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Multi-winglet Optimization using Geometric Programming

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Project Summary: The goal of the proposed research is to formulate the conceptual-stage of a multi-winglet design problem as a geometric program, which is a specific type of convex optimization problem. 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 induced drag of a multi-winglet design.

Since the early days of aviation, fuel reduction has always been a major goal of aircraft design engineers. This target can be achieved by reducing drag during flight. Significant and directly linked to the production of lift, is the induced drag component, which accounts for roughly 40% of the total drag during cruise and constitutes 80% of total drag during the takeoff and landing phases of flight. Conventional winglets are static aerodynamic devices with optimized shapes that introduce significant loads onto the main wing structure that may diminish aerodynamic optimization. On the other hand, adaptive multi-winglets (Fig. 1), where the geometry can be adjusted real-time to the changing flow conditions, have the potential to improve the aerodynamic performance during climb and/or high-speed off-design conditions by providing *adapted* wing lift distribution throughout the flight envelope.

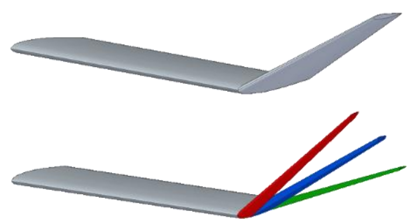

Fig. 1: Top: Single winglet. Bottom: Multi-Winglet – Isometric View.

Developing an optimization analysis based on the reduction of induced drag is a challenging task due to the number of geometric parameters involved with the design of a winglet (e.g. cant angle, sweep angle, span, twist angle, etc.). Vortex lattice, or one-at-a-time sensitivity analysis, methods that were used in the past to search for a low-induced-drag design do not provide always the optimum solution [1]. It is expected that this problem can be addressed by using a form of convex optimization called geometric programming. This type of optimization is chosen due to its lack of convergence loops and lack of a need to tune the model when given new constraints. Applied mathematicians have transformed convex optimization from a specialized research discipline into the realm of a technology and similar to least-squares problems or linear programs; solving standard classes of convex optimization problems is a straightforward task for modern solvers [2].

The technique of geometric programming will require an understanding of constraints and how to relax those constraints to posynomial inequalities. It will also be necessary to understand signomial equalities and how they apply to the constraints of a geometric program. This will all take place in a Python development environment using the GPkit library. Results from the developed model will be compared with computational fluid dynamics (CFD) simulations in Ansys Fluent for model validation and verification.

References

[1]. Jean-Jacques Chattot, *"Low Speed Design and Analysis of Wing/Winglet Combinations Including Viscous Effects" Journal of Aircraft, 2006.*

[2]. Warren Hoburg and Pieter Abbeel, *"Geometric Programming for Aircraft Design Optimization" Journal of Aircraft, 2014.*

The RCEU student's tasks in the project include:

i.) Prepare a literature review on the subject

ii.) Define the design parameters for optimization

iii.) Develop a mathematical model for minimized induced drag.

iv.) Run CFD analysis for the qualified winglet design to validate the analytical solution.

Student Prerequisites

The student will be required to have the following skills: i) Strong background in Aerodynamics and Mathematics; ii) Programming skills: experience with MATLAB, Python and Ansys Fluent; iv) 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 will 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 lab. 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.