Flutter Phenomenon in Aeroelasticity

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ABSTRACT

The aircraft design industry continues to develop sophisticated passenger and cargo planes. However, the development of supersonic jets like the Aeritalia F-104S, Boeing X-32, Concorde, and Raven, among others, continues to be a challenge to aircraft designers. Besides being loud and inefficient, these jets are also believed to be at a higher risk of aeroelastic instability, which may cause flutter damage. Flutter damage has the potential to cause significant damage to an aircraft's wing structure, which may increase the cost of maintenance. As a result, there is a need to find out ways to approximate the impact of flutter, informing ways to suppress it. The current research explores the concept of flutter phenomenon in relation to Aeroelasticity, how to measure the impact of flutter, and how to suppress it.

INTRODUCTION

Aircraft travel is one of the safest modes of transport and cargo transfer. However, it also happens to have the highest maintenance costs. One of the phenomena that raise this cost is the need to mitigate flutter damage. Damage occasioned by flutter instability is an occurrence that many aerodynamicists do not understand well. However, it is widely accepted that the instability is occasioned by flying an aircraft at high subsonic speed speeds. This results in the formation of a flutter boundary, which might be destructive [5]. Due to the need to mitigate the damage due to flutter analysis, aircraft design, and maintenance, companies need to determine flutter characteristics. The current study explores the concept of the flutter phenomenon as a critical component of aircraft safety management. The study explores previous literature covering the aeroelastic problem. Besides, it suggests the different approaches that can exemplify the impact of flight conditions on wing structure. In the end, it presents the different ways that the flutter phenomenon can be suppressed to solve the problem of aeroelastic instability.

AEROELASTICITY

Aeroelasticity is the situation that necessitates the need for flutter analysis at the aircraft design stage. As a result, many scholars have researched the phenomenon. Therefore defining aeroelasticity as the "interdisciplinary study of the combined effects of aerodynamic, elastic, and inertial forces" [1]. Consequently, it is aeroelasticity that restrains the flight envelops, causing resistance in a flight's velocity. As a result, the flight might get diverted, reversed, or experience flutter damage. Diversion occurs when an aeroelastic twist occurs in the wing structure resulting in its collapse [1]. The collapse follows the inability of the vital forces of the structure to withstand the resultant aerodynamic loads.

On the other hand, control reversal manifests in a reduction in control surfaces' effectiveness, detracting them from their intended functionality. The third possible occurrence, flutter damage, is the diverging vibrational response that is birthed by the interaction of elastic, aerodynamic, and inertial forces [1]. However, for flutter to occur, fluid-structure interaction parameters need to have reached specific values.

FLUTTER PHENOMENON

Towards this end, an analysis of how flutter occurs and the specific ways that can be used to mitigate it is necessary. Aeroelastic stability, which is also known as whirl flutter, is the susceptibility that results from the mounting of a rotor or propeller in a wing nacelle [2]. When the plane sets in high motion, aerodynamic forces start acting on the blades. During this time, gyroscopic effects act on the entire rotor, together with its wing structural modes. The two simultaneous forces occasion an instability that can result in structural damage [2]. There are two forms of whirl flutter due to these forces: forward and backward whirl [2]. According to them, the direction that the rotor blades determine the whirl flutter classification such that, if the whirl and the rotor blades are spinning in the same direction, then it is a forward whirl. However, if they spin in different directions, then it is a backward whirl [2]. Whichever the case, the size and flexibility of the rotor blades, the design, and cruise speed determine the aircraft's susceptibility to whirling flutter.

FLUTTER ANALYSIS

The past literature is rich in information about how best to test Aeroelasticity. Some of these tests include ground vibration [3], infrared, and wind tunnel testing. All proponents of ground vibration tests argue that strategies such as using a reduced structural aircraft weight of an aircraft combined with lightweight materials can be used to make more fuel-efficient aircraft. However, in their view, one disadvantage arises [3] [2] [5]. Such an aircraft may become flexible, which may result in structural deformations due to structural under loading. Besides, such under loading may occasion flutter damage [6]. As a result, there is a need to develop strict laws defining desired control laws [7]. Ground vibration tests facilitate the estimation of vibrational modal shapes and modal frequencies by processing various algorithms [3]. The test is credited to the University of Minnesota [3]. However, instead of considering a vehicle like the Laboratory of the University of Minnesota, the second study considered aircraft [3]. Some of the procedure changes from the one used by the Laboratory of the University of Minnesota include the excitation signal, more significant sample size, and the adoption of alternative algorithms.

The excitation signal generated by input force and acceleration was used to measure how flexible the aircraft was. Towards this end, the small flying wing aircraft was suspended using a single flexible spring [4]. The spring's flexibility was assigned priority to approximate free oscillation, as shown in Figure 1 below. Besides, it was attached to the aircraft's COG to allow it to remain at a horizontal position throughout the test [4]. A shaker and an impulse hammer were then used to generate excitation [4]. Modal frequencies and modal shapes were recorded to ascertain the extent of changes. The process and procedures adopted are vital components of the ground vibration test [4]. According to him, aircraft need to undergo ground vibration tests and attain the accompanying certification before being cleared for structural and Aeroelasticity analysis.

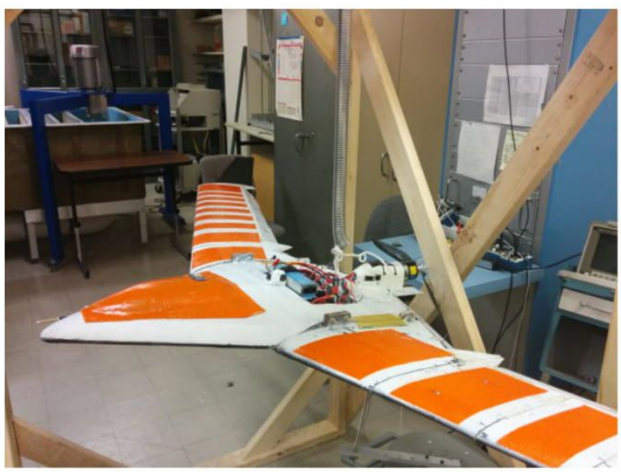

Figure 1: A small flying wing aircraft set up for GVT

The other two approaches include wind tunnel testing and the infrared imaging test. Aircraft manufacturers increasingly prefer wings with lighter structural elements oblivious to the existing safety and performance criteria [5]. However, such structures are associated with enhanced fuel efficiency [3]. Equally, the flexibility that comes with such structures cannot be compared with heavier ones. Besides, they may be susceptible to flutter instability. Based on this background, a study was launched to investigate the changes in a high-aspect-ratio wing in simulated flight conditions [5]. From the study's findings, such conditions result in large structural displacements that occasion wing bending and twisting [5]. Further, the findings of the study are based on the HMAE1 project. Thus, the model, like the GVT, tests using simulated conditions and a small wing aircraft.

The findings collate with and are supported by other findings. For instance, a particular study used the international CRIAQ MDO505 Morphing Wing project framework to validate its research findings [6]. Though simulated, the findings draw a consistent pattern with the studies discussed in previous paragraphs. From the results, it is indeed true that flight conditions due to Aeroelasticity can cause fluttering damage [6]. This notwithstanding, airplane manufacturers can place an aluminum skin on the win without necessarily putting the wing's structure at risk of flutter damage [6]. The infrared approach has also been used to predict flutter characteristics. However, they claim that the technique is not self-sufficient [7]. The researchers in the study were forced to use the wind tunnel tests to validate their findings, highlight the positive points, and make improvements [7]. Nonetheless, they agreed with all the previously discussed articles that performance enhancement of aircraft by using lighter structural elements increases wing structure flexibility, which in return increases the risk of flutter damage.

CONCLUSION AND RECOMMENDATIONS

As the discussions reveal, the creating of lighter and faster jets is something worth recognition. However, it is agreeable that aeroelastic effects constrain this innovation. Undoubtedly, any invention that would help alleviate these risks would be a breakthrough for aeroelasticians. Besides allowing aircraft designers to manufacture highspeed aircraft, the innovation would make air travel safer. Towards this end, the current study explored some of the techniques that aeroelastists can use to evaluate flight conditions' impact on aircraft wing structures. Some of the approaches considered included wind tunnel, infrared, and ground vibration tests. Notably, all these approaches came to the same conclusion that aeroelasticity instability due to the flexibility of lighter wing structures could cause fluttering. Towards this end, there is a need for aircraft designers to adopt flutter suppression techniques to make aircrafts safer. For instance, active feedback controllers can be used to suppress flutter. Alternatively, the adaptive flutter control technique using adaptive pole assignment, non-linear flutter suppression, piezo ceramic actuators, and the fuzzy gain scheduler are some of the suppression techniques [8]. Airplane manufacturers can also consider placing an aluminum skin on the wing without exposing it to flutter damage [6]. The current research covers the flutter phenomenon and aeroelasticity concepts, making it a foundation for further research on the topics.

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