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INTEGRATED CONTROL TECHNOLOGY FOR COMMUTER AIRCRAFT EXPERIMENTAL RESULTS AND FUTURE POTENTIAL

W. Alles, H. Böhret, H. Wünnenberg
Dornier GmbH, Friedrichshafen

Abstract

The progress in the field of flight control and guidance technology for large transport aircraft is considered to be applicable to the class of commuter aircraft.

The definition of the relevant technical components of an integrated flight control system and possible evaluation criteria for the final choice of applicable components are illustrated. Some examples of already realized systems are presented in short. A more detailed description of the development and flight test of an active control system for improving the passenger ride comfort is given.

Further technical research including flight test is necessary to reveal the technical potential and to reduce the economical risks.

1. Introduction

The new generation of the large commercial aircraft as the Airbus A320 respresent a significant step into the future concerning the flight control and guidance technology. These aircraft use the advantages of the modern computer-aided flight control technologies as 'Fly by Wire' and 'Active Control' consequently in the sense of improving the economy, the safety of the flight, the passenger comfort and the simplification of the maintainability. As impressive as these new technologies itselves is on the other hand the high acceptance by the customer-airlines, which are familiar with the operation of complex flight control systems.

In this sense the title of our paper should be interpreted as a question. We don't want to present to you a detailed well-proven concept of a high sophisticated modern flight control system for commuter aircraft based on FBW and ACT, we want to initiate discussions on this subject as to our opinion the time has come to start a process like that now. Dornier as a commuter aircraft manufacturer is engaged in this technical subject for some time with the aim to find out, which of the different components of this technology seems to be attractive for an application of a future generation of commuter aircraft. For this class of aircraft the problems are different. Besides the acceptance by a different type of customer and pilot the question of commercial efficiency of the new technologies are much more stringent as for an airliner, as the additional cost are higher in comparison to the cost of the basic aircraft concerning the today technical standard. So it seems to be impossible to copy for instance the Airbus 320 solution, but there is a need for special cost effective developments and the prove of their technical and economic efficiency by relevant flight test programs. The criteria for a final evaluation but also for a necessary preselection phase could be the following, shown in Fig. 1. The Figure shows the essential basic criteria and the relevant subaspects for the evaluation of new technologies subsumed under the general terms

- economic efficiency,
- safety,
- comfort,
- cost.

An improvement of the economic efficiency is achieved by an increase in flight performance (e.g. due to reduced drag) and a structural stress relief permitting reduction of the structure weight. The service life can be increased by means of punctual operation (flight plan observance) and good maintainability. A progressing automation opens up the vision of a single-pilot cockpit.

Exact flight path observance, failsafe systems and a reliable failure detection together contribute to an increase in safety. This objective can also be achieved by releasing the pilot of subordinate tasks so that he can better perform supervisory functions.

The comfort for passengers and pilot is essentially determined by the dynamic characteristics of the aircraft. Here, the influence of the technical appeal of the aircraft on the acceptance of the user should not be underestimated.

A different factor is represented by the cost. An increase in purchase cost due to new technologies must be compensated by lower operating cost (fuel, crew, maintenance).

2. Integrated Control Technology

2.1 Definitions

Fig. 2 gives a synoptical view on the systems which can be classified as ICT systems. By replacing mechanical links between control elements and actuators by electrical or optical signal lines (fly-by-wire/light) space and weight savings are possible. In addition, the man-machine-interfaces can be designed more flexible. As essential advantage, however, this feature establishes the prerequisites for advanced signal processing. Such basic functions as stabilization, decoupling, coordination and compensation permit a largely free design of the aircraft dynamic characteristics and the utilization of the entire flight envelope. Since a fly-by-wire-system has to meet the same safety requirements as a conventional flight control system, redundant design is indispensable and the realization expenditure is correspondingly high.

The progress in the field of autopilot and flight management systems for large transport aircraft should also be applied to the class of commuter aircraft. The following examples are to be given: Generation of optimum flight paths concerning time, energy, noise and passenger comfort; automatic guidance on such paths up to the automation of entire flight sections (e.g. autoland). By means of an automatic boundary control, the excess of limit values for angle of attack, speed, etc. can be avoided. Utilization of performance reserves without subjecting the pilot to high stress is possible and safety can be increased.

An essential component of integrated control technology is represented by 'active control technology' measures. In order to define these measures clearly in opposite to the other ICT measures, tasks which can not be performed by the pilot - or only with an unjustifiable expenditure - shall be classed under this item. Here, FBW signal processing does not represent a necessary prerequisite for ACT measures; however, it should be regarded as basis for an advanced conception.

Concerning this matter the following items are to be mentioned:

- artificial stabilization,
- manoeuvre/gust load alleviation,
- flutter suppression,
- optimal wing camber.

Besides an increase in operational economic efficiency (e.g. reduction of trim drag), structural relief and an increase in passenger comfort are the essential objectives. This shall be explained later by means of several examples.

A completion of the overall conception can be realized by means of consequent electric signal processing also including the actuators. The application of electromechanical or electrohydrostatic actuators (each actuator has its own integrated hydraulics) makes the expensive hydraulic pipe systems superfluous. Thus, weight can be reduced, reliability and maintainability are increased.

2.2 Examples

In the following, the essential ICT elements shall be illustrated by a short description of already integrated systems.

At the present the most famous civil application of the FBW technology is the Airbus A320; the concept of the flight control system is known by a multitude of publications.

Another example - which comes closer to the class of commuter aircraft - is the control system of the VFW 614 - ATTAS of the DFVLR (see Fig. 3). Of course it is an experimental system, so the computational power (5 computers are coupled by means of an optical bus) is much higher than it should be necessary for a commuter aircraft. A dual redundant flight control system is sufficient to meet the safety requirements, a safety pilot with conventional mechanical control system serves as 'back-up-system'.

A typical example for an active control system is the load alleviation system (LAS) of the Airbus A320 (Fig. 4). Ailerons and spoilers are used to take influence on the change of the lift distribution (e.g. caused by gust) to reduce structural stress and weight.

A further example of a realized and flight tested ACT-system for commuter aircraft is OLGA (Open Loop Gust Alleviation). Within a research program the design objective of this system was a considerable improvement of the passenger comfort particular in the frequency range between 0.3 Hz and 1 Hz. In this frequency range the aircraft accelerations caused by gusts are high and additionally the human sensitivity to accelerations has its maximum.

According to Fig. 5 the gust compensation of the OLGA system is realized by the following philosophy:

- Computing of the gust velocity from the angle of attack and the aircraft motion parameters (airborne wind computation).
- Symmetrical aileron deflection as a function of the gust velocity for compensation of the gust induced lift (direct lift control) at the wing.
- Simultaneous elevator deflection for compensation of the pitching moment of the symmetrical ailerons.
- Additional elevator deflection for the compensation of the gust induced lift at the horizontal stabilizer.

The symmetrical aileron deflection for direct lift control was considered the most cost effective design within this research programm.

For the optimization of the system and for the support of the specification of the hardware elements intensive wind tunnel investigation were performed. Fig. 6 shows a scaled model of the aircraft DO 28 TNT which was used for flight test. The model was built for use within the Dynamic Wind Tunnel Simulation of the DFVLR, and was equipped with powered control surfaces and all necessary sensors for the onboard measurement of the gusts. The gust generator consisted of two moveable flaps, which were installed into the nozzle of the wind tunnel. These flaps were driven by servo motors, enabling the device to produce gusts similar to the natural atmospheric turbulence.

The wind tunnel experiments gave a profound insight into the influence of the different system parameters, especially the interaction of the downwash with the gusts, the influence of nonlinearities and the systems effectiveness depending on gust frequency. These results gave valuable data for the specification and the realization of the gust alleviation system for the full scale aircraft.

For the flight tests, the DO 28 TNT aircraft was equipped with the sensor package, the digital control unit and the two electromechanical actuators. The symmetrical aileron deflection is produced by one of these actuators and superimposed to the pilots aileron command by a mechanical adding gear. The second actuator drives the horizontal stabilizer in series to the existing trim motor.

The flight tests demonstrated that the design objectives of the system were met and that a good agreement between the performance data from wind tunnel investigations, hardware in the loop simulation and flight test was obtained. Fig. 7 shows the time history of the symmetric aileron deflection (ER), the vertical acceleration (AZ) and the pitch rate (Q) with OLGA ON and OLGA OFF from a flight in gusty weather conditions. The improvement of the passenger comfort is clearly revealed by this figure. A more quantitative evaluation is shown in the power spectra densities of the vertical acceleration and the pitch rate in Fig. 8. At low frequencies, the gust alleviation with respect to vertical acceleration (ϕ_{AZ}) is about 10 dB, that means a reduction by a factor of three. In the frequency area shortly below the 5 Hz first wing bending mode a small excitation of the vertical acceleration is visible, at higher frequencies the aircraft motion is not affected by the OLGA system.

The flight tests demonstrated the feasibility and the advantages of a direct lift control system for gust alleviation for a future commuter aircraft. However, with respect to handling qualities of the primary aileron controls and the certification problems with failure modes, the symmetrical aileron deflection should not be used for DLC. Further studies demonstrated the advantages of a flap in flap system (Fig. 9).

With the flap in flap system only the part of the landing flap behind the flap roof is used for direct lift generation. To reduce failure effects and hinge moments, each wingside is devided in three flap in flap segments. All six flap in flap segments are independently moveable and have their own relatively small electromechanical actuator. Wind tunnel tests proved the good performance of this configuration with high lift and low drag and moment coefficients.

Independent from the used direct lift generation device, a further major result of the OLGA flight tests was, that the passenger comfort is not only influenced by vertical acceleration in the lower frequency area. In contrast, if the vertical acceleration in the lower frequency area is suppressed, the passengers get more susceptible to other parameters of discomfort like aircraft oscillation at the first wing bending mode, lateral acceleration and engine noise.

Therefore, an overall concept for passenger comfort improvement has to include also a gust alleviating yaw damper and the suppression of the first wing bending mode oscillation by an active structural damping system.

An active suppression of structural oscillations (flutter suppression) improves not only the passenger comfort, but has also the big advantage of structural load alleviation.

Fig. 10 shows the computational results for the application of an active structural vibration damper. The objective comprised the reduction of manoeuvre and gust loads, flutter suppression and the improvement of the passenger comfort.

A simple 5-mass model for the bending modes served as basis. Three acceleration sensors were utilized and elevator as well as symmetrically deflected ailerons were applied as effectors.

On account of this approach the basic definition of rigid bodies is transformed into an elasticity definition by supplementing two eigenmodes (no control). An ideal structural vibration damper considerably reduces the acceleration reaction caused by gusts. Also in the critical frequency range as far as air sicknesses is concerned a small amplitude damping is achieved.

Thus, a combination of OLGA and flutter suppression offers a great potential to improve ride qualities and reduce structural stress.

3. Appraisal

Up to now one important question could not have been answered: To what extent the DOC (direct operating cost) can be reduced by the application of advanced technologies? The literature offers estimations which may be valid for large transport aircraft: By means of a manoeuver/gust load alleviation, a DOC reduction of 2 - 4 % can possibly be achieved, and for the reduction of the natural stability a value of approx. 2 % is expected.

However, on account of different operating conditions and structural characteristics, these values cannot be directly transformed to the class of commuter aircraft. Fig. 11 shows the trial to perform at least a qualitative evaluation concerning the above-mentioned criteria. Besides the introduction of new AP/FMS systems, according to this evaluation, particular interest must be placed on FBW/L technologies and ACT in order to achieve progress in the field of economic efficiency.

4. Concluding Remarks

The integrated control technology is a promising area also for the future generation of commuter aircraft. Nevertheless the technical, but even more the economical risks are still high. Therefore detailed technical research including flight test activities seems to be necessary for the final evaluation of possible concepts. This will include also the experience of the operators, who are flying the modern commercial civil transport aircraft equipped with these types of systems.

Abbreviations

ACT	Active Control Technology
AEA	All Electric Aircraft
AP	Autopilot
ATTAS	Advanced Technology Transport Aircraft System
DLC	Direct Lift Control
DOC	Direct Operating Cost
FBW	Fly by Wire
FBL	Fly by Light
FMS	Flight Management System
ICT	Integrated Control Technology
LAS	Load Alleviation System
OLGA	Open Loop Gust Alleviation System
TNT	Advanced Technology Wing

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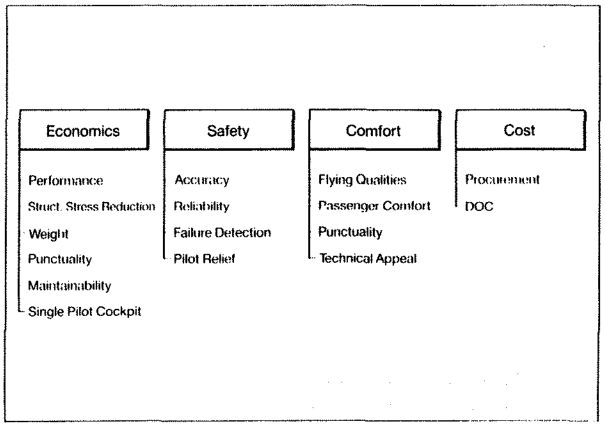


Fig. 1: **ICT - Exspected Benefits/Appraisal**

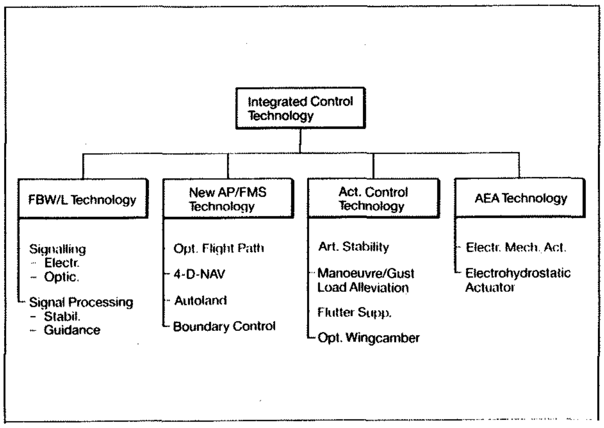


Fig. 2: **ICT - Integrated Control Technology**

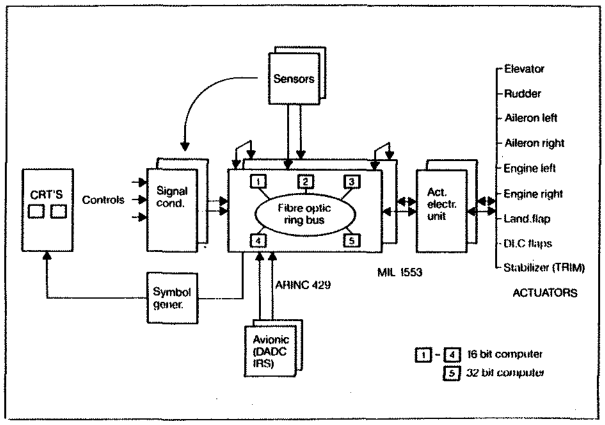
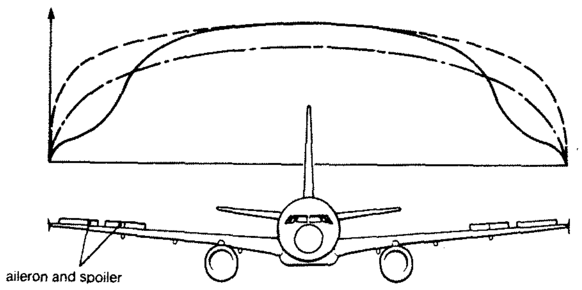


Fig. 3: **DFVLR - ATTAS**
Dual Redundant Fly-by-Wire/Light
Flight Control System



—·— Wing lift distribution, 1 g horizontal flight
--- Wing lift distibution at up-gust
— Wing lift distibution at up-gust with LAS

Fig. 4: A320 Load Alleviation System (LAS) Reduced wing load/bending moments/weight

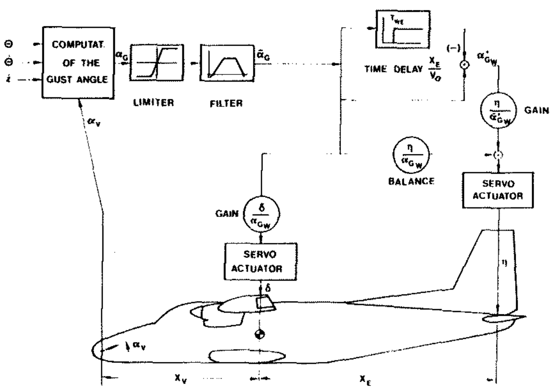


Fig. 5: Functional Diagram of the OLGA Gust Load Alleviation System

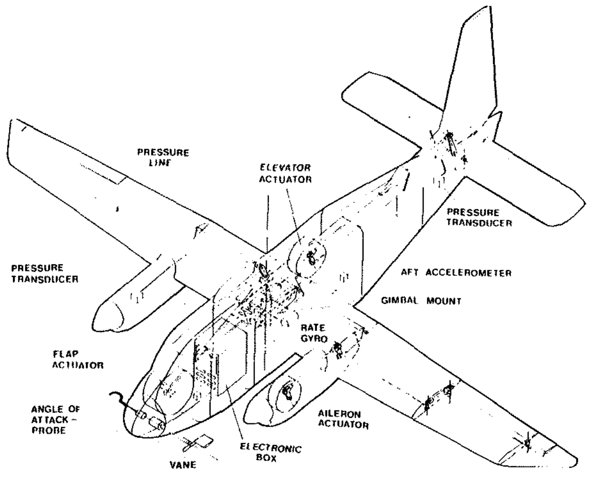
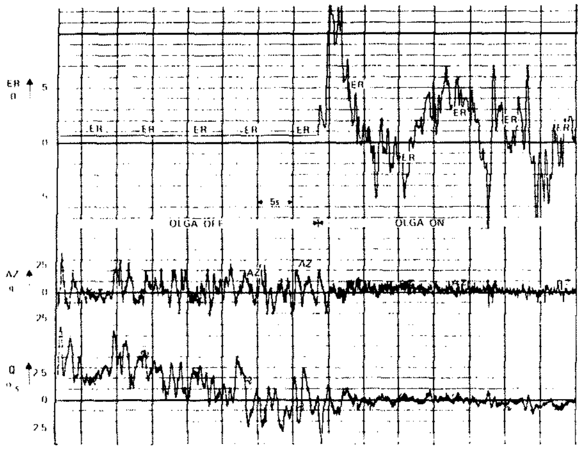


Fig. 6: DO 28 TNT Windtunnel Model



Symmetrical Aileron Deflection ER
Vertical accelleration AZ
Pitch Rate Q

Fig. 7: Time History in Turbulent Flight (Flight Test Results)

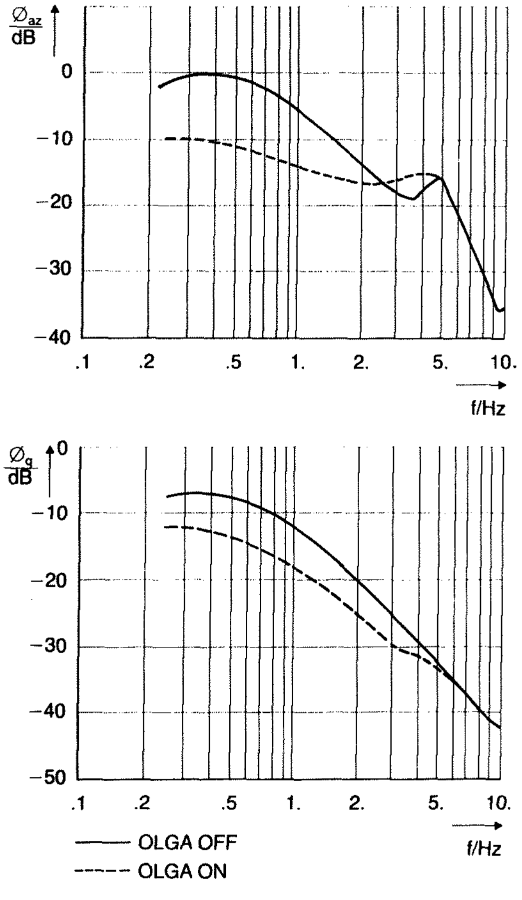


Fig. 8: Spectrum of Vertical Accelleration and Pitch Rate (Final Flight Test)

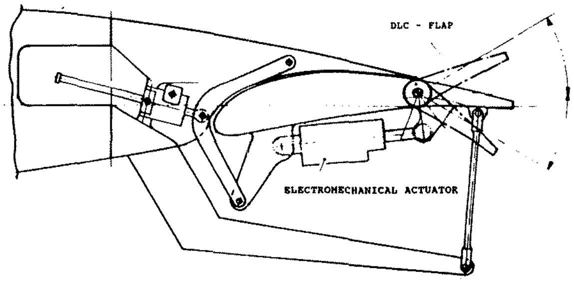


Fig. 9: Flap-in-Flap System for
Gust Load Alleviation

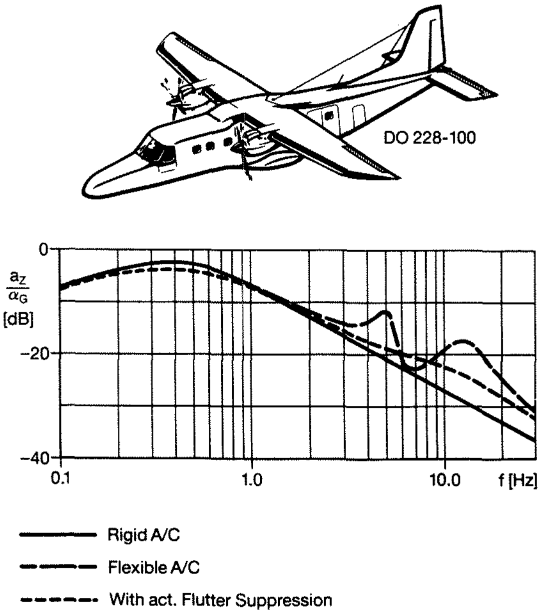


Fig.10: Damping of Structural Modes
(Computed Results)

ICT	Economics	Safety	Comfort
FBW/L	++	+	
AP/FMS	++	++	+
ACT	++		+
AEA	+	+	

Fig.11: Appraisal of the Different ICT-Systems
High Benefit (++), Benefit expected (+)