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EFFECTS OF WINGLET ON THE AEROELASTIC CHARACTERISTICS OF A UAV

Evren Sakarya[1] and Umut Susuz[2]
TAI Turkish Aerospace Industries
Ankara, Turkey

ABSTRACT

In this study, effects of winglet addition on an unmanned aerial vehicle wing are investigated with aeroelastic concerns. Winglets having different mass characteristics, weight and center of gravity, are added to original wing. Added winglet weight on the tip of the wing changes the structural dynamics drastically. Change in dynamics and added aerodynamic surface also changes the flutter speed of the aircraft. Flutter speed change with different winglet configurations are investigated.

INTRODUCTION

A winglet's main purpose is to improve performance by reducing drag. Exact size and angle can change depending on the aircraft, and winglets may be incorporated during early design and manufacturing or added later. The improvement in aircraft performance due to winglet addition comes from the tradeoff between induced drag reduction and added wetted area increasing the profile drag. However such a gain may come with a penalty, arising from aeroelasticity. Adding a mass and surface to the tip of a long wing may completely change the structural behavior of the wing which in turn may result in completely different aeroelastic behavior (i.e. reduction in flutter speed). To avoid or reduce the aeroelastic performance drop, precautions must be taken during the design phase of winglet.

CAD model of winglet used in this study is shown in Figure 1. Winglet is attached to the wing tip using an adapter plate.

[1] Structural Dynamics & Aeroelasticity Engineer, Email: esakarya@tai.com.tr
[2] Structural Dynamics & Aeroelasticity Engineer, Email: ususuz@tai.com.tr

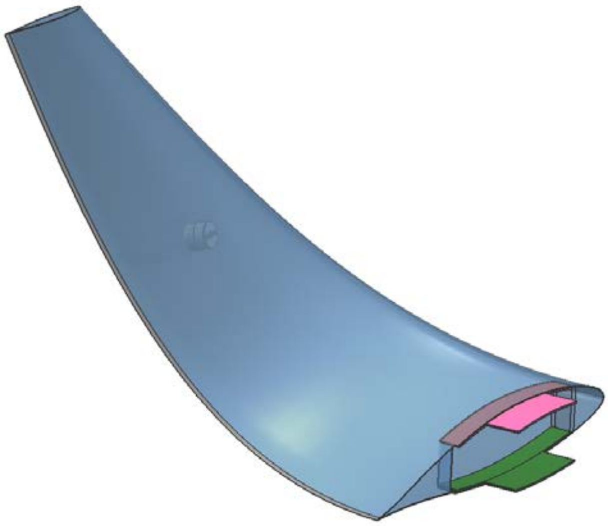

Figure 1: *Winglet Structural Model*

MODELLING

Structural Model

Finite Element Model of the winglet is available in Figure 2. This FEM represents the structural properties of the real structure. The Joint Master FEM of the whole aircraft (including winglet) is also given in Figure 3. Model features 14000 nodes and 13500 elements including multi point constraints and concentrated mass elements.

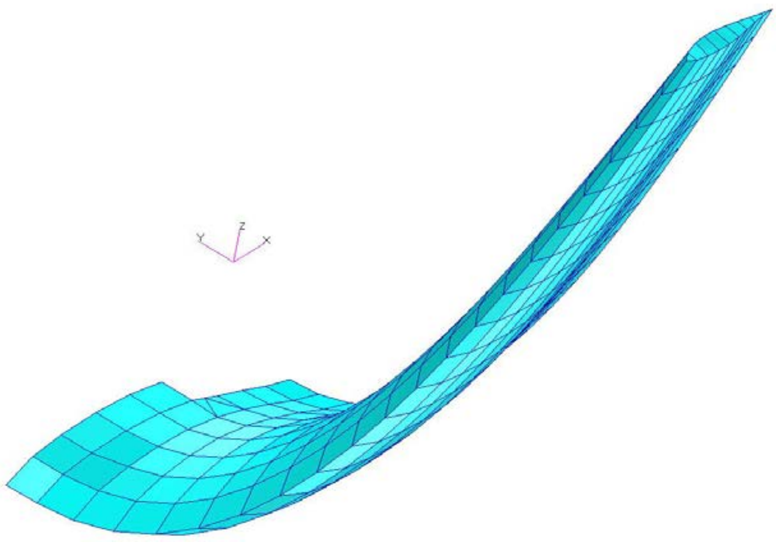

Figure 2: *Winglet Structural Finite Element Model*

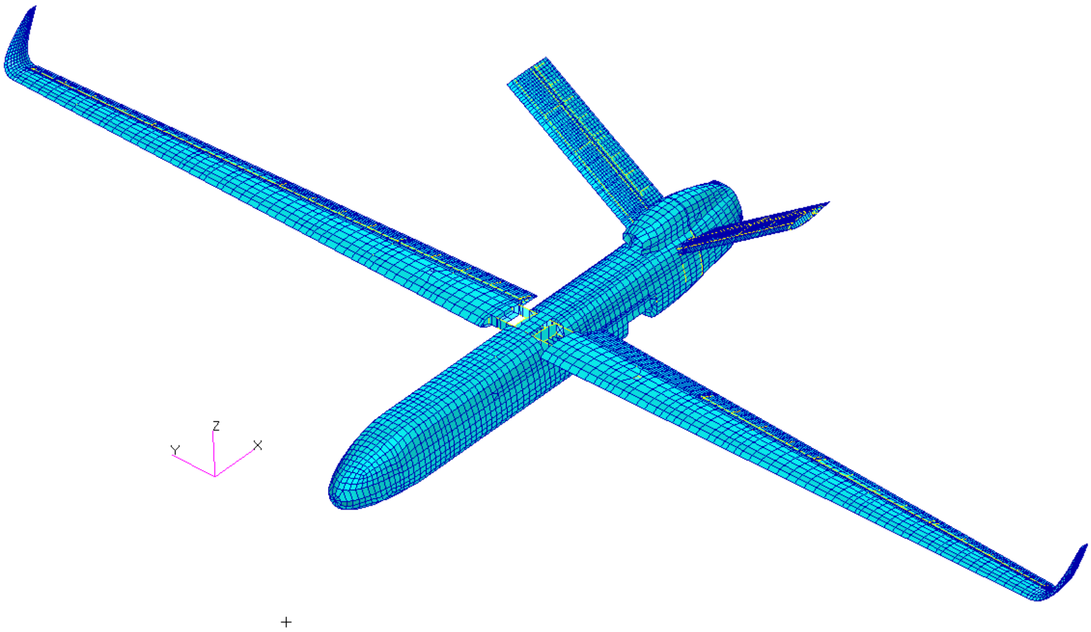

Figure 3: Joint Master FEM

Different mass and cg (center of gravity) locations for winglet are modeled; configurations are listed in Table 1. Only x axis cg location is varied as distance from a nominal case where it matches with the rest of wing x-cg. Cg variation along the x axis has the most critical effect on torsional behavior of the wing. Representative views of different winglet cg locations are shown in Figure 4.

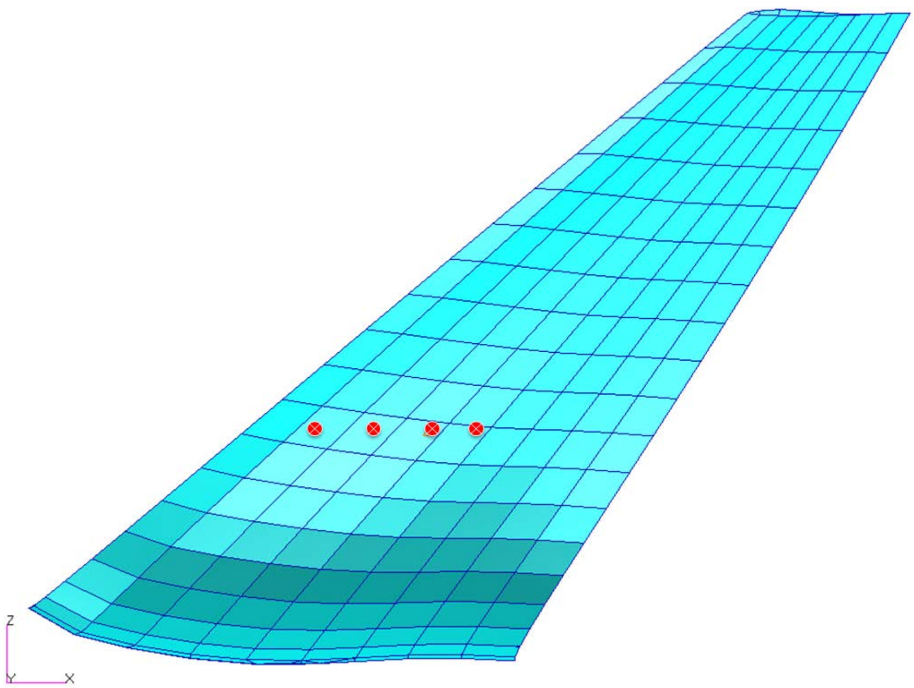

Figure 4: Different CG locations of the winglet

Table 1: Configurations

#	**Winglet x-cg location (mm)**	**Winglet mass (kg)**
C 0	No winglet	No winglet
C 1	-100	1.4
C 2	-100	2.4
C 3	-100	3.4
C 4	-100	5
C 5	0	2.4
C 6	+160	2.4
C 7	+260	2.4

Aerodynamic Model

An aerodynamic panel model is prepared for the aeroelastic analyses. Figure 5 shows the aerodynamic model with macro elements. Model consists of 1072 aerodynamic elements. Winglet section is modeled via different macro elements in order to achieve correct geometry.

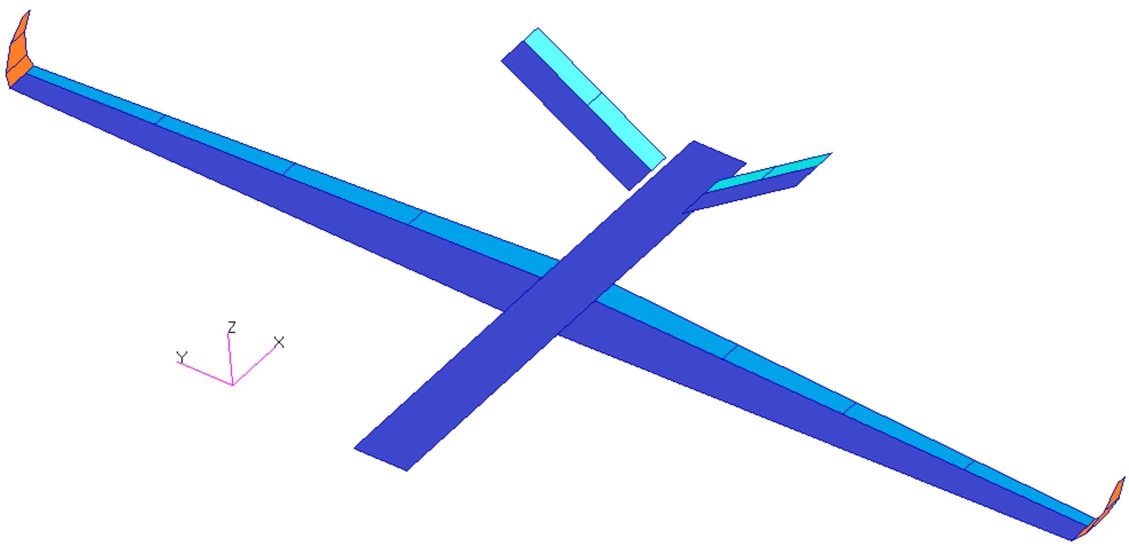

Figure 5: Aerodynamic Model

MODAL ANALYSES RESULTS SUMMARY

Using the Joint Master FEM, modal analyses were performed to get natural frequencies and mode shapes. In Table 2 natural frequencies compared to configuration 0 is shown. It can be seen that winglet mass change affect bending frequencies, while cg location change also affect torsional modes.

Figures 6-8 show mode shapes for aeroelastically critic modes of the aircraft. Mode shapes are shown for configuration 2. General view of mode shapes look similar for different configurations even though eigenvectors related to winglet area change significantly.

Table 2: Comparison of Natural Frequencies

	Percent change in Natural Frequency (with respect to C 0)			
Mode Shape	**C 2**	**C 7**	**C 1**	**C 4**
Wing out-of-plane Symmetric 1st Bending	-13.86	-13.86	-8.31	-28.14
Wing Inplane Symmetric 1st Bending	-19.28	-19.43	-13.36	-34.50
Wing out-of-plane Symmetric 2nd Bending	-17.22	-17.99	-10.85	-28.99
Wing Anti-symmetric Torsion	2.63	-1.80	-1.25	-1.95

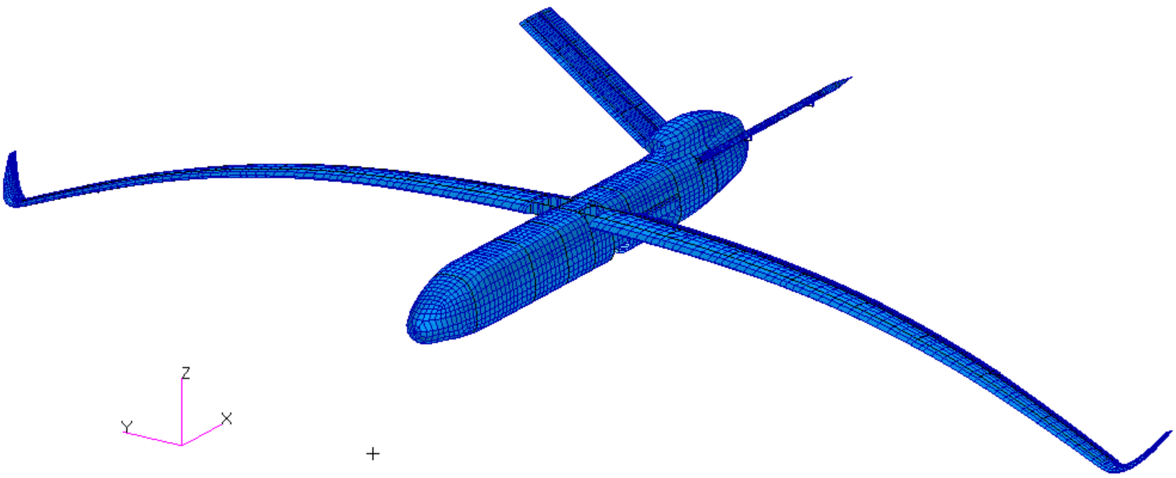

Figure 6: 1st Symmetric Wing Bending

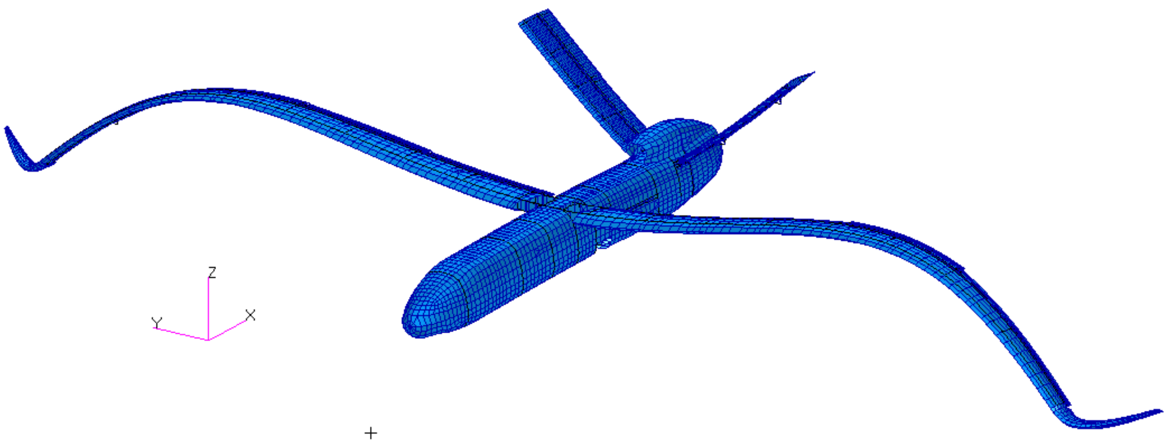

Figure 7: 2nd Symmetric Wing Bending

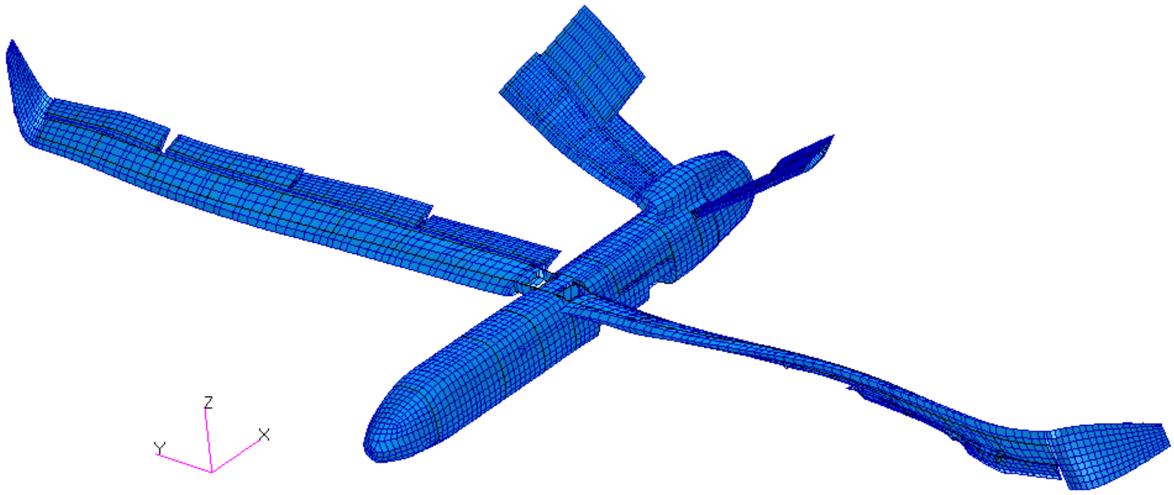

Figure 8: Wing Anti-symmetric Torsion

FLUTTER ANALYSES

Flutter analyses are carried out for sea level altitude for each configuration. Flutter speed for different configurations are calculated and related damping and frequency graphs are presented in Figures 9-12. Frequency plots show only related flutter mode for clear presentation.

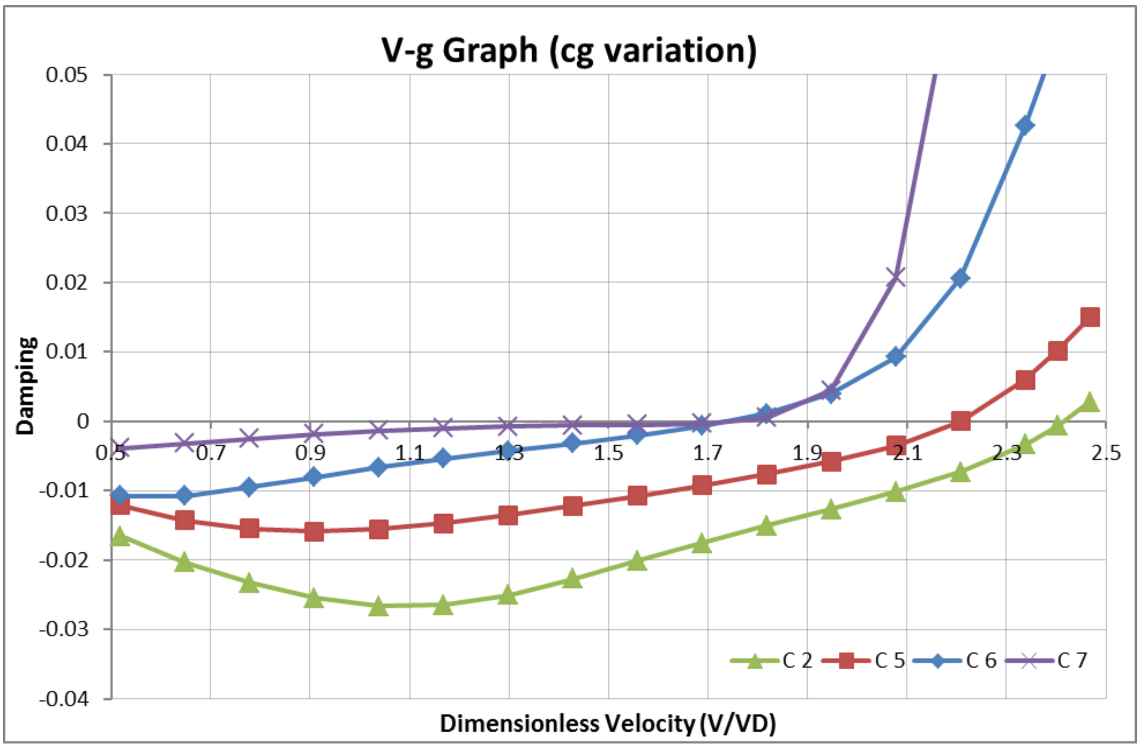

Figure 9: V-g graph for cg location variation

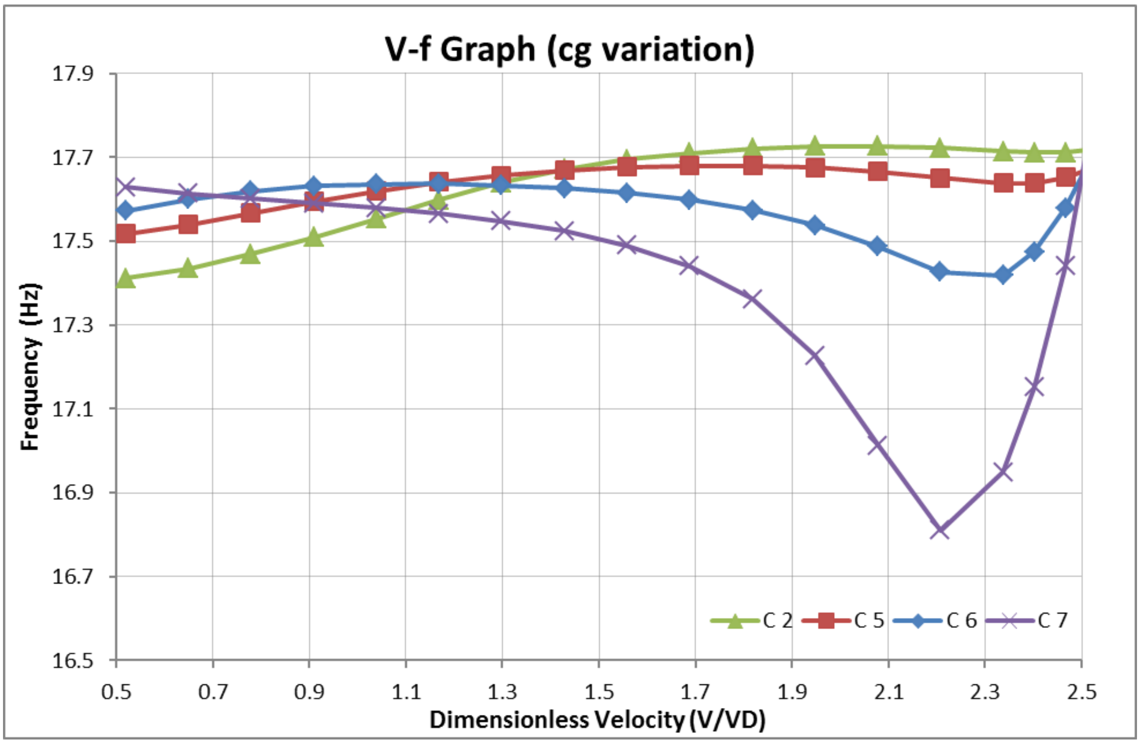

Figure 10: V-f graph for cg variation

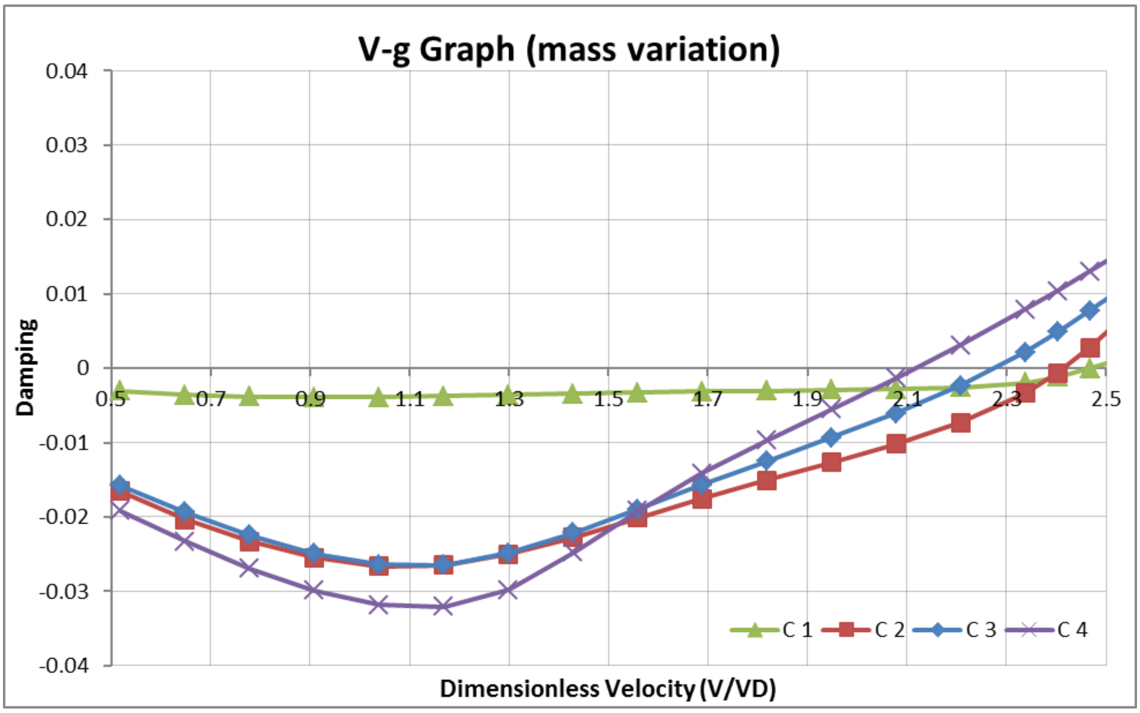

Figure 11: V-g graph for mass location variation

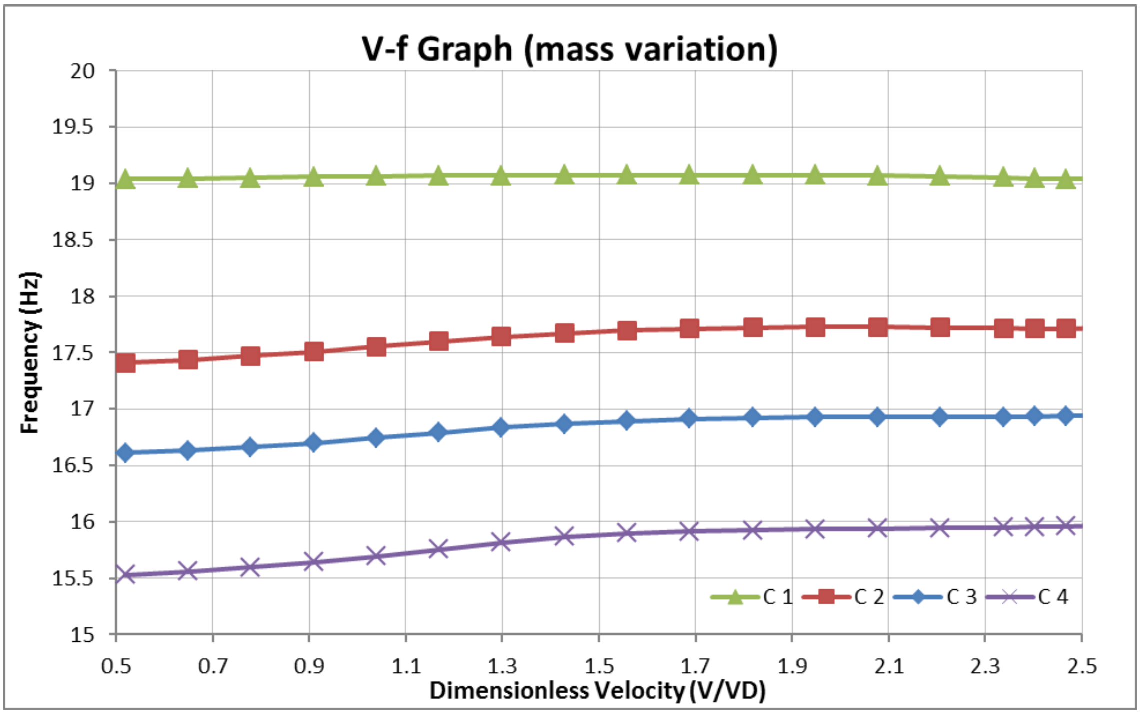

Figure 12: V-f graph for mass variation

RESULTS

It can be seen that winglet decreases flutter speed for every configuration. This is an expected result as the added mass effect is bigger than added stiffness for bending motion and thus leading to lower bending frequencies. As the mass of winglet is varied keeping its cg location constant, it can be seen that flutter speed decreases. Other cases demonstrate effect of winglet cg location where it can be seen that as the x-axis cg location is moved to aft of the aircraft flutter speed decreases dramatically. This is in response to torsion mode shape change. Torsion mode frequency also becomes more responsive to changing flight velocities leading to coupling between bending and torsion modes. Table 3 summarizes flutter speed for configurations evaluated.

Table 3: Flutter Speed

Configuration	Dimensionless Flutter Speed (V/VD)
C 0	2.48
C 1	2.47
C 2	2.41
C 3	2.28
C 4	2.12
C 5	2.21
C 6	1.74
C 7	1.74

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