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Review of hybrid laminar flow control systems

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ABSTRACT

The aeronautic community always strived for fuel efficient aircraft and presently, the need for ecofriendly aircraft is even more, especially with the tremendous growth of air traffic and growing environmental concerns. Some of the important drivers for such interests include high fuel prices, less emissions requirements, need for more environment friendly aircraft to lessen the global warming effects. Hybrid laminar flow control (HLFC) technology is promising and offers possibility to achieve these goals. This technology was researched for decades for its application in transport aircraft, and it has achieved a new level of maturity towards integration and safety and maintenance aspects. This paper aims to give an overview of HLFC systems research and associated flight tests in the past years both in the US and in Europe. The review makes it possible to distinguish between the successful approaches and the less successful or outdated approaches in HLFC research. Furthermore, the technology status shall try to produce first estimations regarding the mass, power consumption and performance of HLFC systems as well as estimations regarding maintenance requirements and possible subsystem definitions.

1. Introduction

Aircraft manufacturers as well as research organisations try to reduce the fuel burn of aircrafts for many years and the ambitious environmental goals of ACARE's Vision 2020 and Flightpath 2050 lead to an even higher focus on the efficiency of aircraft. There are different ways to reduce the fuel burn and thus the emission of carbon dioxide and nitrogen oxides of aircraft like new engine technology, improved system integration as well as improved aerodynamics. Flow control by means of keeping the flow laminar over wetted surfaces as long as possible during cruise is one way of reducing the overall fuel burn. The laminar flow control technology for aircraft was first experimentally tested in wind tunnels in the late 1930s in the US [1]. The research activities in the US as well as in Europe continued until the early 1960s when the interest in this topic decreased. Due to the oil embargo by the OPEC in the 1970s and the resulting rapid increase of fuel prices, the research on laminar flow control system was revived. New technology led to significant achievements during wind tunnel and flight experiments but still major manufacturing issues and other operational obstacles prohibited an economic installation of the fuel saving technology on new aircraft [2].

Flow control is defined by Liddle [3] as the modification of local flow parameters without external geometric change. High-lift systems are therefore not considered as flow control since the geometry is changed when the systems are deployed to increase wing area and camber resulting in a higher lift coefficient as well as maximum angles of attack. Flow control can be divided into Laminar Flow (Control) and Turbulence Manipulation as depicted in Fig. 1. Turbulence Manipulation can be further divided into Active Flow Separation Control by means of actuators (AFSC) and Passive Turbulent Flow Control. Passive Turbulent Flow Control devices are mainly applied to reduce the skin-friction drag of turbulent flows by energising the boundary layer. Examples for this kind of flow control are riblets and vortex generators. With AFSC it is tried to control the boundary layer development and to delay separation effects to enhance control surface effectiveness for flaps, rudders and elevators to name only a few [4]. An enhanced rudder efficiency (e.g. through higher deflection angles without separation) can lead to a decreased wetted area of the vertical tail plane which results in reduced skin friction drag during all flight phases. Since a failure of such an AFSC system applied to a smaller sized rudder may be catastrophic for the design condition (one engine inoperative at low speeds), stringent reliability requirements must be met.

Laminar Flow systems aim at delaying the transition from laminar to turbulent airflow over wings, tail planes or nacelles as far aft as possible to reduce the overall aircraft drag. It can be divided into full Laminar Flow Control (LFC), Natural Laminar Flow (NLF) and Hybrid Laminar Flow Control (HLFC) as a combination of the first two methods. HLFC combines a moderate amount of suction at the leading edge with a following suitable pressure gradient. This reduces the overall complexity

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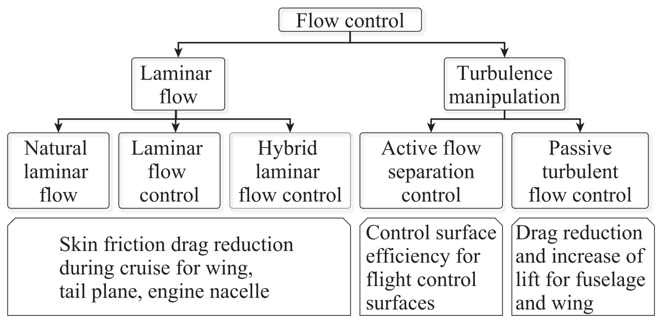

Fig. 1. Different types of Flow Control applications.

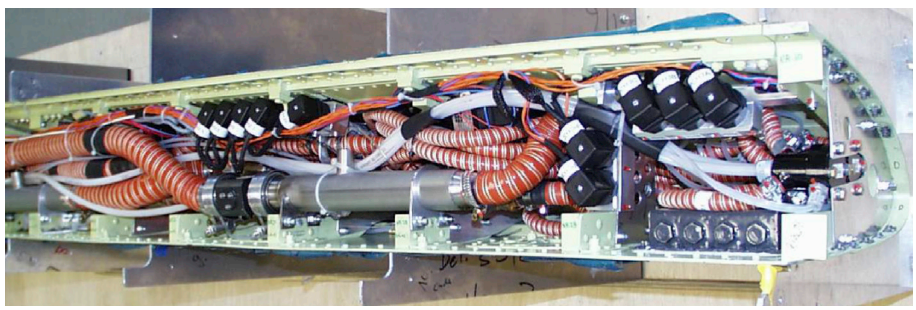

Fig. 2. Leading edge of the Do 228 test aircraft equipped for HLFC flight test [83].

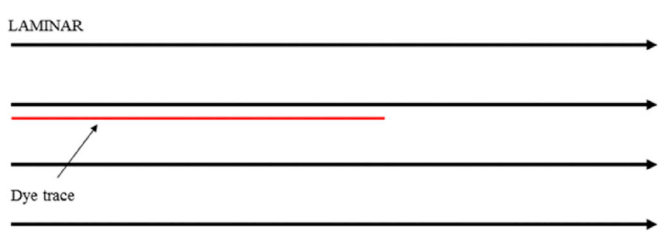

Fig. 3. Dye trace in laminar flow [82].

and weight of the suction system and does not interfere with the main part of the wing. Nevertheless, it requires a suitable shape of the succeeding main wing geometry which might have to be reworked for retrofit applications.

Henke [5] points out, that the development of an HLFC system is a highly interdisciplinary task. For the A320 fin flight test performed in 1998, four different groups were identified: The aerodynamics group will specify the suction distribution. The system and structure groups will then have to develop hardware to achieve the requirements from the aerodynamics and, finally, the flight test preparation group has to integrate the developed hardware for the flight test. If a group has to modify something, this has an effect on the other groups. If the system is applied to the leading edge of a wing, it even needs to share the space with the leading edge part of the high-lift system or the ice protection system resulting in increased complexity and the participation of even more disciplines. The limited space is depicted in Fig. 2, where the suction system and instrumentation for the flight test of the Do 228 test vehicle is shown (although more complex than necessary due to the testing of different anti-contamination devices as well as different ice protection systems). In section 2, the research methodology is explained, section 3 explains the fundamental aerodynamics behind laminar flow control systems, section 4 gives overview of the HLFC system design and issues, and section 5 covers the progress made so far with emphasis on various analytical studies and flight tests that have been performed throughout the World.

2. Research methodology

The starting point of the literature research was the literature provided by the predecessors on the topic. Further literature was found based on the referenced sources as well as literature which referenced the already available sources using google scholar and google search. The key words “Hybrid Laminar flow control” and “laminar flow control” were utilized in the search engine. Further research papers regarding the particular topic were found, once research institutions and researchers focusing on specific tasks in the development of HLFC systems were identified. Research projects were identified through the acknowledgements in papers as well as through current project proposals mentioning other projects. For the US projects, the document server from NASA was searched regarding relevant documentation.

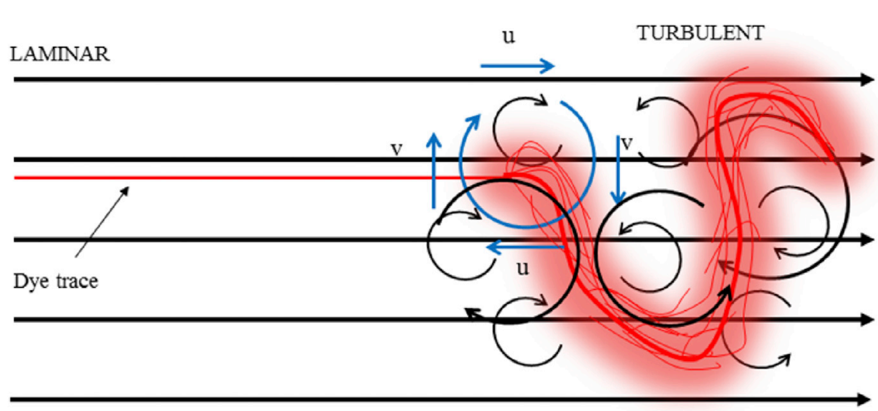

Fig. 4. Dye trace in turbulent flow [82].