

Development of a Mid-Fidelity Aerodynamics Model of a Blown Wing

September 28, 2018

1 Project Purpose

The purpose of this project is to develop a computationally cheaper model for the aerodynamics of propeller-on-wing interactions.

2 Project Importance

In the last few years, the technology front has witnessed the increasing popularity of electric aircraft utilizing distributed propulsion, enabling electric vertical takeoff and landing, or eVTOL. The X-57 Maxwell, illustrated in Fig. 1, is an eVTOL concept currently under development at NASA. Such aircraft are being considered for use as air taxis, urban commuter aircraft, and personal transport. While single propeller-on-wing interactions have been modeled successfully, the emergence of eVTOL designs make it desirable to model multiple propeller-on-wing interactions for design optimization, as well as single propeller-on-wing interactions in more complex cases. This is due to the fact that distributed propulsion has an aerodynamic effect on lift that is not yet well understood at a fundamental level. Traditionally, aerodynamics have been modeled using computational fluid dynamics (CFD). However, the intense computational cost of CFD makes its use in design optimization impractical. It then becomes desirable to develop less computationally expensive models that can be used in optimization. With such a model, optimization algorithms could be utilized to quickly and effectively realize the dream of commercial-quality eVTOL aircraft.



Figure 1: The Maxwell X-57 eVTOL aircraft currently under development at NASA. Image from nasa.gov, public domain.

3 Project Overview

Computational design optimization is a process that is only as effective as the computer model it uses. In this study, a model will be developed that would run significantly faster than CFD, which is the current model of choice. The model to be attempted will include a three-part process, integrating a 2D strip method, vortex lattice method, and vortex particle method in order to characterize the aerodynamic performance of a blown wing.

3.1 Two-Dimensional Panel Method

After the user defines external flow conditions, the wing is divided into several representative cross sections, or panels. At each cross section, two-dimensional aerodynamic properties are calculated using the code XFOIL. XFOIL is a two-dimensional panel method used to evaluate the flow field over an airfoil, including parameters such as lift, drag, and point of flow separation as a function of angle of attack. At each panel, a sweep of two-dimensional properties at varying angles of attack are calculated and stored as look-up tables to be referenced in later stages.

3.2 Vortex Lattice Method

Simply integrating the results from two-dimensional cross sections does model flow characteristics roughly, but does not account for the change in angle of attack produced by induced drag and a detached wake. In order to adjust for induced drag, traditional 2D strip methods may utilize the Vortex Lattice Method (VLM). A lift distribution is assumed as an initial guess and used to calculate circulation at wing horseshoes, from which the induced angle of attack is computed. The effective angle of attack is determined according to:

$$\alpha_{\text{effective}} = \alpha_{\text{geometric}} - \alpha_{\text{induced}} \quad (1)$$

The effective angle of attack seen at every cross-section is then used to calculate the new local coefficient of lift from the look-up tables generated during pre-processing, constructing a new lift distribution across the wing. The circulation of the VLM is then updated and the process is iterated until convergence is reached. The model's workflow is diagramed in Fig. 2

3.3 Vortex Particle Method

While the VLM addresses the issue of induced drag altering angle of attack, it does not account for flow separation. In this study, a model of flow separation will be explored by building the separation line from points indicated by the 2D Strip Method at each cross section. The detached wake will then be modeled using the viscous Vortex Particle Method (VPM), which solves for the flow field using the vorticity form of the Navier-Stokes equations. The VPM code used in this implementation has been developed by Eduardo Alvarez, a doctoral student at BYU's FLOW Lab[4].

Note that this approach ignores the effects of cross-flow on separation, but significantly simplifies the analysis. Hence, one purpose of this study is to evaluate the accuracy of such a model, specifically to determine its usefulness in design optimization.

3.4 Propeller-on-Wing Interaction

Finally, the model will be adjusted to include interactions with a propeller blowing on the wing. The propeller model developed by Alvarez and Ning[4] will generate the inflow evaluated by the 2D Strip Method.

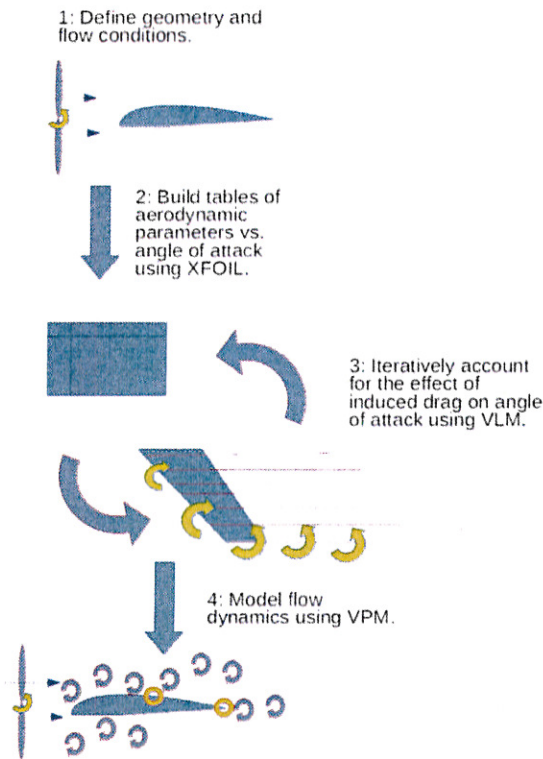


Figure 2: A workflow diagram of the proposed model.

4 Qualifications of Thesis Committee

4.1 Faculty Advisor: Dr. Ning

Dr. Andrew Ning graduated from Stanford University with a Ph.D. in Aeronautics and Astronautics in 2011. He has worked at the National Renewable Energy Laboratory on wind turbine aeroelastic analysis and optimization, and currently does research in aerodynamics optimization of aircraft and wind turbines[1].

I currently work as a research assistant for Dr. Ning in the FLOW lab, am currently taking his aircraft design class, and as a member of his capstone team. This team is to design and build an unmanned airplane for the AUVSI-SUAS competition this year.

My consistent contact with Dr. Ning and his expertise in the field of aerodynamic optimization make him an excellent coach for my honors thesis.

*nice!
good working
relationship
already!*

4.2 Faculty Reader: Dr. Gorrell

Dr. Steven Gorrell worked for eighteen years at the Air Force Research Laboratory Propulsion Directorate. He is an internationally recognized expert in high performance computing, hi-fidelity time-accurate CFD, and Particle Image Velocimetry. He currently uses these methods to study unsteady flow physics in high performance gas turbine engine fans and compressors. [3]. Given his considerable background in researching unsteady flow dynamics, Dr. Gorrell is well-qualified to act as the Faculty Reader of this study.

4.3 Department Honors Coordinator: Dr. Jensen

Dr. Brian Jensen graduated from Brigham Young University with B.S. and M.S. degrees in Mechanical Engineering, and from the University of Michigan with a M.S. degree in Electrical Engineering and Ph.D. in Mechanical Engineering. Since working for more than a year at Sandia National Labs, he has performed research in micro electro-mechanical systems and compliant mechanisms among other topics at BYU[2]. Dr. Jensen's extensive research experience qualify him to evaluate the methodology of my research for this project.

5 Project Timeline

A proposed long-term schedule is included below.

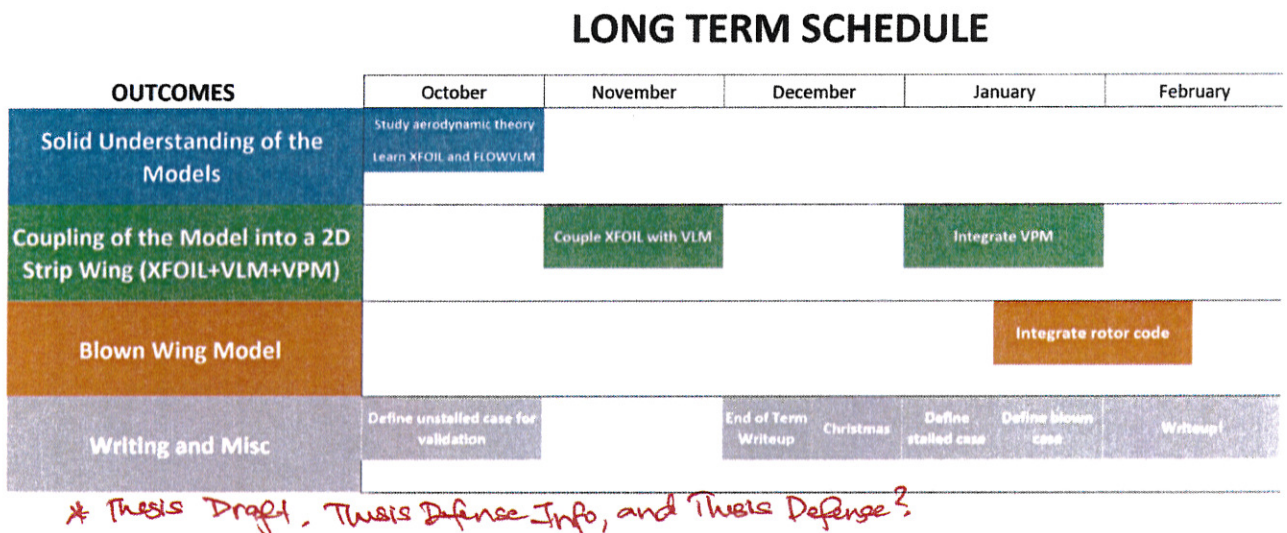


Figure 3: A long term schedule for the research and writing I plan to do.

6 Culminating Experience

I hope to present my findings at the Utah Conference on Undergraduate Research (UCUR) on 22 February 2019. Proposals are accepted through 30 October 2018, which leaves more than sufficient time for some initial research and a satisfactory proposal. Additionally, if the model proves useful enough for design optimization (or another equally fortuitous outcome from my research), I hope to publish a conference paper for the AIAA Aviation 2019.

*has he submitted UCUR proposal?
good.*

7 Conclusion

The advent of new technologies such as eVTOL vehicles is exciting. The development of a fast model of sufficient fidelity is one small step on the road to realizing such concepts by improving the accuracy of design optimization algorithms. If it turns out to be of sufficient fidelity, my proposed model could do just that. If not, it still promises to shed light on the development of such an algorithm. Either way, it will certainly push on the technology front as it moves further towards the future.

8 Acknowledgments

I could not have begun the journey of even proposing this honors thesis without my research mentor and friend, Eduardo Alvarez, whose ideas and understanding made this possible.

References

- [1] Ning, Andrew. Biography. FLOW.byu.edu.
- [2] Jensen, Brian D. Biography. me.byu.edu.
- [3] Gorrell, Steve. Biography. me.byu.edu.
- [4] 1 Alvarez, E. J., and Ning, A., Development of a Vortex Particle Code for the Modeling of Wake Interaction in Distributed Propulsion, 2018, pp. 122.