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ANALYSIS OF THE EFFECT OF FLOW TRANSITION OVER THE WINGS OF THE BLADE DEMONSTRATOR

Roger Larsson[1]

[1]Saab Aeronautics, Linköping, Sweden

Abstract

This paper describes the Saab analysis concerning the natural laminar flow (NLF) transition of the "*Breakthrough Laminar Aircraft Demonstrator in Europe*" (BLADE) flight-test, which was performed 2017. It shows the methods used and the results from the flight-test and computational fluid dynamics (CFD) analysis performed on the geometries given by AIRBUS and transition lines given by DLR. The use of the Saab wing concept has the potential to reduce the total aircraft drag by about 9.4 % for a typical cruise condition if the technology used for producing the Saab wing panel is applied to both the wing and empennage of a typical A320 like aircraft. This is concluded from the flight test results in combination with the performed CFD calculations.

Keywords: Flight test, Flow transition, CFD, Drag reduction

1. Background

The Clean sky program, 2008-2016 with a budget of €1.6 billion, and Clean sky 2 program, 2014 – with a budget of €4 billion, were initiated to work towards a decrease of the environmental impact of air transport. Evolutionary improvement in material, aerodynamics as well as engine efficiency have, over the years, contributed to relative efficient aircraft configuration. The effects of air transport has however increased at such a rate that they outweigh these improvements (Figure 1) and a more dramatic change was needed to meet the ACARE 2020 and 2050 goals set up to protect the environment of our planet. These goals state significant reductions in CO_2 and NO_X emissions as well as the noise level. The Clean Sky program targeted areas named Green Regional Aircraft, Smart Fixed Wing Aircraft, Green Rotorcraft Sustainable and Green Engines, Systems for Green Operations and Eco-Design to take an over-all perspective of the air transport sector. In the Smart Fixed Wing Aircraft part of the Clean Sky and Clean Sky 2 programs investigations of different concepts have been made. In addition, technologies such as passive and active means to reduce the aerodynamic drag as well as load alleviation to weight and drag has been looked at. An early question was about proving concepts and technologies in a flying demonstrator.

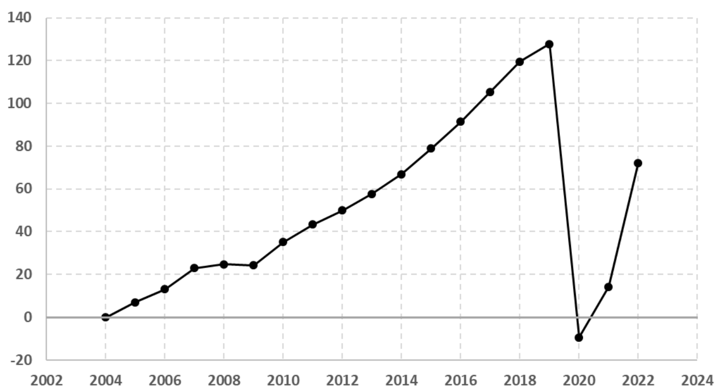

Figure 1 – Increase in passenger transport in percentage since 2004. Data from Statista.

2. Introduction

This paper describes the Saab analysis of the NLF transition over the outer panels of the "Breakthrough Laminar Aircraft Demonstrator in Europe" (BLADE) aircraft. This analysis investigates the aspect of drag reduction, using technology for producing new aerodynamically efficient wings, which has been one of the main goals in the Smart Fixed Wing Aircraft (SFWA) part of the Clean Sky program. The BLADE demonstrator aircraft is an Airbus A340 with modified outer wings as can be seen in Figure 2. The upper surfaces of the outer wings was produced using two different concepts. The left wing panel is based on the Saab design of using a smooth upper wing surface without joints, rivets etc. that can create steps, gaps or other surface imperfections. The right wing panel is based on the GKN design, which is a more traditional concept, but still with improved surface quality compared to similar aircraft concepts flying today. The BLADE aircraft was instrumented to be able to detect transition from laminar to turbulent flow over the outer wing panels.

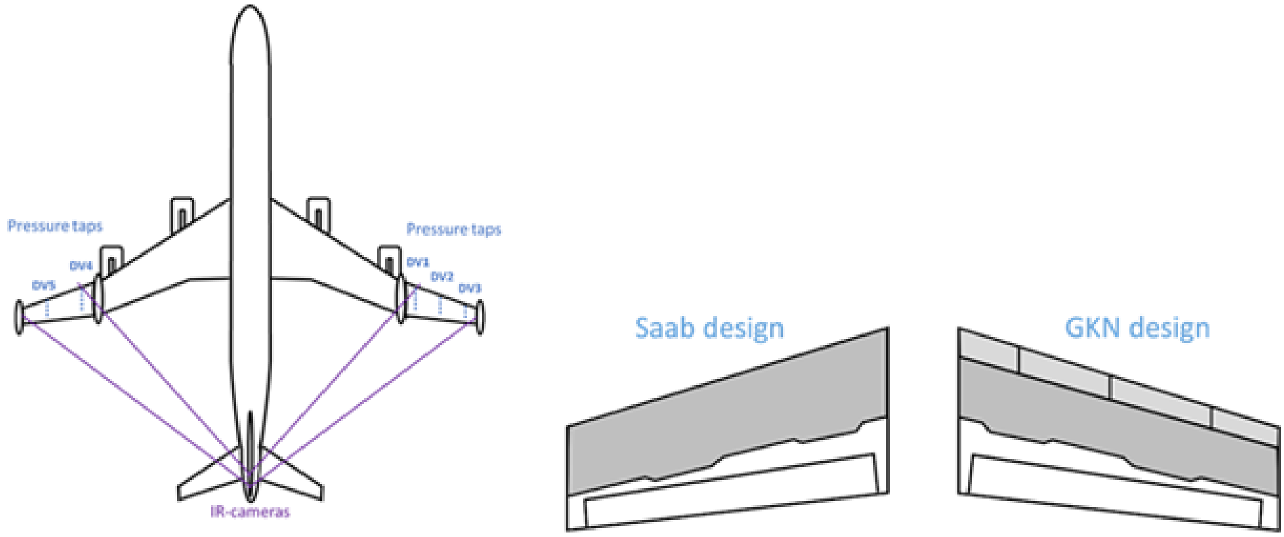

Figure 2 – The BLADE demonstrator aircraft with the different wing panel designs.

3. Method

The method used for the analysis is based on flight-test data in combination with CFD calculations. The flight test data was used to get the transition line as well as providing a pressure reference for the CFD calculations. CFD calculations were used to calculate the resulting aerodynamic drag where the transition boundary were taken from flight-test data.

3.1 Flight test data analysis

To be able to make this analysis, an initial investigation of the data from the measurements and geometry provided by AIRBUS and the transition line analysis made by DLR was made. This included looking at the pressure tap measurements as well as evaluating the transition lines that were provided. An example is shown in Figure 3, where the evaluated transition line is shown as a green line in the left part of the figure. The right part of the figure includes the pressure measurements including 95% confidence interval to be able to see the variation during the exposure time. For the studied flight, presented in this paper, test points at different speeds and altitudes were made. This resulted in different angles of attack, but also in different shapes of the wing at the different test points.

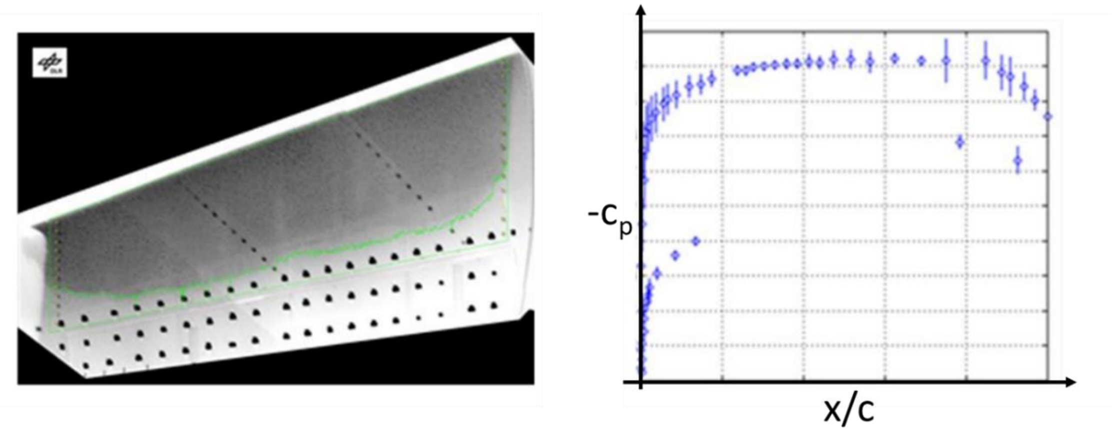

Figure 3 –IR data including a transition line (left, data from DLR) and pressure measurements including 95% confidence interval (right, data from AIRBUS).

3.2 CFD analysis

The data from flight-test has been used together with Navier-Stokes CFD calculations made at Saab. Four different CAD geometries were provided by AIRBUS to handle the different wing shapes. For the CFD calculations, the EDGE code [1] has been used. The CFD mesh was prepared using ANSYS ICEM CFD [2]. An unstructured mesh type was chosen for the CFD analysis. Here, great care was taken to generate a mesh that could be used for several analysis purposes. The use of a structured grid is usually preferred for transition analysis, since this gives a less noisy pressure solution needed for the prediction of the transition location. However, here the transition line is taken from flight-test and then an unstructured mesh is good enough. The geometry and part of the mesh can be seen in Figure 4. The CFD calculations were made for an all-turbulent wing reference case and with transition lines based on flight test analysis for the left wing and right wing respectively. An analysis of the drag for the wing panels was made on the results from the CFD calculations. Comparisons of the left and right wings, with the transition lines included, have been made, but also towards the fully turbulent case.

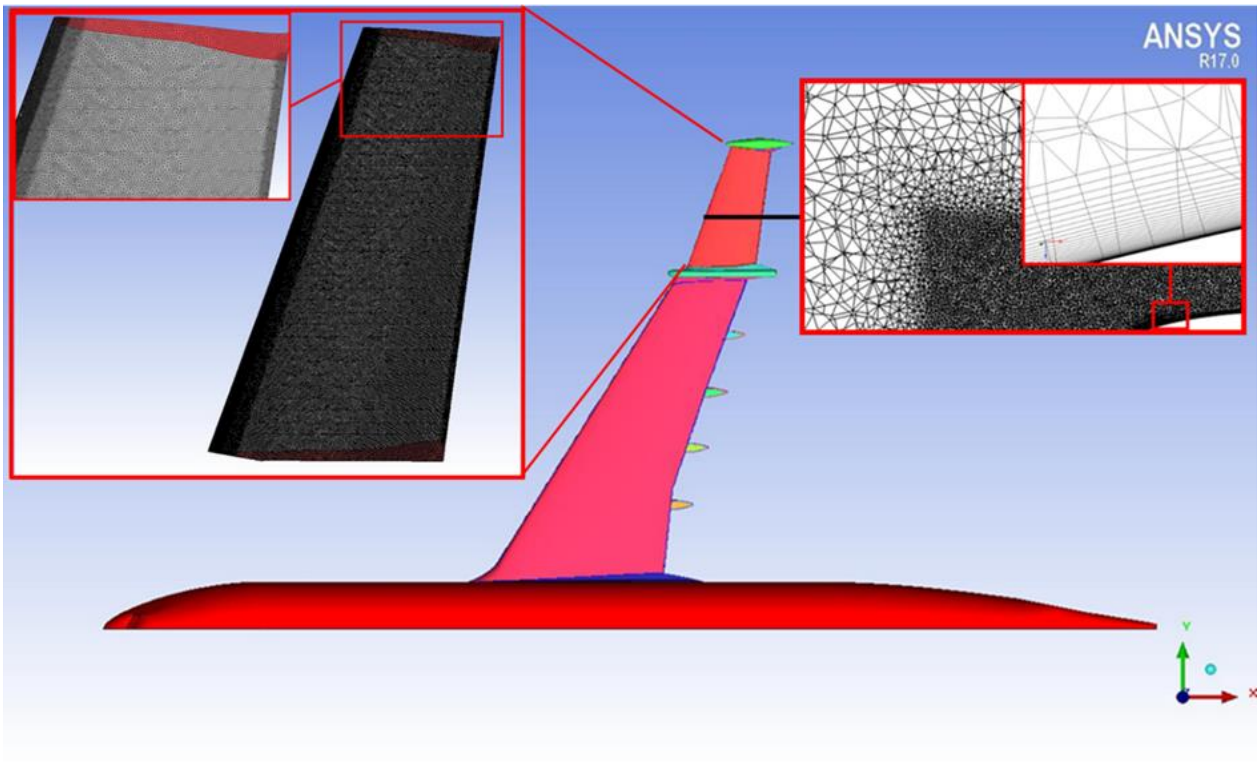

Figure 4 – Geometry provided by AIRBUS and parts of the mesh used for the CFD analysis.

A comparison between the CFD calculations and the pressure measurements are shown in Figure 5. As can be seen the agreement are very good for the most part. The shock positions agree and the pressures agree for the most part. The exception being for the outer part on the right wing (DV3) where there is a difference over the mid chord part of the panel. The transition lines used for these calculations are shown in Figure 6 and the resulting skin friction coefficient from the CFD calculations are found in Figure 7.

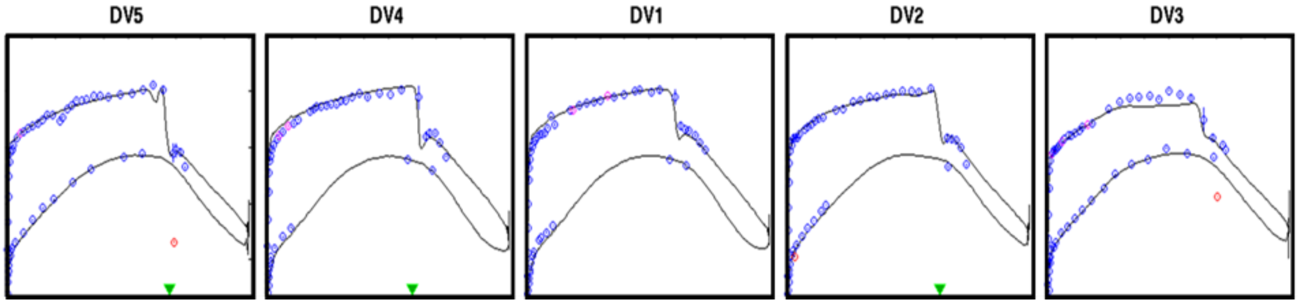

Figure 5 – Comparison of pressure coefficient from CFD calculations with flight test measurements.

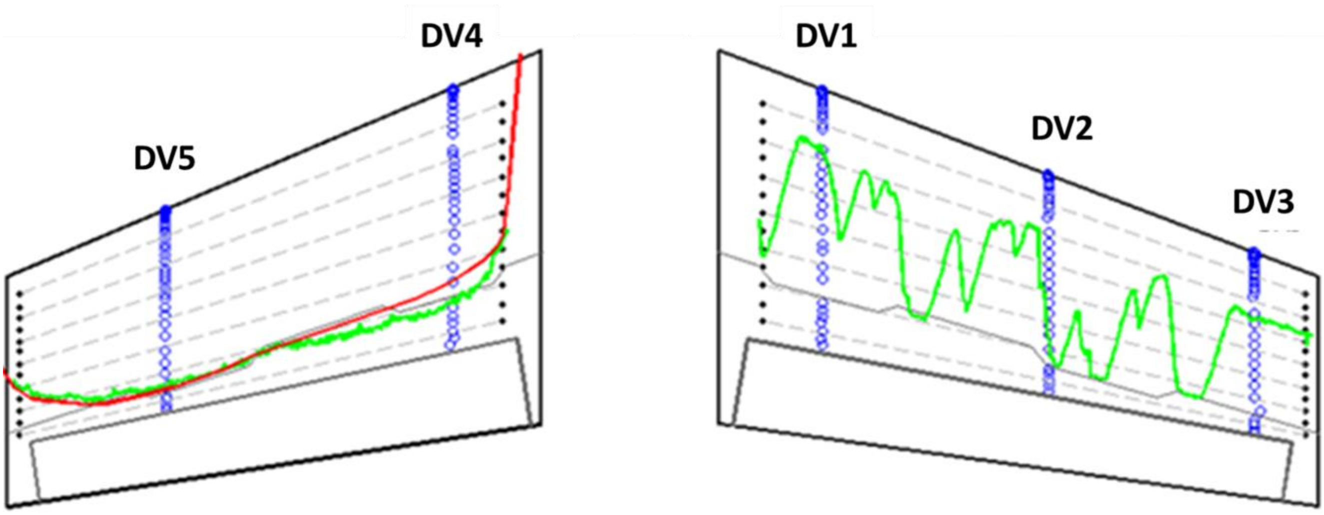

Figure 6 – Transition lines used for the CFD calculations based on flight-tested data, detected by DLR shown in green and some minor adjustments from Saab in red for the left wing panel.

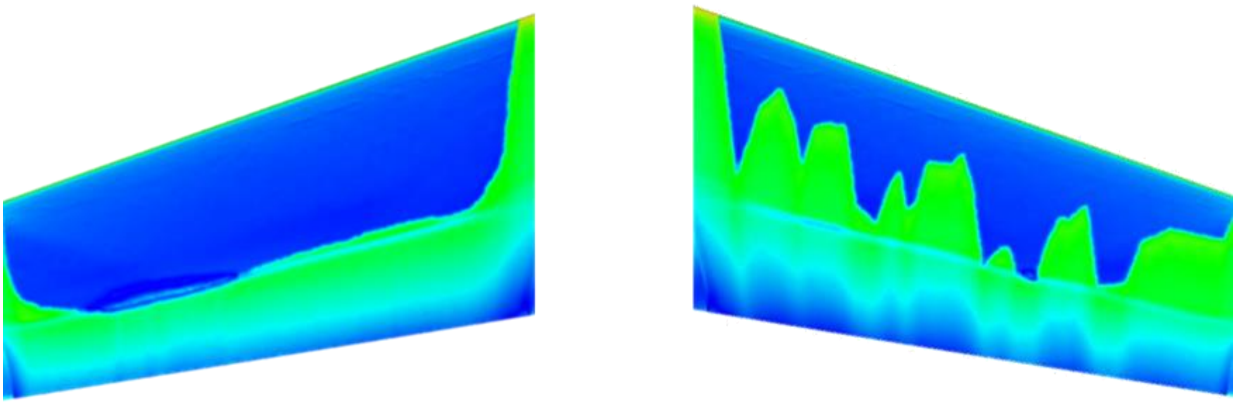

Figure 7 – Skin friction from CFD calculations based on transition line from flight test.

3.3 Drag analysis

The analysis of the aerodynamic drag was focused on the skin friction part of the outer wing panel of the BLADE demonstrator aircraft. It was done to see the results more clearly. This could give a prediction of the potential gain if the proposed design concepts were to be used in a new aircraft design. Of cause, the pressure drag is also of interest, but since there are pods inboard and outboard of the wing panels and the wing profile on the lower side of the panel was changed to decrease loads at the span-wise joint to the main wing, which could disturb the pressure, this was not included in the analysis. Figure 8 shows the effect on the lift coefficient and the resulting friction drag reduction as a delta compared to the fully turbulent case. Both geometrical solutions, left and right wing panel, give a significant drag reduction. The left wing has a delta reduction of 15 cts. (drag counts) compared to the 10 cts. for the right wing panel for this case.

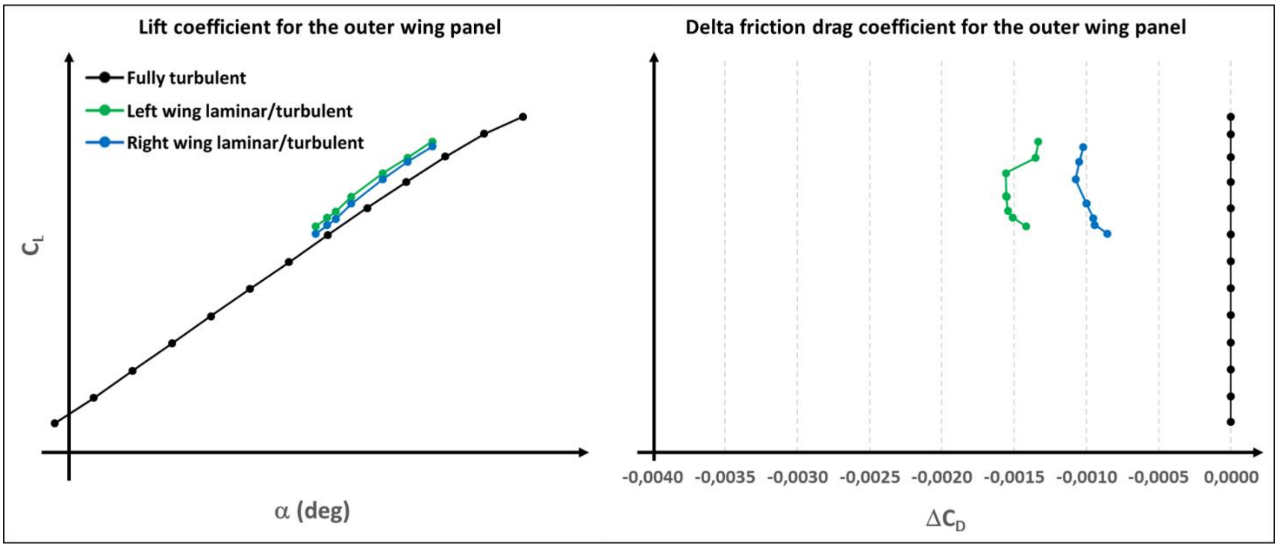

Figure 8 – Lift and delta frictional drag coefficients for the fully turbulent, left and right wing panel.

One of the goals of the BLADE demonstrator was to verify the effects of the new wing production technologies for a future AIRBUS A320-type of aircraft. To predict the effect of the decreased friction drag shown in Figure 8, an analysis based on A320 data has been performed. Geometrical data for an A320 has been taken from [4] and [5]. The 0.25% chord sweep is 25° compared to the BLADE wing panel's 17,9°. The analysis has been done for a cruise case at an altitude of 11 km. For the prediction to be relevant for an aircraft with a lower wing sweep angle, the cruise speed needs to be reduced from Mach 0.78 to 0.73 according to [4]. For the BLADE demonstrator the chosen design C_L=0.65, which will be used in the analysis. The drag coefficient for these Mach and C_L values is C_D=0.0361 or 361 cts. when using data from [5]. A drag estimation for the A320 aircraft has also been made using the methodology described in [4]. This results in a C_D=357 cts., which gives confidence that the estimation of the A320 drag coefficient is good enough for the prediction made here.

The transition from laminar to turbulent flow can be triggered by different mechanisms. In [6], three of these are given as Tollmien-Schlichting, Cross-flow and Attachment line instabilities. The transition can also come as so-called wedges due to surface contamination [7]. For the analysis here, the transition for the A320 baseline is taken to be 5% of the chord based on [8], which states that the transition from laminar to turbulent flow is close to the leading edge. A similar effect can also be seen in the wind tunnel test described in [6], where the transition is close to the leading edge of the vertical fin outside of the area where suction is applied. When looking at the results from the modified wing panels of the BLADE demonstrator in Figure 6, the point of the transition line is closer to 60% of the wing chord. Parts at the wing root and tip that are an exception, due to the interference with the fuselage and wing tip flow, therefore it is assumed that the increased laminar part of the upper wing surface is about 50%.

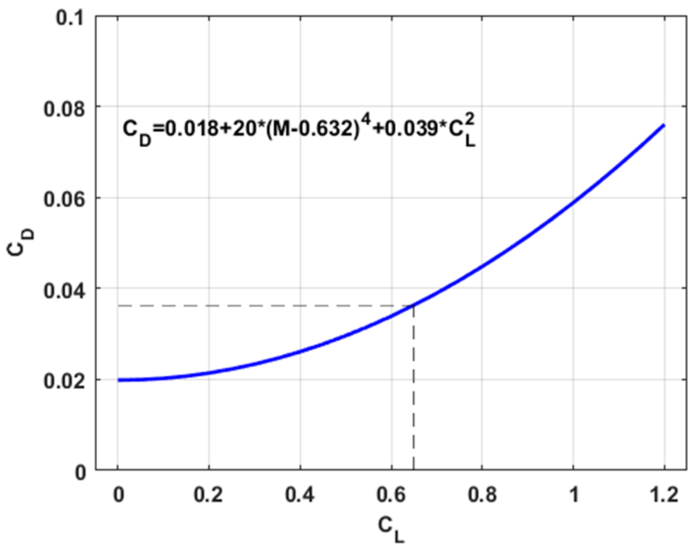

Figure 9 – A320 drag coefficient for M=0.73 with a model taken from [5].
The dashed line show C_D=0.0361 for design C_L=0.65.

To get the drag reduction for different parts of the aircraft an estimation of an A320 with a reduced wing sweep, matching the BLADE demonstrator, has been made using the method in [4]. The resulting drag is close to the estimation of the original A320 aircraft mentioned earlier. The drag components are shown in Figure 10. As can be seen, the friction drag for the wing accounts for $\Delta C_{D0,\,w}$ = 65 cts. For the flight-tested wing panel, at the design point, there is a 25% decrease in friction drag since the reduction of 50% only affects the upper part of the wing. The lower part of the wing has not been designed for laminar flow and therefore no resulting drag reduction is achieved. This gives a reduction of 16.3 cts or a 4.5% drag reduction of the aircraft total drag. If the laminar wing technology is applied to the empennage, using the laminar surface on both sides and not only on one side as for the wing case, another 17.5 cts (4.9%) can be saved. This is based on the fact that the empennage accounts for $\Delta C_{D0,\,emp}$ = 35 cts and the reduction is 50% since both sides of the surfaces are affected. This will, together with the wing contribution, lead to a 9.4% overall drag reduction. The result is in line with the predictions made in [3] where it is stated that “Potential Drag Savings (aircraft level) of at least 10%, Wing, Tail, Nacelles”. Even further gain could be made if the technology is applied to the lower surface of the wing. This would however mean a wing without high-lift devices on the leading edge and the problem of shielding against contamination at take-off and landing.

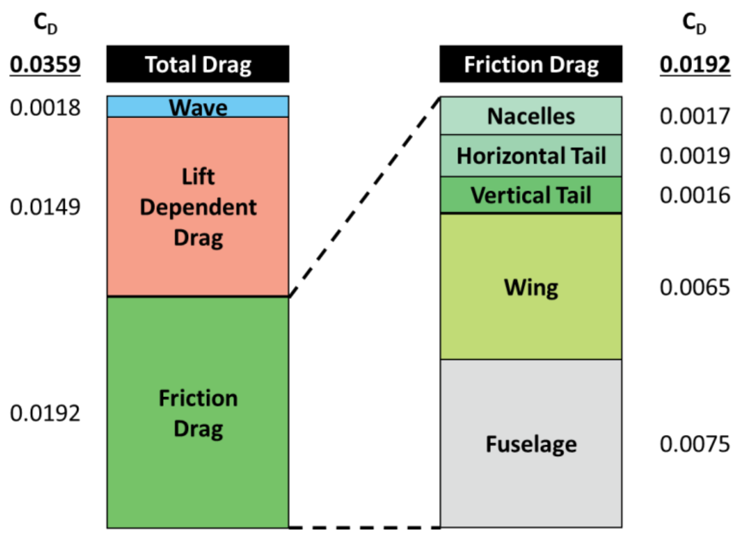

Figure 10 – Drag components of an A320 with a reduced wing sweep.

4. Conclusion

The BLADE demonstrator has been an important part of the verification of the desired reduction of aerodynamic drag and hence fuel consumption of air transport, using technologies studied in the Clean sky and Clean sky 2 programs. The two manufactured concepts of the outer wing panels of the demonstrator aircraft show that care has to be taken when designing the wing. Steps and gaps play a significant role in the process of designing a laminar flow wing. The analysis of the NLF transition, using the CFD method described, based on the BLADE flight-test data, shows that there is a potential drag reduction of about 9.4% for a typical cruise speed if the Saab wing production technology is used on the wing and empennage of a A320 like aircraft. The Saab production method results in a wing and empennage without steps and gaps from the leading edge back to about 60% - 70% of the wing chord. The outer wing panels of the AIRBUS 340 BLADE demonstrator aircraft was designed to enhance the natural laminar flow. This was done by reducing the wing panel sweep and tailoring the wing profile upper surface. To be able to realize laminar flow over a larger part of the lifting surfaces, the use of active flow control technologies are probably needed.

5. Contact Author Email Address

Mailto: Roger.gunnar.larsson@saabgroup.com

6. Copyright Statement

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