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STUDY OF THE BENEFITS OF A SEMI-MORPHING WING CONCEPT

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Abstract

The concept of a semi-morphing wing is presented. Instead of elastically deforming the structure the adaptation of the wing geometry to the flight conditions is achieved by means of the deflection of a high number of complementary and redundant classical wing control surfaces. A complex flight controls system is designed to allow using these control surfaces as multi-objective devices, addressing in parallel aerodynamic efficiency, loads alleviation, and vehicle control while still ensuring safety of operation by means of appropriate flight control laws re-configuration in case of failures. The paper presents the benefits for the case of a turboprop driven regional aircraft.

Keywords: Aerodynamics, Morphing Wing, Regional Aircraft,

1. Introduction

Conventional transport aircraft design is reaching a plateau in terms of improvements of the aerodynamic efficiency to support reduction of cost of operation and environmental impact. Remaining levers mainly lie in the area of further increasing the wing aspect ratio to reduce induced drag and the use of laminarity to reduce friction drag. Both elements come with significant technical difficulties, e.g. the impact of the static and dynamic loads on the larger span flexible wings and the associated potential structural weight increases that may compensate the aerodynamic benefits, or the impact of contamination on the aerodynamic behaviour of the laminar components.

An additional possibility is the use of morphing wings, that is, wings that change their shape in flight to be optimal at different flight conditions, to improve its controllability and to actively reduce manoeuvre or gust loads to allow lighter wing structures. A lot of research is being conducted in this area with many different concepts being tested in laboratory conditions but practical difficulties remain in implementing and certifying a system that is indeed capable to produce a significant deformation of the wing structure in real flying conditions.

An intermediate approach would be the concept of a semi-morphing wing, for which the geometrical adaptation to flight conditions is achieved by means of the deflection of a high number of complementary and redundant classical wing control surfaces like ailerons, spoilers, flaps, etc. Although this strategy may be not as optimal from the aerodynamic point of view as real morphing, it offers other advantages such as simplicity and reliability. There is an associated increment in system weight that partially compensates the aerodynamic gains or the wing structural weight reductions, but on the other hand, the redundancy in control surfaces opens the additional possibility to substitute the traditional hydraulic system for the controls by Electro Mechanical Actuators (EMA), with the corresponding weight reduction but no impact in safety.

Similar concepts have already been implemented, at least partially, in large jet driven transport aircrafts (e.g. A350) but the benefit for smaller turboprop driven regional aircraft or multi-mission military transport aircraft have not been so largely explored. The concept is especially interesting for this type of aircraft given the large variety of missions that need to be considered during their design (operation from city airports, freighter, search and rescue, humanitarian relief missions from non-prepared runways, firefighting, etc.)

As part of the EU CleanSky 2 project Airbus Defence & Space is preparing a flying demonstrator of such a wing concept. A C295 aircraft (Figure 1) is being modified to serve as a test bed for this technology. The aircraft is equipped with new ailerons, spoilers, active winglets and smart flaps (Figure 2). A complex flight controls system commands these devices to work as multi-objective control surfaces, addressing in parallel aerodynamic efficiency, loads alleviation, and vehicle control while still ensuring safety of operation by means of appropriate flight control laws re-configuration in case of failures.

The paper presents the semi-morphing wing concepts, and in particular quantifies the benefits obtained in terms of drag, aircraft control and load alleviation by means of a combination of numerical studies and experimental data. The test bed is expected to perform its first flight at the end of 2021.

Figure 1 – Airbus Defence & Space C295

2. Description of the Semi-Morphing Wing Demonstrator

Compared to the baseline version of the C295 the semi-morphing wing demonstrator will incorporate the following elements (Figure 2):

- Winglets with EMA actuated trailing edge control surfaces (Figure 3)
- New optimized multi-functional flaps with EMA fast actuated tab (Figure 4)
- Electro-mechanically actuated (EMA) ailerons with optimized shape
- Electro-mechanically actuated (EMA) spoilers

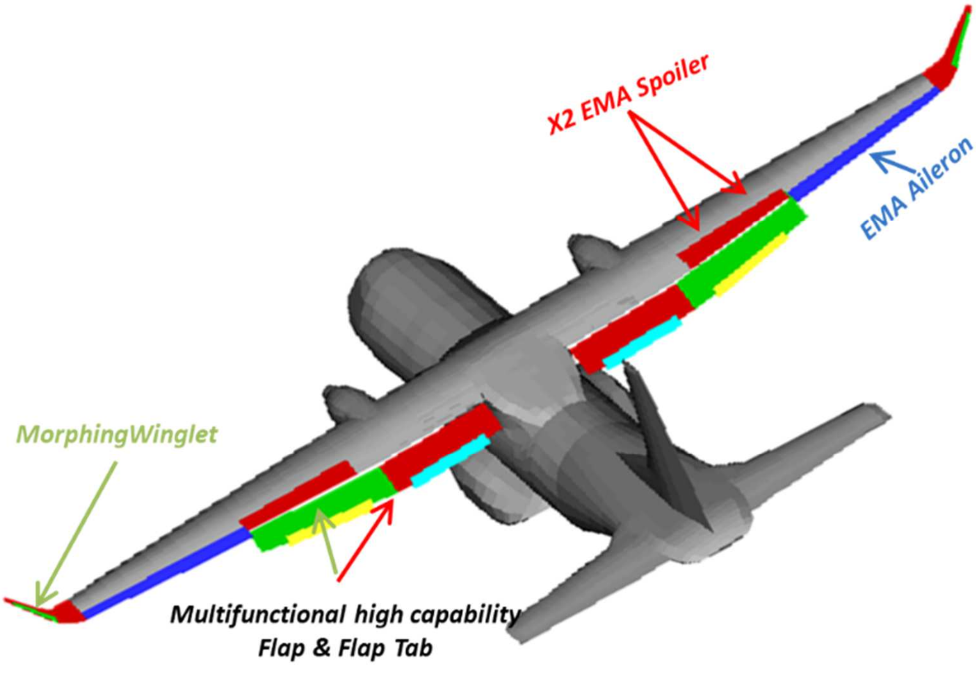

Figure 2 –C295 semi-morphing wing demonstrator

Figure 3 –Active winglet

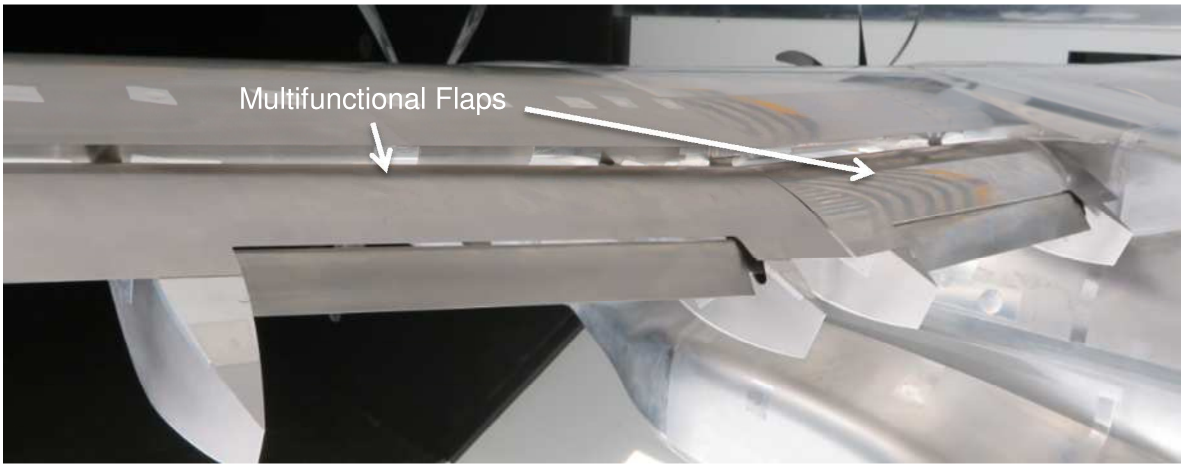

Figure 4 –Multi-functional flap

The allocation of functional capabilities per movable is the following (Figure 5):

- ACTIVE WINGLETS:
    - Drag optimization in cruise and take-off/climb conditions
    - Roll Control
    - Manoeuvre Load Alleviation (MLA)
    - Gust Load Alleviation (GLA)
- AILERONS
    - Roll Control
    - High-Lift
    - Manoeuvre Load Alleviation (MLA)
    - Gust Load Alleviation (GLA)
- SPOILERS
    - Lift-Dump
    - Speed Brake
- MULTI-FUNCTIONAL FLAPS
    - Adaptive continuous setting to optimize maximum lift and aerodynamic efficiency (for take-off and rejected landing) as a function of available field length, aircraft weight and centre of gravity, and ambient conditions.
    - Drag optimization in cruise through variable camber control
    - Manoeuvre Load Alleviation (MLA)

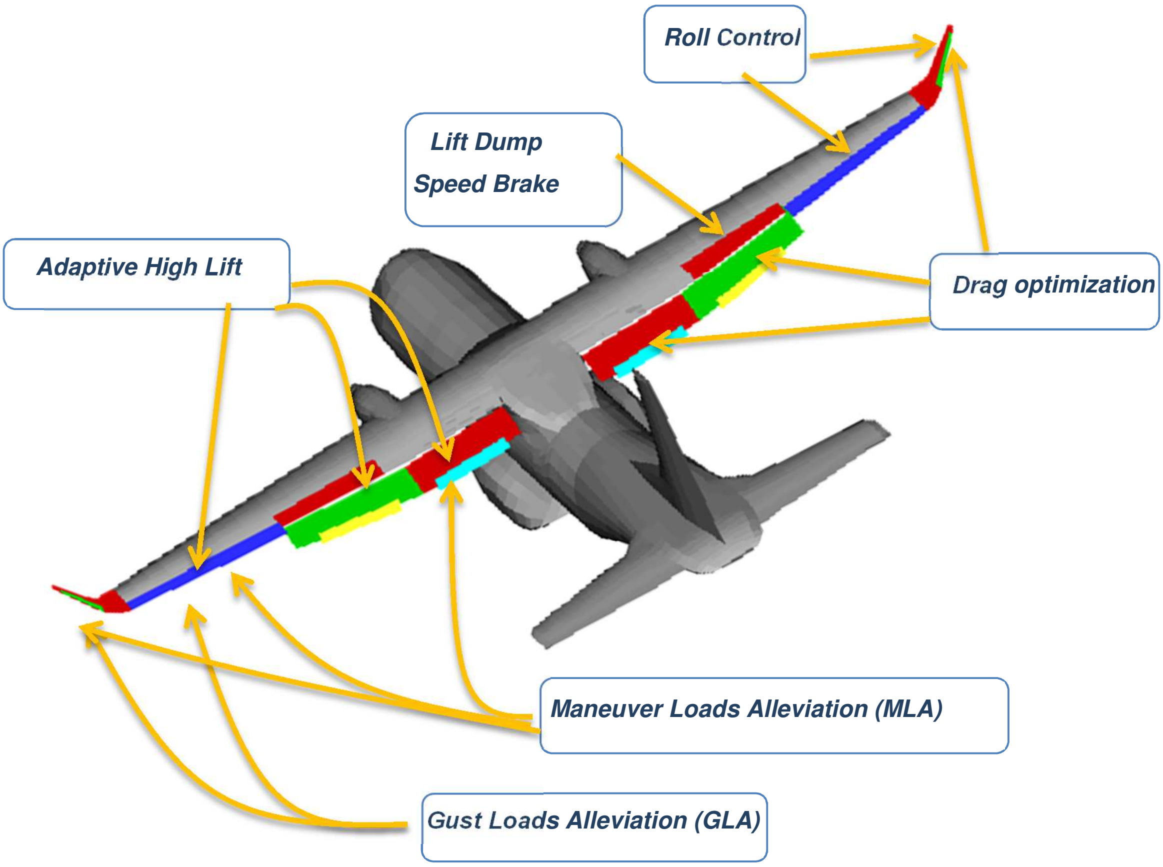

Figure 5 –Allocation of functionalities per device

3. Simulation Means

The design and the analysis of the benefits of the semi-morphing wing have been performed through a combination of CFD (Computational Fluid Dynamics) and Wind tunnel testing.

3.1 CFD Model

Two different Reynolds Averaged Navier Stokes (RANS) CFD solvers have been used; ANSYS-CFX version 16.1 to evaluate the non-powered aircraft and ANSYS-Fluent version 15.0 to evaluate the propeller-aircraft interaction effects (Figure 6). In both cases, the turbulence model used has been the k-ω SST with automatic wall functions.

The propellers are modelled as actuator discs using a so-called virtual blade model where source terms based on the Blade Element Momentum (BEM) theory are introduced in the RANS model.

A multi-domain hexahedral structured mesh with non-conformal interfaces and boundary layer refinement for $y+\sim 1$ is used.

Reference [1] presents more details of the model as well as a full validation versus experimental data.

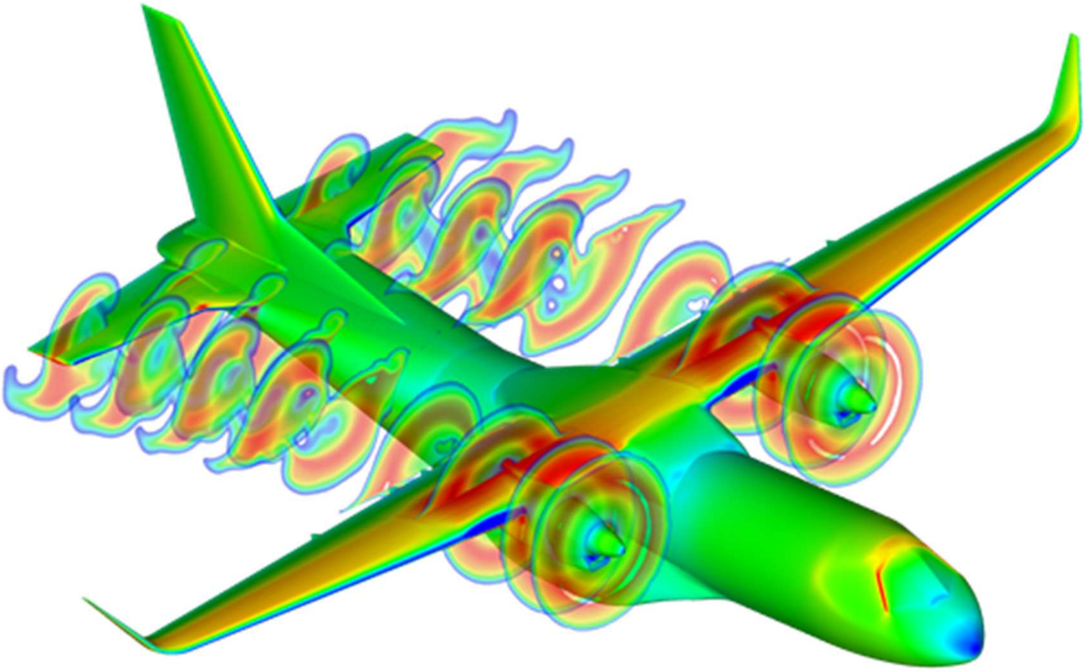

Figure 6 –CFD model

3.2 Wind Tunnel Test

A motorized 1:8.6 scaled wind tunnel model of the flight test bed with the semi-morphing wing devices has been designed and manufactured as part of the CleanSky 2 POLITE and PERTURB projects. The model has been tested at both the RUAG LWTE atmospheric low-speed wind tunnel in Emmen/Switzerland (Figure 7) and the ONERA F1 pressurized low-speed wind tunnel in Fauga-Mauzac/France (Figure 8). These tests have allowed confirming the aerodynamic design and the expected benefits and to gather the data required to prepare the aerodynamic data bases feeding the different customer processes, namely loads, aircraft performance, flight control laws and handling qualities.

Figure 7 –Model in RUAG LWTE.

Figure 8 –Model in ONERA F1.

4. Drag Reduction

As described above the drag reduction function is assigned to the active winglet and the multi-functional flap. In the following, the effect of these devices is presented.

4.1 Active Winglet

In the design of a winglet different compromises need to be met between the drag reduction capability, the increased wing loads, the sensitivity to flutter, the impact on handling qualities, etc. The resulting winglet geometry and its aerodynamic lines are optimized for a particular design conditions while respecting the above-mentioned constraints. For off-design conditions, the drag benefit will decrease or in extreme cases may even be negative. The addition of a trailing edge control to the winglet allows adapting the winglet camber depending on the particular flight conditions and thus extracting additional benefit across the flight domain.

This effect was initially demonstrated using CFD (Figure 9) and then confirmed by the wind tunnel tests (Figure 10).

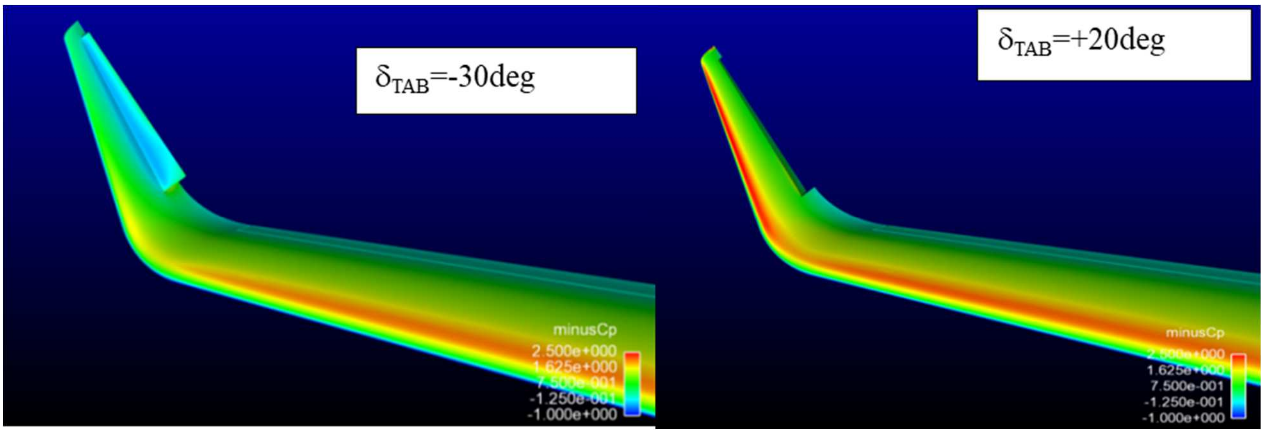

Figure 9 –Winglet flap CFD study

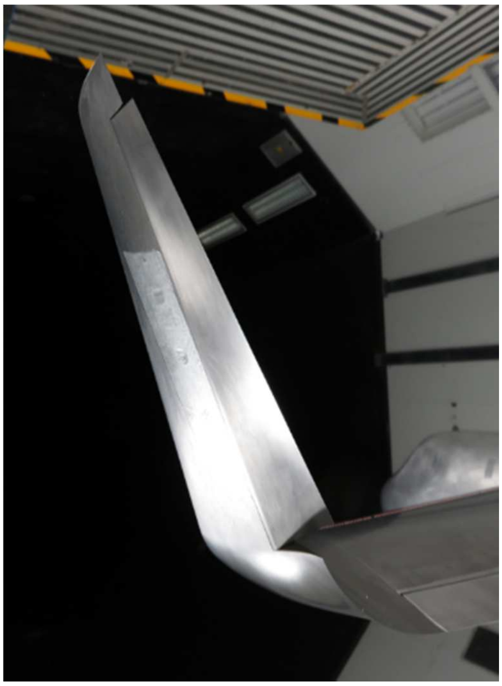

Figure 10 –Winglet flap wind tunnel tests

The results are respectively shown in Figure 11 for CFD and Figure 12 for the tests. The drag increment vs. winglet flap deflection is presented for different aircraft lift conditions. It can be seen that it is possible to derive an optimum law for the deflection of the flap as a function of aircraft lift to maximize the drag reduction. This law is presented at the bottom of each figure.

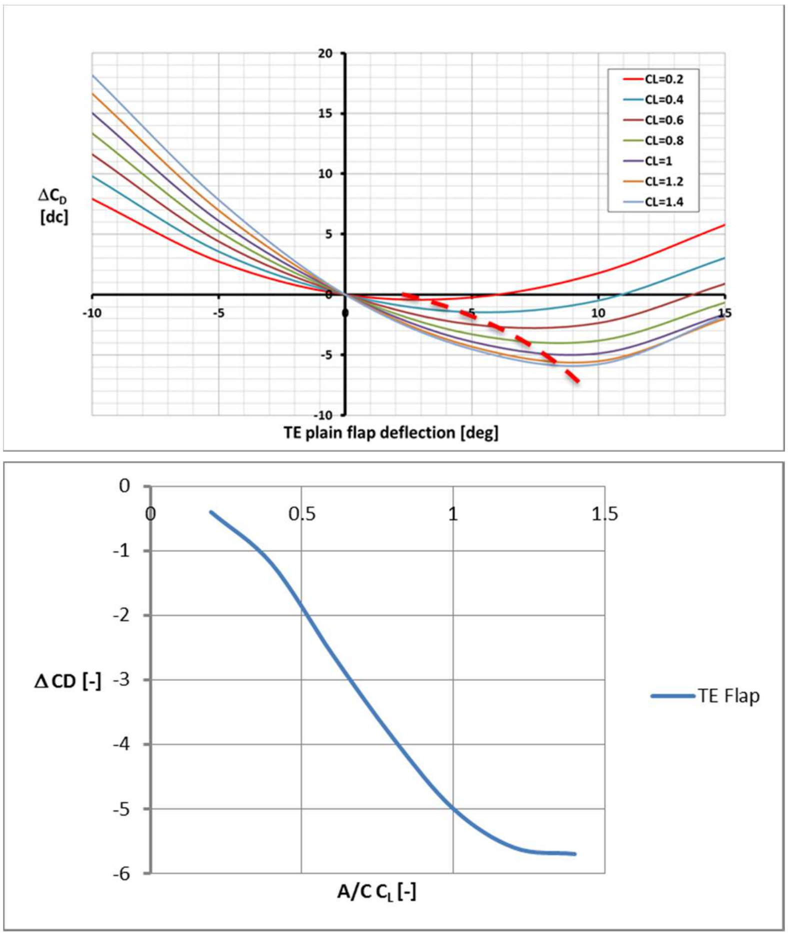

Figure 11 –Effect of winglet flap on drag (CFD)

The experimental results show even a larger benefit because the saturation with the flap deflection is delayed compared with the CFD calculations.

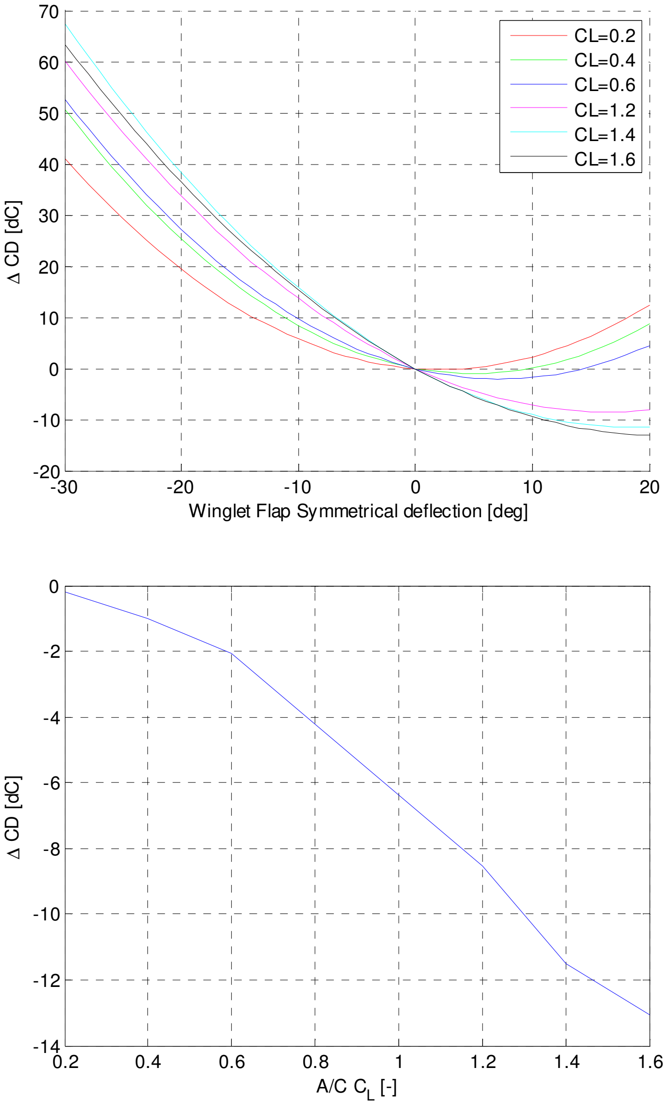

Figure 12 –Effect of winglet flap on drag (WTT)

4.2 Multi-Functional Flap

The benefit of the multi-functional flap in terms of cruise drag is achieved by means of the flap tab component deflection (Figure 13). Two mechanisms come in play, the adaptation of the lift distribution along the wingspan to the instantaneous flight conditions plus the control of the fuselage cruise attitude by the re-distribution of the total lift between the wing and the fuselage.(Figure 12).

Figure 14 presents the effect of the tab deflection on drag for a couple of tab chords (% refers to the complete wing sectional chord) calculated by CFD. It can be seen that the tab needs to be progressively deflected to a more negative position as the flight speed is increased. It is interesting to note that the flap effect on drag complements very well that of the winglet as it is most efficient at the lower lift coefficients that is the area where the active winglets provides smaller benefits.

The flap tab has also a function as part of the high lift system. The extremely demanding requirements coming from the operation in city airport and non-prepared runways result in the need of a double slotted flap (Figure 15). The negative tab deflections required for the drag reduction function would result in a flap-tab geometry that would compromise the achievable maximum lift during landing, because of the resulting non-optimal gap and overlap values. Finally it was decided to prioritize the high-lift function and to eliminate the drag reduction function for the flap tab. It would still be possible to implement such a function on a less demanded case.

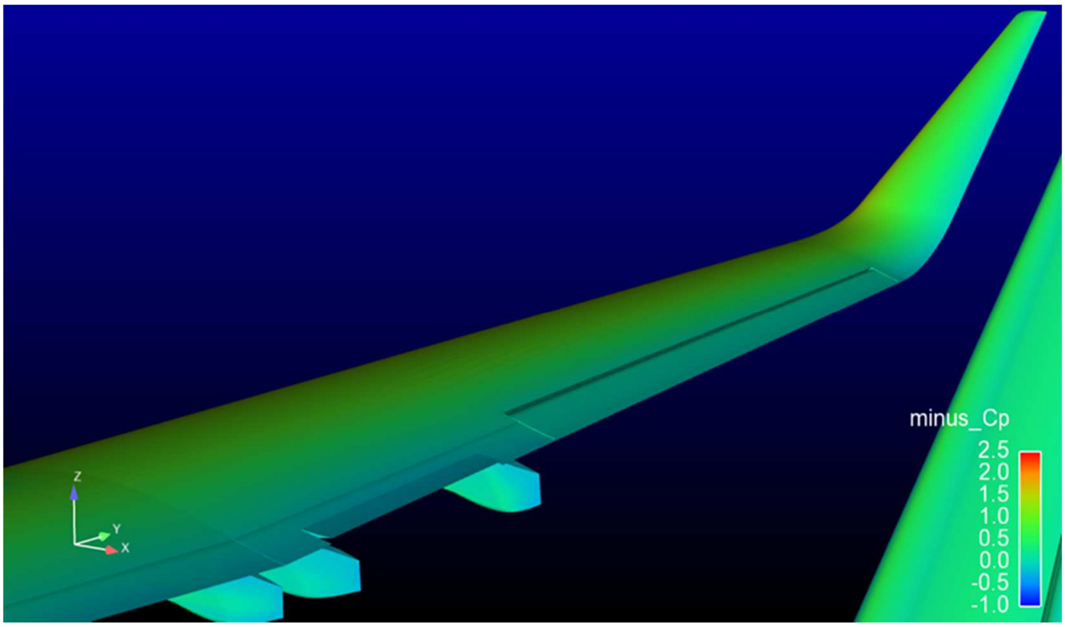

Figure 13 –Flap tab CFD study.

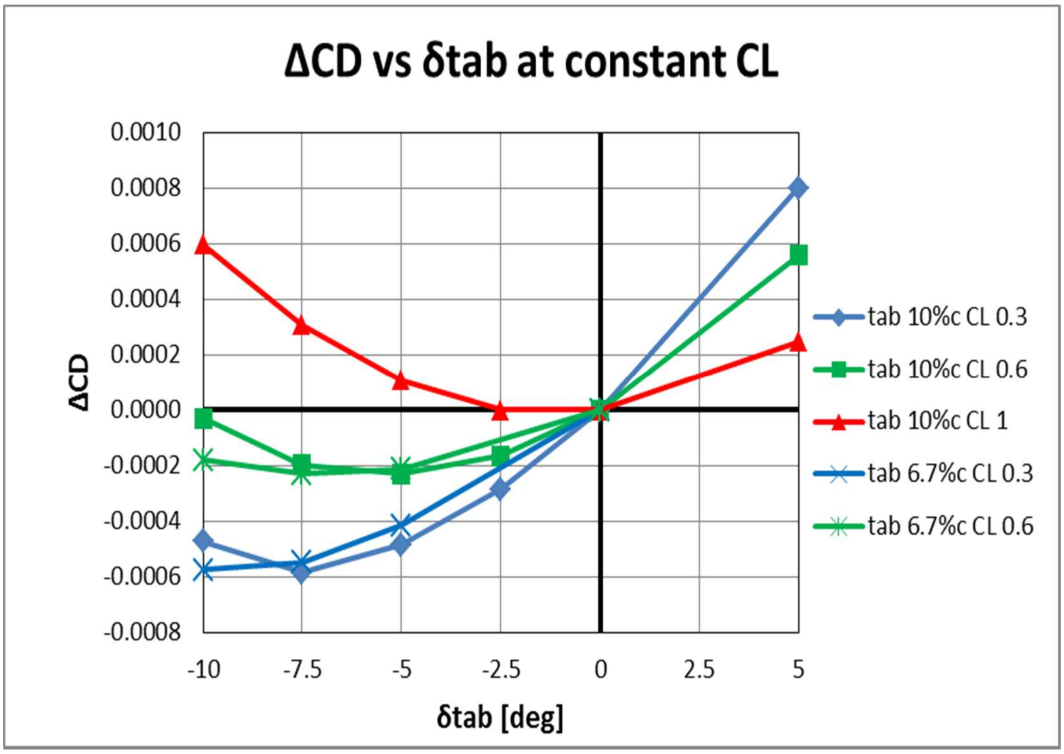

Figure 14 –Flap tab effect on drag.

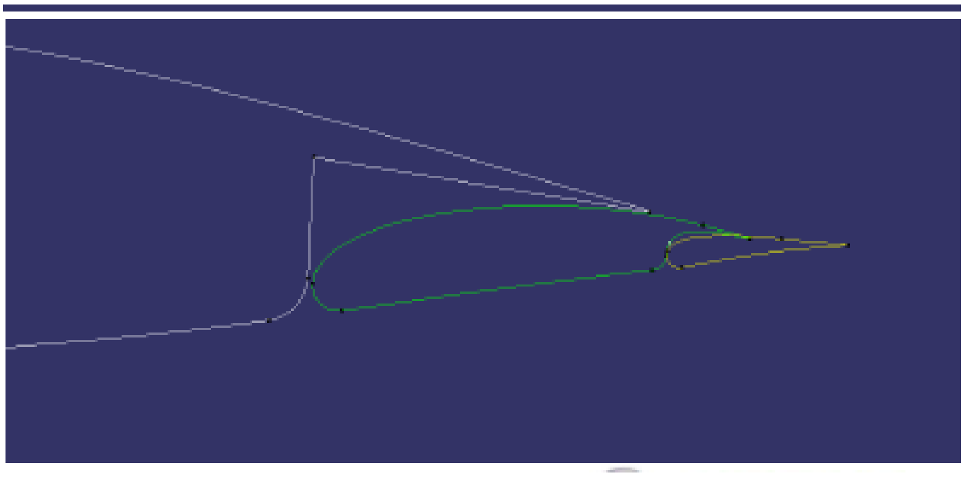

Figure 15 –High-Lift geometry

5. Roll Control

The ailerons are the obvious primary roll control, but the winglets flaps can be used as secondary control surfaces to increase roll control capability (for instance to increase cross-wind capability or to allow the use of a larger symmetric aileron deflection to contribute to high-lift) and to provide adequate roll controllability in case of aileron failure (e.g. EMA jamming).

Figure 16 shows a comparison of the wind tunnel results for the rolling moment introduced by an antisymmetric winglet flap deflection and that of the ailerons. The roll capability of the winglet is of the order of 20% of that of the aileron.

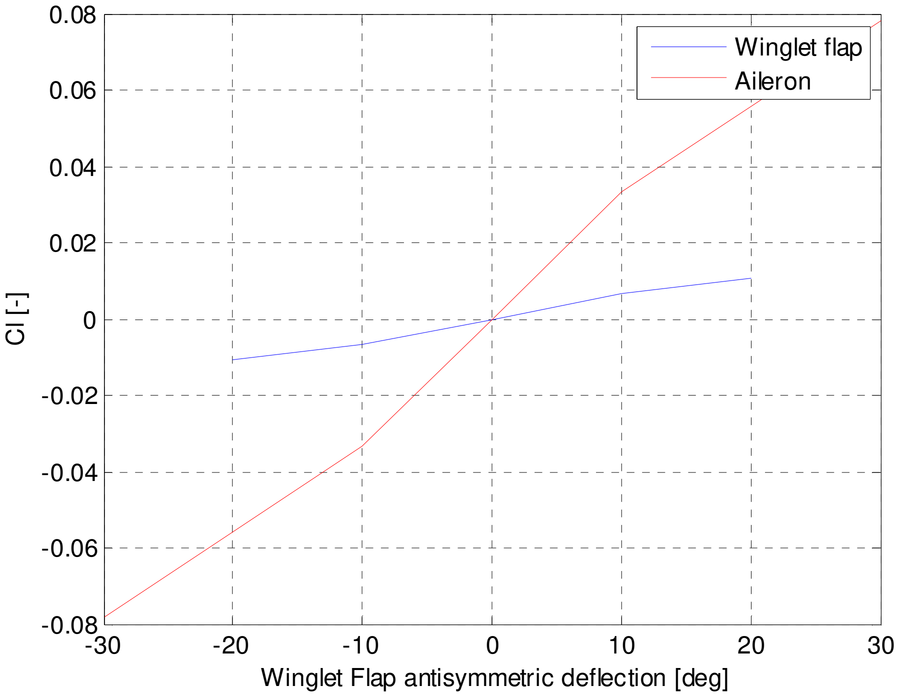

Figure 16 –Winglet flap effect on roll

6. Load Control

As described above the load alleviation function is assigned to the active winglet, the aileron and the multi-functional flap. In the following, the respective effect of these devices is presented.

6.1 Active Winglet

Figure 17 and 18 show the effect of winglet flap negative deflection on the wing root bending moment respectively calculated by CFD and from the wind tunnel tests. For the experimental results, the model rolling moment resulting from a winglet flap deflection on one of the wings only is used to derive this bending moments. For the typical high speed critical manoeuver conditions the lift coefficient reaches values between 0.4 and 0.6. For this range of conditions, it can be seen that the reduction in bending moment is of the order of 10%.

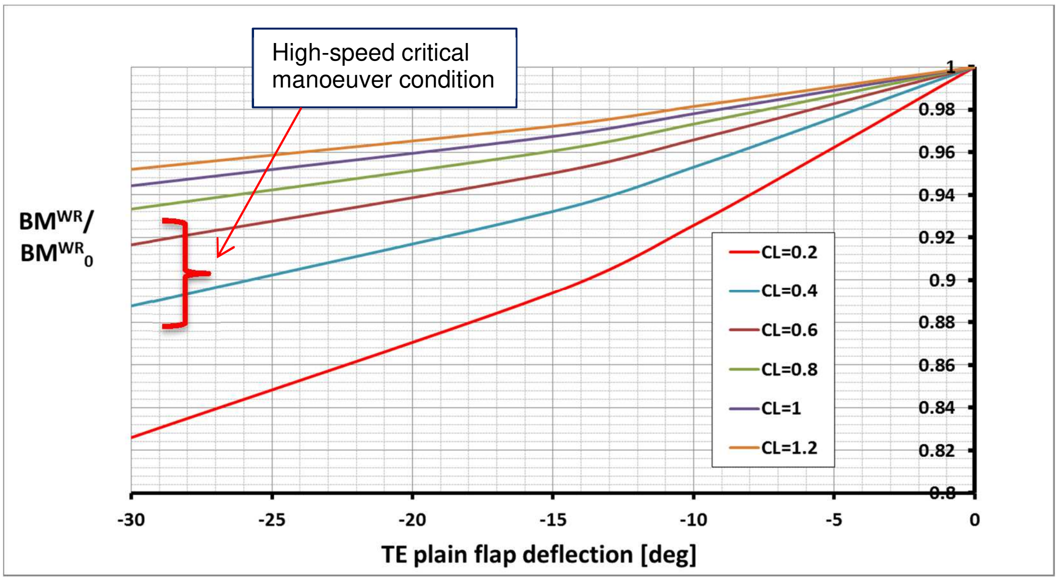

Figure 17 –Winglet flap effect on bending moment. CFD

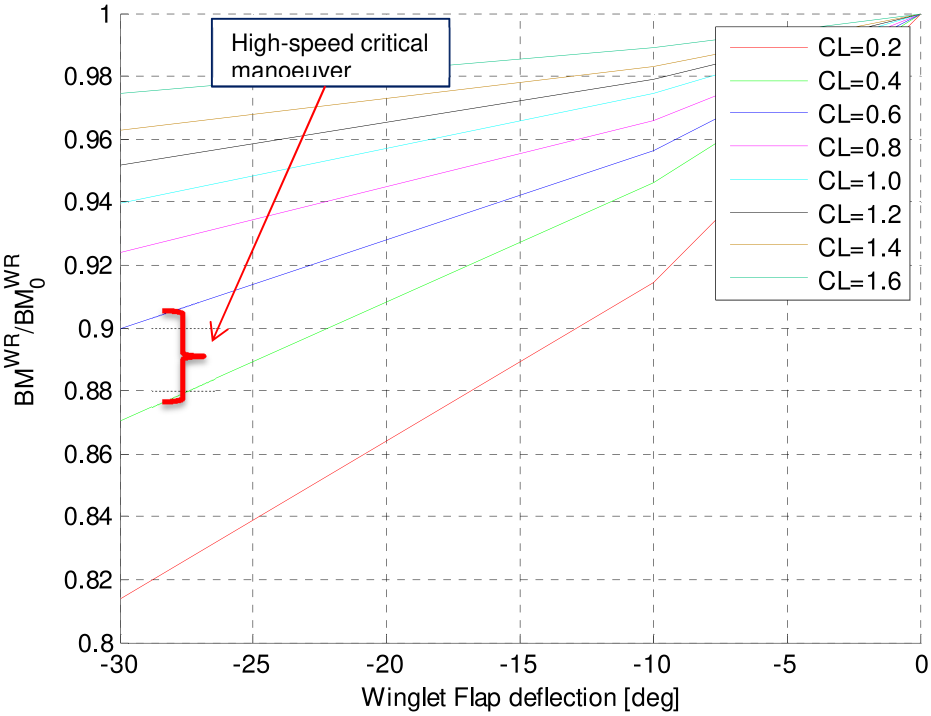

Figure 18 –Winglet flap effect on bending moment. Wind Tunnel Test

In case of continuous turbulence or gust environment, two strategies can be followed. In a simple scenario a maximum negative winglet flap deflection is generated prior to the gust encounter to unload the 1g load distribution. Alternatively, the winglet tab can be used in an active gust load alleviation system

6.2 Multi-functional tab

Positive flap tab deflections can be used to shift the lift distribution inboard during manoeuvres and thus reduce the wing root bending moment at constant overall lift. This effect is demonstrated in Figure 19, where the effect of the inboard flap tab deflection on wing root bending moment obtained in the wind tunnel tests is shown as a function of aircraft trimmed lift and tab deflection. It can be seen that for the higher lift coefficients the result is a reduction of the bending moment. As a reference for a 2.5 g's manoeuvre at V_C a typical lift coefficient of the C295 is of the order of 0.8 for which a reduction of the wing root bending moment better than 2% is obtained.

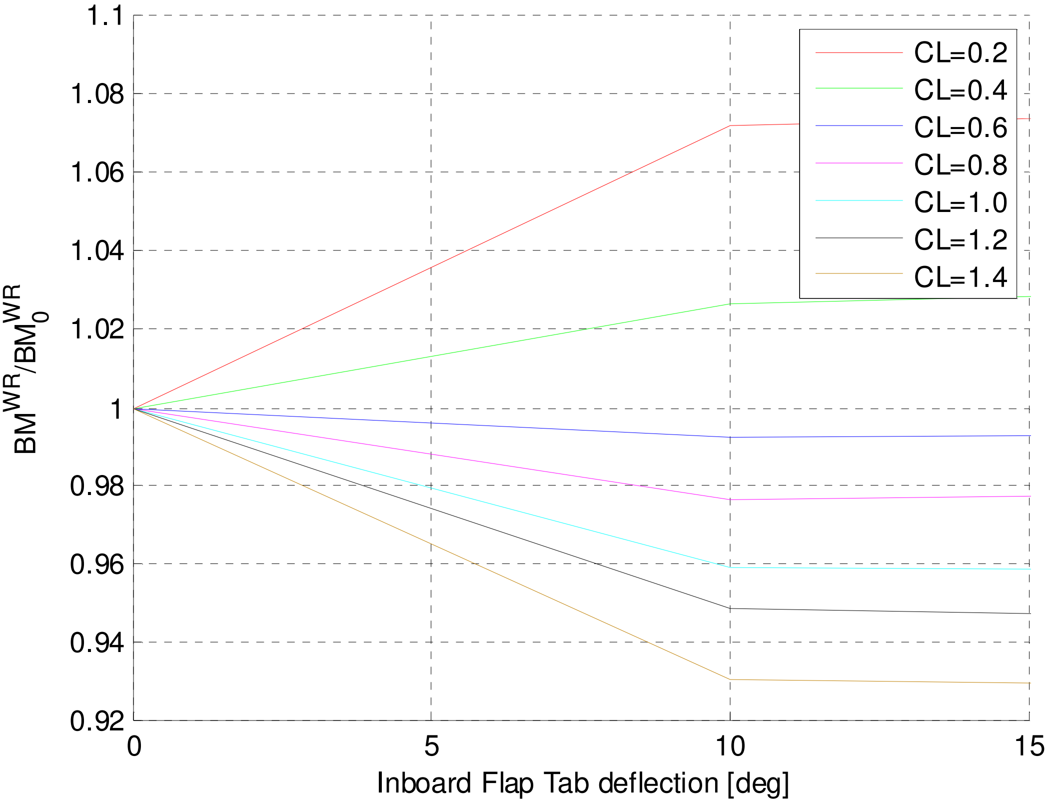

Figure 19 –Flap tab effect on bending moment WTT

6.3 Aileron

Negative symmetric aileron deflections during manoeuvres can also be used to further shift inboard the lift distribution for either manoeuvre or gust load control. Figure 20 presents the effect of the aileron deflection on wing root bending moment obtained in the wind tunnel tests as a function of aircraft trimmed lift and aileron symmetric deflection angle. For the 2.5 g's conditions at V_C (C_L=0.8) the bending moment can be reduced up to 33% for the full aileron deflection range. The level of bending moment reduction through symmetric aileron deflections has to be harmonized with the need to maintain roll control through antisymmetric aileron deflections and the limitations due to aileron saturation. This is where the contribution of the winglet flap to the roll control can be used to support the aileron especially at high manoeuvre speed where the roll control requirements not so high.

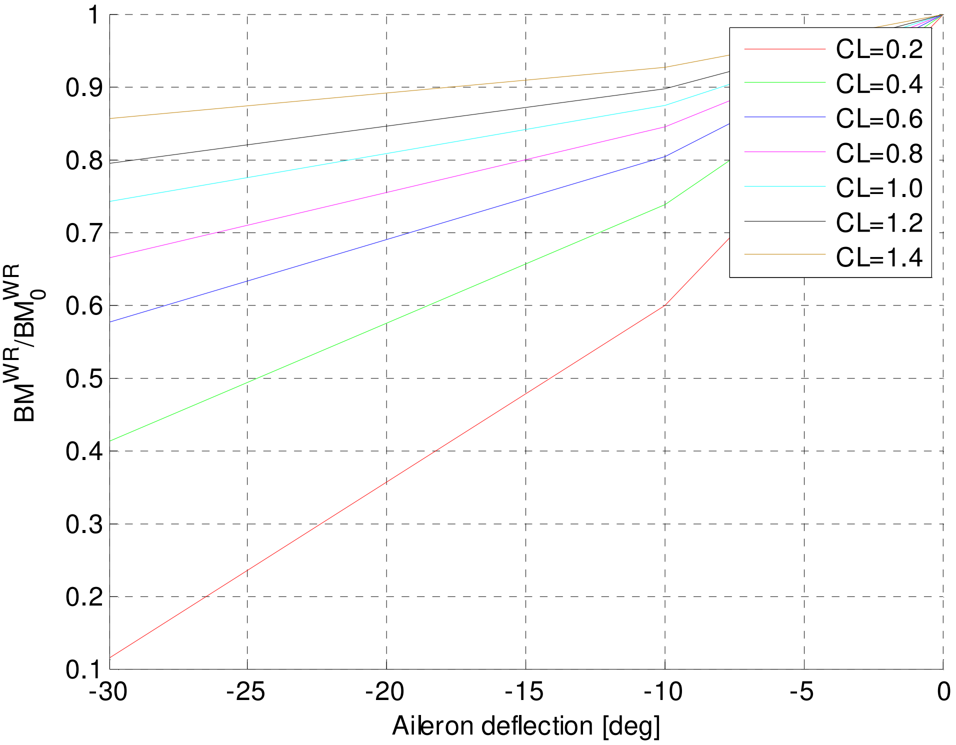

Figure 20 –Aileron effect on bending moment WTT

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9. Copyright Statement

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