Mechanics

Aerostructures Test Wing

Test data can be used to refine predictions of the onset of flutter.

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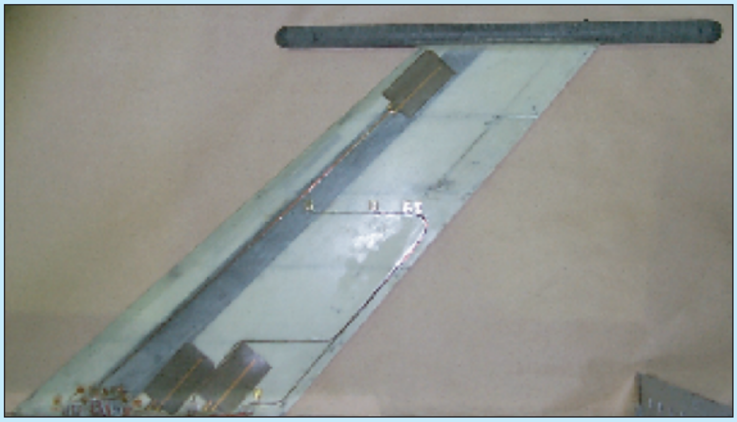
The Aerostructures Test Wing (ATW) was an apparatus used in a flight experiment during a program of research on aeroelastic instabilities. The ATW experiment was performed to study a specific instability known as flutter. Flutter is a destructive phenomenon caused by adverse coupling of structural dynamics and aerodynamics. The process of determining a flight envelope within which an aircraft will not experience flutter, known as flight flutter testing, is very dangerous and expensive because predictions of the instability are often unreliable.

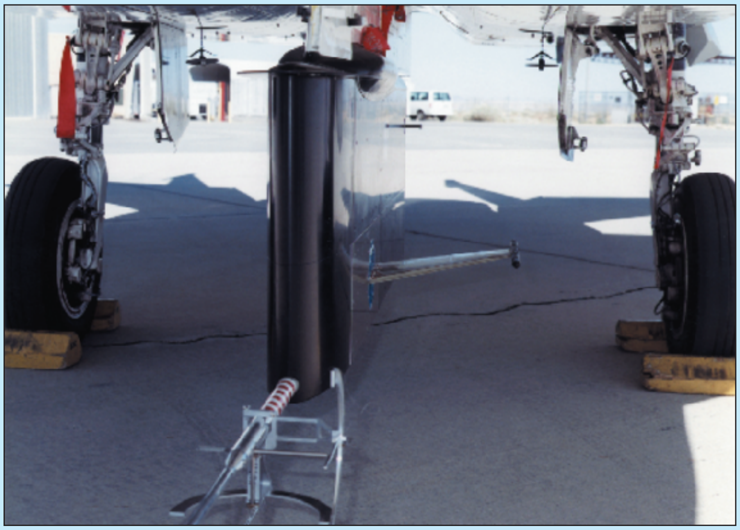
The ATW was a small-scale airplane wing that comprised an airfoil and boom (see upper part of Figure 1). For flight tests, the ATW was mounted on the F-15B/FTF-II testbed, which is a second-generation flight-test fixture described in “Flight-Test Fixture for Aerodynamic Research” (DRC-95-27), *NASA Tech Briefs*, Vol. 19, No. 9, September 1995, page 84. The ATW was mounted horizontally on this fixture, and the entire assembly was attached to the undercarriage of the F-15B airplane (see lower part of Figure 1).

The primary objective of the ATW project was to investigate traditional and advanced methodologies for predicting the onset of flutter. In particular, the ATW generated data that were used to evaluate a flutterometer. This particular flutterometer is an on-line computer program that uses μ-method analysis to estimate worst-case flight conditions associated with flutter. This software was described in “A Flutterometer Flight Test Tool” *NASA Tech Briefs*, Vol. 23, No. 1, January 1999, page 52.

Flutter predictions can be evaluated only by comparison with measured flight conditions at which flutter was encountered. Therefore, the ATW was designed to enable the safe observation of the flutter instability. It was essential to ensure that the destruction of the ATW did not cause any damage to the host F-15B airplane. The ATW was constructed out of fiberglass, composite, and foam. Hence, the entire ATW was lightweight and frangible, so any pieces that struck the F-15 airplane would exert only minimal effects and would cause no damage.



AEROSTRUCTURES TEST WING (TOP VIEW)



AEROSTRUCTURES TEST WING MOUNTED ON THE F-15B-FTF-11

Figure 1. The **Aerostructures Test Wing** was a small-scale airplane wing that was subjected to flight tests to investigate flutter and related phenomena.

It was also important to ensure that the ATW could generate data that are sufficient for the flutterometer and other means of flutter prediction. This requirement was satisfied by incorporating an excitation and measurement system into the ATW. The excitation was provided by commanding frequency-varying sweeps of energy through a set of piezoelectric patches on the surface of the wing. The measurements were provided by strain gauges throughout the wing and accelerometers in the boom.

The first phase of the ATW program was pre-flight ground testing. This testing was performed in consideration of both static and dynamic properties of the ATW. Deflection tests were performed to determine the sizes of static loads that could be borne by the ATW. Vibration tests were also performed to determine the dynamic modal characteristics of the ATW. It was shown that the first bending and torsion modes were at frequencies of 14.05 and 22.38 Hz. The data from these tests were

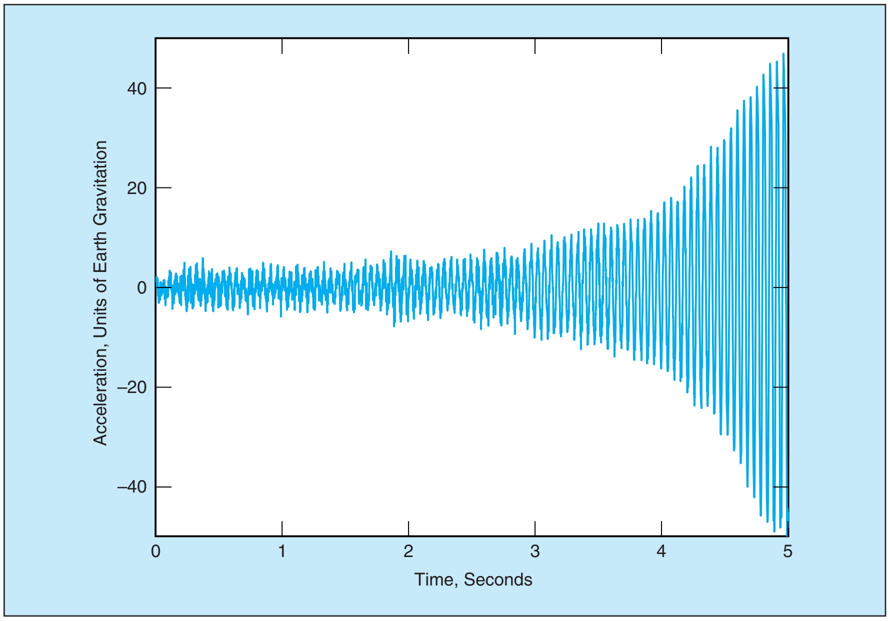


Figure 2. This **Accelerometer Response** shows the onset of flutter.

used to generate computational models for predicting the onset of flutter.

The second phase of the ATW program was a flight test for envelope expansion. In this phase, it was required to analyze experimental data acquired at a series of test points with increasing velocity and dynamic pressure. At each test point, the ATW was excited with a frequency-varying input and its responses were measured by sensors. The resulting flight data were telemetered to a control room and analyzed by the flutter-prediction methodologies. A total of five flight tests were performed in April 2001.

A flutter instability of the ATW was encountered at approximately mach 0.83 at an altitude 10,000 feet (≈3 km). The wing was broken such that the boom and roughly 30 percent of the wing were lost. The pieces fell to the ground without striking the F-15B aircraft or FTF-II testbed. The flutter incident was quite demonstrative of the phenomenon. The instability was encountered during a slow acceleration from mach 0.825 to mach 0.830. The damping changed dramatically during this acceleration. The ATW went from stable, with accelerometer responses going from approximately 3 g (where g = the standard gravitational acceleration at the surface of the Earth) to unstable during a time interval of only 5 seconds (see Figure 2).

The data from the ATW were analyzed to evaluate the flutter-prediction methodologies. The results indicated that computational models were able to predict the onset of flutter reasonably well, but that small errors in the models could cause large errors in the predictions. The traditional approaches for analyzing flight data were shown to afford a capability to predict the onset of flutter only during operation at flight conditions near the instability. The flutterometer was shown to be somewhat conservative in the worst-case estimates of flutter, but it presented a reasonable prediction of flutter at flight conditions that were far from the instability.

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Flight-Test Evaluation of Flutter-Prediction Methods

Experiments have demonstrated the accuracy of predictions of instability.

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The flight-test community routinely spends considerable time and money to determine a range of flight conditions, called a flight envelope, within which an aircraft is safe to fly. The cost of determining a flight envelope could be greatly reduced if there were a method of safely and accurately predicting the speed associated with the onset of an instability called flutter.

Several methods have been developed with the goal of predicting flutter speeds to improve the efficiency of flight testing. These methods include (1) data-based methods, in which one relies entirely on information obtained from the flight tests and (2) model-based approaches, in which one relies on a combination of flight data and theoretical models. The data-driven methods include one based on extrapolation of damping trends, one that involves an envelope function, one that involves the Zimmerman-Weissenburger flutter margin, and one that involves a discrete-time auto-regressive model. An example of a model-based approach is that of the flutterometer. These methods have all been shown to be theoretically valid and have been demonstrated on simple test cases; however, until now, they have not been thoroughly evaluated in flight tests.

An experimental apparatus called the Aerostructures Test Wing (ATW) was developed to test these prediction methods. [The ATW is described in the immediatley preceding article, "Aerostructures Test Wing" (DRC-01-37)]. The ATW is a small wing-and-boom assembly that has a complicated and realistic structure similar to that of a full-scale airplane wing. The ATW was flown by use of an F-15 airplane and an associated flight-test fixture. The ATW was mounted horizontally on the fixture and the resulting system was attached to the undercarriage of the F-15 fuselage, as shown in preceding article.

For a flight test of flutter-prediction methods, the ATW was flown on four occasions during April 2001. The flight test involved measuring accelerometer responses as a series of test points. The airspeeds of these test points were increased until the onset of flutter was encountered at 460 knots of equivalent airspeed (KEAS) [≈237 m/s equivalent airspeed].

Predictions of the speed associated with flutter were computed at every test point. In each instance, the prediction was based on data from the current test point and any