Active anti flutter control

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1 Introduction

Dynamic Aero-elasticity is the branch of physics and engineering that deals with the interactions between the inertial, elastic, and aerodynamic forces that occur when an elastic body is exposed to a fluid flow. Flutter is a dynamic instability of an elastic structure in a fluid flow, caused due to the body's deflection and the force exerted by the fluid flow and undergoes simple harmonic motion, zero net damping, and so any further decrease in net damping will result in a self-oscillation and eventually failure.

This oscillation/vibration can cause structural failure and hence considering flutter characteristics is an essential part in designing an aircraft. In order to reduce this damping effect the passive methods currently being used are:

- Material stiffening
- Mass balancing

The FAA regulations require a commercial transport to be flutter free at speeds 20 percent greater than the design dive speed. [1] In fighter aircrafts,[2] The total damping coefficient, shall be not less than 3 percent for any critical flutter mode for all altitudes and operational flight speeds.

2 Motivation for Active flutter supression

There are several advantages in moving to the active system for flutter suppression over the traditional passive approach. Stiffening and mass balance solutions are too expensive. If the problems arise in the latter stages of the design process it requires redoing and altering aerodynamics and inertia. As stated in [3], if a subsonic commercial aircraft wing increases aspect ratio above ten, substantial stiffness for flutter suppression may be required. The aeroelastic vibrations characterized by weak damping reduce the fatigue life of the structure and consequently lead to catastrophic failures of the aircraft components.

Non linearities arising from control surface free play, stiffness non linearities due to large deformations, structural damping non linearities and aerodynamic non linearities lead to limit cycle oscillations (LCO). LCOs are sustained constant amplitude oscillations due to aeroelastic interactions. In these cases the passive systems act as a narrow pass filter in the linear zone and requires feedback control, capable of negating these oscillations[4]

3 Methodology

The working principle of an Active flutter suppression follows that the aircraft motion would be captured by sensors that in turn would command the control surfaces or other changes in the shape of the aircraft to achieve desired dynamic behaviour.[5]

Unlike flight control systems for stable aircrafts such as gust alleviation, ride comfort and handling quality, an Active flutter suppression requires stabilizing of an unstable plant which are of high frequencies and complex flutter mechanisms.

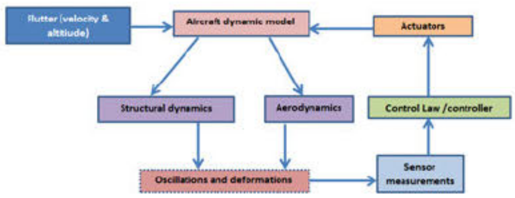

Fig. 1 . Active flutter suppression block diagram

4 Measurement and control law

Accelerometers and strain gauges are often used. While accelerometers can directly measure oscillations (integrating the acceleration twice), strain gauges measure the deformations of the structure caused by the surrounding unsteady flow. Both bending and torsion gauges are installed. All of these devices are designed to sense the motion of the structure itself (see Fig.1), however, there are also emerging sensing techniques which focus on direct sensing of the unsteady flow around the surface, as stated in [6] hot-film gauges provide direct information on flow oscillations caused by gust or flow oscillations.

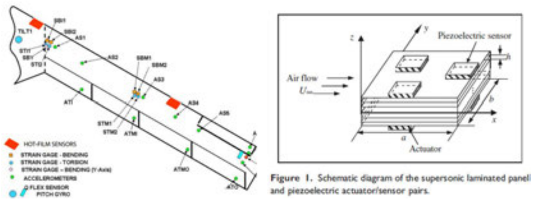

Fig. 2 . Sensors

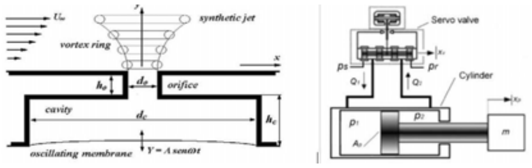

Fig. 3 . Synthetic Jet and electrohydraulic actuators

Besides, some other new technologies such as fiber bragg grating (FBG) sensors are also used for flutter detection [7]. As explained in [8] and [9], since the wavelength of maximum reflectivity depends on several parameters such as fiber temperature or mechanical strain, Bragg gratings can be used as strain sensors.

4.1 Actuators

As stated in [10] the main decisions that must be made to design a flutter suppression system are the selection of an actuator, of a control objective and of a control law.

Closed loop action of control surfaces possible with high band width actuators. Electrohydraulic servoactuators are often employed to deflect control surfaces. However, active flow control emerging techniques such as synthetic jets actuators (SJA) at the walls are also used to change the flow around the wing either by blow or suction. These technologies rely on adding or removing fluid at the wing surface which is equivalent to shape modification.

Some of the advantages of SJAs for flow control over control surfaces are: less complicated mechanisms, less weight and control reversal is avoided.

As explained in [11] the actuator consists of a spanwise slot on the upper part of the wing through which air is sucked in and then blown out with added momentum. This way the flow around the wing can be changed for gust alleviation.

5 Testing

Prototype testing on scaled models have been taken up both in experimental flight tests for validation of mathematical models, ground vibration tests and wind tunnel tests. The identification, in flight, of the aeroservoelastic characteristics of a flight vehicle pose a challenge due the input and output used for system identification would be noisy.

Fig. 4 . few of the testbeds used for Active flutter suppression system (from top)NASA DAST.Lockheed X56,B-52 and F404

6 Current developments

In the year 2000, rapid developments occurred in computational structural dynamics simulations and Assessment of fatigue life of structures due to aeroelastic oscillations. The years leading to 2010 demonstrated optimized aircraft structures to overcome low speed flutter characteristics by composite materials. From the year 2012, investigations were carried out for composite materials behaviour using advanced computational tools against the AFS associated problems.[12]

7 Challenges in Active Flutter Supression

From a certification point of view, AFS increases the complexity in the certification process mainly due to multidisciplinary nature and requiring uncompromising reliability.

Secondly, availability of test data to the aeroelastic community is largely varying due to import restrictions and defense issues. Thirdly, inconsistent and widely accepted equations for active control applications.

Other challenges and research areas include designing control laws by means of higher order multi-degrees of freedom mathematical models, along with validation and verification. Also a transparency in approaches and reduction of sensor noise and error [7].

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