Dynamic Structural Test Tutorial

Research, design, and validation of new structures requires a variety of tests from static load testing to aerodynamic testing as shown in Figure 1. To measure the structural integrity of the test article, you need measurement instrumentation that can read all of your sensors. Oftentimes, tests requiring sample rates over 1 kS/s are considered dynamic tests. National Instruments categorizes tests that require sample rates more than 10 kS/s as dynamic structural tests. This includes aerodynamic, impact, vibration, blast, and ballistics testing.

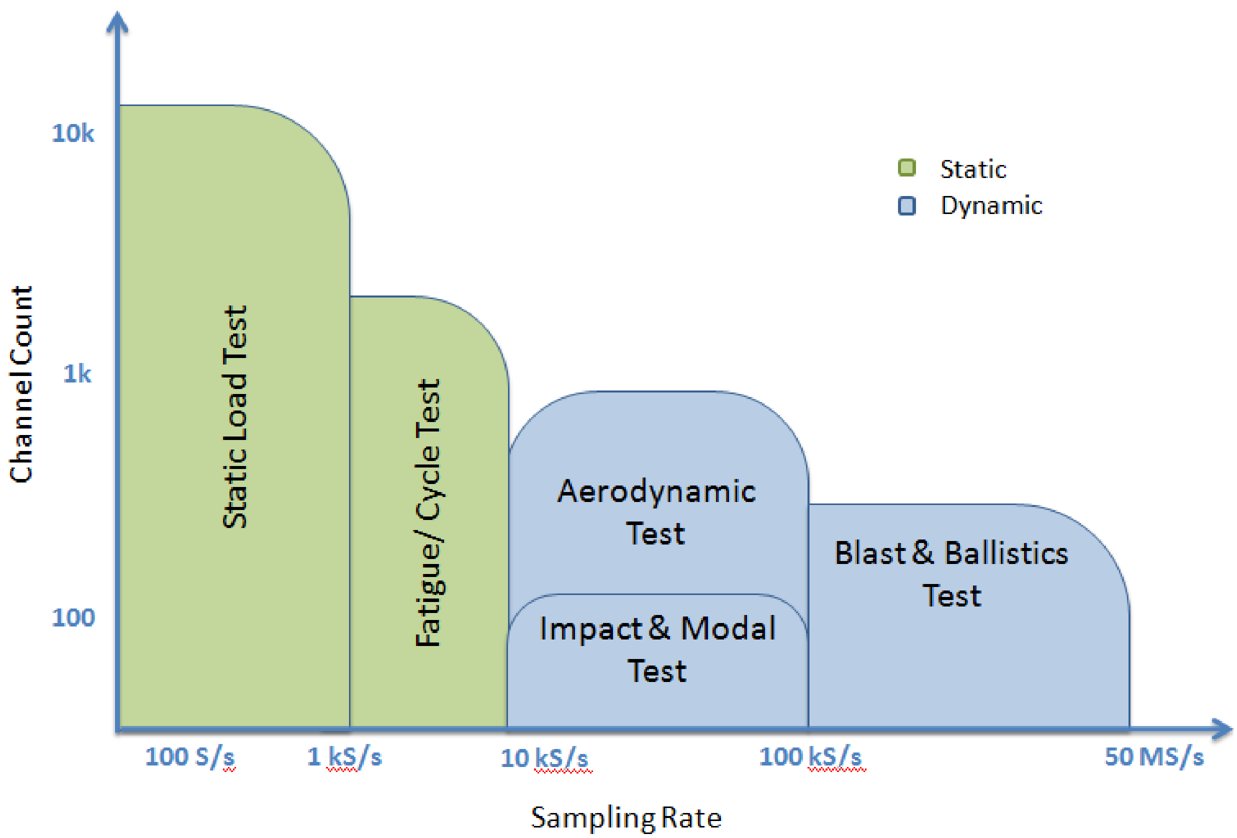

Figure 1. Structural tests are divided into static and dynamic applications.

Aerodynamic Testing

Introduction

Aerodynamic test, also known as wind tunnel test, is used to improve the aerodynamic design of aircrafts, rockets, automobiles, wind turbines, and even bicycles. Engineers use wind tunnels to reproduce dynamic operating conditions and study the movement of air around and through the test article. Most commonly, they measure the aerodynamic forces being imposed on the structure. Aerodynamic tests require detailed and accurate data in a very short time, though requirements vary greatly depending on the size of the test article and the goals of the test. Test articles can include full-scale structures or scaled models, which are commonly used in aerospace due to the cost and size of structures. Engineers can then use the model data to predict affects on full-scale structures to understand and improve performance.

Overview of Wind Tunnels

Wind tunnels are usually designed for a specific purpose and speed range, from subsonic to supersonic, required for jet and rocket testing. Wind tunnels can be open, drawing air in and out of the tunnel, or closed, recirculating the air inside of the tunnel. Air is moved with a series of fans that are powered by large electrically powered drive motors or jet engines and then turned around the corners by turning vanes. The fans can cause turbulence that affects the accuracy of the test, so flow straighteners are used to prevent the turbulence from reaching the testing subject. Full-scale testing can require very large test sections or rooms. When testing small objects or models, the test section includes a small viewing port and instrumentation for mounting the models as shown in Figure 2.

The test section typically has a circular cross-section and smooth surfaces to reduce drag and turbulence. The test subject is kept in the center of the section to minimize impact of the walls, but correction factors are used to relate the wind tunnel test results to open air results. When testing at supersonic speeds, advanced cooling is required to safely dissipate the heat that is generated.

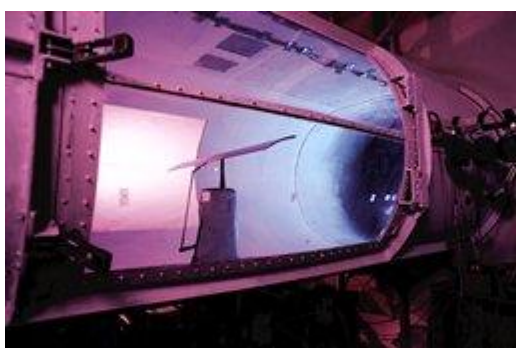

Figure 2. Wind tunnels reproduce dynamic operating conditions.

Wind Tunnel Tests

Though there are several different types of aerodynamic tests, the most common is to directly measure aerodynamic forces and moments on the model. In this type of test, the model is mounted on an internal or external force balance typically consisting of a three- or six-component strain gage balance. A six-component balance can measure the forces (lift, drag, and lateral forces) and moments (yaw, roll, and pitch) that determine an aircraft’s motion through the air. You can carefully control the flow conditions in a wind tunnel to affect the forces on the model and the flow parameters, Reynolds number and Mach number:

- **Reynolds number** – Ratio of inertial forces to viscous forces; quantifies relative importance of the two force types for given flow conditions
- **Mach number** – Ratio of object speed to sound speed; determines the magnitude of many of the compressibility effects

Both numbers depend on the velocity and gas density in the tunnel and must match to the desired flight condition to study the actual airflow and compare with theoretical results. The force measurements require post-processing to account for the flow parameters.

In some tests, the model includes pressure taps across the surfaces of the model. Pressure taps are small holes drilled perpendicular to the model. The pressure measurements account for normal forces on the model and are used to derive performance. Pressures can also be measured through small tubes aligned with the flow elsewhere in the tunnel. A series of tubes, known as a rake, can be used to measure total pressure along the wall of a model or within the tunnel itself. Total pressure is a combination of static and dynamic pressures. In practice, pressure measurements are not typically used to measure aerodynamic performance because of the large number of pressure taps required to resolve pressure variations.

Figure 3. The most common aerodynamic tests directly measure aerodynamic forces and moments on a scaled model.

Diagnostic testing is another type of testing, not used to provide overall aircraft performance but only to understand flow phenomenon. Instrumentation includes pressure taps, total pressure rakes, laser Doppler velocimetry, and hot-wire velocity probes. Depending on the type of instrumentation steady-state flow or unsteady, time-varying, flow information can be measured.

The last testing type includes flow visualization, which also provides diagnostic information. Techniques include free stream smoke, laser sheets, or surface oil flow. These methods assume that the flow visualization medium moves exactly with the flow. Shadowgraphs or schlierin systems are used to visualize the shape and location of shock waves in compressible flows.

More recently, aerodynamicists take advantage of the power of computers and software to use 3D computational fluid dynamics (CFD) to evaluate designs before physical models or prototypes are available. CFD simulations can provide aerodynamic forces and moments, as well as flow rates, pressure, and heat transfer for analysis. Combining computational methods with wind tunnel testing reduces the need for model testing before full-scale testing.

Impact Testing

Impact testing is used to test a structure's ability to resist high-speed loading. To select an appropriate material to last for a structure's expected lifespan, you must be able to predict the type of impact that the product will encounter. You can then run tests to ensure safety and reliability of the structure. The most common tests include pendulum and drop testing. Pendulum testing swings a weight from a certain height to break or strike the testing subject. The pendulum swings to a lower height that you can use to calculate the energy that was lost. Drop testing entails dropping the material or structure from a specified height or dropping an object onto the testing subject to understand the impact energy by measuring sensors at the base. Energy and impact velocity are two key measurements made during an impact test. More recently, instrumented impact tests, where load cells are fitted to the dropped object, are known to be the most accurate and to provide the most detail about material fractures. In instrumented impact tests, you can use measurements made by high-speed data acquisition instrumentation to generate curves showing force, energy, velocity, and deformation versus time.

Modal Testing

Modal analysis is the study of the dynamic properties of a structure under vibration excitation. With modal analysis, you can extract the modal parameters (dynamic properties) of a structure. The modal parameters, including natural frequency, damping ratio, and mode shape, are the fundamental elements that describe a structure's movement and response to ambient excitation as well as forced excitation. Knowing these modal parameters helps you understand a structure's response to ambient conditions as well as perform design validation.

- **Natural (or Resonant) Frequency** - The frequency at which any excitation produces an exaggerated response. This is important because excitation close to a structural's natural frequency can lead to fatigue, damage, or complete structural failure.
- **Damping Ratio** - The ratio of the actual damping over the amount of damping required to reach critical damping (damping level at which the system experiences no oscillation).
- **Mode Shapes** - Deformation patterns at natural frequencies that take on a variety of different shapes.

Figure 4. You can measure vibration with an accelerometer and impact hammer.

Two types of modal analysis are performed in industry today: experimental and operational. Experimental modal analysis, the most commonly used form of modal analysis, is the traditional method in which you use a device, such as a hammer, to excite a structure and then measure the response. Then you can calculate the transfer function and use certain modal parameter extraction algorithms to extract the dynamic properties of the structure. Experimental modal analysis is most effective in design validation and finite element analysis (FEA) verification.

Blast and Ballistics Testing

Blast and ballistics testing are used to test structural behaviors under explosive loading as well as the actual weapons and explosives. Engineers perform tests in explosive chambers, ballistics test facilities, or in open land when large spaces are needed. This type of testing requires advanced instrumentation to capture temperature, pressure, and strain measurements at very high sample rates (million of samples per seconds). Engineers typically combine video captures with the measurement data to record the tests. Because the tests are typically expensive, software computations are often run to simulate the results before executing the physical tests.

Figure 5. Booster rockets endure thorough ground tests before they take to the atmosphere.

Conclusion

There are a variety of dynamic structural tests, including aerodynamic, impact, modal, blast, and ballistics tests. Each test has unique requirements, but they all require advanced instrumentation and software to accurately collect dynamic measurements and analyze the results. You can use the various structural tests during research, prototyping, and design validation phases to ensure quality materials, components, and structures.

References

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