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Experimental Test Pilot

A380: Development of the Flight Controls

Part 1

This article is the first of a series intended to explain what has been done for the development of the flight controls laws of the A380.

The General Principles of the Design

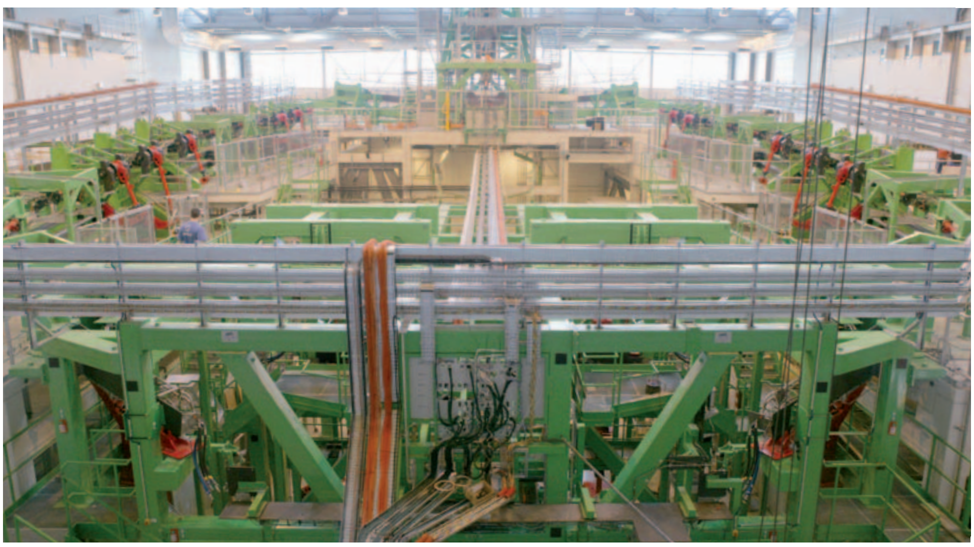
Very early in the development process, the design office has to take many important decisions related to flight controls such as how many computers, flight controls surfaces, and hydraulic circuits are needed. All that is dictated by the analysis of failures, associated with a first estimation of the likely flight characteristics. In case of multiple failures, the aircraft must remain flyable.

One of the failures that could have the most adverse consequences and that leads to a lot of decisions is the non-contained explosion of an engine rotor disc. It is assumed that a part of this disc will penetrate the fuselage or the wing with "high" energy. The engine is designed and built in such a way that this should not happen, but this is a supplementary precaution. The potential trajectories of this part are computed according to very precise rules. It must be checked that all the energy sources (mainly electricity and hydraulic) will not be affected at the same time, which could have catastrophic consequences. Obviously, this study is far more complex on a quad than on a twin due to the number of rotors involved. It is to be noted that this scenario, while extremely rare, happened recently, on an A380 from Qantas taking off from Singapore. Even though the aircraft was in a severely damaged and degraded situation, the crew had all the means to land safely, and the analysis of the event confirmed that the design, in terms of reconfiguration choices, was appropriate.

Numerous other factors are taken into account when choosing the general architecture. The most important is the need to minimise weight, obviously whilst keeping the same level of safety.

The development of the flight controls laws for a Fly-By-Wire aircraft is a complex process. It starts by computations based on estimated aerodynamic models of the aircraft, which are then checked and adjusted thanks to wind tunnel tests. This allows a first version of the computers to be prepared. The next step is the installation of these computers on a simulator where the latest aerodynamic models have been integrated. Evaluations can start, first with "development simulator" pilots specialized in this job, and then with the test pilots nominated to follow the program. At the beginning, numerous small problems are found and there is a progressive evolution of the computers. The real proof comes with the test flight itself as, even if the models are generally reliable, they are rarely fully representative of the aircraft at low speed, high speed and in the ground effect. Also, at the beginning of the flight tests, for the first time, pilots are exposed to the accelerations of the aircraft in response to their commands. Flexibility of the structure can have consequences

Figure 1
A380 Iron Bird



on comfort, but can also induce effects on the flying characteristics.Often, the models used for computations or in the simulator are correct so that after tuning on ground and validation in flight, there is nothing else to do. But it occasionally happens that the aircraft behaviour is not in line with the expectations and an aerodynamic identification in flight is needed to allow further tuning of the models in order to enable the design office to define the next standard of the computers. Sometimes it is difficult because the modelling of the ground effect is not satisfactory or the flexibility of the aircraft does not permit a correct simulation. In this case, the development has to be performed in two phases, first with models and then directly in flight. When in flight, engineers and pilots decide in real time what adjustments are necessary. They are using their knowledge, judgement, common sense and feelings (seat of the pants flying). Some non-specialists consider that the flight test task is only to validate results obtained in a simulator. This is not correct, as, for a significant number of tests, methodologies have not evolved since the last century, except for the help given by the computers. Most of the time, qualitative feelings and impressions are still showing the way.

In order to save time, the flight test engineers have a tool called AFDX Digital Injection System (ADIS), which allows them to modify in real time some characteristics of the computers. For safety reasons, all the new possible adjustments are checked in a simulator before using them in flight.

The development of the flight controls laws is a fascinating adventure: every day there are new surprises, some good and some bad. The A380 has not been the most difficult aircraft in this respect, thanks to the excellent aerodynamic characteristics.

Fly-By-Wire and Associated Improvements

Fly-By-Wire has brought a lot to aviation. Obviously the ease of flying and the protections to avoid loss of control are well known, but that is not all.

In the past, flight controls were designed to meet two sets of criteria: they had to be “well harmonised” and had to meet the criteria for certification. With Fly-By-Wire, three possibilities have been added: improve safety by restricting manoeuvres which could lead to a loss of control, reduce the weight of the structure with the prohibition of some actions, which may increase the loads and finally improve comfort for the passengers. Adding all these functions leads to more and more complexity for the flight controls computers.

The Main A380 Characteristics

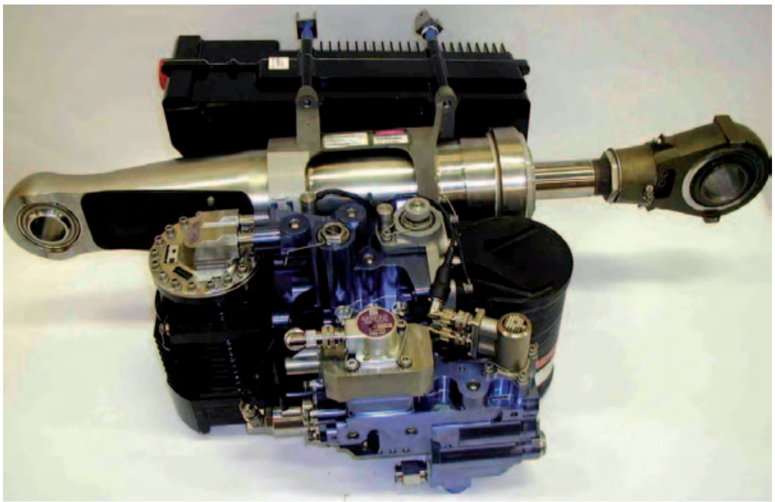
A general description of the main characteristics of the A380 flight controls will allow us to gain a better understanding of the tests performed.

The A380 has seven flight controls computers: three Primary Computers (PRIMs), three Secondary Computers (SECs), and one Back Up Control Module (BCM). Any of the three PRIMs can ensure the full control of the plane without restriction. The SECs do not provide stabilized control laws as do the PRIMs but they are more robust to the loss of some information. They also have different software than the PRIMs so that a bug in one category of computer does not “contaminate” the others. All computers have a command and a monitoring lane. Finally, there is a BCM, available in case of failure of all PRIMs and SECs.

The A380 has only two hydraulic circuits instead of three on the Airbus of the previous generations. The third circuit has been replaced by local hydraulic generation: for some servo-controls, a small electrical motor creates the hydraulic energy to power it. These systems are called EHA (Electro Hydraulic Actuator) or EBHA (Electro Backed up Hydraulic Actuator: fig. 2). This new type of architecture with only two circuits allows the saving of several hundred kilograms on the A380, mainly thanks to the reduction of the number of pipes. It also creates a new level of system segregation safety.

Some control surfaces have been split into several parts controlled by different electrical and hydraulic sources. There are two rudders instead of one on all other Airbus and four elevators instead of two. On each side, there are three ailerons

Figure 2
A380 EBHA Rudder



instead of one on the A320 family and two on the A340 and A330. Each of the surfaces (except the spoilers) is activated by two servos using different hydraulic circuits or EHA or EBHA. Two or three different computers (PRIM and SEC plus BCM) control each of the servos. Therefore, a lot of failures are needed to lose the control of one surface.

When the four engines (or their generators) and the APU are no longer available, electricity is coming from a Ram Air Turbine (RAT).

The Identification of the Aircraft

To ensure that the adjustments to the control laws are well adapted to the characteristics of the plane, the design office needs a good aerodynamic model. This is initially achieved through simulation. However some tuning can only be finalized and validated in flight. So, the identification of the aircraft stability and control characteristics in flight is among the first priorities of the program. On the A380, about one month after the beginning of the flight tests, in April 2005, flight 16 was devoted to identification of these characteristics in pitch. Then, during the months of July and August, about 15 flights were dedicated to similar tests in roll, pitch, effect of the engines… More were performed during the following months.

These identification flights are completely different from those which must be done at the end of the development in order to prepare the aircraft models for installation in the training simulators. For these last flights a very specific process has to be followed. The training simulators do not need to represent the flight characteristics in extreme situations. On the other hand, in order to develop the flight control computers, the design office needs to have a good identification of the aerodynamic characteristics at the limits of the flight envelope.

The Take-Off Rotation Law

On the A340-600, the development of the take-off control law proved to be rather difficult. It is worth explaining the issue here to show the kind of obstacles that can be found.

All the pilots agreed that, on the A340-300, the reaction in pitch during the rotation at take-off, whilst being acceptable, was a bit sluggish. As the A340-600 was planned to be about 100 tons heavier than the A340-300 and longer by about 12 meters, a study was launched to improve the reaction of the -600 during the rotation. Numerous tests were performed in the simulator and then the new control law was installed on the A340-300 used for development. The team was happy with the results. Subsequently, the take-offs of the first two flights of the A340-600 were performed in direct law in order to improve progressively our knowledge of the aircraft. Following the landing from the second flight, it was planned to perform another take-off with the brand new rotation law. It just happened that the Captain of the A340-600 had been in charge of the development of this law. At the beginning of the manoeuvre, the aircraft exhibited a strong Pilot Induced Oscillation (PIO). The pilot reacted naturally to an unexpectedly strong response of the aircraft. The oscillations stopped after six cycles.

Why this surprise, as everything was well prepared? The forward part of the A340-600 is longer than on the -300 and, with this lever, the crew had the feeling of being projected too quickly into the air and therefore reacted immediately, creating this PIO. All the work done prior to the flight could not be used as such. So, after a minimum of development in the simulator, to have a good starting point for the control law, the tuning was performed during a flight with around 15 take-offs.

The principle is rather simple: with the help of the ADIS, at each take-off, it is possible to improve what the pilots are feeling and the flight engineers have on their traces. As an example, the law can be made more or less efficient at the initial pilot command. It is also possible to reduce the pitch rate when approaching the take-off attitude, but not too early and not too late. If there is a risk of tail strike, the pitch rate must also be controllable to almost zero very quickly. The flight test engineers have to play with a lot of variables such as pre-command, damping, filtering and so on, so as to reduce the take-off distances and ensure safety in all the critical cases such as engine failure, early rotation… To perform this tuning well they must have a perfect understanding of the effect of all parameters.

This example shows the limits of what is possible to perform with models or with the simulation for some flight phases, particularly close to the ground. However, the conclusion must not be that models have to be disregarded. Very good preparation is fundamental in order to have a solid starting point and to give to the flight test engineers well-adapted tools with the ADIS.

After the lessons of the A340-600, we decided to keep the same methodology to develop the rotation law of the A380: a basic and simple preparation using models and simulators followed by the development with flight tests.

For all these tests: development of a rotation law and, later on, measurements of take-off distances, there is always a risk of tail strike because we are frequently on the limit of manoeuvrability of the aircraft. Therefore, the aircraft is equipped with a tail bumper, the same that is used for the VMU tests.

The first flight for development of the A380 take-off rotation law was performed on December 29th 2005 with a very experienced crew: two test pilots, one test flight engineer (in the cockpit) and two flight test engineers both specialists of flight controls. After 15 take-offs, the

Figure 3
A380 take-off from Toulouse-Blagnac Airport

results were satisfactory. Later on, in February 2006, another flight allowed the team to fine-tune the protection, which was designed to avoid getting a tail strike. It is to be noted that during these tests, we did experience a slight tail strike on the tail bumper, proof that we were looking for the minimum margin while keeping the safety level. The computations performed later on, demonstrated that the tail strike would not have happened on the fuselage without the installation of the bumper. Finally, a last flight was performed at the beginning of March 2006 to validate the law at very heavy weights, as the behaviour has to be checked for all the weight and CG combinations. The first take-off was performed at 596,5 tons, more than 30 tons above the MTOW. Our experience has shown that it is always better to be heavier for this type of flight as, very often, our customers are asking for an increase of the MTOW very quickly after entry into service. This way of working avoids launching, later on, new tests which could even lead to a further modification of the law. Additionally, sufficient fuel was necessary to fly to Istres Air Force Base (South of France) to perform all the tests. The choice of Istres airport to perform this flight was due to the runway length of 5000 meters, which allowed us to be efficient after each take-off by executing overweight landings without overheating the brakes. These landings added to the difficulty of the tests.

Immediately at the end of the development of this law, the flights for measurements of take-off distances started with EASA crews.

The Landing Pitch Law

The development of the pitch law at landing was quite quick. From the beginning, we were aware that landing the A380 was very easy. However some adjustments were necessary for the various flight conditions: weights and CG positions. For the flight part, an initial tuning was performed as the controls were judged to be a bit too sensitive.

But the main modification was the suppression of what is called the "de-rotation" law on A340 and A330. On these aircraft, as soon as the main wheels touch the ground, this law is engaged and helps the pilot to control the pitch attitude until the front wheels are on ground. This law does not exist on the A320 family but was installed during the development of the A340 because, during a demonstration flight, an airline pilot encountered Pilot Induced Oscillations (PIO) in this flight phase. The reason is that the A340 touches down with a rather high pitch attitude, and on the rear wheels of the bogies having a "nose up" position. Added to which, the touchdown of the nose wheels is performed with a slight nose down attitude. The nose wheels, and obviously the pilots, must "descend" from a relatively large height at landing. This "de-rotation" law reduces the authority of the stick in pitch during this phase in order to be able to smoothly control the nose gear to the ground, without risk of PIO.

A similar law was installed on the A380 by precaution, despite the fact that the A380 has none of the characteristics of the A340. In all cases, it appeared that this law was only engaged for two or three seconds and therefore was probably useless. In May 2006, during flight 221 of aircraft 1, we used the opportunity provided by the tuning of the pitch law for approach and landing to make the decision to remove it, keeping the flare law engaged during this phase. After several landings, it appeared that this was the right solution and from then on, all landings were performed with this modified law in order to be sure that there was no adverse consequence.

Later on, some minor final adjustments were made on the approach and flare law. The target was to satisfy the majority of pilots! The most important modification during this period was the increase of pitch authority when at high weight to reduce the risk of hard landing in case of emergency turn back.

Part 2 will include the development of the lateral law (the "ailerons waltz") and the tuning of the low speeds and high speeds protections.

Safety First

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