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NEW FLIGHT CONTROL LAWS FOR LARGE CAPACITY AIRCRAFT

EXPERIMENTATION ON AIRBUS A340

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Abstract

This paper presents the main stages of an experimentation on Airbus A340 to test new flight control laws. These control laws actively control the first flexible modes of the aircraft in order to increase the flight control system bandwidth. The results obtained during the flight test allow the concept to be validated, and a new standard to be defined for the flight control system and autopilot of future large civil aircraft, like the A340-500/600 and the A3XX.

Introduction

The introduction of fly-by-wire and digital computers on the A320 defined a new standard for flying civil aircraft. This definition comes from 20 years of experience acquired in the field of flight controls since Concorde (1969), which has been flying with a three analog flight control system, and the A300B (1983/1985), which was used to test the sidestick and A320 type control laws. This historical reminder shows how progressive the Airbus electrical flight control system development was in order to take all aircraft control criteria and the Airlines' requirements into account.

Today, air transport growth is making the aeronautical industry become aware of the necessity of developing high capacity long-range aircraft. These large aircraft are characterized by flexible structures which lead to new technological challenges (aircraft design, pilotability, ...). As regards the flight control system, this flexibility increases the interaction between control laws and structural dynamics modes, the frequency of which becomes lower. Traditionally, this aeroservoelastic coupling is solved by filtering, which prevents flight control laws from exciting flexible modes. For future large flexible aircraft, this method seems difficult to apply because it will be impossible to reduce structural vibrations without reducing flight control law bandwidth. So it becomes necessary to actively control both the lower elastic modes and the handling qualities modes in order to provide the Pilot with acceptable response time during manœuvres, and the Passenger with a high level of comfort.

To take up this challenge, a new methodology was developed, to take aircraft flexibility into account directly when conceiving flight control laws. As this concept was completely new, it was decided to test it in flight on the A340-300, the most flexible Airbus aircraft, to assess it. The process is similar to the one used for testing the A320 control laws on the A300B. This paper summarizes the main stages of this experimentation.

Flight control law design

The general objective of the flight control laws integrated in a fly-by-wire system is to improve the natural flying qualities of the aircraft, in particular in the fields of stability, control and flight envelope protection. The stick inputs are transformed by the computers into pilot control objectives which are compared with the aircraft response given by sensors or estimators.

When the aircraft size is increased, its flexibility is greater, and interaction with the flight control system can occur. Indeed, sensors used by the control laws not only measure the flight path, but also the structural vibrations. The closed-loop stability of the aircraft can be modified, and particular precautions must be taken. Traditionally, the control laws are filtered in order to avoid coupling with structural modes and to obtain satisfactory stability margins.

Moreover, some structural modes can be excited in turbulence conditions, and uncomfortable vibration levels can be generated. For the A340, a damping function, called CIT (Comfort In Turbulence), was

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defined in order to attenuate the fuselage response to turbulence by increasing the damping of the fuselage modes. Because the fuselage mode frequency is higher than the flight control law bandwidth, there is no interference with the flying qualities (see Figure 1).

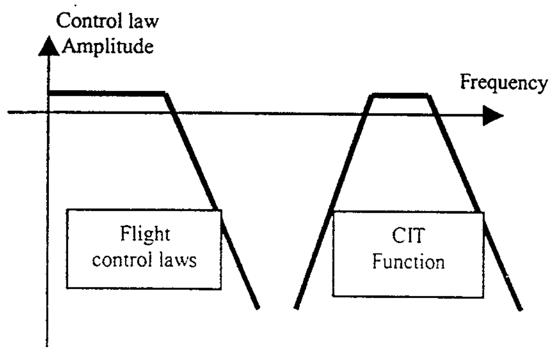

FIGURE 1 - Frequency distribution with classical approach

For more flexible aircraft with a much lower structural mode frequency, it seems difficult:

- to filter the control laws without downgrading performance,
- to conceive independently the flight control laws and a structural mode function.

For these reasons, a new methodology was developed in order to conceive at one and the same time a system which control both rigid and flexible modes (see Figure 2). This methodology is based on automatics techniques, which were defined on the basis of experience acquired on previous programmes.

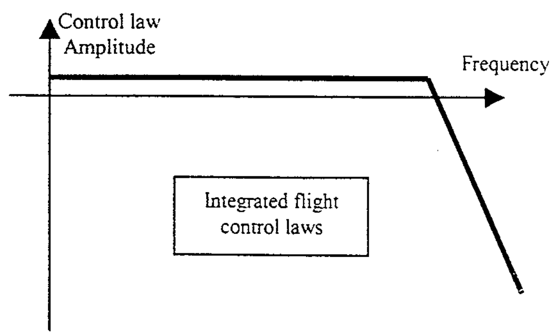

FIGURE 2 - Frequency distribution with integrated approach

Active control of flexible modes allows the damping of main structural modes to be increased, which gives the possibility:

- to improve comfort,
- to reduce loads in turbulence,
- to avoid the coupling between pilot and flexible modes for future large aircraft.

Moreover the control law bandwidth extension makes it possible:

- to improve the handling qualities of the aircraft,
- to avoid Aircraft Pilot Coupling (APC) by minimizing the dephasing in the flight control loop.

The general philosophy of the Airbus flight control system is maintained. It means that for longitudinal control, stick position is translated into vertical load factor, whereas lateral control is achieved through roll rate or sideslip objectives. Static stability is restored at the limits of the normal flight domain with activation of specific protections (angle of attack, high speed, ...).

The flight control laws achieve these objectives, while controlling at the same time the structural modes. It is a generalization of active control, which can be made owing to the fly-by-wire system.

In order to validate this concept, it was decided to test it in flight on the A340-300. Indeed, only in-flight experimentation makes it possible to evaluate the handling qualities in a fully representative environment. A real test was needed in order to demonstrate the concept with respect to the uncertainties of the aeroelastic model and get rid of the known limitations of a ground-based simulator, as well as setting a methodology for flight test of such type of control law.

New flight control laws were designed on the whole flight envelope with handling qualities and flexible mode damping objectives. For the synthesis, structural filters were cancelled, and a complete aircraft model, including flight mechanics and aeroelasticity, was used.

In order to actively control the fuselage modes, specific accelerometer locations were defined at the ends of the aircraft, while a specific pitch gyro was located near the airplane center of gravity. Other information needed for the flight control laws was provided by the ADIRUs (Air Data and Inertial Reference Units) located at the front of the fuselage. The control surfaces used were exactly the same as those used by the basic laws.

The actuator characteristics were taken into account in the synthesis, and the necessary computing times were estimated. In order to actively control the flexible modes (which means phase control), it is necessary to precisely know and control the dephasing between sensor acquisition and control law order emission. A computing time of 10 ms was selected as an objective for specific lanes in order to guarantee good robustness properties in the whole flight domain.

Dynamic controllers obtained by the synthesis methodology were transformed into static gains and filters.

Because the structural stability was ensured by active control, and not by a passive way, higher feedback gains were obtained which gives the possibility to improve the performance of the control laws (rise time, perturbation rejection, ...).

Validation and System integration

The control laws were then defined in SAO (Spécification Assistée par Ordinateur), the Aerospatiale graphic language to specify control laws and system logics, and automatically coded. The first validation was made with OCAS (Outil de Conception Assistée par Simulation), which allows the aircraft behavior with the control laws to be assessed in a non-linear environment. Simulations representative of pilot inputs were made in order to judge the handling qualities of the aircraft.

Concerning the system area, OSIME (Outil de SImulation Multi Equipement) was used to verify the correct functioning of the new control laws in the whole system (primary computers, secondary computers, servo-controls, ...) and to check the compatibility with current monitoring.

Once the validation was finished, concerning both control law and system areas, the integration in the FCPC (Flight Control Primary Computer) was made. Particular precautions concerning the respect of a short and constant computing time were taken. The use of the SAO specification allowed a sequencing of the control law computation to be easily defined, which guarantees a computing time of 10 ms (between sensor acquisition and control law order transmission). It was decided to keep the usual A340 laws and to implement the new control laws in parallel in order to compare the behavior of the two flight control laws. The switching of a law to the other one was programmed by SPATIAAL (Système Pour Acquisition et Traitement d'Informations Analogiques ARINC et Logiques) which allows several pre-programmed and pre-validated configurations to be selected during flight.

Finally, a complete validation on the A340 simulator was made with the real equipment. The flight control system behaviour was judged to be good for flight test.

Flight test

The first flight test was performed at the end of 1996 on A340-300 MSN 1. For take-off and climb the usual A340 laws were used. In cruise, calibrated inputs were injected on the control surfaces in order to check the aircraft stability in closed loop before selecting the new control laws (which computed orders were analyzed in open loop). Indeed, the computation of transfer functions in real time (thanks to telemetry) between the sensors and the control law orders allows the aircraft stability in the real environment to be verified with the Nyquist criterion. For all the axes, the new control laws had excellent stability margins, and they were selected by SPATIAAL.

Handling qualities were then assessed for different aircraft configurations (approach, cruise, ...) and different manœuvres (level change, turn, engine failure, ...). The pilots found the aircraft very precise and easy to fly. The response times obtained were better than those achieved with normal A340 laws. Even though increased time responses are not necessary for the A340, it makes it possible to assert that this new concept is suitable for a more flexible aircraft.

An in-flight structural mode excitation system was used with SPATIAAL in order to measure the effects of the control laws on flexible modes. A reduction in fuselage acceleration levels in a ratio of two was obtained for the y and z axes, which allowed the margin relative to flexibility induced APC and the comfort to be improved.

Other flight tests were carried out with different mass cases (fuel, payload, ...) in order to verify the robustness of the control laws. It was shown that the new control laws were very robust as regards the stability and performance aspect. The robustness properties come from the methodology synthesis, which was made on a set of aircraft models, but not from the introduction of many parameters in the control laws computation. This principle allows the failure case management to be simplified.

It was recently shown than this concept is applicable to the autopilot control laws as well, by using the manual control laws for its inner loop. The use of the same piloting function gives the possibility to reduce the development period for a new aircraft, while the methodology allows the basic autopilot performance limitations resulting from flexibility effects to be alleviated.

Some studies are now being made to optimize the development of this type of control law by introducing the aeroelastic models on the validation tools (OCAS, OSIME) and the simulators.

Conclusion

This successful experimentation defines a new standard for the flight control system and autopilot of future large civil aircraft, like the A340-500/600 and the A3XX. The active control of structural modes through the fly-by-wire system allows a high level of handling qualities and comfort to be obtained in spite of aircraft flexibility.

Aerospatiale is thus already preparing the future, in order to give the Airlines a large capacity aircraft in the required time, within costs, and in the tradition of flight control systems at the service of aircraft control and passenger comfort.