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A380 - Flutter tests

1. Definition of flutter

Flutter is the coupling of different oscillation modes on a system. Let's take an example on an aircraft. In flight, due to its flexibility, the wing can oscillate in torsion and in flexion. The frequencies of these two motions are depending on speed. If, in some conditions, they are identical or very close one to the other, there can be an "auto-excitation". It means that the oscillation on one axis can amplify the other one and vice-versa, therefore increasing the energy. If the amplitude becomes too large, a rupture may occur very quickly.

This phenomenon is similar to what happens when a child is on a swing. Moving the legs at the right frequency amplifies the motion of the swing and increases the global energy.

Flutter can also occur on structures other than aircraft. Some of you may have seen the impressive images of the rupture of the Tacoma suspension bridge in the USA, about 60 years ago. The very strong wind led to amplify several oscillation modes until the rupture. Now all suspension bridges must be sized to resist to the strongest winds.

2. Flutter characteristics

On an airplane, flutter is characterized by oscillations diverging very quickly. Therefore, the risk of flutter inside the flight envelope, and even well outside the borders to have a safety margin, are not acceptable. On big transport aircraft, there is a huge number of vibration modes of different parts: wings, engines, empennage, control surfaces... On top of this, it depends on the quantity of fuel in the wings and in the empennage, on the speed and many other parameters.

Figure 1
A380 first flight over the Pyrenees

Theoretical computations are now very reliable and allow to determine in advance the potentially critical conditions. They are based on mathematical models of the structure of the aircraft. These models are then adjusted thanks to ground tests where the aircraft is excited with variable frequency oscillators. Such tests are performed on a development aircraft before the first flight and last several days. Despite this good level of analysis, exploring the flight envelope in speed and Mach must be done carefully.

Four engines aircraft give more frequently difficulties in the area of flutter. The reason is that the external engines may be strong contributors to various oscillations.

3. Flutter test flights

Flutter flights are obviously risky. Until the full opening of the flight envelope, the crews perform these tests with all the safety equipment: parachutes, helmets, life jackets, lifeboat... The emergency evacuation door (tunnel going through the cargo door) is also armed.

Several parameters have to be considered: CAS, Mach, weight, fuel repartition. For the same flight conditions, for example, it is often necessary to perform flights with various amounts of fuel in the tank of the horizontal tail plane: full, half full and then empty, because this difference modifies the oscillation frequencies and therefore the flutter characteristics.

Safety must be ensured well above VMO, because in case of wind gradient, this value may well be exceeded. In flight, the regulations ask for the demonstration that the aircraft is free of flutter up to VD (D for Dive, as in some cases, this speed can only be demonstrated in a dive). The difference between VMO and VD is usually around 50 kts on a classical aircraft. But on fly-by-wire aircraft, this margin has been reduced thanks to the high speed protection. In case of over speed the aircraft will react to limit the speed excursion. Depending on the type of aircraft, if the protec-

Figure 2
A380 3/4 front view

tions are lost, the maximum authorized speed may be reduced according to what has been validated. On the A380, we have VMO = 340 kt and VD = 375 kt.

What has been explained for speed is also valid for Mach Number. On the A380, the values are MMO = 0,89 and MD = 0,96.

Above VD and MD, the certification regulations require a theoretical demonstration that there is a supplementary speed and Mach margin where the aircraft is clear of flutter.

For each test point in flight, oscillations at variable frequencies are sent to some flight controls via a specific computer. A single test lasts 3 minutes. The frequency increases during the first part, then decreases to come back to the initial value. The crew can feel well the coupling modes as, at this time, there is an increase of the amplitude of the oscillation. If necessary, the test can be stopped immediately either by the pilots or by the flight test engineers. It is difficult to know in advance what amplitude is adapted for each speed in order to have a sufficient structural response for a proper analysis. Therefore the engineers have at their disposal several levels of excitation for each mode. Sometimes in flight, test points are restarted to obtain an amplitude well adapted for the analysis, but not too strong to avoid damages of the airplane.

All parameters are transmitted by telemetry to the ground. Each test point is analysed by specialists, as soon as the measurements are completed. This review takes a variable time, according to the degree of confidence and coherence with the models. Sometimes the clearance to go ahead for the following test point is given immediately. The crew may also have to wait several minutes for the clearance. It has also happened on some programmes that the flight had to be stopped for further analysis.

Flight controls are excited in different ways. For the ailerons, there are symmetrical and anti-symmetrical modes. For the first ones, the ailerons of both wings are deflected simultaneously in the same direction. For the anti-symmetrical modes they are in opposition (like in a roll control mode). Most of the tests are performed with the ailerons but some are also done using elevators or rudder.

The test points have to be performed in direct law in order to avoid introducing flight controls deflections due to an outside source. In the past, before the A380, the pilots were not authorized to touch the side stick during the test and therefore execution was rather difficult. The altitude was maintained using the trim wheel. The bank angle was kept close to zero with very small pressure on the pedals. At high Mach, differential thrust was sometimes used to control roll, due to the reduced roll induced by the rudder. The speed had to be maintained with a good precision with the thrust lever. One of the key difficulties was that any action on the thrust gave a pitching moment that had to be compensated with the trim wheel. One of the pilots was in charge of maintaining the trajectory: altitude and heading and the other one was keeping the speed. Obviously a good coordination was needed.

The crews were concerned about their ability to maintain the flight parameters very precisely due to the large inertias of the A380. Each test point lasted for 3 minutes and had to be performed with an electric trim and no trim wheel. Finally, the Design Office prepared a specific direct flight control law such that the test conditions could still be maintained by action on the stick. Everything then became straightforward.

Progression in speed (CAS) is generally slow, by step of 15 kts. In parallel, for each speed, the Mach Number has to be increased progressively as the relationship between Mach and CAS is a function of altitude.

For high Mach Numbers, it is not always possible to maintain the altitude during 3 minutes because drag increases rapidly with Mach. In this case, tests are performed in descent and, as variable frequency oscillations could not be used, it is replaced by what we call “pulses”, which are abrupt impulses sent by computers to the flight controls. Above MMO, it is quite frequent to find buffeting of various levels. This buffeting generally reduces the risk of flutter as it disorganizes the potential oscillations of the different modes.

The final test is the dive at VD / MD. It is necessary to start at the ceiling of the aircraft. Then, with full thrust, the crew begins the dive until reaching MD in descent. MD is kept with a speed increasing up to VD. At the conjunction of MD / VD, the test is over and the pilots can throttle back and pull gently on the stick. During all the tests, pulses are sent to the flight controls on the various axes. The flight test engineers must act quickly as for some aircraft, the drag is such that the rate of descent is high.

4. History of the A380 flutter tests

On the A380, the envelope opening at VMO / MMO was performed at flight n°5 without specific flutter test due to the good results obtained after analysis of the ground tests.

The first real flutter flight was flight n°21, on June 9th 2005, about one and a half months after the beginning of the flight tests. Take-off weight was 533 tons and landing weight 485 tons (normal MLW is 386 tons). During this flight, with maximum fuel in all tanks, the speed has been increased up to VD (375 kt) at a low Mach Number.

The following flutter tests were performed during flight n°51, at the beginning of August 2005. Why such a delay between these two flights ? The reason is that priority had been given to other activities, mainly the validation of the final aerodynamic configuration: slats and flaps deflections... During this second flutter flight, the envelope has been opened up to the conjunction VD and MMO, without any abnormal finding in flight. However, when on ground, it appeared that there were serious damages on the belly fairings. Clearly, reinforcements were necessary before the next flutter flights.

At the end od August, a new flutter flight was performed with modified belly fairings. The target was to open the flight envelope up to the conjunction of VMO / MD. It was the first opportunity to fly above MMO. This has been done by step, but when the aircraft reached a value slightly above 0.95, the Mach Number suddenly jumped up to 0.98. The reason was a shock wave crossing the static pressure sensor and it was not possible to stabilize precisely MD = 0.96.

Starting from mid September, one or two flutter flights were performed every week. It was not possible to do more as some time was needed for data analysis and on top, as the aircraft was well shaken during each flight, there was a need for a thorough inspection. For all these flights, the amount of fuel in the tanks was adjusted to cover all the situations, one of the key issues being the fuel quantity in the trim tanks.

The campaign was interrupted for some weeks due to a commercial campaign. Then, on the 1st of December 2005, the dive at VD / MD was performed. We were aware of the difficulty to stabilize precisely MD due to this shock wave influencing the measurement. The test was repeated several times, reaching an indication of 0.988. Finally the flutter specialists agreed that this was sufficient to certify the aircraft.

After the flutter tests came the time of the tuning of the flight control laws, as it is necessary to demonstrate that with the protections, it is not possible to exceed the cleared flight envelope. This will be the subject of another article.

Figure 3
A380 over Switzerland

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