Modal And Harmonic Analysis of Aircraft Wing

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Abstract- *Modal analysis is as important as carrying out a static structural analysis, because our aircraft will always experience exposure to different gust wind (which can cause turbulence) and vortex with different force frequency. If our structure is not properly design to with stand such frequencies (i.e. for the force frequency not to be equal to the natural frequency of our structure), it will lead to catastrophic failure of the structure. Natural frequency of structure will vary, depending on three key parameters. Which is the shape of the structure (stiffness/aero elasticity), the material used in the structure and its damping ratio. We know that the higher the response of our structure to force frequency, the lower is its natural frequency, while damping ratio tend to increase The Study is to be carried in different comparison cases, in other to obtain a better structural result. The function of stringers and spars, the longitudinal stiffeners in the wing. The designing of spars in a wing is also shown with the help of screenshots in CATIA V5 software. Load representative of an aircraft will be considered in this study.*

I. INTRODUCTION

Modal analysis is as important as carrying out a static structural analysis, because our aircraft will always experience exposure to different gust wind (which can cause turbulence) and vortex with different force frequency. If our structure is not properly design to with stand such frequencies (i.e. for the force frequency not to be equal to the natural frequency of our structure), it will lead to catastrophic failure of the structure. Natural frequency of structure will vary, depending on three key parameters. Which is the shape of the structure (stiffness/aero elasticity), the material used in the structure and its damping ratio. We know that the higher the response of our structure to force frequency, the lower is its natural frequency, while damping ratio tend to increase.

Hence, we are going to run modal analysis on the selected wing box CAD model and check it harmonic response to different forced vibration frequency (which are within the gust and vortex force frequency for low attitude aircraft).

1.1. Modal Setup

The root edges are used for the fixed support as used in all previous analysis. Maximum modes to find is set to 6 (which is sufficient to cover six different fundamental frequency modes).

1.2 Modal Result

Table below shows the natural frequencies of the wing-box structure and its mode shape maximum total deformation from a minimum of zero;

1.	6.4758	1.9476
2.	8.1325	1.9
3.	9.58	1.8923
4.	11.37	1.9546
5.	12.834	1.9792
6.	14.484	1.8433

Mode shape figure for the six modes are shown below;

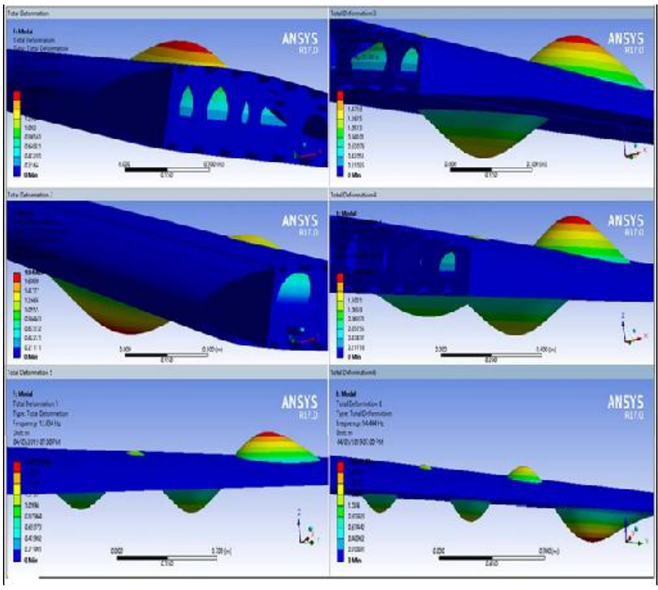


Figure1. Six Modes of Wing-Box Natural Frequency Vibrational Deformation

As observed from the above figure, these low frequency modes seem to occur at the top surface of the fuel tank, which deform in the Z-axis for the entire mode. Hence to increase the natural frequency of the aircraft, a different fuel tank structure can be considered (e.g. the bag type), or increase the structural stiffness of the fuel tank to the wing-box structure. But note that the frequency shown above are within the safe band. Because from study carried out by Robert, John and Walter, on Airplane wing vibration due to atmospheric turbulence. Shows higher normalized spectrum power for lower frequencies of the atmospheric turbulence for frequencies ranging from 0.001Hz to 1Hz. This range of frequencies also applies to the wing tip velocity normalized by the gust velocity at different location along the wing span, as shown below:

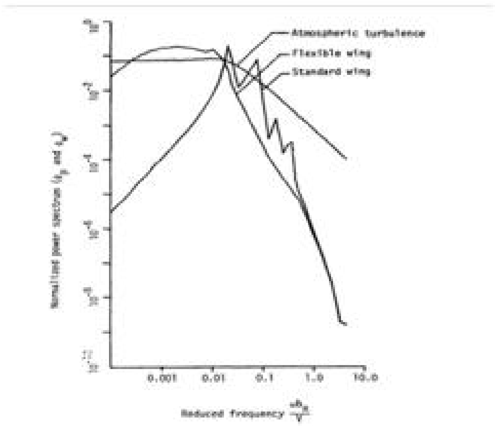
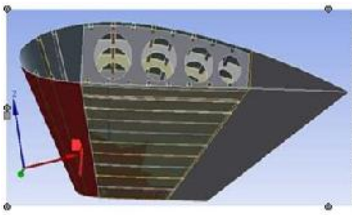


Figure 2. Spectrum of Atmospheric Turbulence for Length Scale 40.2m and Spectrum of Velocity at Wing Tip for Flexible and Standard Wings.

1.3 Harmonic Response Setup

Frequency range is set from 0 - 15Hz (Since our natural frequency went up to 14.484Hz), with 15 solution intervals (This will display results for every change in 1Hz in linear form).

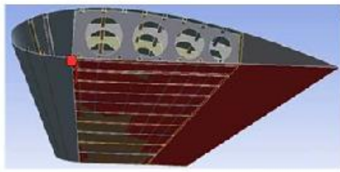
The root edges are used for the fixed support as used in all previous analysis. Wfuel is also applied as force load onto the base of the fuel tank structure. In order to apply and distribute the wind pressure force from figure 2, we have created a tabular data to apply a range of this force on the bottom portion of the L.E surface and the bottom portion of the remaining surface, separately, as shown below;



Tabular Data

	Frequency [Hz]	Magnitude [Pa]	Phase Angle [°]
1	0.	0.	0.
2	1.	1500.	0.
3	2.	1650.	0.
4	3.	1800.	0.
5	4.	1950.	0.
6	5.	2100.	0.
7	6.	2250.	0.
8	7.	2400.	0.
9	8.	2550.	0.
10	9.	2700.	0.
11	10.	2850.	0.
12	11.	3000.	0.

Figure3.FirstPressuredistribution



Tabular Data

	Frequency [Hz]	Magnitude [Pa]	Phase Angle [°]
1	0.	0.	0.
2	1.	250.	0.
3	2.	375.	0.
4	3.	500.	0.
5	4.	625.	0.
6	5.	750.	0.
7	6.	875.	0.
8	7.	1000.	0.
9	8.	1125.	0.
10	9.	1250.	0.
11	10.	1375.	0.
12	11.	1500.	0.

Figure 4.SecondPressureDistribution

1.4 Harmonic Response Result

Firstly, the we take a look at the frequency response graph, to study the change in amplitude of the vibration of the wing-box structure due to the applied load.

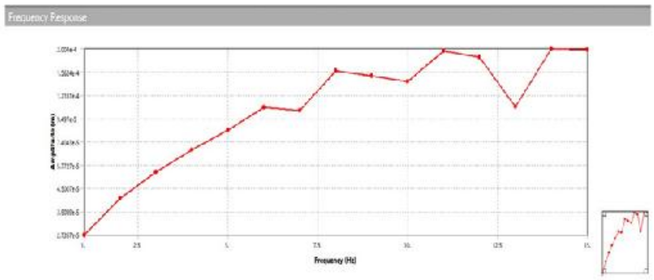


Figure5.HarmonicFrequencyResponse

Frequency [Hz]	Amplitude[m]	PhaseAngle[ ]
1	2.7357e-005	0.
2	4.0322e-005	0.
3	5.375e-005	0.
4	6.7981e-005	0.
5	8.3845e-005	0.
6	1.0712e-004	0.
7	1.0381e-004	0.
8	1.5848e-004	0.
9	1.4979e-004	0.
10	1.4144e-004	0.
11	1.9565e-004	0.
12	1.833e-004	0.
13	1.0794e-004	0.
14	2.004e-004	0.
15	1.9717e-004	0.

The above reading is taken in the X-orientation (i.e. about the chord line orientation). The amplitude shows a steady increase up to the lower natural frequency (i.e. 6.4758Hz). And then decreases and increases again when the next gust and turbulence vibrating frequencies matchesthe wing-box natural frequencies. And the amplitude decreases immediately after these frequencies.

We can view the impacts on the maximum total deformation of the wing-box when the gust and turbulence vibrating frequencies and the wing-box natural frequencies matches each other (i.e. Resonant frequency). This is tabulated and a graphical representation of it is done below;

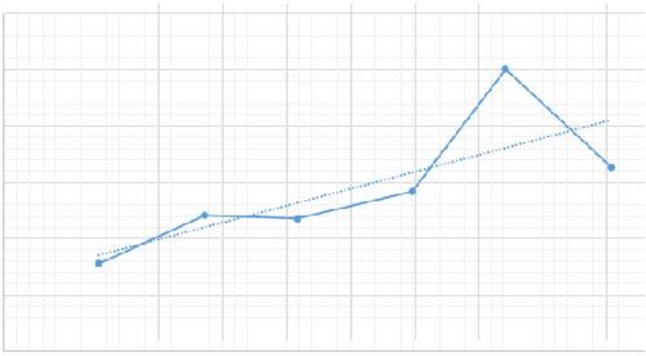


Figure6.FrequencyvsMaximumTotalDeformation

Frequency [Hz]	MaximumTotal Deformation[m]
6.4758	0.015537
8.1325	0.024167
9.58	0.023614
11.37	0.028391
12.834	0.050122
14.484	0.032724

Linear(MaximumTotalDeformation[m])

Above graph shows the increase in total deformation as the resonant vibration frequency increases. And total maximum deformation experiences a peek value at 12.834Hz and at 8.1325Hz, which lies above the linearity line. It should be noted that there will be increase in the number of expected gust that the wing is to experience as altitude band increase or a reduction in the gust velocity

N/B: For a more practical approach and result, the Prodera and HBM tools can be used which allows the use of visual sensors for both generating vibration and reading the modal response (through the strain gauges).

II. CONCLUSION

Computational design and analysis were carried out on a wing-box structure to evaluate its strength and resistance to resonant. Optimization was first carried out to improve its structural efficiency by 63.2% from its initial designed performance. Finally, a critical modal and harmonic response analysis was carried out to ensure that the wing box is capable of withstanding wind (turbulence/gust) vibration (i.e. its natural frequency is well out of range of the forced vibration frequency values). Hence the computational analysis was done with a high margin of success.

2.1. Scope for Future Work

We can proudly state that optimization of any given design/object is nearly infinite, because;

- Material property can be optimized, for its young's modulus, composites, structure etc.
- The shape of the object can also be modified in different ways. Like for our wing box structure, we can:
- Use different cross section (shape) for the stringers can be used also for parametric observation. Or even changing the diameter of this circular cross section.
- Vary the number of ribs and its location.
- Study different joint system, sizes, numbers etc (this could be rivetted, wedded, bolted etc)

REFERENCES

[1] Design and Structural Validation of Aircraft Wing by Eduhive, 2018.

[2] Dynamic Mechanical Analysis of an Aircraft Wing with Emphasis on Vibration Modes Change with Loading by LicaFlore, Albert Arnau Cubillo, 2015.

[3] Stress Analysis and Weight Optimization of a Wing Box Structure Subjected to Flight Loads Immanuvel D., Arulselvan K., Maniiarasan P., Senthilkumar S, 2013.

[4] The Thickness of an Aircraft Wing Skins Optimization Based on Abaqus Zhengran Yang, Yi Jiang, Cong Huang, 2014.

[5] The Variation of Gust Frequency with Gust Velocity and Altitude BY N. I. Bullen, 1957.

[6] Airplane design (Aerodynamic) Prof. E.G. Tulapurkara.

[7] Air-foil Coordinates: http://m-selig.ae.illinois.edu/ads/coord/naca4412.dat.

[8] https://my.solidworks.com/reader/forumthreads/91471/lift-coefficient-on-2d-airfoil.

[9] https://wsww.youtube.com/watch?v=LAIB7qK-9pE&t=877s
https://www.youtube.com/watch?v=BFnkZGx218s

BIOGRAPHIES

ANWAR ANSARI is a Master student of school of AEROSPACE ENGINEERING (BEIJING INSTITUTE OF TECHNOLOGY, BEIJING CHINA).Presently, He is pursuing his Master of Science (MSc.) under the Chinese Government Scholarship(CSC).
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