CONTROL OF FLOW SEPARATION FOR FIXED WING AIRFOIL APPLICATIONS*

Avraham Seifert
Associate Professor of Mechanical Engineering, School of Mechanical Engineering Tel-Aviv University, Tel-Aviv Israel

Carl P. Tilmann
Senior Technical Advisor, Aerodynamic Configuration Branch
Air Force Research Laboratory, Wright-Patterson AFB, Dayton, Ohio

I. Overview

The purpose of this chapter is to provide a summary of the past, present and future airfoil boundary layer separation control studies as an example of active flow control application. The practical importance of boundary layer separation control has been identified already by Prandtl (1904), when he introduced the boundary layer concept and characterized its failure, i.e., separation. Avoiding boundary layer separation would bring us closer to the ideal flow conditions with enhanced system performance at lower energetic cost. Boundary layer separation control heavily relies on the performance of flow control actuators and sensors, which are reviewed in another lecture in this course.

Preliminary-pioneering separation control efforts will be reviewed first. These will include shear-layer and airfoil transition and separation control studies. The state-of-the-art in airfoil separation control will then be critically reviewed. This will lead to recommendations of required progress that has to be made in order to explore the great potential of active separation control as an enabling technology for future aeronautical, transportation, and many other fluid related systems.

The first system study to consider the application of unsteady active flow control (AFC) for transport aircraft was conducted in the late 90's by Mclean et al. (1999). They considered multiple applications of AFC and concluded that simplifying the high-lift system, while maintaining $C_{l,max}$, is the most promising application. It could lead to lower part count, lighter structure, cost reduction and most importantly (current authors' interpretation) to 1-2% cruise drag reduction due to the elimination of all external flap positioning actuators. These benefits could result from effective and robust boundary layer separation control. However, a decade later, its conclusions are far from being realized. Why? Two main reasons can be identified. First, the investigators linearly extrapolated from existing low Reynolds number results both to high Re and to higher flap deflections with linearly increasing lift increment, with respect to what is known from uncontrolled deflected flap data. Second, at the time, published work did not include a CFD design tool as an enabling technology, so ad-hock assumptions had to be made. Until a computational design tool for unsteady boundary layer separation control would become available, flow control would largely remain an art. Hopefully, once such a tool is available the artistic magic would not disappear, since this complex field of study requires immense innovation.

II. History and Background

While Chapters 1 and 2 have thoroughly described the physics and provided a comprehensive introduction to AFC; here, we briefly highlight key aspects of history related to fixed wing separation control.

Boundary layer control (BLC) research dates back to the turn of the 20th century, when Prandtl (1904) introduced the concept of the boundary layer, its failure (i.e. separation), and a possible remedy (e.g., removal of the near wall fluid by slot suction). Half a century passed before Schubauer and Klebanoff (1956) conducted the first active flow control experiment when they artificially triggered Tollmien-Schubauer waves in a laminar boundary layer. An additional 20 years passed before – in the mid 1960's – Collins and Zelenevitz (1975) conducted the first separation control experiment, using boundary layer transition promotion by sound emanating from the tunnel walls that eventually lead to separation control.

In the above mentioned and other subsequent studies, transition promotion and separation control were mixed. Moreover, a limited range of Reynolds numbers was investigated. The airfoil experiments of Seifert et al. (1996) and Seifert and Pack (1999) resolved the frequency scaling issue and demonstrated the active boundary layer separation control technology at chord Reynolds numbers ranging from 100,000 to 30,000,000. The wall mounted hump experiments by Seifert and Pack (2002) demonstrated the validity of previous findings related to frequency scaling in a fully turbulent environment and provided benchmark data for CFD validation. The above fundamental experiments paved the way to many studies aimed at applying the knowledge to specific geometries, on the way to making this technology useful for real-world applications.