1-1-2020

Circulation Control Optimization Using Geometric Programming

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Previous participation in RCEU: Yes

Project Summary: The research goal is to formulate the conceptual-stage of an adaptive circulation control elevon (AC^2E) design problem as a geometric program (GP), which is a specific type of convex optimization problem. This research work will explore the capability of AC^2E's to act as active flow control (AFC) devices, based on the application and manipulation of Coanda flows, on a delta wing platform aiming to reduce in size or eliminate conventional control surfaces on-board.

Developing systems that have adequate control authority to trim, maneuver and improve takeoff and landing performance without the need of conventional control surfaces is of major importance in military aviation today. Due to the increasingly sophisticated threat environments that military aircraft need to operate, high maneuverability and aerodynamic performance is required to enhance the survivability of fighter aircraft. Delta wing geometry is a popular configuration in military aviation due to its aerodynamic performance and maneuverability at high speed flights. Although delta wing platforms are designed for high speed flights, they still have to operate at low speeds and high angles of attack (takeoff and landing), where the flow may become partially or fully separated, which may lead to stall. The flow field around a delta wing aircraft is often highly unsteady and this control method may significantly lose its control authority in separated or partially separated flow conditions. On the other hand, AFC techniques have shown promising potential for lift enhancement and maintaining control authority under separated flow conditions.

Although AFC is regarded as the revolution that aerodynamics was waiting for, for a long time, and despite the fact that it is a well-proven method for enhanced lift and control surface performance, there are still challenges (mass flow requirements, wing complexity etc.) to overcome in order to achieve an effective and operating AFC system. Circulation Control (CC) keeps the boundary layer jet attached to the wing surface for longer compared to a conventional wing and thus increases the lift generated on the wing surface (Fig. 1). Attempts and methods to determine and control separation regions are present in literature. However, the ability to accurately determine specific regions and control separation and/or supercirculation while reducing the mass flow rate requirement will introduce a novel approach on AFC systems' implementation.

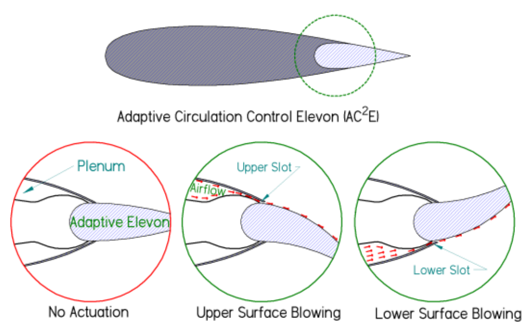

Fig. 1: Conceptual design of the Adaptive Circulation Control Elevon.

Convex optimization, which offers significant advantages over nonlinear optimization methods typically used in aircraft design, will be used to derive a mathematical model in order to minimize the required mass flow rate for efficient CC. GP is a mathematical method, which can efficiently optimize large sets of equations with a large number of variables using characteristics of arithmetic and geometric averages. It is a convex optimization framework that enables rapid design re-optimization over a broad mission space. Signomial programming, which is a useful extension of geometric programming, includes constraints that cannot otherwise be formulated as a GP will also be used in this project. Results from the developed mathematical model will be compared with computational fluid dynamics (CFD) simulations for model validation and verification.

The RCEU student's tasks in the project include:

i.) Develop a mathematical model for CC optimization.

ii.) Design and run simulations using Ansys Fluent.

iii.) Validate and verify the optimized model using computational data.

Student Prerequisites

The student will be required to have the following skills: i) Strong background in Aerodynamics and Mathematics; ii) Good understanding of AFC methods; iii) Programming skills: MATLAB and Python iv) Experience with Ansys Fluent and XFLR5; v) Experience with writing technical reports; v) A minimum GPA of 3.6 is required.

Student Duties & Deliverable

The project will require an extensive computational and analytical effort but also the archiving of results in a formal manner. The student will present current results and report progress on a weekly basis. A final report will be submitted during the ~12th week and evaluated by the mentor. The student can also have the opportunity to present the findings in UAH seminars for undergraduate research or national symposiums/conferences. A tentative timeline for 12 weeks is as follows:

Week 1-2: Study the literature
Weeks 3: Identify the design parameters and set performance goals
Weeks 4-5: System definition and modeling
Weeks 6-7: System analysis and data collection using Ansys.
Weeks 8-10: Compare results and if the performance meets the specifications, then finalize the design
Weeks 11-12: Analysis and documentation of the results including a poster.

Mentor Supervision and Interaction

During the summer semester, the mentor spends the majority of his time working in the lab and assist students during experiments. Thus, the mentor will have regular interactions with the RCEU student. The student will also have daily interactions with the three graduate students who work and conduct research in the labs. Direct supervision, mentoring, and evaluation of the project by the mentor will occur weekly at regularly scheduled project meetings. In the weekly meetings the current status of the project, recent results, difficulties encountered, next steps, and address any other issues that may come up will be discussed.