Effects of Leading Edge Vortex Flaps on Delta-type Highly-flexible Wings

PROPOSAL

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Introduction

On August 13, 2001, an unmanned aerial vehicle (UAV) named Helios achieved a world altitude record for sustained horizontal flight of 96,863 feet. Not long afterwards, Helios experienced catastrophic structural failure when it encountered low altitude turbulence that induced pitch instability[5]. Designed by Aerovironment, Helios was built around the requirements for flight at high altitude necessitating an extremely light structure. Unfortunately, this compromised its ability to withstand the stress of high freestream turbulence caused by weather at lower altitudes. As UAVs continually take on new roles, their design faces the challenge of satisfying mission imposed constraints while maintaining well balanced flight characteristics across multiple flight regimes.

Such challenges are even more evident in the area of small UAVs, a class of UAV that is currently experiencing wide growth in mission capability and potential application. Successfully used by ground troops to perform localized reconnaissance, small sized UAVs have now found application in roles as varied as agriculture and firefighting. The primary benefit offered by a small UAV is that it can be easily packed, transported, and deployed in a time sensitive manner without extensive ground support. Portability has been achieved by either making the UAV extremely small, such as quad-copters, or by conventional winged vehicles that can be disassembled and packed. In general, the payload capacity of these types is limited. The challenge lies in achieving an easily packable design capable of carrying a useful payload while successfully performing its mission in varying flight conditions.

A unique design concept exists that would fulfill the need for an easily packable UAV as well as offer an alternative solution to several design challenges that hinder the expansion of UAV roles at high altitudes. It has been proposed to design a foldable wing of delta planform made of highly flexible material such as Polyimide film (Figure 1). The primary advantage of a highly flexible delta wing is that it naturally lends itself to a variety of packing options while maintaining light weight and durability. Such a wing is uniquely suitable to a portable UAV design because the delta shape allows for a system of folding spars hinged at a single fuselage location. This could be applied to several of the portability and deployment challenges facing UAVs, including high altitude long endurance (HALE) class vehicles, rendering some unique solutions. Specifically, a UAV employing this type of wing has the potential to be air-dropped by another aircraft or balloon, and possibly boosted to operating altitude on a rocket. In the case of HALE vehicle operations such as Helios, these deployment methods could provide the capability to avoid much of the atmospheric turbulence that often compromises their light structures.

Objective

Several key obstacles stand in the way of implementing a flexible delta wing design. The most significant obstacle is that, at low speeds, delta wings generally have poor lift and drag aerodynamic characteristics compared to higher aspect ratio wings. The maximum lift-to-drag ratio, also known as aerodynamic efficiency, is much lower than that of conventional wings. This is of critical importance in performance terms since the range of a propeller driven aircraft (typical of UAVs) is directly proportional to its maximum lift-to-drag ratio[2]. Additionally, with the current wing design focused on efficient packing and deployment, the trailing edge of a flexible wing is not suitable for conventional control surfaces. In order to further improve this wing design, enhancements to the aerodynamic and control issues must be addressed.

A solution exits in the form of leading edge vortex flaps (LEVF). LEVF devices have been shown to improve slender delta wing aerodynamic characteristics by reducing drag and increasing the maximum lift-to-drag ratio[6]. Slender delta wing aerodynamics are dominated by a strong vortex pattern that occurs near the wings leading edge. The net effect of this vortex is to create a region of suction on the wings upper surface that increases drag as well as lift. LEVF devices have the ability to position the leading edge vortex such that the force vector due to suction is tilted forward in the direction of flight, adding a thrust component and effectively reducing drag. A LEVF system consisting of single or possibly multiple element(s) could be used to increase the lift-to-drag ratio by as much as twenty percent[1].

There is also potential to utilized LEVF devices to provide longitudinal and lateral control in the absence of conventional control surfaces. This configuration would facilitate the flexible wing concept, keeping control actuators and support structure localized along the leading edge while allowing the wing to neatly fold back along the fuselage. Although an initial study has recently been conducted on the aerodynamic properties of highly flexible delta wings, there currently lacks supportive computational and experimental data, investigating the aerodynamic enhancements of LEVF devices on slender and non-slender flexible delta-type wings[7]. This lack poses a significant obstacle to implementing the proposed design concept.

The proposed research is to determine the effects of leading edge vortex flaps on slender and non-slender delta-type highly-flexible wings. The primary objectives are as follows:

a) Measure changes in aerodynamic and stability performance characteristics generated by leading edge vortex flaps in various leading edge sweep configurations.
b) Determine the potential for using LEVF devices as a method of flight control.

Using results found in a previous study as a starting point, this research would focus on generating data that documents the effects of LEVF devices on slender and non-slender delta-type highly-flexible wings. Its ultimate goal is to propose an LEVF design that could potentially address both the aerodynamic and control challenges facing the foldable delta wing concept.

Methodology

In order to design an LEVF device that effectively improves the performance of a flexible delta-type wing, it is essential to understand how lift, drag, and pitching moment vary with flap deflection angle, chord length, and leading edge radius.

The research activities will consist of three phases. Phase 1 will involve investigating LEVF configurations using computational fluid dynamics (CFD) software. Design variables will include flap cross sectional shape, length, gap, and leading edge radius. Each configuration will be compared based on changes in lift-to-drag ratio. A secondary aspect of the CFD simulation will be focused on understanding the relationship between leading edge vortex location, flap deflection, and maximum lift-to-drag ratio obtained for each configuration.

In phase 2, the CFD data will be analyzed with the objective of down selecting the most promising design concept for experimental testing. Once the design is selected, a wind tunnel model will be built and preparations will be made for experimental testing.

Phase 3 will consist of gathering experimental data by testing the model in a subsonic wind tunnel. Aerodynamic and stability data will be tabulated and compared to the CFD predictions. This phase will also focus on determining the suitability of the LEVF design as a flight control surface. Investigations will include longitudinal and lateral controllability effects of LEVF devices as the combination of a flap and aileron. A detailed project timeline is given in Figure 2.

Expected Results

Previous research on a slender, highly flexible sixty degree delta wing showed that a maximum lift coefficient on the order of 1.3 and a maximum lift-to-drag ratio on the order of fourteen are attainable[7]. It is projected that gains of up to twenty percent in maximum lift-to-drag ratio can be achieved by incorporating LEVF devices. As state above, range is directly proportional maximum lift-to-drag ratio. Consequently, range could potentially be improved by the same factor. If LEVF devices can provide the projected improvements in aerodynamic performance and control, the flexible delta wing concept could find multiple applications such as increasing the altitude capability of HALE class UAVs and further improving the ease of packaging and deployment for small UAVs performing localized reconnaissance.

Personal Statement

The author is currently a junior at The Ohio State University pursuing a bachelor's degree in Aerospace Engineering and a minor in Computer and Information Science. His relevant course work has included study of aerodynamics, flight vehicle dynamics and control, flight vehicle structures, and numerical methods. A dean's list student, he has been an active member of the OSU student Design/Build/Fly team and was leader of a student group that successfully presented a poster at the ASEE (American Society for Engineering Education) North Central Section Conference in April of 2013. His interest in performing this research stems from a desire to gain practical experience in applied aerodynamics as well as a deeper understanding of computational methods. The knowledge gained from this project will provide an excellent foundation from which to purse his goal of a career in experimental aircraft design.

Figure 1: Flexible Wing Model in OSU 3'x5' Subsonic Wind Tunnel

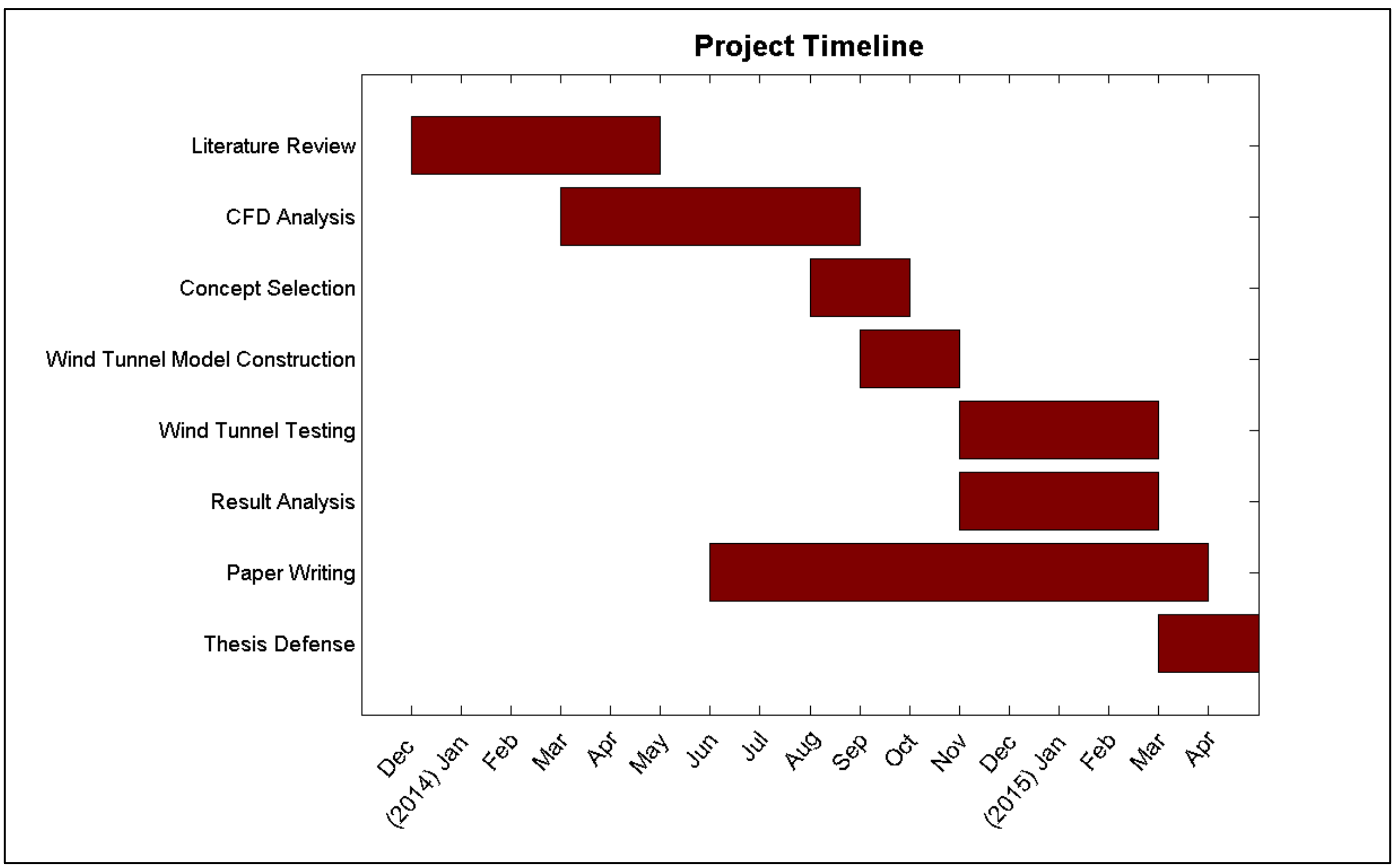

Figure 2: Project Timeline

Bibliography

1. Anderson, John D., Jr. “Fundamentals of Aerodynamics.” 5th ed. New York: McGraw-Hill, 2011.

2. Anderson, John David., Jr. “Introduction to Flight.” 7th ed. New York: McGraw Hill, 2012.

3. Brandon, Jay M., James B. Hallissy, Philip W. Brown, and John E. Lamar. “In-Flight Flow Visualization Results of the F-106B with a Vortex Flap.” Rep. Hampton: NASA Langley Research Center, 2003.

4. Hu, B. K., and J. L. Stollery. “The Performance of 60° Delta Wings: The Effects of Leading Edge Radius on Vortex Flaps and the Wing.” Rep. no. 9004. Cranfield, England: Department of Aerodynamics, College of Aeronautics, Cranfield Institute of Technology, 1990.

5. Noll, Thomas E., John M. Brown, Marla E. Perez-Davis, Stephen D. Ishmael, Geary C. Tiffany, and Matthew Gaier. “Investigation of the Helios Prototype Aircraft Mishap.” Rep. Vol. 1. N.p.: n.p., 2004. Mishap Report. 64317main_helios. NASA, 11 Apr. 2005. Web. 13 Feb. 2014.

6. Rinoie, K., and J. L. Stollery. “Experimental Studies of Vortex Flaps and Vortex Plates Part 1 0.53m Delta Wing.” Tech. no. 9133. Cranfield, England: Department of Aerodynamics, College of Aeronautics, Cranfield Institute of Technology, 1991.

7. Whitfield, C.A., Warchol, M. “Flight Performance Characteristics of Highly Flexible Wing Rogallo-type Aerodynamics with Applications to UAVs.” AIAA Dayton-Cincinnati Aerospace Sciences Symposium, 1-March 2011.