An Investigation on Aeroelasticity Effects in Unmanned Aerial Vehicles

N.Vivek Masthiraj[1], Dr.S.Periyasamy[2]
[2]Assistant Professor, Dept of Mechanical Engg
[1]Anna University, Chennai, India.
[2]Government College of Technology, Coimbatore, India.

Abstract- *Active Aero elastic Wing (AAW) technology represents a new design approach for aircraft wing structures. Aero elasticity was often seen as a problem in the past that had to be eliminated when designing an aircraft. The AAW technology converts static aero elastic deformation into a positive effect during manoeuvring. Current research has been focussing on Active Aero elastic wing technology, which integrates aerodynamics, active controls and structural aero elastic behaviour to maximize air vehicle performance. Active Aero elastic wing technology is an innovative concept which induces wing twist in order to increase the aerodynamic performance of the air vehicle. The aim of the investigation is to determine the different forces induced in the aircraft structure and to find a method to utilize the induced forces for increasing the performance.*

Keywords- Active aero elastic technology, Aero elastic wing, Induced twist, Modal analysis, Wing Divergence, Roll rate

I. INTRODUCTION

Aero elasticity is mainly the concern of the interaction of flexible structures with the surrounding airflow. It is defined as the mutual interaction of aerodynamic (A), elastic (E) and inertial (I) forces, as demonstrated by the classic Collar‘s Aeroelastic Triangle shown in Figure 1. As an aircraft moves through the air, loads act on the structure and cause deformations of the flexible structure. These deformations will change the geometry of the structure which leads to a change in the flow and aerodynamic loads, resulting in a loop of loads and deformations. In most cases the aerodynamic loads and the internal elastic loads in the structure will converge to equilibrium. However, there are cases when the loop becomes unstable, causing increasing deformations leading to structural failure of the aircraft.

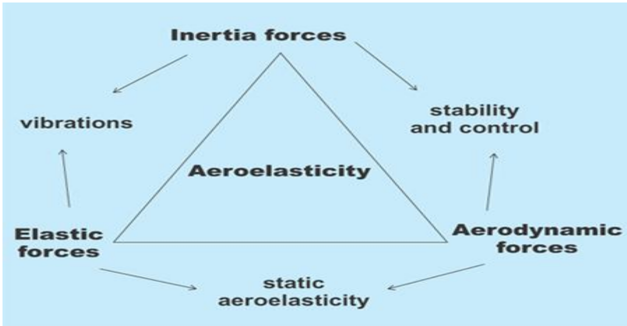


Fig:1 Collar’s Aeroelastic Triangle

II. UNMANNED AREIAL VEHICLE SPECIFICATIONS

1. Weight of the UAV, w = 1.47Kg
2. Wing Span, b = 1m
3. Fuselage length = 0.94m
4. Wing chord, c = 0.2m
5. Wing area, s = 0.2m^2
6. Airfoil used = S9000
7. Maximum speed, v = 17m/s
8. Max. Aileron deflection, δa = 10 deg
9. Electronic speed controller = 40-45A ESC
10. Propeller = 18.5×12 prop

III. ADVANTAGES OF AERO ELASTIC WING OVER NORMAL RECTANGULAR WING

The following are the advantages of using aero elastic wing instead of normal rectangular wing in UAV.

1. Integrated aerodynamics.
2. Integrated structural aero elastic behaviour.
3. Maximization of air vehicle performance.

IV. XFLR5 ANALYSIS OF NORMAL RECTANGULAR WING & AERO ELASTIC WING

4.1 XFLR 5

1. XFLR5 is a software analysis tool for airfoils, wings and planes operating at low Reynolds Numbers. It includes:
2. X Foil's Direct and Inverse analysis capabilities
3. Ability to perform wing design and analysis based on Lifting Line Theory, Vortex Lattice Method, and 3D Panel Method

In this paper Vortex lattice method is adopted to carry out the analysis. By using this software the aerodynamics parameters such as Co-efficient of Lift (C_L), Co-efficient of Drag (C_D) and Co-efficient of Moment (C_M) were tabulated in Table 1&2. Figure 2 shows the effect of aero elastic wing on Lift.

Table:1 Results of Normal Rectangular Wing

S.NO	FLAP ANGLE α (DEG)	C_L	C_D	C_M
1	0	0.2336	0.0027	-0.0405
2	1	0.2346	0.0029	-0.0405
3	2	0.2649	0.0033	-0.0429
4	3	0.2862	0.0038	-0.0454
5	4	0.3075	0.0043	-0.0479
6	5	0.3287	0.0049	-0.0503
7	6	0.3499	0.0055	-0.0528
8	7	0.3710	0.0062	-0.0552
9	8	0.3920	0.0069	-0.0577
10	9	0.4131	0.0076	-0.0601
11	10	0.4340	0.0084	-0.0626
	Σα =55	20.3859=ΣαC$_L$		

Table:2 Results of Aero elastic Wing

S.NO	TIP TWIST (DEG)	C_L	C_D	C_M
1	0	0.2336	0.0027	-0.0405
2	1	0.2652	0.0034	-0.0354
3	2	0.2968	0.0042	-0.0304
4	3	0.3284	0.0050	Horizontal (Category) Axis M
5	4	0.3958	0.0060	-0.0202
6	5	0.3911	0.0071	-0.0152
7	6	0.4224	0.0082	-0.0102
8	7	0.4534	0.0094	-0.0052
9	8	0.4842	0.0107	-0.0003
10	9	0.5148	0.0121	0.0046
11	10	0.5452	0.0136	0.0094
	Σα =55	24.8517=ΣαC$_L$		

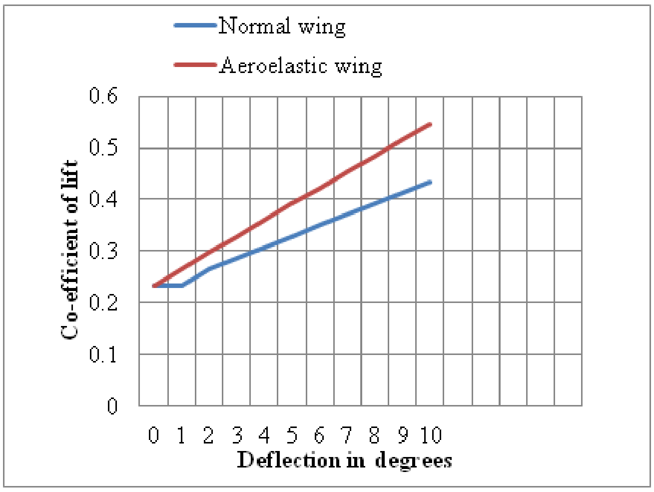


Fig: 2 Effect of aero elastic wing on lift

V. CATIA V5 DESIGNS OF NORMAL RECTANGULAR WING & AERO ELASTIC WING

3D models of normal rectangular wing and aero elastic wing were developed using the software CATIA to be analyzed using ANSYS. Figures 3 & 4 illustrate the 3D models of normal rectangular wing and aero elastic wing respectively.

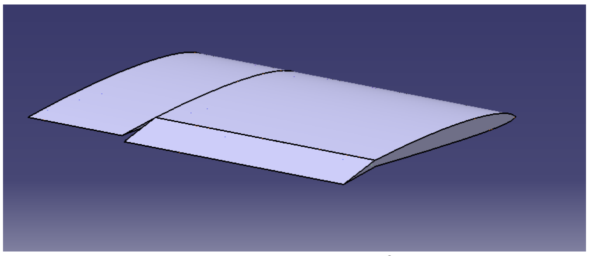


Fig: 3 Normal Wing with 10^0 flap angle

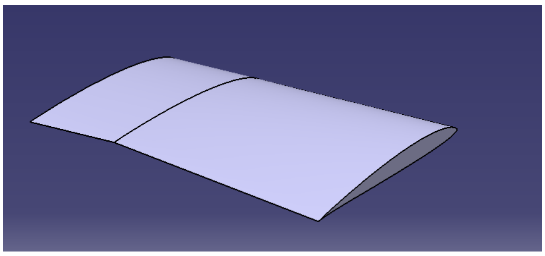


Fig: 4 Aero elastic Wing 10^0 twist

VI. CALCULATIONS FOR ROLL RATE

The following are the critical design points for ailerons:

1. Responsiveness at low speeds with large deflections.
2. Responsiveness at high speeds with small deflections.
3. Comfortable stick forces throughout flight envelope.

Another term for responsiveness is roll authority. Although responsiveness at low speeds is imperative (low dynamic pressure requires greater deflection or control surface area, or a combination of the two), high speed functionality is significant as well. It has been known for a long time that a pilot's conception of adequate roll control is tied to the helix angle made by the wing as the airplane rolls at a given square of airspeed ;pb/2V. In this expression, p is the roll rate in radians per second for full aileron deflection, b is the wing span (in ft or m), and V is the airspeed (in ft/s or m/s). Thus, it is recommended that for specific types of aircraft the following ratios are met or exceeded:

Cargo or heavy-lift aircraft:

$$\frac{pb}{2V} > 0.07$$

Fighter aircraft:

$$\frac{pb}{2V} > 0.09$$

Roll Rate is found using the formula:

$$\frac{pb}{2V} = \frac{-C_L\delta a}{C_{lp}} \times \delta a$$

Where,

p - roll rate in degree per second for full aileron deflection

b - Wing span in meter (1meter for both wings)

$C_L\delta a$ –Roll authority in per degree

C_{lp} - Roll damping in per degree

δa - Aileron deflection angle in degrees (10 degrees)

V - Airspeed in m/s (10 m/s)

For Normal Rectangular Wing:

- $C_L\delta a$ = 9.8735×10^{-3} per degree
- C_{lp} = -0.01375 per degree

Therefore the Roll Rate, p = 244.144 deg/sec

For Aero Elastic Wing:

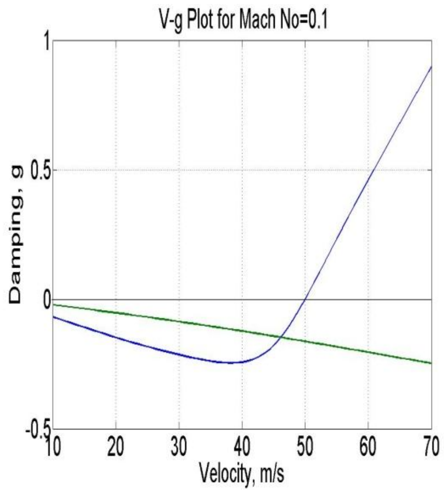
- $C_L\delta a$ = 0.01240 per degree
- C_{lp} = -0.01555 per degree

Therefore the Roll Rate, p =271.125 deg/sec

From the above calculations, it can be seen that Aero elastic wing has a higher roll rate than Normal rectangular wing.

VII. FLUTTER ANALYSIS

The Flutter analysis of the wing is done using NASTRAN – Aero elastic analysis. The required flight loads of the mission and the Finite Element Models of the two types of wings in IGS format are the inputs for the analysis. The output of the analysis is expressed in the form of the following graphs.



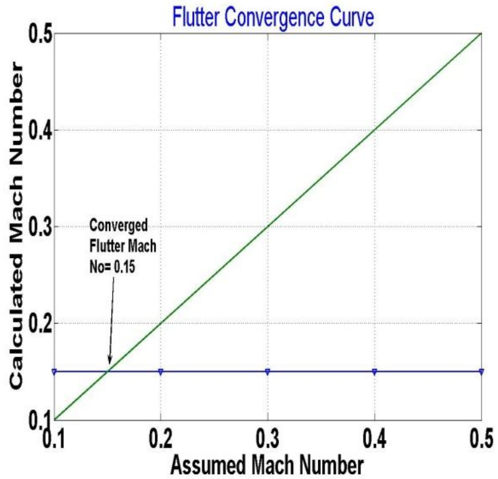


Fig: 5 Wing divergence speed and Flutter speed graph for Normal Wing

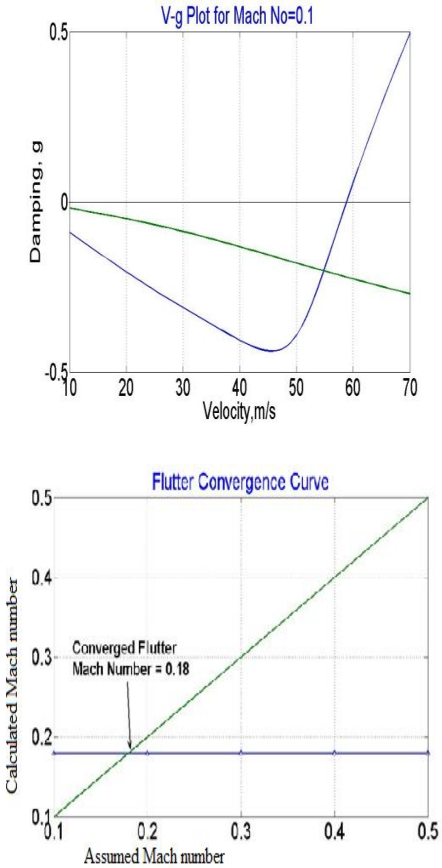


Fig:6 Wing divergence speed and Flutter speed graph for Normal Wing

From the above graphs the Wing divergence speed (V_D) and Flutter speed (V_F) of both wings are calculated.

Normal Wing	Aeroelastic wing
Wing divergence speed (V_D) = 48 m/s	Wing divergence speed (V_D) = 50 m/s
Flutter speed (V_F) = 58 m/s (0.15*330)	Flutter speed (V_F) = 60 m/s (0.18*330)

VIII. CONCLUSION

The primary aim of this project is to design an Aero elastic Wing structure applicable to a lightweight UAV. Therefore the focus was on developing an optimal design for an Active aero elastic wing structure. A comparative study was conducted between the existing rectangular wing structure and the current design of an aero elastic wing structure. The results of the study can be summarized as follows:

1. Both Normal and Aero elastic wing aerodynamic parameters were analyzed in XFLR 5.From the comparison of the Aero elastic wing and normal wing, it was seen that the aerodynamic efficiency figures for Aero elastic wing were higher than those for normal wing and the co-efficient of lift for the same amount of deflection. This is illustrated in Figure 2.
2. From the roll rate calculation it can be seen that an aero elastic wing has better efficiency in manoeuvring performance. The roll rate for Aero elastic wing was found to be higher than that for a normal wing.
3. The results obtained from aero elastic analysis show that aero elastic wing has more wing divergence speed when compared with normal rectangular wing.

Therefore the proposed aero elastic wing structure can be applied to wing structures of small scale aircraft such as UAVs, Missiles etc.

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