Vibrations in Aircraft

10.6

Aircraft are used all over the world for many purposes, such as transportation of cargo, personal and business travel, and national security. Many of us take aircraft safety for granted. The safety record of commercial aircraft is outstanding because aircraft designers and engineers have put a tremendous amount of effort into their design.

Aircraft undergo many types of vibrations. Usually, passengers only notice minor vibrations, such as noise and flexing of the wings, which are normal and perfectly safe (**Figure 1**). There can be more serious, abnormal vibrations in aircraft, however, and aircraft designers and engineers constantly study these vibrations to make aircraft safer. In this section, you will learn about how vibrations can start in aircraft and what is done to minimize them.

Figure 1 The wings of commercial airliners are designed and constructed to be flexible. Most wave motion that the wings experience is accounted for in the design.

Causes of Vibrations

Vibrations in modern aircraft have several causes, most of which are not unusual or dangerous. For example, vibrations happen during extension and retraction of landing gear, deployment of aerodynamic brakes (**Figure 2**), and takeoff and landing. The operation of the engines also produces constant vibrations. All these vibrations are expected and have been minimized by appropriate design features.

Figure 2 Aerodynamic brakes cause normal vibrations in aircraft.

Other normal vibrations experienced by an aircraft come from the mass distribution and the structural stiffness of the aircraft. Usually, very low-amplitude vibrations result when typical forces act on the aircraft due to airflow over the surfaces. Most passengers hear these vibrations as background noise. The vibrations get much larger in turbulent (rough) air, and passengers can actually feel them. Sometimes, when the engines are operating at certain levels, increased vibration may occur due to resonance. This is normal and often sounds loud only because the waves are transferred through the frame of the aircraft to the ears of the passengers. Even the operation of mechanical components such as pumps can cause some vibration in aircraft.

The flight crew quickly becomes familiar with normal aircraft vibrations. They detect these vibrations by sight, sound, and feel. As an added precaution, aircraft engineers put sensors in the engines in case abnormal vibrations start that are not detected by the crew. Each aircraft has different characteristics and slightly different but normal vibrations, but an experienced crew gets used to them.

Abnormal vibrations can be quickly recognized because they often occur suddenly and are accompanied by an unfamiliar noise. They can be steady or random, can have an obvious source, or can be difficult to pinpoint. Causes include malfunctions in mechanical equipment, an engine rotor imbalance, irregular airflow over an external part of the aircraft that is damaged or not closed properly, excessive wear, and free play (parts that can vibrate with little force acting on them).

Types of Vibrations

Buffet is a type of random vibration that is usually caused by an interruption of airflow. Buffet is often felt when the aerodynamic brakes (Figure 2, page 469) are used or when the aircraft flies through turbulence. In addition, a certain amount of noise is to be expected due to the operation of the engines. Aircraft noise is a vibration caused by the rapid back-and-forth movement of one part of the aircraft.

The most dangerous type of vibration in aircraft is aeroelastic flutter (or simply flutter). Recall aeroelastic flutter from the discussion of the Tacoma Narrows Bridge in Section 10.4. When the energy added to the vibration by the airflow around the wings of an aircraft is greater than the energy lost as a result of damping, the result is a rapid vibration, or fluttering, of the wings. If the wing flutter lasts long enough and has a large enough amplitude, it can cause the aircraft to fail.

WEB LINK

To see a video of flutter in the tail wing of an aircraft,

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Testing for Flutter

Flutter is very rare in modern aircraft, but it must be produced when testing new aircraft. One type of flutter test is called a pulse test. In a pulse test, the pilot controls the aircraft such that the airflow is suddenly and drastically disturbed around the wings. Engineers then monitor the wing flutter from the ground and study how the vibration decreases over time. If the aircraft does not pass the pulse test, then the engineers modify the design of the wing. If the aircraft passes the pulse test, then the engineers proceed to a sweep test.

In a sweep test, the engineers produce large computer-generated vibrations in the wing (**Figure 3(a)**). The computer controls the frequencies of the vibrations produced in the wings, and a wide range of frequencies is used, one at a time. To pass the sweep test, the flutter induced in the wing should dampen quickly; that is, within a few seconds after the computer-generated vibrations stop (**Figure 3(b)**). If an aircraft fails the sweep test, the engineers modify the design of the wing. Modifications include finding new ways to dampen the vibrations and making the wing more rigid. The wings cannot be made too rigid, however. If too rigid, they will eventually develop small fractures that can cause them to fail.

CAREER LINK

Many industries, including the aerospace industry, test vibrations to ensure product safety. To learn more about careers in the aerospace industry,

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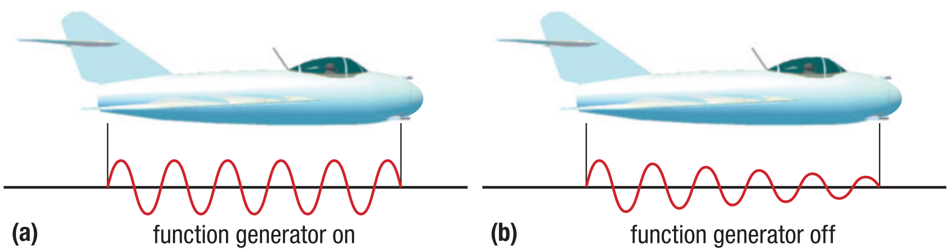

Figure 3 (a) When flutter is induced by a computer (function generator), the wing vibrates with large amplitudes. (b) When the function generator is turned off, a properly designed wing will vibrate with progressively decreasing amplitude.

New aircraft are designed so that flutter cannot occur at any normal flight speed or even when predictable malfunctions occur. In fact, the engineers design the aircraft to be flutter resistant under speeds and conditions far beyond the expected performance of the aircraft. If the aircraft flies at an abnormal speed, say, far beyond the design limits, or if a serious unpredictable event occurs, then flutter can occur on rare occasions.

Flutter can be distinguished from buffet because the flutter vibrations can occur in smooth air and seem to originate from the aircraft rather than from irregular airflow.

It is up to the flight crew to judge when and how they should respond to an abnormal vibration. The crew usually responds by levelling out the aircraft and decreasing the speed. If the problem persists or gets worse, the flight crew may decide to attempt an emergency landing at the nearest airport. This option is only used under the most extreme circumstances, when passenger safety is an issue.

Pogo in Rockets

Rockets can develop longitudinal vibrations during launch. During launch, the propellant pipes can experience low-frequency disturbances, which can periodically change the propellant flow rate. Since the propellant flow rate is changing periodically, it can affect the thrust of the rocket, which periodically increases and decreases several times in a second. Normally, the mass of the rocket is so large that the variations in thrust cause very little change in acceleration, so this effect goes unnoticed. However, if the frequency of the thrust vibrations matches the natural or resonant frequency of the rocket, then resonance can take place. In this case, the rocket will feel like it is surging back and forth like a pogo stick. Engineers eliminate the pogo effect by changing the length of the propellant pipes, which changes the frequency of the thrust vibrations. They also add dampers to the propellant pipes, which eliminate the pipe vibrations to help ensure that the flow rate is constant.

10.6 Summary

- Properties of mechanical waves influence the design of structures.
- Aircraft experience various vibrations. Most vibrations are normal and pose no threat to the operation of the aircraft.
- Aeroelastic flutter is the most dangerous type of abnormal vibration in aircraft, but modern aircraft rarely experience flutter.

10.6 Questions

1. Describe three normal types of vibrations in aircraft. Include one example for each. K/U C
2. Why is it so important that the flight crew of an aircraft monitor and respond to abnormal vibrations quickly on aircraft when similar vibrations in a car might be ignored? K/U
3. In a graphic organizer, compare aeroelastic flutter in a bridge and in an aircraft in terms of how flutter is caused and the effect on the object. K/U C
4. Explain why the flight crew of an aircraft is better at identifying abnormal vibrations than any passenger on the aircraft. K/U
5. List three ways that pilots and engineers can prevent or stop aeroelastic flutter once it has started. K/U
6. Describe the pogo effect in rockets by answering the following questions: K/U C
   (a) What causes the pogo effect?
   (b) Why is it called the pogo effect?
   (c) What can be done to prevent the pogo effect in rockets?
   (d) Describe one way you could demonstrate the pogo effect to your peers.
7. **Figure 4** is a diagram of a jet engine. Examine the figure, and explain why a jet engine might cause more serious vibrations if it becomes unbalanced. T/I A

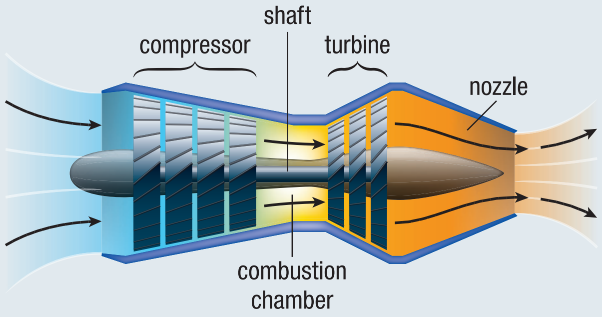

Figure 4

8. Research jet engines on the Internet or using print resources. How do the noise levels produced by different types of jet engines compare with each other? Organize your findings in a web page or format of your choice. T/I C

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