The Need of Large-Scale HLFC Testing in Europe

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Abstract

Laminar flow has the potential to significantly reduce the fuel burn of transport aircraft. Whereas for smaller aircraft laminarity can be achieved passively by suitable shaping, active boundary layer control by suction is necessary for larger aircraft. For those aircraft laminarity can be obtained by applying suction at the leading edge before the front spar in combination with a suitable shape of the wing box. The applicability of such hybrid laminar flow systems was shown the 1990s. However, the suction systems of that time were very complex and heavy. Meanwhile much simpler and lighter suction systems are available. These should be further developed and validated by large-scale ground and flight tests in order to demonstrate their feasibility.

Keywords
Laminar flow, hybrid laminar flow control, flight testing

1 Introduction

According to current projections by Airbus [1] and Boeing [2], air traffic worldwide will increase by 5% annually over the next twenty years. This represents a doubling of air traffic every fifteen years. Currently, the airlines are replacing older aircraft with newer, more fuel-efficient ones so that the total demand on jet fuel has increased only slightly. However, by 2020, mid- and older-generation aircraft will represent only 5% of the fleet in service [1, page 6], and the benefits of fleet rejuvenation based on the technology of the “new-generation aircraft,” i.e. the A320neo / B737max, A350 / B787, and the A380 aircraft, will come to an end. At that point, without the introduction of new technologies, any increase in air traffic will directly result in a corresponding increase in atmospheric pollution.

For environmental compatibility we have to either find new technologies to reduce the fuel burn or we have to limit air traffic growth by higher ticket prices or by regulatory means. Such means would have to be put into place by an international organization accepted worldwide, such as the United Nations or its agency, the International Civil Aviation Organization (ICAO). The enforcement of such regulations would not be an easy task as can already be seen from current efforts of the European Commission to gain world-wide acceptance of the European emission trading system [3].

It is expected that most of the air traffic growth will occur in the emerging markets [4], especially in China and in India. Any legal limitation would be seen as affecting the development of these countries, and thus be unacceptable to them. Therefore, it is better to avoid attempting to regulate by developing new technologies that offer sufficient fuel-burn reduction to offset future growth in air traffic.

Today, the HLFC technology promises significant fuel-burn reduction and shows a high technological readiness. In order to explain the benefit of the HLFC technology, we have to distinguish between short- and long-range flights. For long-range flights, the share of fuel consumption during take-off and landing is comparatively small. For this reason we primarily have to consider technologies for fuel-burn reduction in cruise. In this flight regime, we obtain guidance from the specific range equation which measures the performance of an aircraft in cruise. This is given as

$$SR = \underbrace{1/TSFC}_{engine} \cdot \underbrace{V \cdot L/D}_{aerodynamics} \cdot \underbrace{1/W}_{structure}$$

where TSFC is the thrust specific fuel consumption, V the flight velocity, L/D the lift over drag ratio, and W the weight of the aircraft. The specific range is a simple consequence of the fact that, for steady flight at constant altitude, the weight of the aircraft has to be balanced by the lift and the its drag is equal to the thrust of the engine. The integration of the specific range yields the “Breguet range equation” [5].

There are three important quantities to consider:

- Fuel consumption of the engine.
- Aerodynamic efficiency of the aircraft expressed as “velocity*lift/drag.”
- Aircraft weight.

Regarding the engine, impressive progress in fuel efficiency has been achieved over the last decades and the latest aircraft generation will benefit from this progress. Further improvements in fuel efficiency are expected through the introduction of advanced engine concepts such as UHBR turbofan or CROR. Advanced materials such as those already being extensively used for the latest aircraft generation, will allow for a lighter weight aircraft structure.

Further reduction in fuel burn, however, must come from augmenting the aerodynamic efficiency. It seems to be difficult to increase the cruise speed above today’s cruise Mach numbers without encountering an excessive increase in wave drag (as was shown with Boeing’s “Sonic Cruiser” project). Therefore, the main effort should concentrate on reducing the aircraft drag. Its two largest parts are the lift-dependent drag and the friction drag as shown in Figure 1 taken from [6].

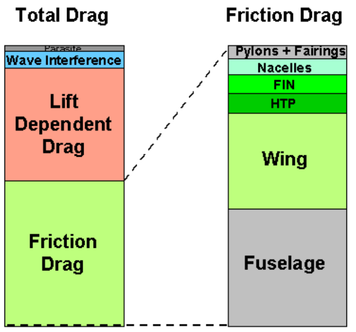

Fig. 1 Drag breakdown of a typical transport aircraft

Because the lift-dependent drag of today’s aircraft has already been optimized, further drag reduction measures can only be applied to the reduction of the friction drag.

Friction drag is created in the boundary layer of the flow around the aircraft. The boundary layers of today’s transport aircraft are turbulent. Turbulent friction drag reduction can be achieved by riblets, which are being investigated within the European CleanSky SFWA project. Laminar flow, however, has a larger potential for drag reduction. It can be applied to wing and tail surfaces. Under the conditions

- leading edge sweep angles below 23^0,
- Mach numbers up to 0.75, and
- Reynolds numbers up to 25 Million,

laminarity can be achieved by shaping [6], i.e. by merely applying a suitable pressure gradient.

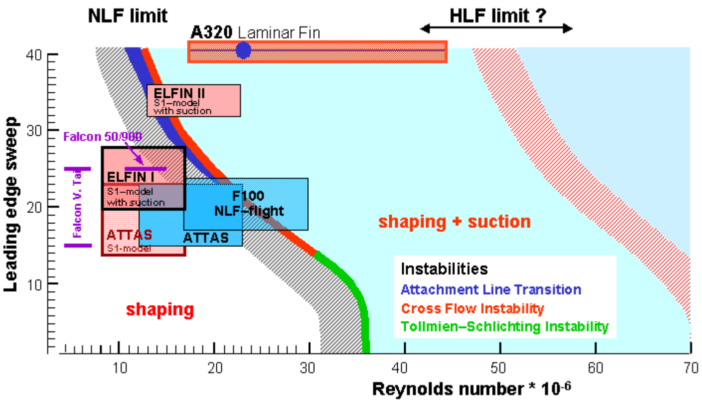

Fig. 2 Reynolds number and sweep range for laminar flow

When the above conditions are violated, i.e. for tail surfaces or wings of larger aircraft, the help of boundary layer suction is needed to obtain laminar flow.

2 Hybrid laminar flow control

To realize laminar flow control, suction can be applied over the whole wing surface, as for the X21 research aircraft [7, p. 110]. However, today's preferred solution is the application of suction at the leading edge before the front spar so that the space in the wing box can be reserved for fuel storage. Behind the front spar, laminarity is then sustained by shaping. This combination of active laminar flow control before the front spar and passive laminarity behind it is called Hybrid Laminar Flow Control (HLFC).

Fig. 3 HLFC system on A320 fin

The principal feasibility of HLFC for large transport aircraft was shown by NASA/Boeing with an HLFC system on the wing of a B757 aircraft [7, p. 118] and by Airbus with the fight tests of an HLFC system on the vertical tail plane of an A320 aircraft [7, p. 118], [8]. The suction systems for those tests were designed to explore the limits of HLFC and, thus, were rather complex as can be seen from Figure 3. With this complex system, we could vary the suction distribution over a wide range to explore the envelope of applicability of HLFC. After having shown that HLFC does deliver the aerodynamic results, we will have to continue to develop simpler and lighter systems to obtain the overall benefit for the aircraft. A major step was the simplified suction system developed within the European ALTTA project [9] shown in Figure 4. This system works without the complex structure of classical systems and is currently being refined within the German national project HIGHER-LE.

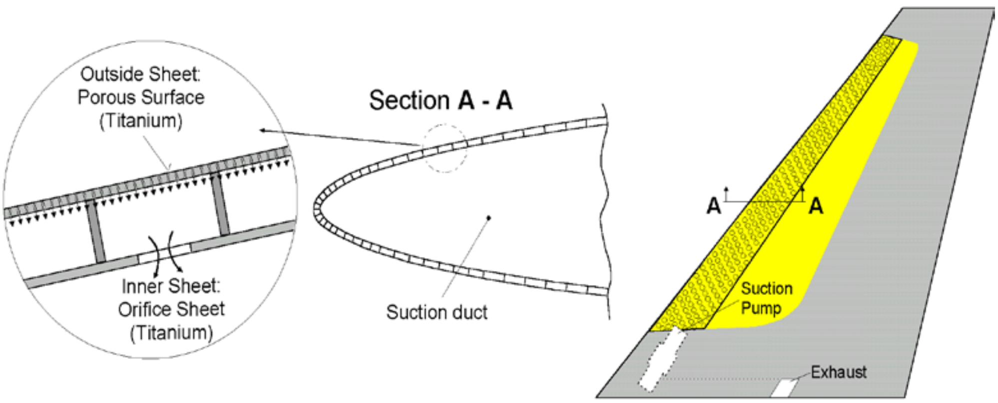

Fig. 4 Sketch of the ALTTA simplified system

3 Future large-scale hybrid laminar flow tests

Having improved the concept of simplified suction, we plan to test a full-sized simplified system in the DNW LLF wind tunnel [10] early in 2014. The main purpose of this test is not aerodynamics, but the validation of the simplified suction system. Emphasis is on minimizing the energy needs and setting up a manufacturing chain for a flight test article which will be used within the AFLoNext project [11].

Having demonstrated a simplified system in the wind tunnel, we will have to validate the system with flight tests. This should be done on the vertical tail plane (VTP) of an A320 so that it can be based on work of the ALTTA and HIGHE-LE projects and on the previous flight test with the A320 HLFC fin. In contrast to the earlier flight test of the 1990s, we plan for a smaller system in which we will replace only the middle leading-edge box of the VTP with a suction system as shown in Figure 5. We will aim for a passive suction system which is driven by the pressure differences occurring naturally on the aircraft [12], [13] so that we do not need a compressor.

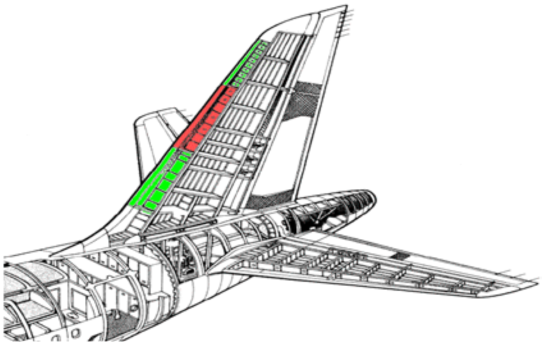

Figure 5: Sketch of the A320 tail with the middle leading edge box taken from [9]

Replacing only the middle box with an HLFC system has several advantages:

- The small system is cost efficient and can be realized with a smaller budget.
- The small system has a minimized impact on the aircraft and is easier to install.
- For later use of an active system, we can place the compressor in the dorsal fairing.

With such a system we plan two flight test campaigns. The first one within AFLoNext will allow for a full assessment of the simplified system. These tests will be performed with extensive measuring equipment: pressure distributions, transition detection with infrared thermography, control of the status of the attachment line boundary layer with hot films, as well as equipment for pressure, temperature, and humidity measurements of the air of the suction chambers and in the suction duct. A second campaign in a follow-on project (possibly within CleanSky II) should last for a longer time period to allow us obtain operational experience. For this, we propose a reduced measuring effort with a fully automated data acquisition system which could be placed in the dorsal fin. We then could retrieve the data after landing using remote wireless technology.

Boeing carried out a flight test with an HLFC system on the VTP of a B787-8 in June 2012 [14]. The HLFC system was tested on the VTP because as they determined, “it is most practical” there [14]. An image of the installed HLFC system can be accessed at www.flightglobal.com. The link is given under [15].

Along with the flight tests on the fin, we need to advance a simplified HLFC technology for the leading edge of a wing. This more difficult, because the HLFC system has to share its space with the high-lift and the ice protection system, which is a major challenge. A first step will be carried out with a manufacturing demonstrator which will be built within AFLoNext. To further advance the technology, we need a large full-scale ground demonstrator for a wing segment equipped with all of the necessary systems. Such a demonstrator should be realized as follow-on activity within a larger demonstration platform of CleanSky II. With this path we will be able to mature the HLFC technology within this decade.

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