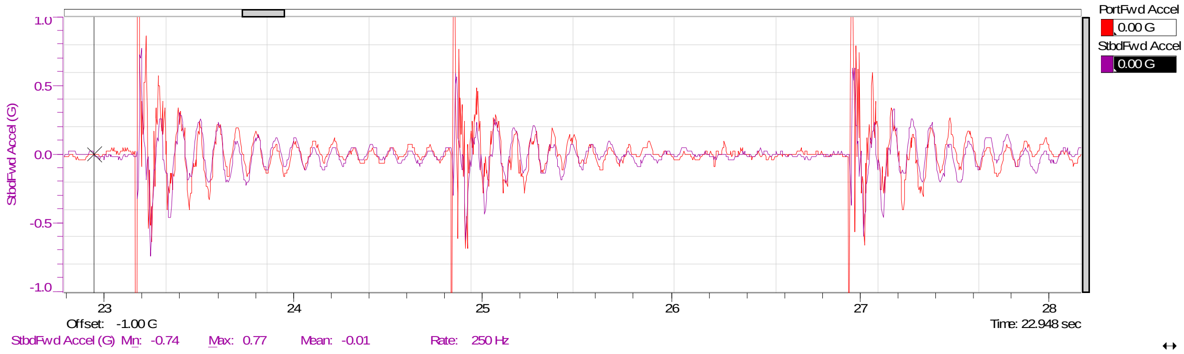
<u>Zenair Flutter Testing - Analysis of the Results – Nigel Bamber</u>

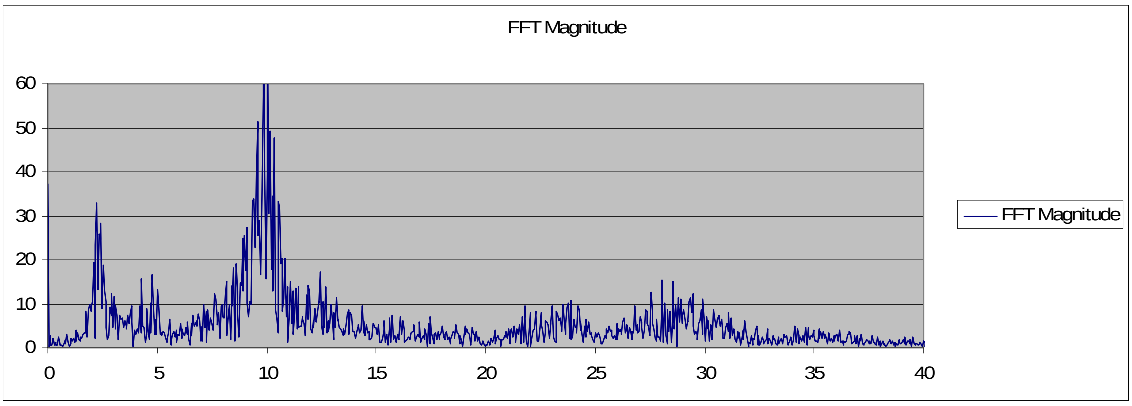
Our objective during the flutter flight tests was to find out whether the natural structural vibration modes of the wings were sufficiently well damped up to our required maximum test speed, and that there would be no danger of damage being initiated if they were excited by an external disturbance such as a gust or a sudden control input. In the tests, the applied disturbances were intentional violent control stick shakes and taps. The aircraft was also flown through severe turbulence found immediately underneath active cumulus clouds.

On the ground, the wing tips were tapped with a large steel bar (with a suitable wood block to protect the wing skin) to find the principal natural modes. This is analogous to flicking the edge of a wine glass to make it ring. The ringing note will be at the first natural frequency.



The trace above shows the accelerations on the port and starboard wingtips as it "rings" after three taps. The horizontal axis covers a time period of five seconds. The vertical axis shows the measured acceleration of the accelerometer. The ringing dies away because of the natural damping of the structure. The ring is at around 10 Hz which is the wing's first natural bending frequency. The trace is not a pure sine wave and we can see that there is some other vibration mode present as well.

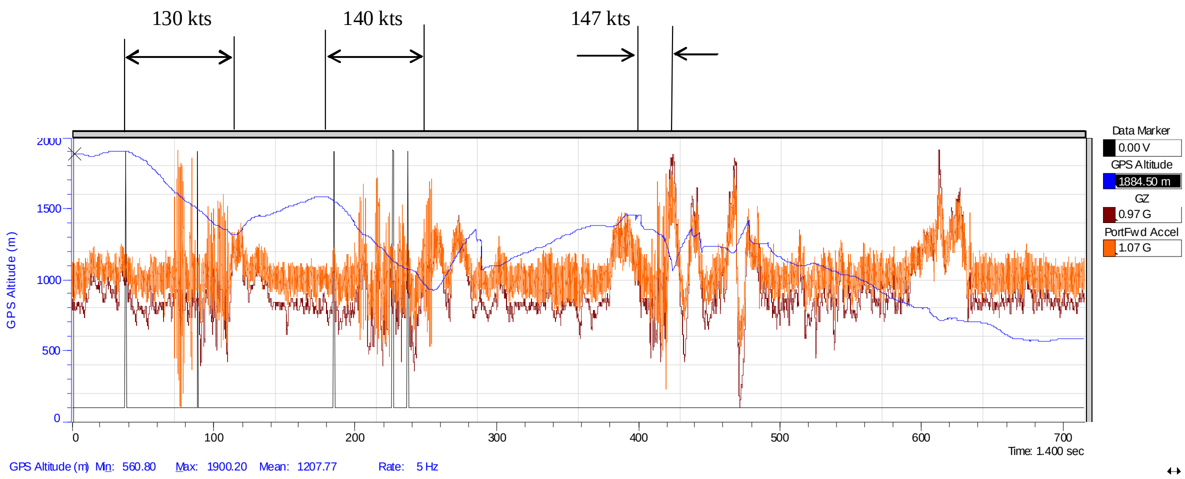
Fourier analysis is a mathematical process which allows us to break down this complex mix of vibration modes into its constituent simpler vibrations at their individual frequencies. In effect it gives us a vibration spectrum.



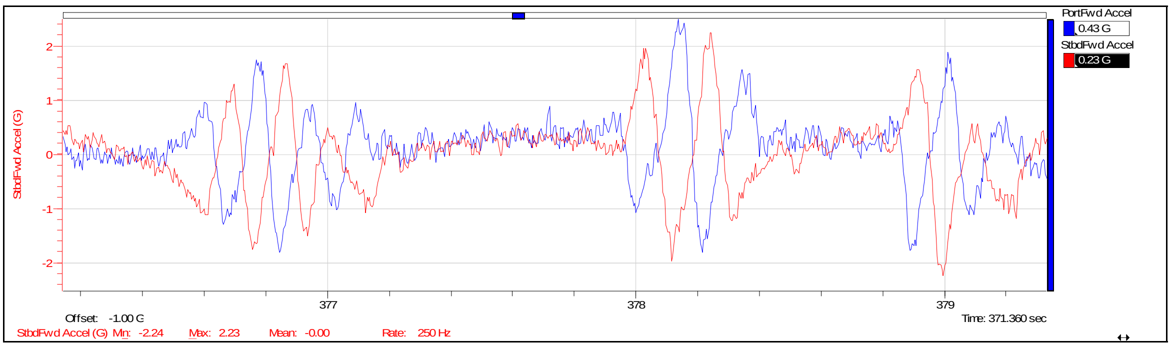
In the Fourier plot the horizontal axis represents a range of frequencies between 0 and 40 Hz. The vertical axis is an arbitrary scale showing the amount of vibration going on at each frequency. We can see the basic wing response at 10

Hz, but below that is another vibration at 2 Hz. This turned out to be the frequency that the aircraft rocks from side-to-side on its tyres. There are also smaller peaks at 23 and 29 Hz that probably represents other natural frequencies of the wing such as the second symmetric and first asymmetric bending modes - or even a rear fuselage torsional mode.

In the air, the acceleration time traces look even more complicated. Below is a typical plot, the orange line shows the wingtip accelerations from stick shakes at 130, 140 and 147 knots IAS. The blue line is a simultaneous plot of the height from the logger's self-contained GPS, and shows the aircraft diving during the high speed flutter tests and climbing back to bale-out height in between each trial.

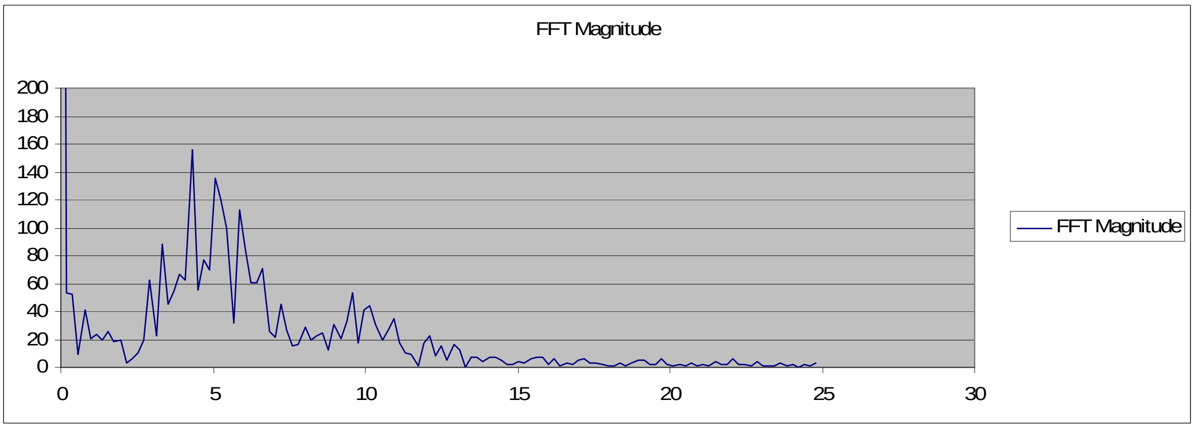


In order to make sense of the plots you have to expand the horizontal time-scale of the plot so that you can examine individual stick shakes, and exclude all surplus data. This produced results as shown below.



This trace shows the wingtip accelerations as Francis shook the control stick from side to side and then released it. The red and blue traces are from the port and starboard tips, and are out of phase during the excitation period showing that the aircraft was rocking laterally. The vibration dies away quickly showing that it is well damped, and the motions of the two tips slides more into phase, meaning that there is some symmetric action (ie wing bending) going on. The trace shows that there are a lot of different frequencies involved, including the background noise from engine vibration, aerodynamic buffet and small gusts.

Again, a Fourier Analysis can be carried out to break this down into the component frequencies to clarify things.



This analysis of three shakes shows Francis's input shakes at 4, 5 & 6 Hz, but also shows the lesser wing structural response at around 10 Hz. The zero Hz peak is what is known as a "rigid body motion", i.e. the non-oscillatory overall motion of the aircraft. The aircraft was pulling up slightly as the shake was carried out. The fact that the input shakes did generate a measurable response at the wing's primary bending frequency but that the response on ceasing the excitation was heavily damped shows that the aileron mass balances have done their job.