

Flutter clearance techniques and tools for gliders

Louw van Zyl¹

¹*Council for Scientific and Industrial Research, Pretoria, South Africa, lvzyl@csir.co.za*

Abstract: The flutter clearance of gliders pose some special challenges. Modal frequencies are low, making suspension of the glider for ground vibration testing challenging. The low frequencies also make large amplitudes of excitation desirable. In flutter flight testing space for excitation systems and telemetry systems is limited.

Keywords: Ground vibration testing, vacuum support, pneumatic exciter, flutter flight testing.

Introduction

The flutter clearance of gliders poses some unique challenges. The low frequencies of the lower elastic modes make it challenging to support the glider during the ground vibration test (GVT) without influencing the elastic modes. The low frequencies also imply that, when using accelerometers as sensors, large amplitudes are required to produce reasonable output signals. Typical electro-dynamic exciters do not have sufficiently long strokes.

In flutter flight testing the challenge is to excite the glider without significantly changing its characteristics, and to do so over a wide frequency range. The ideal is for all available data to be studied before proceeding to a higher speed test point. Gliders are generally too small to accommodate sophisticated telemetry systems. It is also very time-consuming to land and download data from onboard recorders between test points. The result is that the pilot often has to make the decision to proceed based on his own observations.

Methodology

The present solution for the suspension of a glider during the GVT is to suspend it from a vacuum support, similar to the pneumatic supports that are commonly used in aircraft GVTs. The bellows (Figure 1 and Figure 2) is partially evacuated instead of pressurised. There is an interesting difference: the heavier the aircraft that is supported on pneumatic supports, the higher the pressures in the supports and the higher the stiffness and the higher the damping from air flow in the connecting pipes. The heavier the glider that is suspended by a vacuum support, the lower the pressure in the support and the lower the stiffness of the support and the lower the damping. The vacuum support has electronic height control using a linear potentiometer inside the support (Figure 3). It can also be actively controlled by adding an excitation signal to the height control signal. The maximum usable amplitude is 50 mm, i.e., 100 mm peak-to-peak (which leaves a 20 mm margin to the end stops). The support has two accumulators, one at a pressure adjusted to be slightly lower than the pressure required to lift the glider, the other at a pressure slightly higher than the pressure required to lift the glider (Figure 4). The smaller and symmetric pressure differences result in smoother operation than would be possible with maximum vacuum and atmospheric pressure. Height control and excitation of the vacuum support is performed via a pneumatic servo-valve that can connect either accumulator to the support. The unsteady support force is continuously measured using a piezo-electric force washer. The unsteady support force is also measured during excitation from other positions on the airframe. With the ability to excite using the support and by always measuring the unsteady support force it is possible to completely eliminate the vertical support stiffness using multi-input, multi-output processing. The stiffness of the support can be reduced by connecting it to a large tank. Care must be taken to minimise the length of the connecting tube. The oscillating motion of the air in the tube can actually introduce an anti-node of the support, i.e., a frequency at which the support becomes very stiff. This will in general not be noticeable in the GVT results. The air flow in the tube also introduces damping and artificially increases the measured damping of the modes in which there is significant vertical motion at the suspension point, by implication the centre of mass of the glider.

The second challenge is that large vibration amplitudes are required at the low frequencies to generate a sufficiently large acceleration for accurate measurement. This was accomplished using pneumatic long stroke exciters (Figure 5). The shaft of the pneumatic cylinder is supported in two air bearings. The maximum usable amplitude of the exciters is 100 mm, i.e., 200 mm peak-to-peak (which leaves a 25 mm margin to the end stops). Each pneumatic exciter has two accumulators, similar to the vacuum support. One of the accumulators is used to supply the air bearings, typically at 1.0 bar to 2.0 bar (gauge) and the other to supply the servo valve to drive the piston of the exciter, typically at 0.10 bar to 0.25 bar (gauge). The movable rod of the exciter is a tube and the stinger which attaches the exciter to a force

transducer or impedance head is attached to the inside of the tube close to its centre. This reduces the total length and space requirements for the exciter and still allows for lateral movement at the end of the stinger. The application of a pneumatic exciter is shown in Figure 6.



Figure 1. Inside of the vacuum support bellows



Figure 2. Top lid of the vacuum support



Figure 3. Central column of the vacuum support

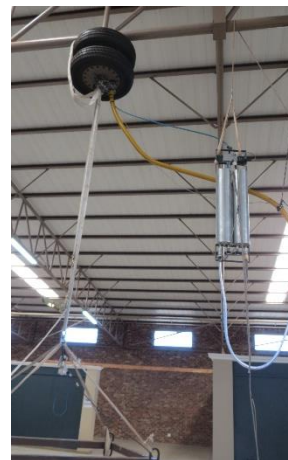


Figure 4. Vacuum support, accumulators and tubing

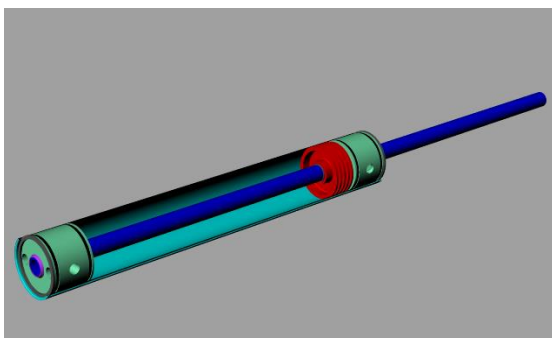


Figure 5. Inside of the pneumatic exciter



Figure 6. A pneumatic exciter connected to a glider wing, with accumulators in the foreground

The GVT system was not specifically designed for glider GVTs, however, it has some useful features. One of the features of the system is that it uses the CAN bus architecture to reduce wiring substantially. Up to 8 accelerometers are connected to a node (Figure 7). The nodes are connected to a host PC in daisy-chain fashion, i.e., there is a single

cable that connects all the accelerometers on the glider to the PC. The node collects time data from the accelerometers and processes the time histories to cross spectral densities. The results are then sent to the host PC over the CAN bus. The accelerometers are digital output MEMS sensors. Electro-magnetic interference is virtually eliminated by digitizing the signal in the sensor. Each accelerometer consists of a micro controller unit (MCU), sensor, CAN interface, power supplies and LEDs. LEDs are used to indicate the status of each accelerometer and is useful for fault tracing.

The orientation of the sensors is important to measure the mode shape correctly. Each accelerometer measures in 3 directions and measures down to steady state. The accelerometers are stuck to the glider without regard for orientation. Once all sensors are mounted the aircraft is tilted by a small angle in pitch and in roll. From the change in output the orientation of each sensor can then be calculated. Three-dimensional measurement at each node point makes it easy to transfer the GVT data to the aerodynamic model.

Excitation for flutter flight testing is provided by a lightweight rotating annular wing exciter (Figure 8). Very little torque is required to spin the annular wing, making it possible to use a small motor and amplifier. Operation in flight is simple, when power is applied the motor performs a frequency sweep and then stops. The behavior is programmed in the motor's amplifier. Instrumentation typically consists of 4 accelerometers on the wings, arranged to distinguish between symmetric and anti-symmetric modes and between bending and torsion deformation, 4 accelerometers on the empennage, a tri-axial accelerometer at the centre of mass and a pressure sensor for recording air speed along with the vibration data.

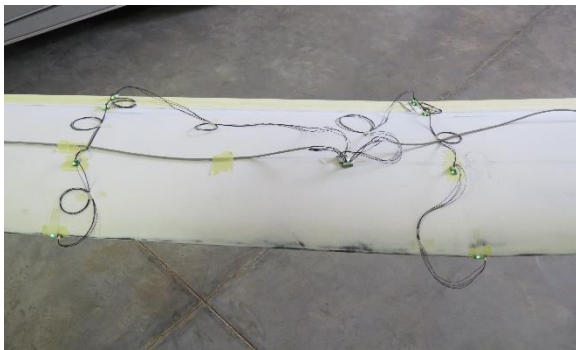


Figure 7. A CAN node and its 8 accelerometers



Figure 8. Annular wing exciter mounted on a glider wing

Modern cell phone technology makes it possible to send the flight test data to the ground in near real time. A 4G USB dongle is plugged into the data recording computer. After each test point the data is processed to power and cross spectral densities and the processed data is stored in a directory marked for synchronisation. If a test point is flown in an area with cell phone reception (usually from the first skyward pointing side lobe) the data can be accessed within a few seconds of completing the test. The challenge is no longer technical, but legal. The time histories can still be accessed after each flight.

Results

A typical driving point transfer function is shown in Figure 9. The first selected peak corresponds to the rigid body mode of the glider suspended from the vacuum support. The frequency of this mode was calculated as 1.293 Hz, damping 9.74% and modal mass 29.4 kg. The low modal mass compared to the mass of the glider is an indication of the amount of wing bending that is present in the rigid mode. The second selected peak corresponds to the first symmetric wing bending mode, with frequency 1.804 Hz, damping 3.27% and modal mass 25.2 kg.

The driving point transfer function for excitation from the vacuum support is shown in Figure 10. This transfer function is valid for an un-suspended glider, but excitation levels are low because the centre of mass does not move much in most elastic modes. It shows no rigid body mode or anti-symmetric modes. The first wing bending mode frequency is at 1.551 Hz and damping 0.24%

The corrected driving point transfer function is shown in Figure 11. The first two modes are replaced by a single mode corresponding to the first symmetric wing bending mode of the un-supported glider. The frequency of this mode is 1.551 Hz, damping 0.24% and modal mass 21.7 kg. Both the frequency and damping of the mode is affected by the correction.

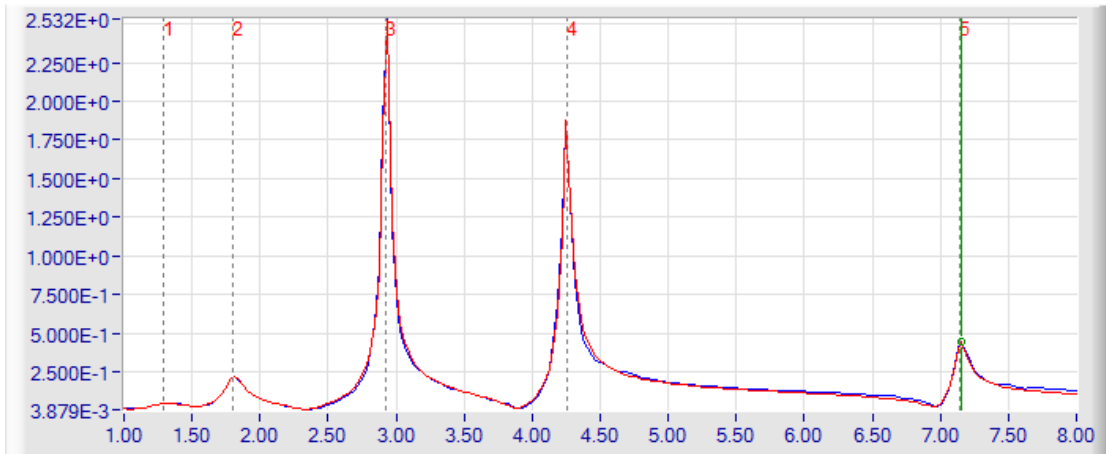


Figure 9. Driving point transfer function amplitude, vertical excitation at the wing tip

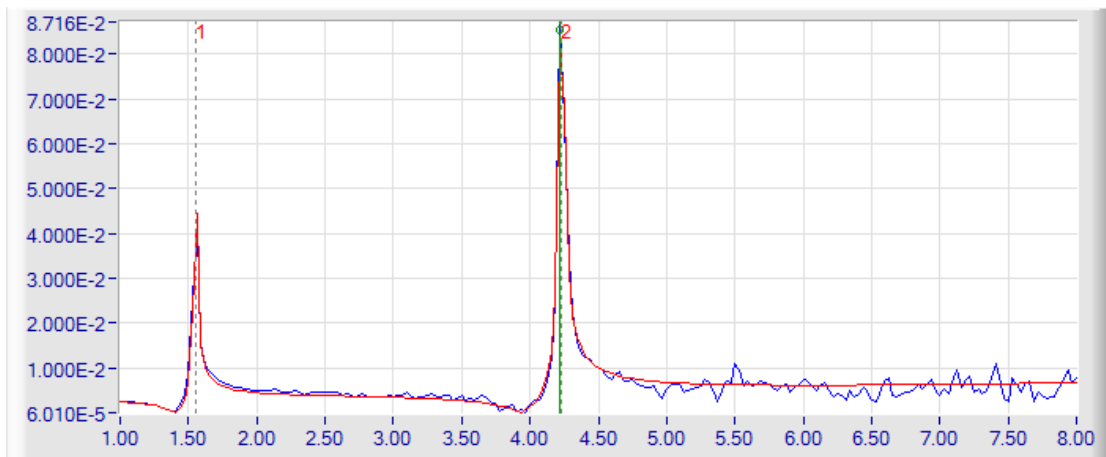


Figure 10. Driving point transfer function amplitude, excitation from the support

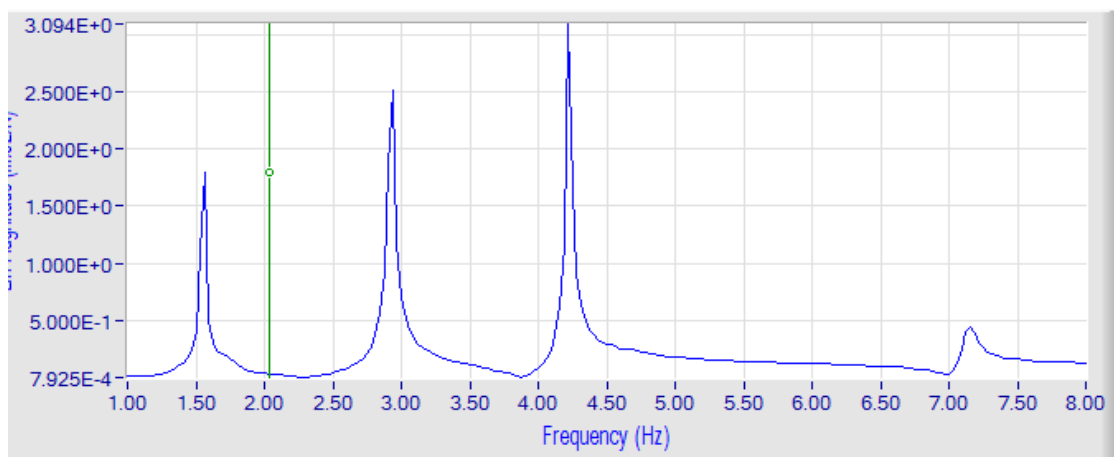


Figure 11. Driving point transfer function amplitude, vertical excitation at the wing tip, corrected for vertical support stiffness