# Effects of Aerodynamic Flutter on a Flight Surface Actuator

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## 1. Introduction

The purpose of this paper was to study the effects of aerodynamic flutter on a flight surface actuator. The forces generated by this type of flutter were studied on an electrohydrostatic actuator (EHA).

The effects of flutter were modeled and analyzed. Current methods of controlling flutter include dynamic mass loading and changing stiffness by design. The paper proposed an alternative way to dynamically control the effects of flutter on flight surfaces that use electrohydrostatic actuation.

Through analysis, it was found that in EHA systems, two parameters would impact the response of flutter: damping ($B$) of the mechanical load, and the effective bulk modulus of the hydraulic oil ($\beta_e$). There are systems available that can be implemented to change these variables dynamically. The results of changing these variables are discussed and presented here.

## 2. Aerodynamic Flutter

### *2.1 Introduction and Definition*

Aerodynamic flutter is an important concept in the aerospace field because it greatly affects the structural integrity of modern airplanes and spacecraft. Flutter was first observed on a Handley Page O/400 twin engine biplane bomber in 1916. [1] Since then, the concept was studied in detail in the hope that a sound analytical proof would be found. Many techniques had been developed and used by engineers and scientists to study the effects of flutter. They included in-flight tests, prototypes in wind tunnels, and computer modeling. Studying the effects of flutter can be challenging and, for this reason, it has become an interdisciplinary field—one that includes aerodynamics, aeroelasticity, mathematics, and mechanics.

Aerodynamic flutter is defined as "a self-excited or unstable oscillation arising out of the simultaneous action of elastic, inertia, and aerodynamic lift forces upon a mass, or a system of masses." [2] This kind of vibration is not inherent only to the field of aerospace. Analogous effects are also seen on bridges, electrical wires, and buildings.

### *2.2 Modeling Techniques*

Analytically speaking, "the formulation of flutter equations and their solution can be a very tedious and time-consuming task. It usually results in an eigenvalue problem, which can be quite complex, or even practically impossible to solve by analytical methods." [3] However, when attempting to solve for an exact solution, an elastic body—which normally has an infinite number of degrees of freedom—is replaced by a body with only three degrees of freedom. [4]

It is important to note that the elastic properties of materials makes modeling quite difficult. When the elastic response of a material is non-linear, the use of linear solutions yields inaccuracies. Therefore, yielding an analytical solution is often too cumbersome when computer models yield reasonably accurate results.

## 3. Electrohydrostatic Actuator

### *3.1 Introduction and Definition*

In the aerospace field, actuation systems usually refer to the group of devices that are responsible for the control of a flight surface—aileron, elevator, rudder, spoiler, airbrake, and slats. An EHA is a device that combines applied hydraulic forces with accurate electronic control. Previous systems were centralized and relied on valves that would control the flow of the hydraulic fluid, and consequently the control of the flight surface.

Modern EHA devices control the position and angular speed of the pump electronically. Computer control of flight surfaces are mandatory to achieve some aggressive flight performances desired by some military aircraft. New EHA devices allow accurate control and quick response time of flight surfaces.

### *3.2 Flight Surface Actuator*

In most EHA systems, a DC motor controls a hydraulic pump. For a flight surface actuator, the hydraulic pump provides the appropriate pressure and flow of hydraulic fluid throughout a circuit. The direction and strength of flow determines the amount of extension or retraction of a piston, which is connected to a control surface. The change in flight surface is felt by the pilot through a change in the flight performance. Please refer to Figure 1 for a schematic of the basic system. The force generated by the piston creates a torque on the flight surface, which has to overcome aerodynamic and inertia loads. [5] Another load that may be felt by the flight surface includes any flutter force.

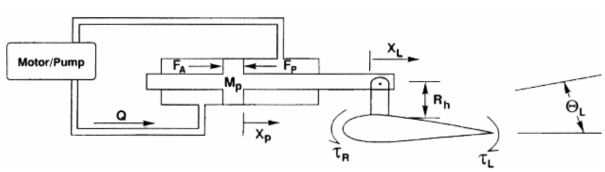


*Figure 1: Basic Flight Surface Actuator* [5]

### *3.3 The EHA Model*

The EHA model to be used in the design of a flight surface actuator was presented by [6]. The circuit diagram and mathematical models are presented in [6] and were used to create a MATLAB model of the EHA system. The flutter force was modeled harmonically as $F = A\sin\omega t$, and was added to the EHA model. The results of adding flutter are shown in Figure 2.

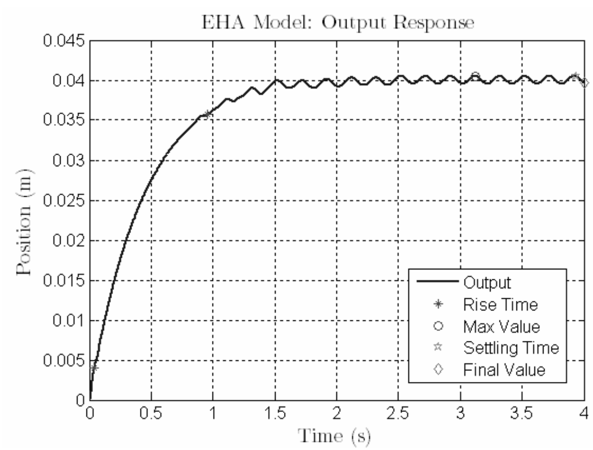


*Figure 2: EHA Output with Flutter*

## 4. Controlling Flutter

Through analysis, it was found that two system parameters can impact the response of flutter: damping ($B$) of the mechanical load, and the effective bulk modulus of the hydraulic oil ($\beta_e$). Damping of the mechanical load stiffens the response of the system. The effective bulk modulus is known as the inverse of fluid compressibility. Compressibility of a fluid is defined as the change in volume over the original volume, during a period of changed pressure. In a hydraulic sense, $\beta_e$ can be interpreted as having an effect similar to a spring. Increasing the damping of the system and effective bulk modulus of the hydraulic circuit changes the spring and damping effects, and can reduce the effects of flutter. This is shown in Figure 3.

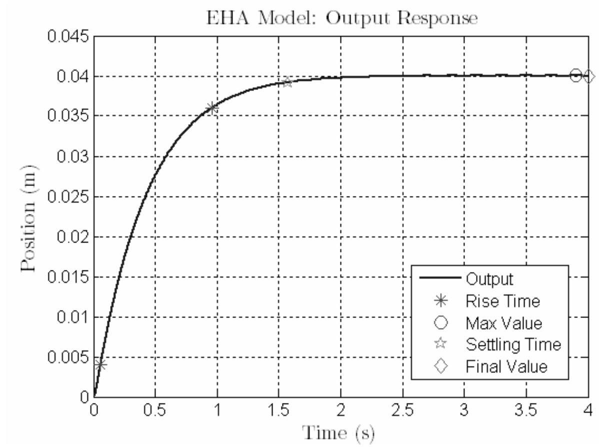


*Figure 3: Effect of Increasing B and $\beta_e$ on Flutter*

## 5. Conclusions

Controlling the effects of flutter is important to the aerospace industry. The proposed methods of controlling flutter demonstrate that it is possible to control the effects of flutter by new means, as opposed to mass balancing and structural stiffening. The methods could be implemented dynamically which would provide a method of reducing flutter forces when they first appear and on-the-fly.

## References


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