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Aeroelasticity

What is Aeroelasticity?

An airplane's wing generates an upward force, known as lift, when it passes through air. Although lift is needed for a plane to fly, its effect on the structure of the plane can be harmful. Aeroelasticity refers to the deformation of an airplane's wing in response to aerodynamic forces, such as lift. [1]

AEROELASTICITY, *NOUN*

A term used in the field of aerospace engineering to describe the interaction between a structure and a moving fluid [1].

Static vs. Dynamic Aeroelasticity

Aeroelastic effects are classified as either static or dynamic. While static effects reach an equilibrium, dynamic effects are defined by oscillations [2].

Static Aeroelasticity:

- **Divergence** refers to a process in which the lift a wing produces causes the wing itself to twist. This twisting leads to greater lift, which causes more twisting. The process continues until equilibrium is reached [1]. In order to prevent divergence, a wing must be stiff enough to prevent twisting. If the wing is too flexible or the force of lift is too strong, divergence will occur [2].
- **Aileron reversal** occurs when wing twisting causes the plane's response to the pilot's commands to be reversed from the expected. In other words, when a pilot tries to turn left, the plane will turn right [2].

Aeroelasticity applies to any situation in which a fluid (gas or liquid) flows around a structure [3].

DID YOU KNOW?

Aeroelasticity affects airplane stability, bridge design, and even blood flow through the body! [3]

Dynamic Aeroelasticity:

- Above a critical wind speed, a wing experiences **flutter instability**, which causes the wing to oscillate. Flutter begins when lift twists a wing in one direction. The wing's stiffness resists this twisting. However, when the wing once again reaches its equilibrium position, it is oriented in such a way that lift begins to twist the wing in the other direction (see Figure 1). Rather than dampening, these oscillations can increase to a dangerous level. [1]

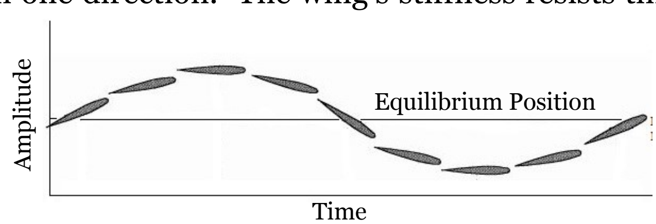


Figure 1: Oscillations of a Wing Experiencing Flutter [4]

Why Should We Study Aeroelastic Effects?

Safety

To achieve efficient flight, modern airplanes are often designed with lightweight materials. However, the flexibility of these materials makes planes susceptible to adverse aeroelastic effects. For this reason, engineers must consider aeroelasticity during the design process. Engineers rely on their understanding of aeroelastic effects to ensure the safety of airplanes [1].

Space Exploration

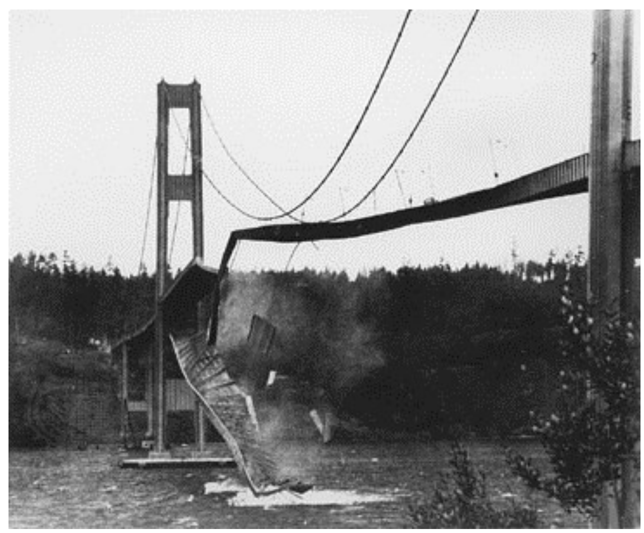
The success of future space exploration missions will depend on our understanding of aeroelasticity. In the future, NASA engineers hope to use inflatable decelerators to slow down rockets entering another planet's atmosphere. However, our ability to design these decelerators is limited by our understanding of aeroelastic properties [5].

Understanding

Because interactions between a structure and a flowing fluid are complex, engineers are still unable to confidently predict and understand aeroelastic phenomena. Hoping to change this, NASA's Langley Research Center is working to establish an experimental benchmark against which mathematical models of aeroelasticity can be compared and validated [6].

How Does Aeroelasticity Affect Me?

Our understanding of aeroelasticity has a major impact on civilian safety. Just as aerospace engineers consider aeroelasticity when designing safe aircraft, civil engineers must consider the aeroelastic effects on buildings and bridges. The collapse of the Tacoma Narrows Bridge on a windy day in 1940 made it clear that aeroelasticity should be considered in suspension bridge design. The cause of collapse was attributed to aeroelastic flutter. The bridge continued to oscillate out of control until the bridge collapsed [7]. If the aeroelastic properties of the bridge design had been fully considered, this disastrous event could have potentially been avoided.



Tacoma Narrows Bridge collapse [8]

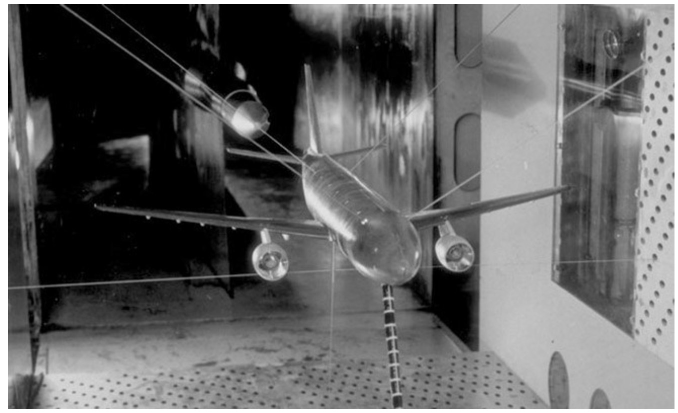
Are Aeroelastic Effects Always Bad?

Although the goal of aeroelastic research is often the discovery of a design that minimizes aeroelastic effects, numerous beneficial uses of aeroelastic phenomena do exist. A wing experiencing flutter instability appears to be an effective source of power generation because it maintains its oscillations. This means that the wing is effectively converting energy from the moving air to energy in the form of oscillations [2]. Hoping to harness this energy, a group of engineers is attempting to utilize the oscillations of aeroelastic flutter to generate electricity [9]. Another beneficial use of aeroelastic deformation is in the optimization of micro air vehicles, which are tiny planes that often rely on flapping wings for thrust. In aircraft with flapping wings, aeroelastic effects are beneficial because they allow the wing structure to exhibit the twisting motion required for effective flapping flight [10].

How Do We Analyze Aeroelasticity?

Many early airplane failed to achieve sustained flight because their designs suffered from aeroelastic problems. The wings of these planes were not stiff enough to resist divergence. To address this issue, flight tests of aeroelastic flutter began as early as 1935. Presently, aeroelasticity is often studied with wind tunnel testing of scale models [1]. The aircraft is also subjected to vibration testing while on the ground. These tests simulate the forces that the aircraft will likely experience while in flight [2]. Flight tests are only conducted as a final means of verifying test results and predictions [1].

Today, engineers rely on computer programs and mathematical modeling to refine aircraft designs. The major challenge in computer modeling of aeroelastic effects is interfacing programs that calculate wing deformations with those that model the fluid flow around a wing [3]. Once a useful model is created, it must always be validated with experimental data from wind tunnel tests of a wide variety of wing designs [6].



Wind tunnel testing of a scale model [2]

Should We Worry About Aeroelasticity While Flying?

Engineers take every precaution to prevent aeroelastic problems in passenger aircraft. Before a plane is declared safe for flight, engineers must make certain that aeroelastic effects will not occur under expected flight conditions [2]. Engineers also conduct aeroelastic analysis to ensure the safety of bridges [11].

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