VIBRATION ANALYSIS OF AN ELECTRIC UAV WING MODEL

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1 Introduction

This paper outlines the random vibration analysis of a structural wing model designed for an electric Vertical Takeoff and Landing (VTOL) Unmanned Aerial Vehicle (UAV) called the Manta. The Manta is designed for agricultural cargo operations as part of the Carleton University Bio-inspired Environmentally Friendly Aerial Vehicle (BEFAV) capstone project. This analysis expands on and updates the original structural analysis of the Manta to determine the vibrational response of the wings caused by the engine and aerodynamic vibration using ANSYS modal and random vibration tools.

2 Wing Design

The base model of the Manta wing is designed in Catia V5. Catia allows for comprehensive design of bodies, surfaces, and part connections. The model is imported into ANSYS Spaceclaim 3D software to finalize the wing topology for use in ANSYS Mechanical. Figure 1 below shows the model setup.

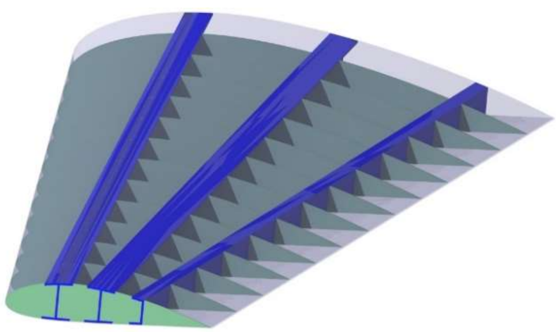

Figure 1: Catia model of the Manta UAV wing – fans omitted for clarity.

The structure is comprised of three aluminum 2024-T3 spars. The two forward I-spars are designed to take the bulk of the load around the leading edge and mid-chord of the airfoil. The aft spar serves primarily as a mounting point for the rotating ducted fan propulsion system mechanism. The wings also feature 6061-T6 aluminum ribs and a composite wing skin. Material data is shown in Table 1.

3 Analysis Setup

The method selected for this analysis is the ANSYS random vibration solver. This platform is used to reduce the complexity of the model. In lieu of providing advance loads from turbulent flow models or aeroelastic responses, the solution uses the statistical Power Spectral Density (PSD) data [2]. Consequentially, the results produced by this simulation are statistical. By utilizing the material data above, the likeliness of wing failure over a certain spectrum of vibration is determined.

Table 1: Material data for Manta UAV wing

Component	Material	Ultimate Strength (MPa)
Skin	Composite Metal Foam	175*
Ribs	Al 6061-T6	296 [1]
Spars	Al 2024-T3	427 [1]

* Material data comes from Manta materials engineer.

Prior to running the random vibration analysis, the natural modes of vibration of the wing must be determined. ANSYS has a modal solver that does exactly this by solving the following homogeneous differential equation [2]:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0 \qquad (1)$$

The modal analysis is setup by treating the wing like a cantilevered beam as is done in [3]. Through this approach, the boundary condition considered for the analysis is a fixed support at the wing root. The spars and wing skin at the root are fixed accordingly. Due to the complex curvature of the wing and its components, linear mesh elements are selected for the analysis. The mesh convergence analysis is done over a size range of 160 mm to 61 mm to ensure the solutions are independent of the mesh size. Figure 2 below shows the first three modes of vibration of the Manta wing determined through the modal analysis.

The modal data is then used to form a random vibration solution. The PSD spectrum data used in this case comes from methods as deinned in MIL-STD-810H for environmental testing of mechanical and aerospace systems [4]. Figure 3 shows the chart of the PSD acceleration spectrum used for the random vibration analysis. In this instance, the bulk of the noise comes from the ducted fans on the Manta wings and canards [4]. Since Manta UAV uses electric ducted fans for propulsion that run at higher RPMs, and thus higher frequencies. These frequencies are outside of the spectrum ranges typically used for propeller aircraft PSD data [4]. For this reason, the Manta can be considered a jet aircraft. Using the PSD data input in ANSYS, the statistical stress level results are computed, as shown in the next section

4 Analysis Results and Discussion

The primary results computed for the current analysis are the total stresses in each type of component, including the skin,

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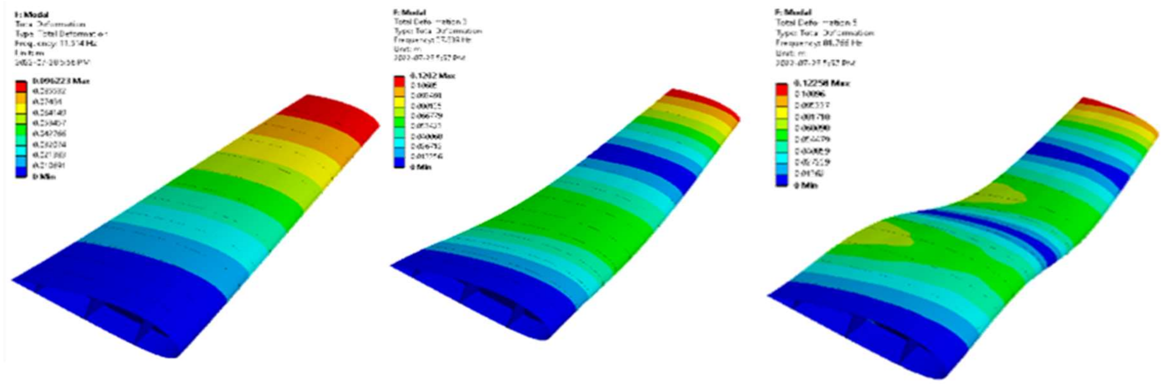

Figure 2: Manta wing vibration modes.

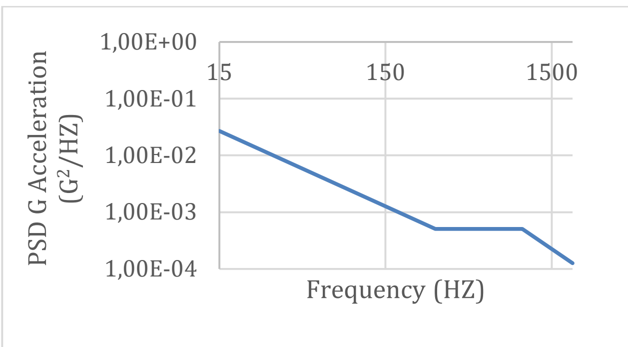

Figure 3: PSD G vibration spectrum from ducted fans.

ribs, and spars. The values presented correspond to the 1-sigma and 3-sigma standard deviations for the stress. The stress calculation in ANSYS is performed using the Von Mises criteria. The ultimate strength values earlier shown in Table 1 are compared with the stress level results.

Table 2 shows the stress levels in each wing component. It is expected that the maximum stress for each component would be low due to the ducted fan vibration – this is due to the fact that ducted fans produce less noise and vibrations than larger propeller and jet engines as seen in [4]. It is also important to note that the Manta UAV flies at much lower Mach numbers and is subject to less aerodynamic vibration as a result [4].

The vibrations are ultimately less intense and cause less disturbance in the structure. As is evident in Table 2, the vibrations caused by the engine and aerodynamic vibrations do not cause any component failures.

Table 2: Statistical stress levels in Manta wing components.

Component	1σ Stress Level (MPa)	2σ Stress Level (MPa)
Skin	0.9	2.7
Ribs	12.2	36.5
Spars	10.9	32.6

The scope of the current analysis is limited by the nature of the vibrations caused by the ducted fans. To expand these results, one can also consider the superposition of effects such as aeroelasticity as well as the effects of more severe aerodynamics like gusts and turbulence.

5 Conclusion and Future Work

Through random vibration analysis of the Manta wings for the engine and aerodynamic vibrational PSD load it was determined that the structure will not fail. Future expansion on this analysis will focus on looking at other vibrational loads and performing the analysis with additional meshes.

References

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