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Aeroelastic Concepts in Civil Aircraft Wings Design

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ABSTRACT

Nowadays, due to increasing aircraft complexity and challenging economic situations, Using a design situation enables us to update higher reliability models as the conceptual design parameters are changed is a particular requirement. Aircraft wings are one of the most important elements of aeroelastic structures which are subjected to different kinds of loadings such as: aeroelastic forces, maneuver loads, and follower forces. In this study, the aeroelastic design considerations for civil aircraft wings are investigated and the aeroelastic analysis of a commercial aircraft wing in the conceptual design phase is considered. Results show that design parameters of the wing subsystems such as heavy engines, control surfaces, fuel tanks and winglets have considerable effects on the wing aeroelastic instability boundaries.

1 INTRODUCTION

Commercial aircraft conceptual designers generally use a combination of experimental and relatively low fidelity analytical methods and simplify the design problem by quantifying design parameters based on experience and a historical database of existing aircrafts. Although, these methods are an effective approach early in civil aircraft design, their efficiency may be restricted when designing for many new technologies. Using a design situation that includes parameterization of design and analysis models and also the models and conceptual design parameters would enable us to update higher reliability models as the conceptual design parameters are changed. This is a particular requirement in the current context of increasing complexity and challenging economic situations. Higher fidelity methods could be employed, with this capability, to make better decisions during aircraft conceptual design.

Aircraft designers have generally tried to limit the effects of aeroelastic deformations. However, due to the fact that lightweight aircraft design has received a considerable attention in recent years, the aeroelastic study of aircraft parts such as a wing has become really important [1-4]. As structural flexibility increases, aeroelastic interactions with aerodynamic forces become an increasingly important consideration in aircraft design and aerodynamic performance. Consequently, accurate prediction of the aeroelastic instabilities is really important to estimate actual flight performance in the design procedure. Furthermore, loading heavy engine nacelles that are subjected to enormous follower forces, different kinds of control surfaces and supplementary parts like winglets is the basic configuration of the most modern transport aircrafts[5]. The geometrical and physical parameters of such sub-systems change the aeroelastic characteristics of the original wing and have a complicated influence on the aeroelastic characteristics of aircraft wings [6-8].

In this paper, some major aeroelastic considerations in aircraft wing conceptual design are studied. Different kinds of systems mounted on a civil aircraft wings are considered and effects of them on the wing aeroelastic stability region are examined. Results can give designers a good insight about the wing aeroelasticity in the aircraft conceptual design phase.

2 ENGINE EFFECTS

Loading external stores is the basic configuration of the modern aircrafts wings. As shown in Fig. 1, heavy engine nacelles, usually, are mounted on transport aircrafts wings. The geometrical and physical parameters of these heavy engines have a complicated influence on the flutter characteristics of aircraft wings. This occurs because of the store inertial and elastic coupling effect with the wing.

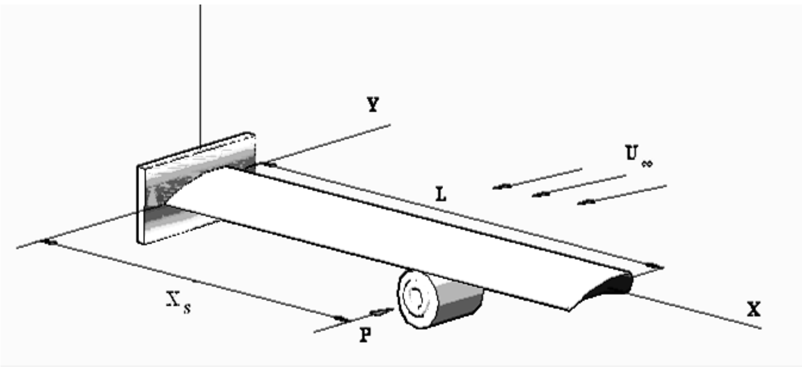

Figure 1: Engine mounted on a transport aircraft wing

2.1 Engine Mass

Engine mass and inertia can affect the wing aeroelastic instability boundary, considerably. Effects of the engine mass on the flutter boundary of an aircraft wing are illustrated in Fig.2 for different values of the wing sweep angle. Figure illustrates that increasing the engine mass value will decrease the flutter speed, noticeably, for all values of the wing sweep angle.

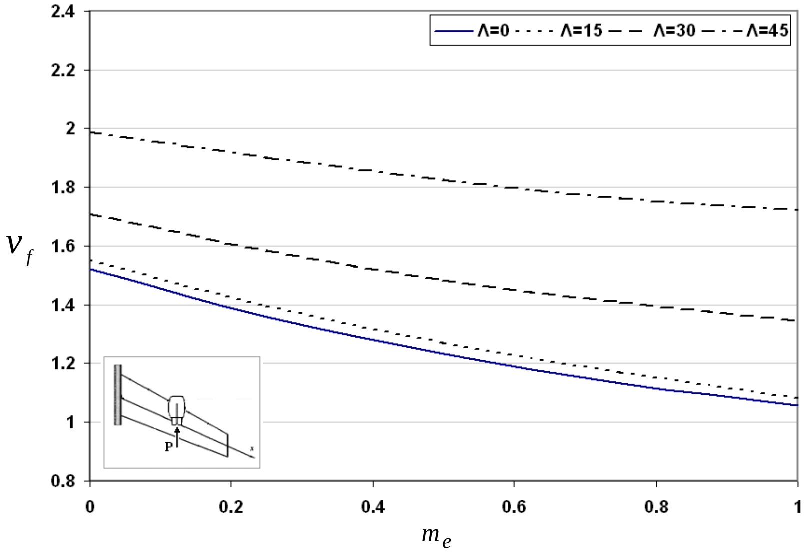

Figure 2: Effects of engine mass on the wing flutter boundary [7]

2.2 Engine Trust

The engines thrust which acts as the follower force on the structure can strongly affect the behavior of the wing vibrations. The dynamic coupling between unsteady aerodynamic loads and engine thrust with the structure motion may cause unstable dynamic motions of the wing with increasing amplitude which are known as flutter phenomena. Figure 3 shows the effect of engines trusts on the aeroelastic stability region of a twin powered engine aircraft wing. It can be seen that increasing the engines trust limits the stability region and leads to flutter in lower aircraft velocities.

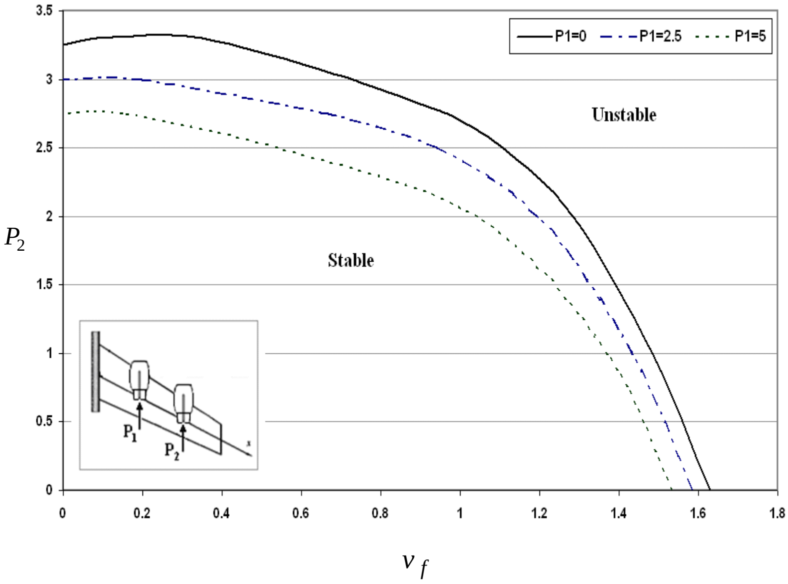

Figure 3: Effects of engines trust on the wing flutter boundary [8]

2.3 Engine Location

Engine mounting location on the wing is one of important design parameters in the aircraft conceptual design phase. Engine attached locations have significant effects on the aeroelastic behavior of the wing. The influence of the spanwise, chordwise and vertical location of the engine on the flutter speed of the wing for selected values of the engine trust are shown in Figs. 4-6. It can be seen in Fig. 4 that increasing the distance of the engine from the wing root will decrease the flutter speed. This is more apparent for smaller values of the engine trust. The instability takes place at zero air velocity for large values of the engine thrust when the engine slides to the wing end. This can be qualitatively explained as the increase of the destabilizing effect of the engine mass and thrust leading to instability, even at zero air speed.

It is observed in Fig.5 that the chordwise location of the engine contributes different aeroelastic behavior for the engine with or without thrust. But, sliding the engine toward the front of the wing will increase the flutter speed, generally. The trend of variation of the flutter speed versus the downward position of the engine as depicted in Fig. 6 is similar to the one for upward position of the engine. The results show that the flutter speed decreases continuously with increasing the absolute value of z_e, and that this decrease is at a greater rate for larger values of the engine thrust.

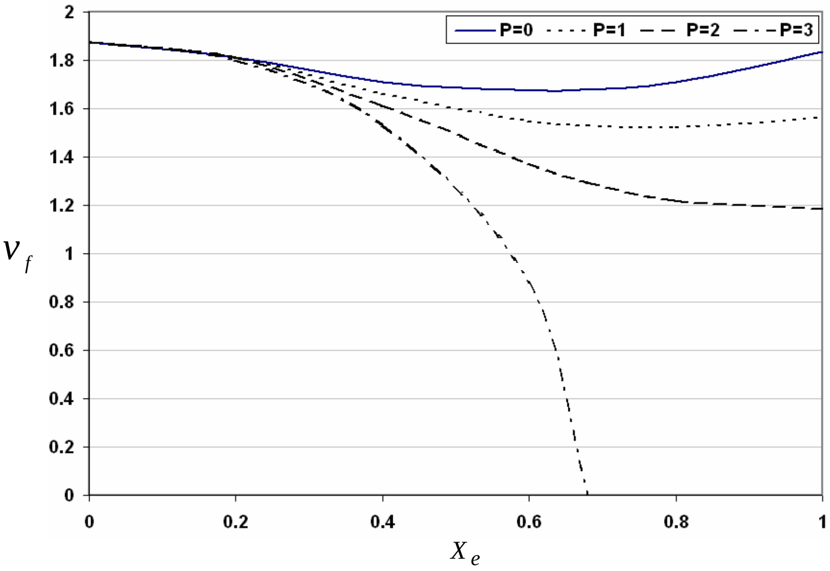

Figure 4: Effects of engine spanwise location on the wing flutter speed [7]

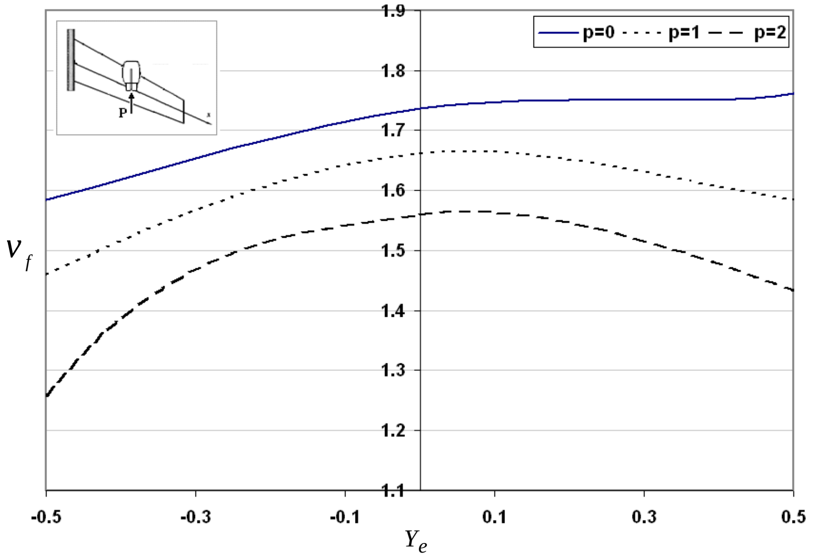

Figure 5: Effects of engine chordwise location on the wing flutter speed [7]

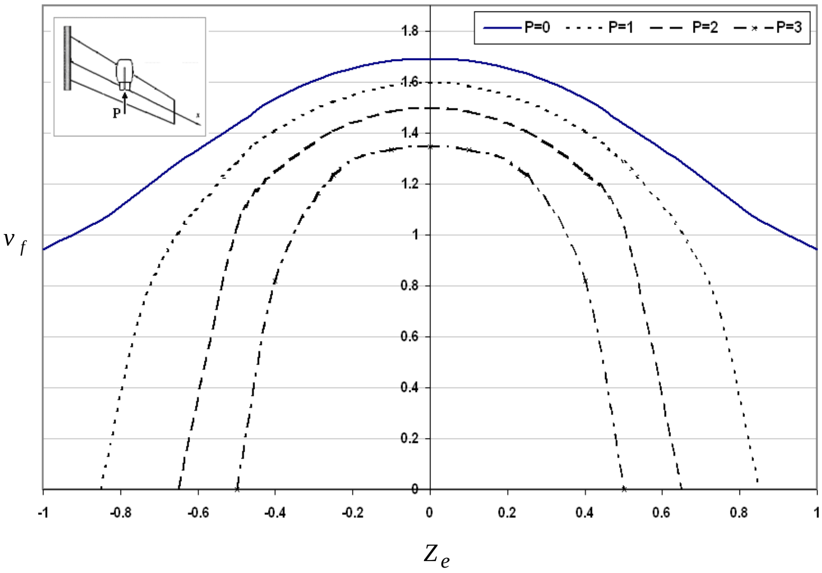

Figure 6: Effects of engine vertical location on the wing flutter speed [7]

2.4 Wing-Engine Connection

Aircraft manufacturers use different systems for fixing the engine to the wing structure. The rigidity and damping properties of this connection have influences on the wing aeroelastic characteristics. This occurs because the destabilizing effects of a civil aircraft high trust heavy engine are transferred to the wing structure through this connection. To study these effects in the aircraft conceptual design phase, one can model the wing-engine connection as shown in Fig. 7. The influence of the wing-engine connection rigidity on the wing flutter speed is demonstrated in Fig. 8. It can be seen that increasing the connection rigidity decreases the flutter speed.

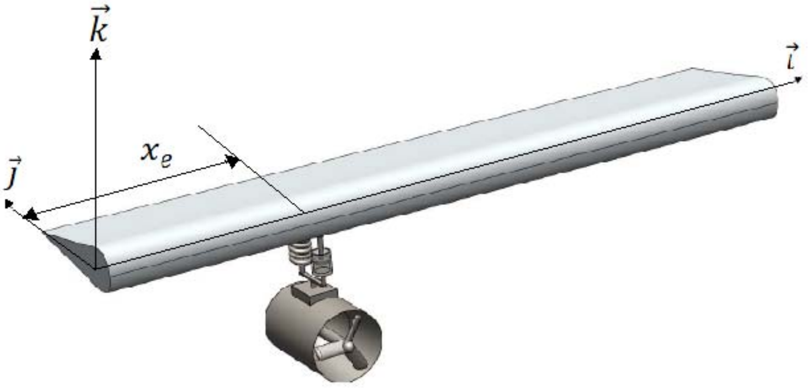

Figure 7: Modeling of the wing-engine connection

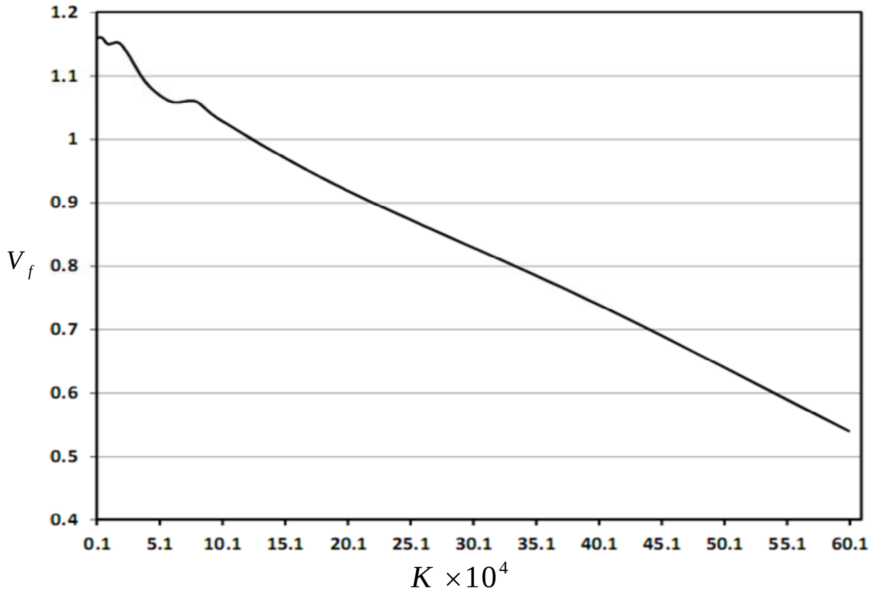

Figure 8: Effects of wing-engine connection rigidity on the wing flutter speed [9]

2.5 Engine Blades Rotation

Engine blades rotational speed cause gyroscopic effects in system and hence the wing flutter speed varies with engine blades rotational speed. Increasing the engine blades rotational speed will decrease the wing flutter speed as shown in the Fig. 9.

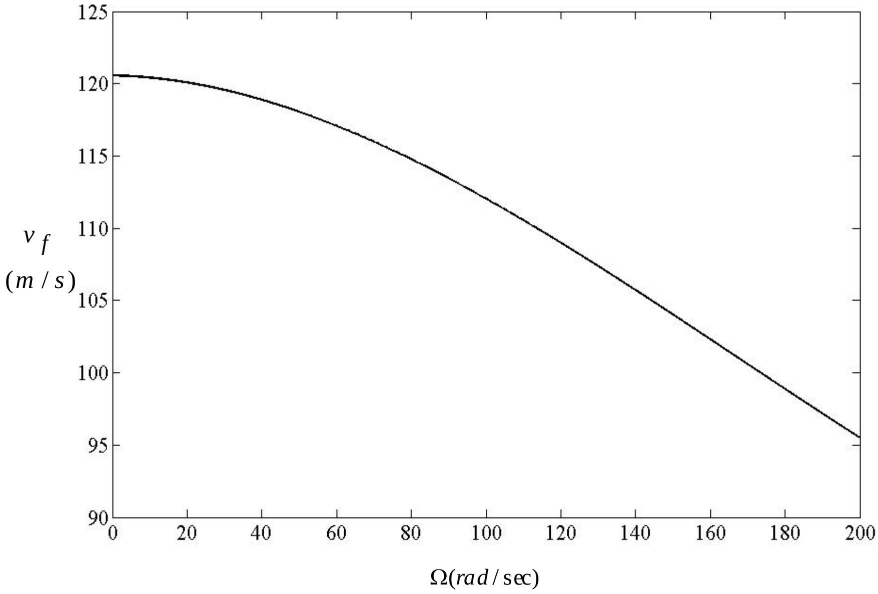

Figure 9: Effects of engine blades rotational speed on the wing flutter speed

3 MANEUVER EFFECTS

In high speed advanced flight vehicles some terms in governing equations are caused by complex maneuvering condition. These terms have significant influence on dynamic response and stability of flight vehicle wings. Due to the numerous degrees of freedom, the aircraft may experience a general angular velocity its components can be sensed in three different spatial planes (Fig. 10).

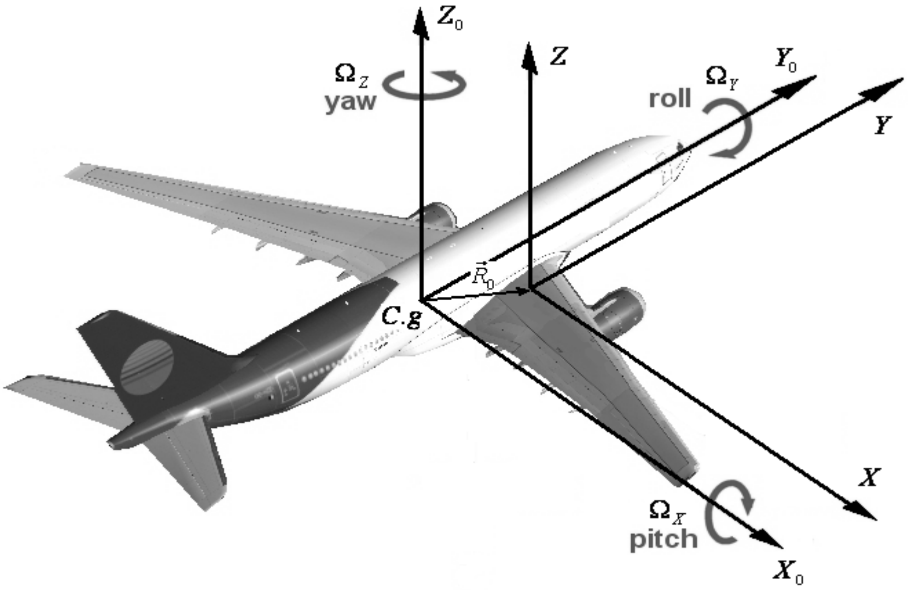

Figure 10: General maneuvers of an aircraft

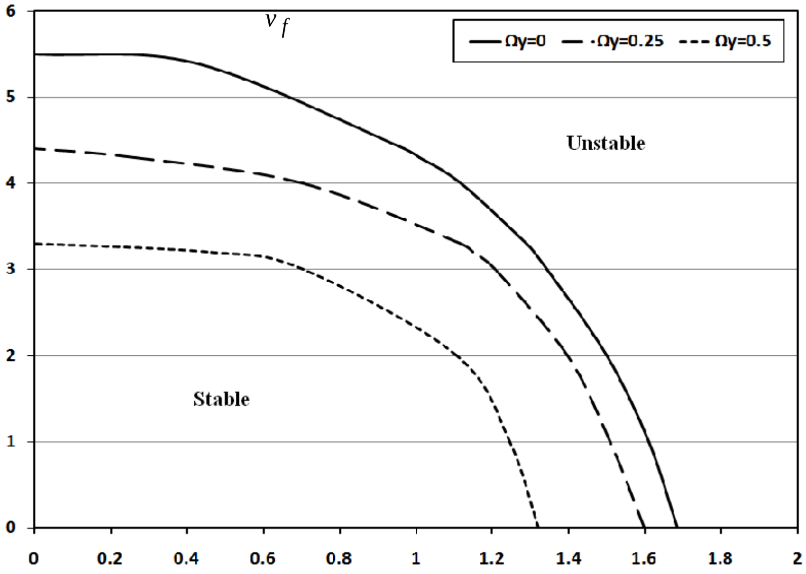

Figure 11: Effects of roll maneuver angular velocity on the wing flutter speed [10]

When an aircraft is undergoing a maneuver, such as roll, flutter can be adversely affected. This means that these aeroelastic characteristics can deteriorate to the point of endangering the safety of aircraft. This fact imply that a reliable analysis of aircraft wing necessitate the development of the refined simulation model featuring the incorporation of the maneuver effects.
Figure 11 shows, for example, the effect of the rolling maneuver angular velocity on the flutter boundary for the wing carrying a powered engine. It is clear that increasing the roll angular velocity constricts the stability domain of the wing, significantly. This is more obvious for higher values of the roll maneuver angular velocities.

4 CONTROL SURFACES EFFECTS

Several control surfaces with different works are mounted on modern civil aircraft wings. Figure 12 illustrates a schematic wing with a control surface, elastically, attached to it. Geometrical and physical properties of these control surfaces may affect the aeroelastic behavior of the wing. Parameters like control surface length, mounted location, rigidity of its connection to the wing and its angle relate to the wing have considerable effects on the wing aeroelastic stability domain. For example, effects of the control surface length on the flutter speed are sketched in Fig. 13.

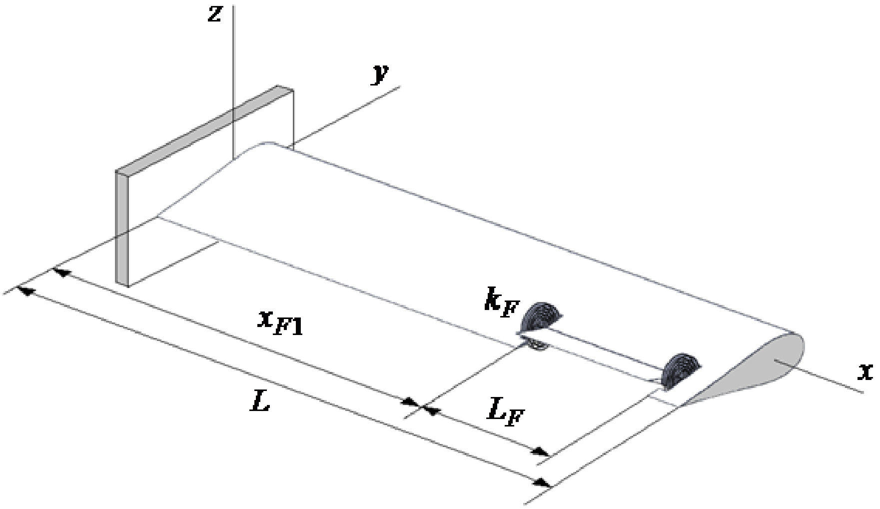

Figure 12: Schematic of a wing with control surface

5 WINGLET EFFECTS

Winglets are wingtip devices intending to reduce the induced drag in aircraft. There are many types of winglets; the most common are those comprising upper elements, only. Mounting a winglet on an aircraft wing may change the structural and aerodynamic properties of the wing and leads to different aeroelastic responses. Indeed, any change in winglet design parameters like winglet length or angle can influence the aeroelastic behaviour of the wing. Figure 14 shows the effect of the winglet mounting angle on the wing flutter speed.

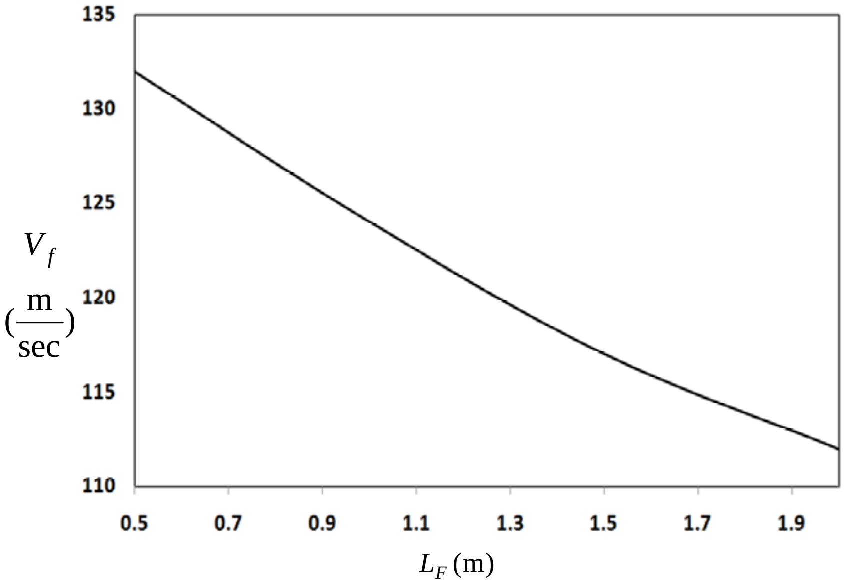

Figure 13: Effects of control surface length on the wing flutter speed

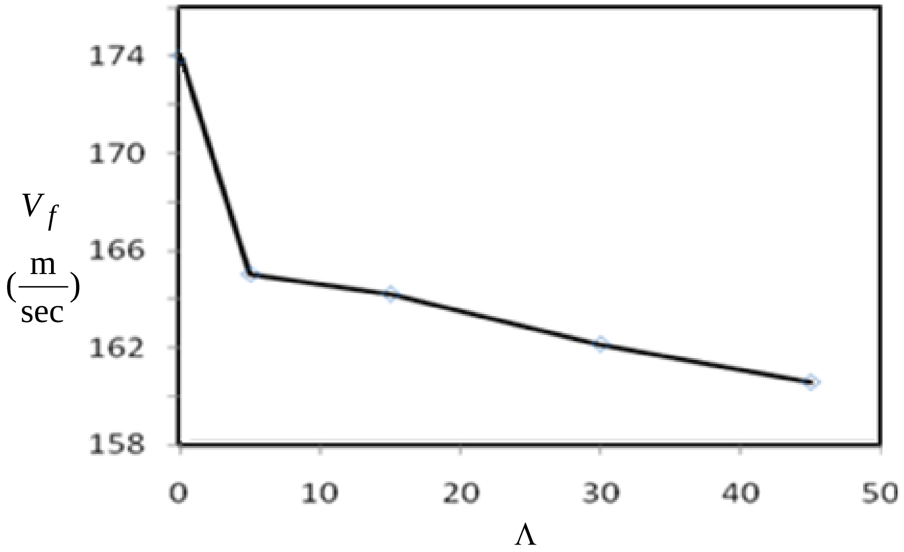

Figure 14: Effects of winglet mounting angle on the wing flutter speed

6 FUEL EFFECTS

In modern civil aircrafts, a big volume of the aircraft fuel is saved in the wing fuel tanks. This fact means that for a reliable aeroelastic analysis of the wing the fuel effects should be considered. To this end, the aeroelastic analysis is performed using NASTRAN and ZAERO software (Fig. 15). The aircraft wing structure is modeled in NASTRAN. Then the aerodynamic loadings due to the wing structure deflections are computed in ZAERO. By coupling these two softwares, the aeroelastic analysis of the wing is conducted. Results show that the fuel located in the wing fuel tanks have considerable role on aeroelastic instabilities. It can be seen in Fig. 16 that flutter speed for the studied wing is 463m/s. this value is 492m/s for a wing with the same geometrical and physical properties and without consideration the fuel effects.

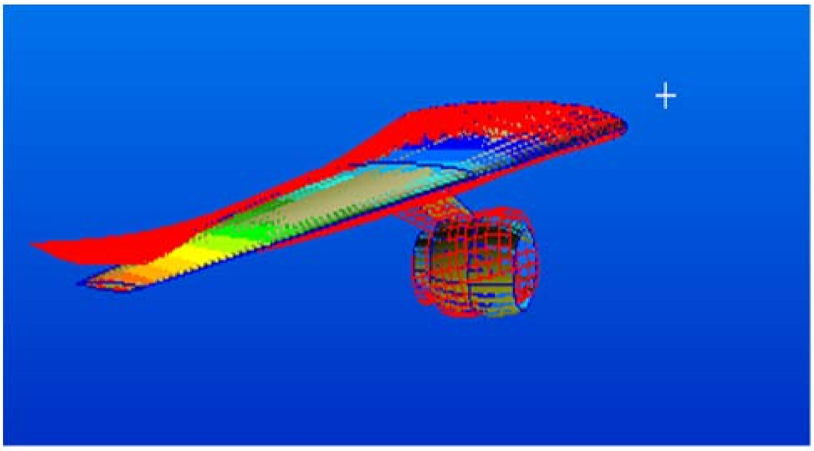

Figure 15: Aeroelastic analysis of an aircraft wing with ZAERO

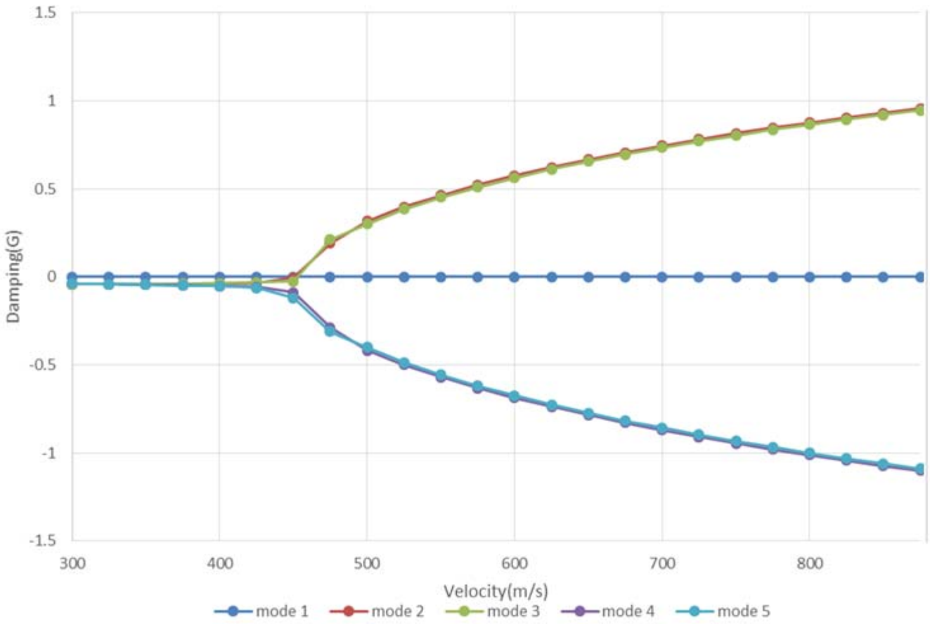

Figure 16: Flutter speed of an aircraft wing with fuel tanks

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