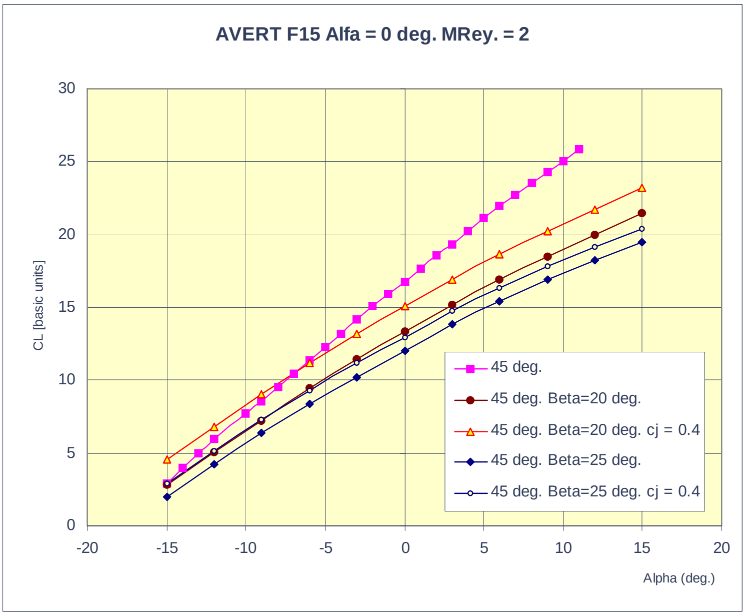

Figure 11 – 2.5D case Flap 45 deg. - Global lift characteristics

At the same time, as presented in Figure 4 and Figure 12, 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.

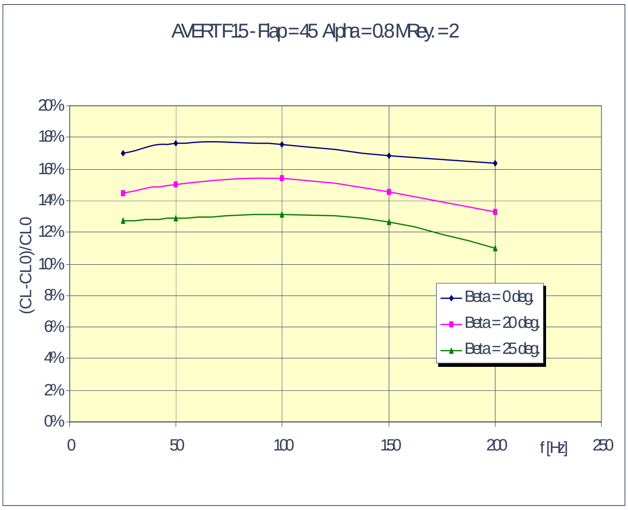

Figure 12 – AFC efficiency in 2.5D cases

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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