Taming the Flutter Monster

FLUTTER IS A phenomenon that has plagued aircraft since their early development. Several German World War I pilots were killed because of flutter in the famous Fokker DVIII monoplane fighter of 1918. Subsequently, Anthony Fokker fixed the problem by matching the torsion and bending stiffness of the cantilevered wing to that of a wire-braced wing. (See *Fokker—The Man and the Aircraft* by Henri Hegener.) Even though he had no idea what caused the problem, his fix solved the flutter problem of one of the best fighters of World War I. Until 1935, all British military fighters were required to have strut-braced wings to avoid flutter.

What Is Flutter?

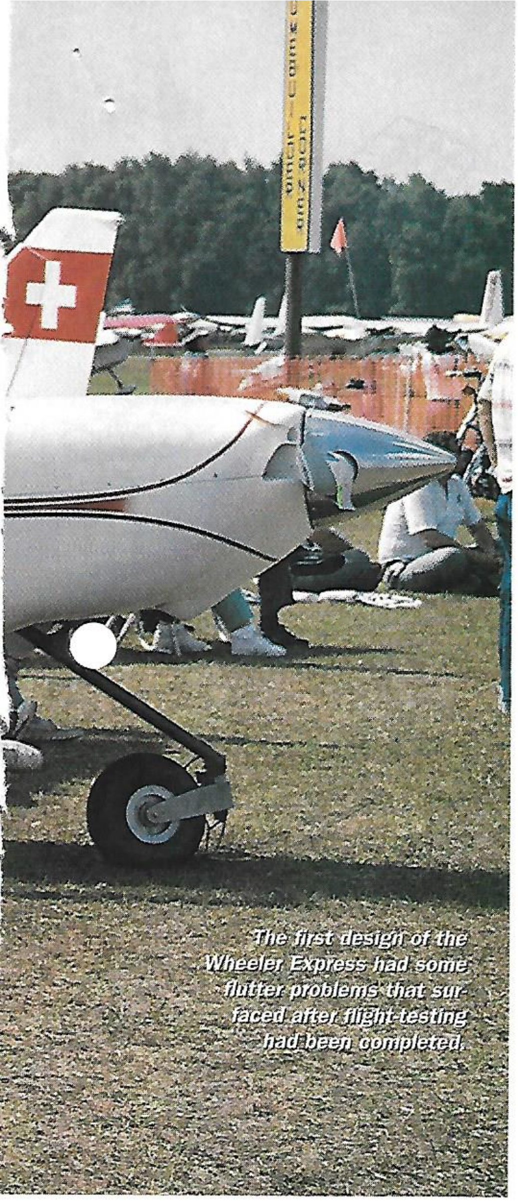
Flutter is caused by the dynamic motion of a surface when acted upon by the air pressure. For example, a wing can twist and increase and decrease its angle of attack. As the angle of attack increases, the lift on the wing will increase, causing it to bend up or down. If the frequency of the wing-twisting matches that of the wing-bending frequency, a resonance can occur such that the wing will continue to dynamically flap and bend until the loads become so large that the wing breaks. This condition is a typical case of wing flutter, and often, the second wing-bending frequency couples with the wing-torsion frequency to cause flutter. A wing or tail can snap off in a fraction of a second.

Because of the severity of this problem, scientists have been attempting to analytically predict and prevent flutter. In the 1940s, hand calculations and tables of aerodynamic coefficients were used, as documented in *Air Corps Technical Report No. 4798*, dated 1942. During the 1970s, aerospace companies began developing computer programs capable of more accurate predictions of flutter.

One such program was developed by Grumman Aerospace Corporation in New York in 1973 and was sponsored by the Air Force Flight Dynamics Laboratory at Wright Patterson Air Force Base in Ohio. This program was titled FASTOP (Flutter and Strength Optimization Program). In 1980 the Air Force Flight Dynamics Laboratory awarded a contract to the University of Dayton to streamline the FASTOP program so it could be used as a flutter-only program, without the optimization capability.

In 1981, the code was reorganized by Dr. Ronald Taylor for faster execution on a CYBER-175. The resulting code was called FASTEX. The code has been used ever since by both the government and industry. In 1991, Aircraft Designs contracted the University of Dayton to modify the FASTEX program so it could run on a PC, and the program SAF (Subsonic Aerodynamic Flutter) was born.

This program not only ran on a PC, but it ran twice as fast on an IBM



The first design of the Wheeler Express had some flutter problems that surfaced after flight-testing had been completed.

BY **MARTIN HOLLMANN**

386 PC than it did on a VAX-II with a Unix operation system. Using this program, Aircraft Designs has had the opportunity to perform the flutter analysis on more than 22 aircraft in the past nine years. Much insight into what causes flutter has been gained during this time, and I will present that information here.

Several misconceptions on identifying and preventing flutter exist as summarized below:

1) An aircraft is free from flutter if the pilot has flown an aircraft at many speeds and attempted to induce flutter by hitting the control stick. Advisory Circular No. 23.629-1A, *Means of Compliance with Section 23.629, Flutter* states that a pilot can't induce flutter excitations in excess of 7 to 10 Hz.

Most flutter speeds occur at frequencies well above these values.

2) If the control surfaces are 100 percent statically balanced about their hinges, flutter cannot occur.

Balancing can often increase the critical flutter speed, but it does not mean that the aircraft is free from flutter.

3) An aircraft has been flown for a long period of time, and as such, it is free from flutter.

Steve Wittman flew his Tailwind for many years. He and his wife were killed several years ago in the crash of his aircraft. The empennage of the tail was never found, and people close to Steve believe that flutter was the culprit. Aircraft structures such as wings and tails usually detach during flight and are usually located many miles from the scene of the final impact.

4) The control stick vibrates during flight. Is this caused by flutter?

In most cases, this is called control-surface buzz, and it is caused by a humpback flutter mode in which the aerodynamic damping curve crosses the zero damping and crosses back over to become negative. If the damping curve continues to be positive, the control surface will, in most cases, separate from the aircraft in a fraction of a second.

Case Study One: The Wheeler Express Tail Flutter

On the way to Oshkosh, on the morning of July 25, 1990, the production prototype Wheeler Express with three people aboard took off from Casper, Wyoming. Shortly afterward it crashed, killing the company test pilot, a salesman and an engineer. The flap actuators had been extended, indicating that the pilot tried to slow the aircraft before impact.

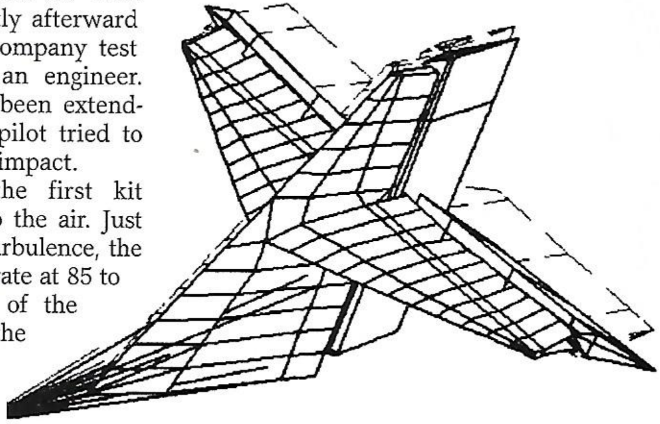
Shortly thereafter the first kit Wheeler Express took to the air. Just after takeoff, in severe turbulence, the empennage began to vibrate at 85 to 90 knots. The severity of the noise still haunts both of the pilots today. The aircraft returned to land, and it was found that severe delamination occurred around the horizontal-tail to vertical-tail attachment. Both of these aircraft had the same tail configuration and attachment. Because of the severe delamination, flutter was suspected.

In 1992 Bruce Decker, a Wheeler Express builder, contacted me to perform a flutter analysis on the Wheeler tail. I received much help from the builders in obtaining information about the geometry, layup schedules, and weights and stiffness of the tail assembly. Faxes sent to Mike Betts from the Wheeler Express Company showed that the horizontal tail was attached to the vertical tail only through the skins. No spar attachments were shown.

A detailed finite element analysis (FEA) model of the tail was set up. The FEA is used in determining the natural frequencies and mode shapes of the structure and control surfaces. The horizontal tail stiffness of the FEA model was matched to the stiffness of the actual aircraft. This is easy to do. Simply apply a force of 100 pounds to the tip of the horizontal tail and measure the tail bending at the applied load. Then perform the same operation in the FEA model.

Control-surface deflections and stiffness are obtained in a similar manner. Simply apply a 10- to 20-pound force at the trailing edge of the elevator and measure the elevator deflection. Then size the control-rod stiffness to match this deflection. The mass balance and geometry of the control surfaces must also be matched to those of the actual aircraft. In this manner, the results from the FEA model will yield the correct, natural control-surface frequencies.

Often, a ground vibration test (GVT) is performed on the actual aircraft to measure the actual natural frequencies and obtain the structural damping. I often work with Sandy Friezner of Specialized Testing Service in Arleta, California, specializing in performing GVTs. However, we did not perform a GVT, and only the FEA results were used in the Wheeler analysis.



The computer program revealed a flutter mode at 11.79 Hz. Both the deflected and nondeflective modes are shown.

The FEA results were used in setting up an input file for the SAF flutter program, and after three weeks of hard work, the SAF showed that elevator deflection frequency of 11.79 Hz crossed zero damping at 87.7 knots and that it coupled with horizontal-

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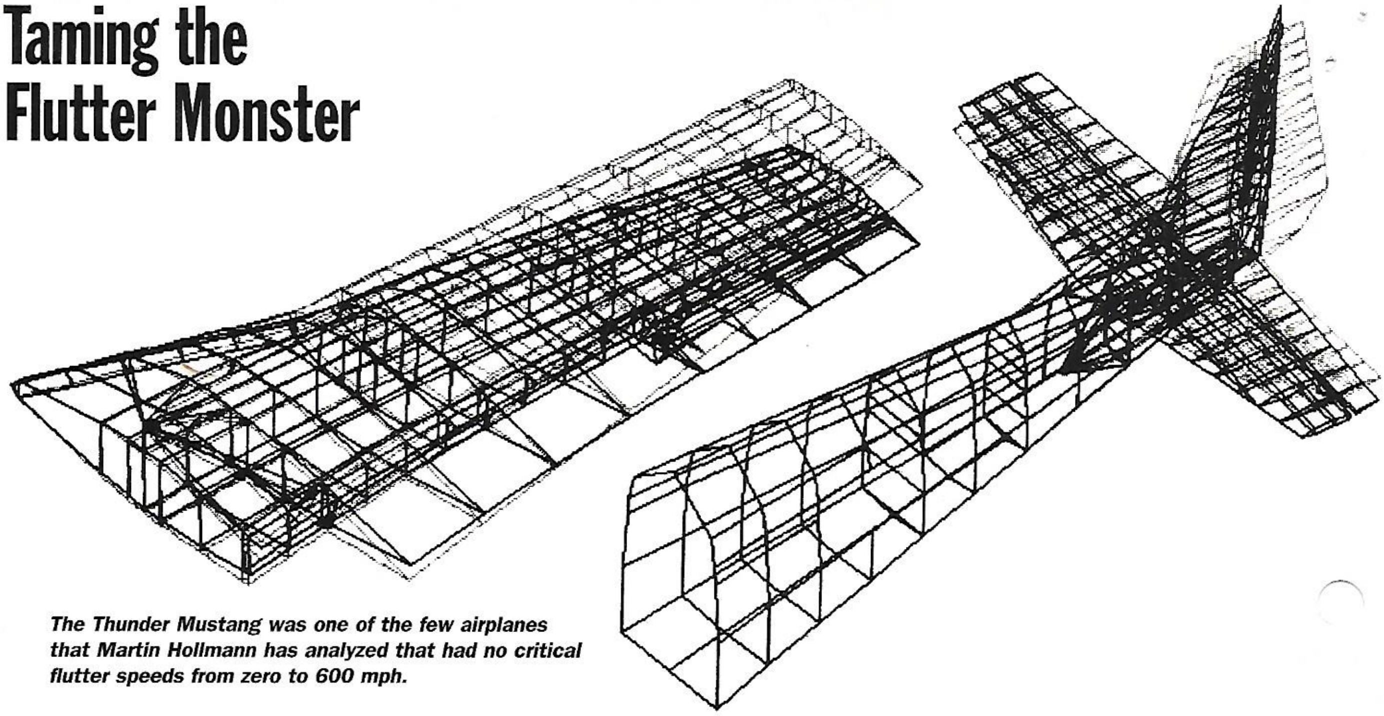


The Thunder Mustang was one of the few airplanes that Martin Hollmann has analyzed that had no critical flutter speeds from zero to 600 mph.

stabilizer bending of 8.1 Hz. Another critical flutter speed occurred at 328 knots. Betts had not told me the speed at which he had encountered flutter. But when I told him of the flutter results, we were both surprised at the accuracy of the analysis.

I then stiffened up the horizontal-stabilizer to vertical-tail attachment and used the tail weights of Ed Bernard's Wheeler Express and reran the flutter analysis. The new analysis showed that no flutter existed for this model. Needles to say, I have been recommending to all Wheeler Express builders that the tail be properly attached. To date, no other flutter problems have been encountered on this sleek, high-performance, composite aircraft.

Case Study Two: The BD-10 Jet Tail Flutter

In 1992 Peregrine Flight International purchased the rights to build and sell the BD-10 Jet. The CEO of the company was killed during the early flight tests. The vertical tail had separated at 380 mph, and flutter was suspected. The new CEO, Joseph Henderson, hired me to perform the post-crash flutter analysis. I set up a detailed model of the tail and wing and found that fuselage-bending was coupling with horizontal-tail bending at 380 mph. My mode shapes from the FEA model were verified by Friezner.

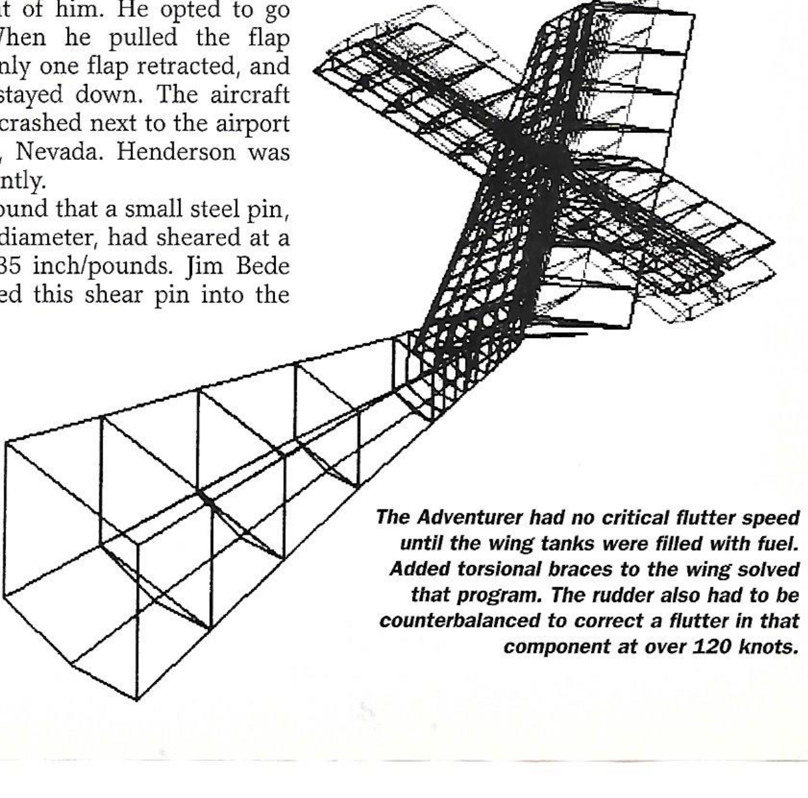
The fuselage and horizontal tail were stiffened, and the flutter problem was solved. A new tail was fabricated and flight testing continued. During these flights, it was found that the control stick vibrated as at the onset of flutter at about 280 mph. Looking at the flutter data, it was found that a small humpback mode existed at that speed. This humpback mode was identified by the damping coming up from negative and crossing zero at 280 mph and then going back down to become negative again. A very small positive damping was shown, and we did not consider this a problem.

Henderson wanted to certify the PJ-2, as the BD-10 was being called. I was to perform the analysis starting in August 1995. A day after I got back from Oshkosh, I heard the tragic news that Henderson had been killed in the PJ-2. As he was coming in on final, with flaps down, a Cessna 150 cut in front of him. He opted to go around. When he pulled the flap lever up, only one flap retracted, and the other stayed down. The aircraft rolled and crashed next to the airport in Minden, Nevada. Henderson was killed instantly.

It was found that a small steel pin, 1/8 inch in diameter, had sheared at a torque of 35 inch/pounds. Jim Bede had installed this shear pin into the flap-actuation system, and it was undersized. This second fatal crash of the BD-10 has brought further development of the aircraft to a halt.

Case Study Three: The Thunder Mustang

One of the few aircraft that I have analyzed that has shown no critical flutter speeds from zero up to 600 knots for all ranges of altitudes and operating conditions is the Thunder Mustang. I helped Dan Denney with the initial design of this aircraft in 1989. However, he hired several in-house engineers to finish the detail design. The aircraft was fabricated o of graphite and aluminum honeycomb.



The Adventurer had no critical flutter speed until the wing tanks were filled with fuel. Added torsional braces to the wing solved that program. The rudder also had to be counterbalanced to correct a flutter in that component at over 120 knots.

After performing the flutter analysis and viewing the structure that the in-house engineers had designed, I told Denney that the skin thickness was twice what it needed to be, and he stated that the aircraft was too heavy. We reduced the skin thickness and replaced the aluminum honeycomb with Nomex honeycomb core and reran the flutter analysis. Again, no critical flutter speeds were found. Friezner performed the GVT to verify the frequencies and determine the structural damping.

Case Study Four: The Adventurer

On Aug. 5, 1997, Adventurer 333, N323VA, suffered an in-flight separation of both wings and the empennage prior to impacting the ground about 5 miles northwest of Fond du Lac, Wisconsin. The pilot had fueled and had just left Oshkosh at 9:30 a.m. Needles to say, he was killed. EAA and AVEMCO Insurance recommended to the Adventurer builders that they contact me to perform a stress analysis on this aircraft. In fact, AVEMCO made the statement that it would not insure the other aircraft unless I had made a stress check.

I performed a stress analysis and a flutter analysis. The flutter analysis of the empty wing with the ailerons balanced showed no critical flutter speed from 0 to 600 knots. However, with 30 gallons of fuel in the wing, a critical flutter speed of 94.3 knots was determined.

Only one lift strut is used for each wing, and only the leading edge torsion box and the fabric of the wing provide torsional stiffness to the wing, so very little torsional stiffness exists. As such, no fuel may be added to the wing. A flutter analysis of the tail showed that the tail had a critical flutter speed of about 120 knots. With the addition of 10 pounds of counterbalance weight to the rudder, the critical flutter speed of the tail goes to 196 knots. As such, counterbalancing to the rudder is necessary.

The second kit-built Adventurer has more than 100 hours on it, and it's being flown by Abe Nagle. See my article called, "What Caused the Break-Up of Adventurer N323VA In Flight?" in the May 2000 issue of *CUSTOM PLANES*.

In summary, we must use excellent judgment when designing flutter-free aircraft. The following are some ground rules that should be followed:

1. Design wings with high torsional stiffness.
2. All control surfaces should be statically balanced about their hinges.
3. Minimize control-surface free play.
4. Control-surface tabs must be irreversible.
5. The critical flutter speed of an aircraft should be 1.2 times the design dive speed.
6. For turboprops, a check for propeller whirl mode should be made.

Furthermore, flutter analysis can now be performed on a PC using a finite element analysis program such as ALGOR and the flutter program called SAF. Aircraft Designs, Inc., sells these programs, and we hold hands-on flutter classes that teach you how to use these programs. We also sell a book called *Modern Aerodynamic Flutter Analysis*. We have also made flutter analysis affordable for those who would rather have a professional engineering office do this complicated analysis. For more information, call Aircraft Designs at 831/649-6212 or visit our website at www.aircraftdesigns.com