Aeroelastic Analysis of an Initially-Pitched Wing

Vanessa Diane Gonzalez, Aerospace Engineering

Mentor: Dr. Zahra Sotoudeh

Kellogg Honors College Capstone Project

Abstract

Studies conducted in the early 20th century by Ludwig Prandtl proposed that the most efficient wing design is one in which has an elliptic-span load. Recent studies have reexamined this claim and have proven that a bell-shaped span-load can minimize induced drag and can be more efficient in certain circumstances. This study uses a numerical analysis approach to study the behaviors of a pre-twisted flying wing that was designed with a bell-shaped span load and compares that to different wing configurations. Nonlinear Aeroelastic Trim And Stability of HALE Aircraft (NATASHA) is a finite element computer program that analyzes the aeroelastic behavior of high-altitude, long-endurance (HALE) aircrafts while simultaneously taking into account the pre-twist of the wing in its analysis. An eigenvalue analysis of various wings with and without an initial twist was achieved to study the stability of the wings at numerous flight speeds. These stable and unstable models were then analyzed using a time simulation to study its aeroeleastic behavior.

Scope of the Project

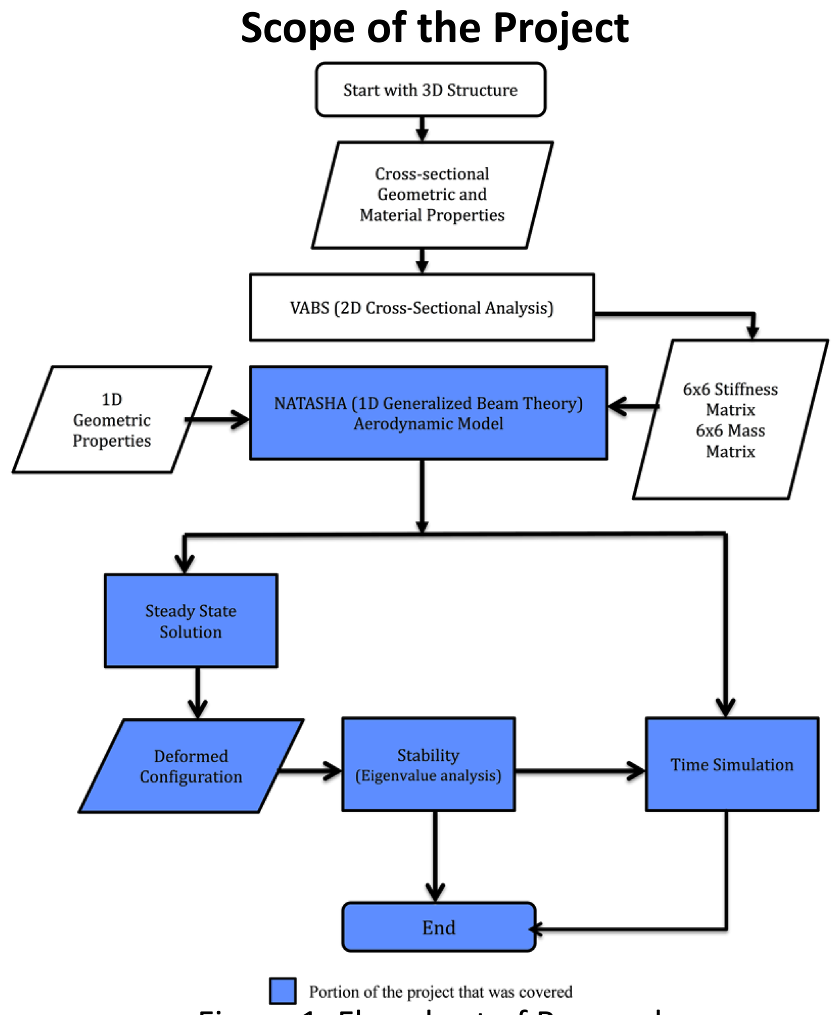


Figure 1: Flowchart of Research

Wings Being Analyzed

Cases
1. Straight swept wing
2. Straight swept wing with twist
3. Tapered wing
4. Tapered wing with twist

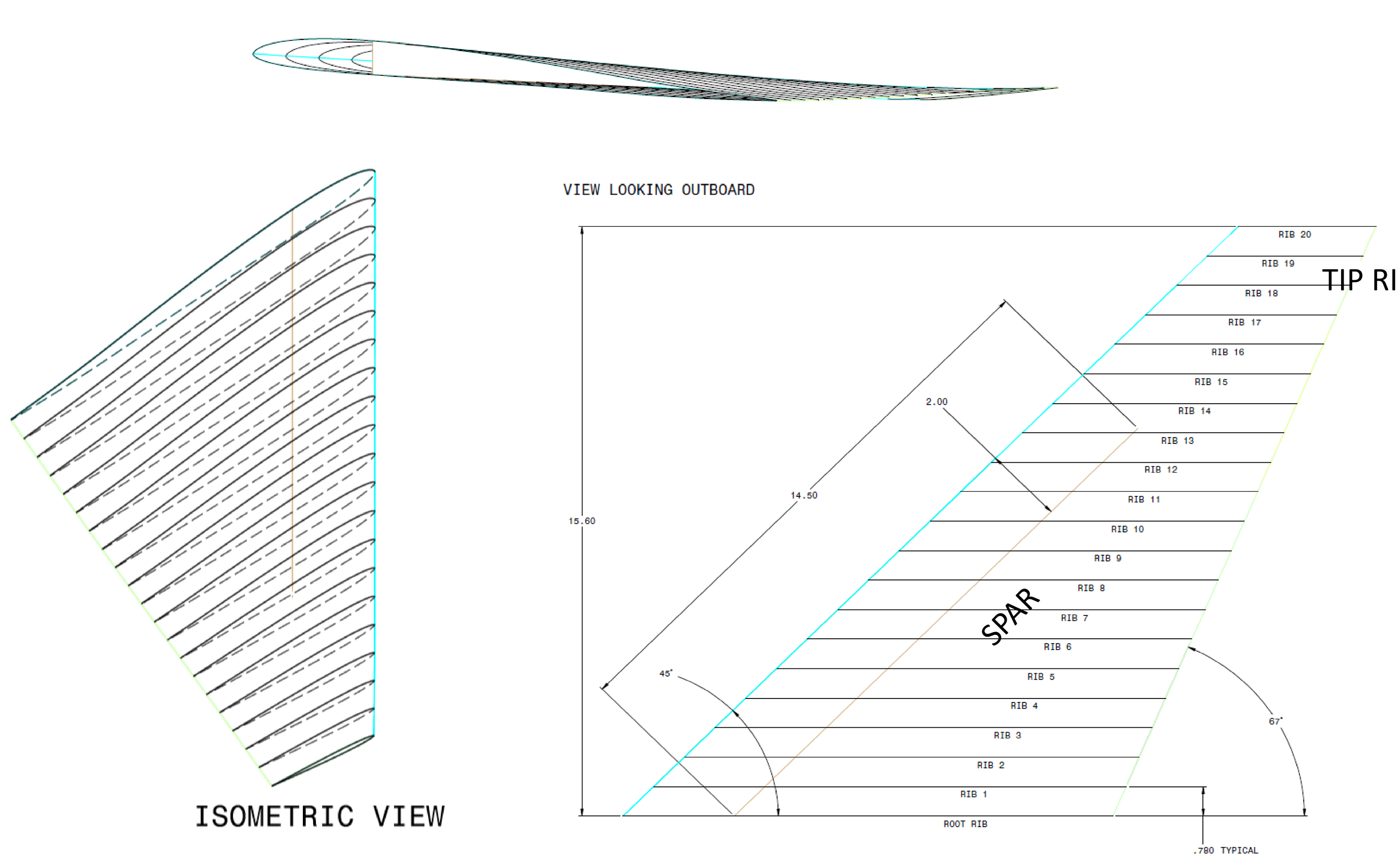


Figure 2: Shows the 3-D, Isometric, and Top View of an Initially-Twisted Tapered Wing.

Eigenvalue Analysis

To be able to find the velocity in which instability occurs for a given case an eigenvalue analysis was performed about the deformed steady-state solution. The eigenvalue analysis can be seen in the Figures 3 & 4. The velocity instabilities for each case are as follows: Case 1: 400 in/s, Case 2: 380 in/s, Case 3: 510 in/s, & Case 4: 550 in/s.

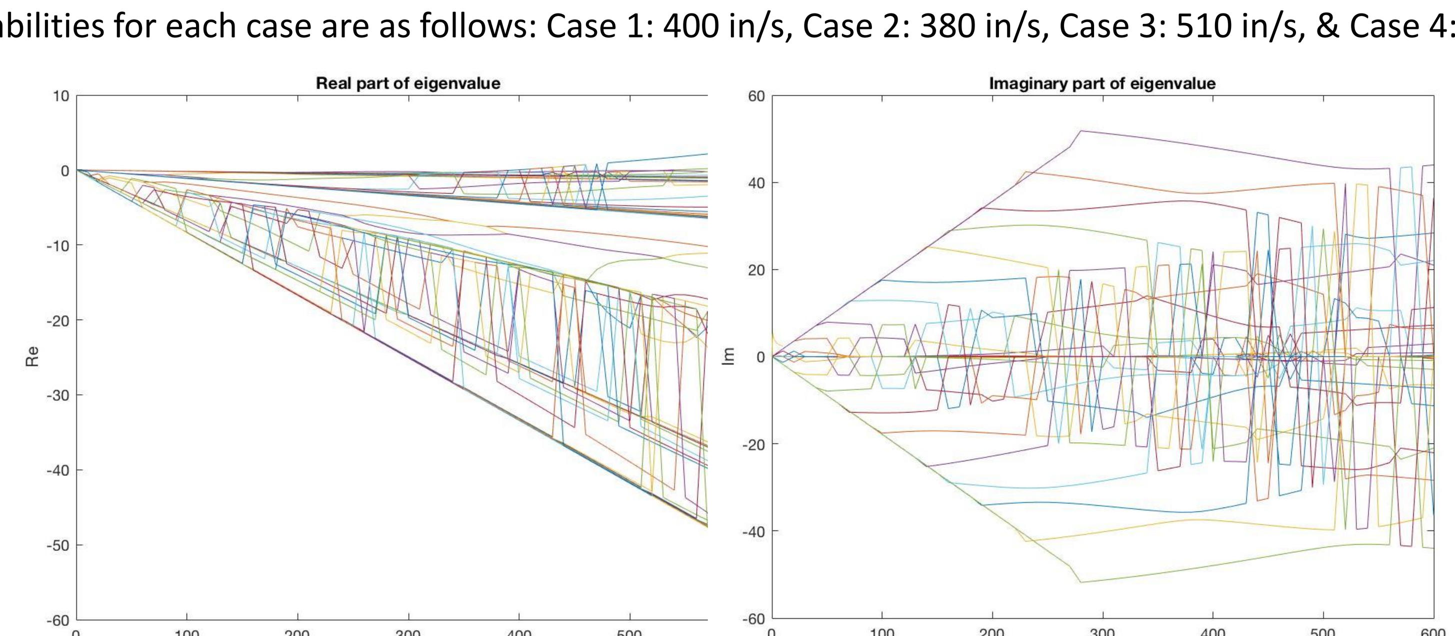


Figure 3: Eigenvalue Analysis for Case 1

Eigenvalue Analysis Cont.

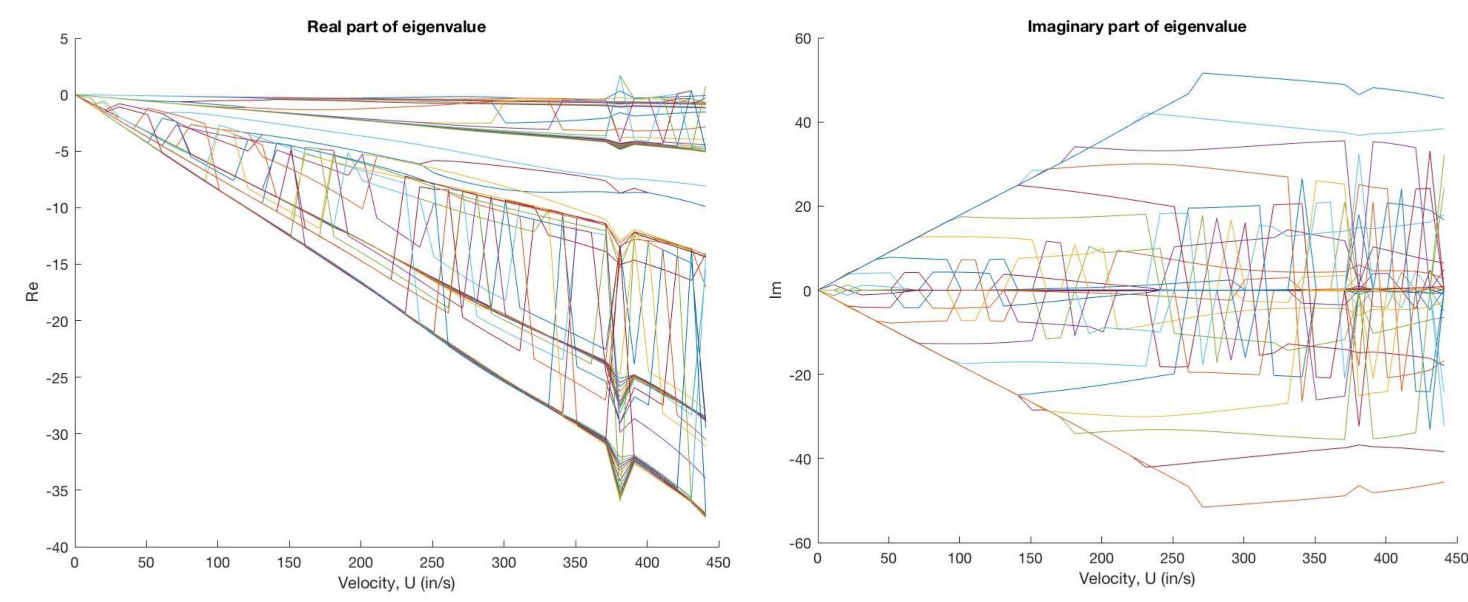
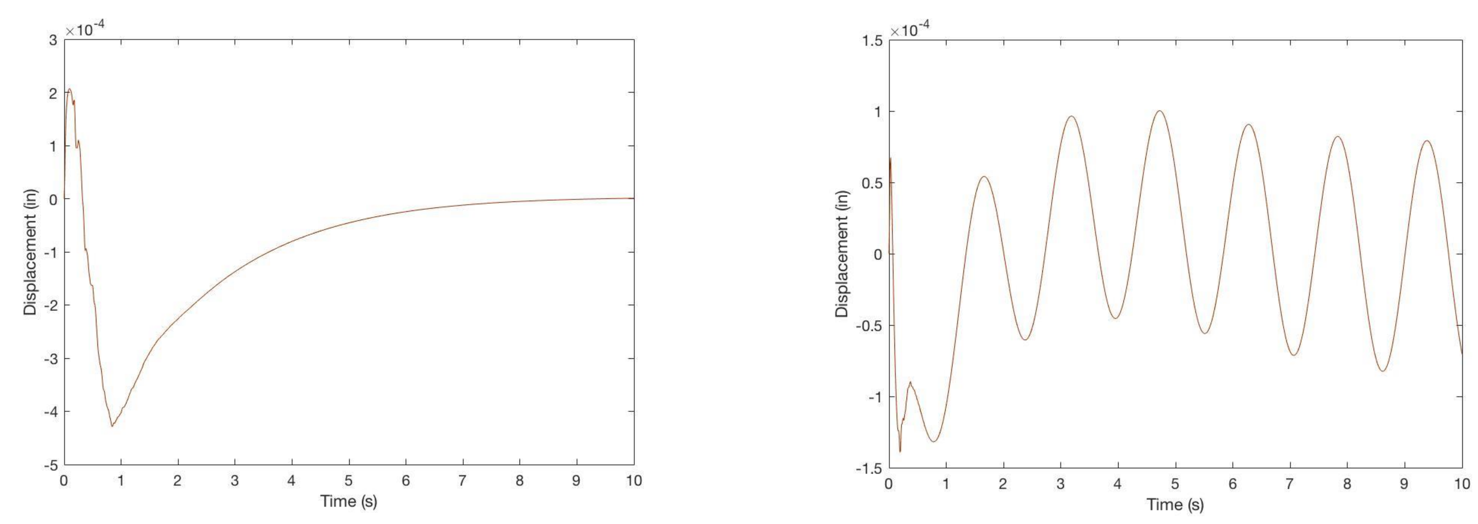


Figure 4: Eigenvalue Analysis for Case 2

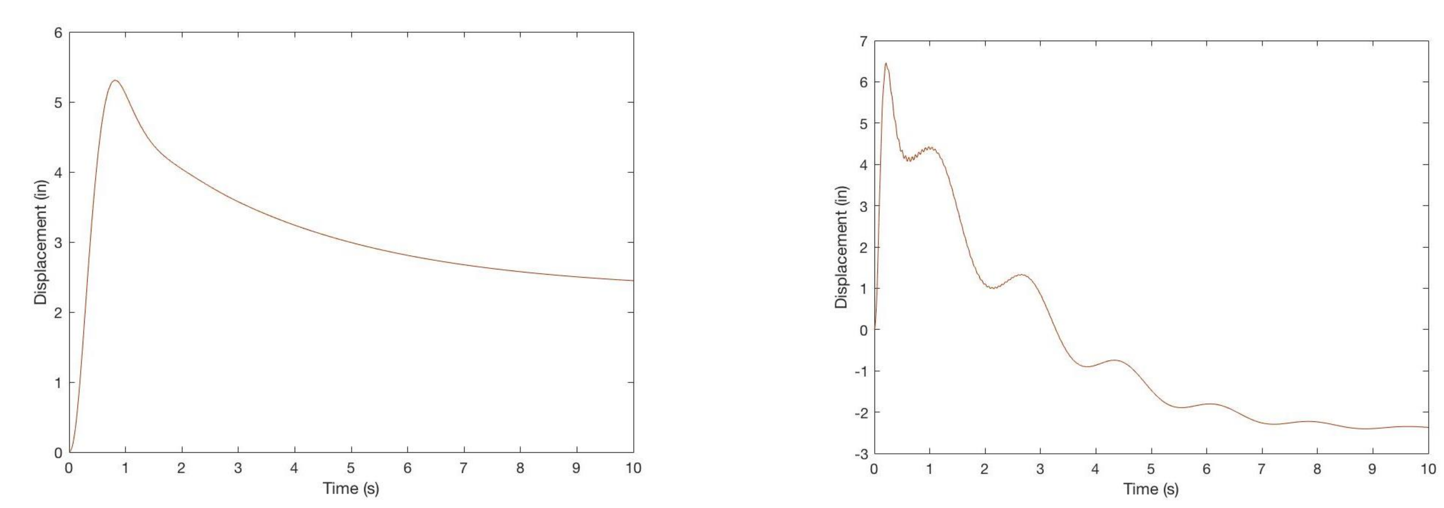
Time Simulation

The time simulations for the cases 1 and 3 displays an oscillatory form of instability and can be seen in Figure 5(b) and 7(b) The figures below (Figure 5-7) show the out-of-plane tip displacement for the given cases at two separate velocities, one stable velocity and the other an unstable velocity.



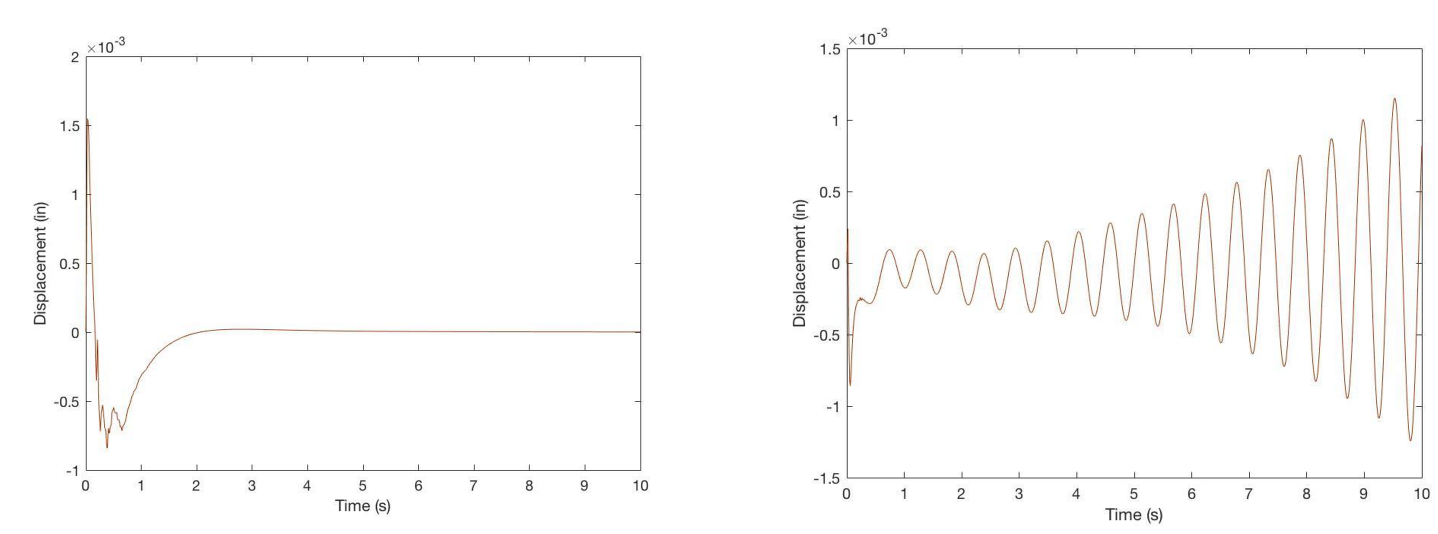
(a) Stable Solution (b) Unstable Solution

Figure 5: Time Simulation for Case 1



(a) Stable Solution (b) Unstable Solution

Figure 6: Time Simulation for Case 2



(a) Stable Solution (b) Unstable Solution

Figure 7: Time Simulation for Case 3

Conclusion and Future Works

In this project, we studied the aeroelastic behavior of various wings at different flight speeds. The eigenvalues analysis approach allowed for an examination of both stable and unstable solutions. This analysis shows that the straight swept wing with twist has a stable solution that is overly-damped and an unstable solution that is under-damped as seen in Figure 6. Future works will focus on a more extensive time simulation and the effects of more complex designs.

Acknowledgments

I would like to thank my mentor, Dr. Zahra Sotoudeh without whom this research project would not have been possible. I deeply appreciate her constant support and helpful advice.

Resources

- Bowers, A. H., Murillo, O. J., Jensen, R. R., Eslinger, B., and Gelzer, C., "On wings of the minimum induced drag: Spanload implications for aircraft and birds," 2016.
- Patil, M. J., and Hodges, D. H., "Flight Dynamics of Highly Flexible Flying Wings," *Journal of Aircraft*, Vol. 43, No. 6, November–December 2006, pp. 1790-1798.