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OVERVIEW OF POTENTIAL EVOLUTIONS OF TECHNOLOGIES APPLIED IN COMMERCIAL TRANSPORT AIRPLANES

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Abstract: Automated systems assisting pilots in the achievement of their essential operating tasks have been one answer provided by the Airframe manufacturers to the problems raised by the present democratization of the Commercial Air Transport. The predicted evolutions of the world air traffic in the next two decades are extremely promising and challenging: indeed they raise very severe issues in terms of airspaces saturation, in terms of air safety and efficiency, and last but not least in terms of environmental consequences. In this time frame, airframe, engine and system manufacturers will have to produce several tens of thousands of aircraft; they will have to consider many technological evolutions in order to face those challenges, in fields as varied as automation, engines, structure, aerodynamics… Yes, next generation airplanes, eco-logical/-nomical (ecological and economical), must and will represent a new technological step forward in transport aviation industry in order to meet extremely demanding challenges.

1. Introduction

The first decade of the XX1st century is an outstanding period for Commercial Transport Aviation. Indeed due to a continuous economic growth and reduced air fares, the passenger traffic is continuously growing: between 2000 and 2007 the total number of passengers has increased by some 36%, whereas the cargo traffic stimulated by the global e-commerce and manufacturing trends is actually growing even faster.

Consequently, the Network airlines and the Low Cost Carriers have ordered and are ordering an unprecedented number of airplanes to face this demand. In the next 20 years, the air traffic is predicted to double, which leads to an expected demand of over 24000 aircraft in that time frame.

The first problem industry has and will have to face, is the saturation of some airspaces and the congestion of airports. Today, 64% of the worldwide traffic is concentrated on 93 airports!
Yes, traffic will grow, will double but airport capacity will not.

The second problem industry will have to face, is the environmental problems: noise levels at Take off and in Approach, gas emissions (CO_2, Nox…), but also hazardous materials. Yes airplanes must be "Greener", and the goal of the "vision 2020" program is a cut off 50% CO_2 emissions.

The third problem industry will have to face is economics: the fuel cost today participates to some 36% of the operating costs (and there is no obvious reason to see its price going down with the rarefaction of the fuel feed stocks), whereas the staff cost participates to some 20% of that cost. It is estimated that over 13500 airplanes will have to be replaced by more economical models in the next 20 years.

The existing response to those challenges is the A380; this Very Large and very long range Aircraft (VLA), already answers to some of these problems, since it is able to carry more passengers, with less flight, with less fuel consumption, with less CO_2 emissions and with less noise.

With the A380 by 2016, "Nearly 10 million more passengers to fly to/from Heathrow with no increase in flights", says Eryl Smith, Business Strategy, Planning, and Development Director

Considering the A380 as the starting point of evolutions, an overview of the potential technological step forwards in automation, structure, engines, aerodynamics, but also in crew layout…will highlight the tremendous challenges to be taken by the aeronautical industry in order to make the Commercial Air transport Travel safe, efficient, economical and environment friendly.

2. COMMERCIAL AIRPLANE TECHNOLOGICAL STATUS IN 2008 A380 era

The A380 which is now operated by Singapore Airlines is the best available answer to the problem of the democratisation of the air transport; not only is it able to transport over 800 passengers, thus answering to their growing number, but it is the first Long Range aircraft which, on a typical 6000nm sector, consumes 2.9L per passenger per 100km with 555 passengers on board.

This represents a gain of some 12% as compared to the other large capacity long range aircraft flying today.The A380 offers an access to any destination in the world, affordable to most people.

2.1. Main contributing factors to such efficiency

Such a drastic reduction of the operating costs of the A380 is caused by :

- The performance of its latest engines: RR Trent 900 and GP 7200 with a by-pass ratio in the range of 9 due to its large fan, which is efficient for its performance as well as for noise considerations. Indeed, those engines associated to the A380 outstanding wing, result in a noise signature of the A380 significantly reduced as compared to any existing VLA (Very Large Aircraft)..

A380 noise footprint on departure with 40% more capacity per flight

- Its structure: it includes more and more composites and advanced materials (Al-Li, Titanium…): on A340 some 15% of the airplane structure was in Carbon Fiber Reinforced Plastics (CFRP) (rear pressure bulkhead + keel beam + horizontal tail plane + spoilers and ailerons + elevators, fin, rudder and flaps) whereas some 25% of the airplane structure is in CFRP on the A380 (same+ rear fuselage + centre wing box) while upper fuselage is made of glare.

- Its aerodynamics : advanced computation of flight dynamics has provided an improved understanding of high Reynolds / Mach wing aerodynamics. A in board more loaded wing gave some 4T weight reduction to the slight expense of induced drag; but improved wave and installation drag handling gave a 1,5% drag reduction.
As an example of the excellent aerodynamics of the wing, let us just consider the airplane approach speed (VAPP) at Maximum Landing Weight (MLW) 391T which is about 139kts, whereas on the A320 at MLW 66T VAPP is 136Kts.

- Its optimised avionics architecture: it is structured as "integrated modular avionics" on an AFDX bus, and it includes 3 basic loops of automation.
These 3 basic loops of automation allow the airplane to safety and efficiently operate within an aeronautical environment more and more complex, and saturated.

2.2 The 3 loops of automation

2.2.1 Introduction of automation in the cockpit

In the past 4 decades, airframe manufacturers have used all new available technologies, in all aspects of aircraft design, to answer to the evolving constraints of the aeronautical environment (huge increase in the number of aircraft flying in our skies, raise of public and of media expectations in terms of flight safety and raising requirements in flight efficiency and economics improvements.

Those constraints were and are still today quite conflicting and paradoxal, more particularly in a world where a lack of trained and experienced pilots is growing fast.

Amongst available technologies, airframe manufacturers did call for automated systems for most of the functions associated to the flight operations.

Why? Because automated systems have a great level of autonomy since they can achieve several tasks sequentially or simultaneously on their own, once initialised and controlled by the pilot.

In this changing and most constraining environment, the essential tasks of the pilots are getting somehow harder to be properly, efficiently and safely achieved, more particularly under time pressure. Thus pilots need to be assisted in the execution of their tasks by proper "autonomous" tools, such as automated systems.

2.2.2. What tasks should be automated?

Airbus has developed automated systems to play to human strengths and compensate for their weaknesses. Thus by looking at those strengths and weaknesses, one soon discovers where pilot need automation and where he does not. Not to mention all the strengths, it is clear that human beings are complex, able of both analysis and synthesis, thus able to decide.

The human being has a very special memory which allows him to memorise lots of sensations, past experiences, feelings, processes he has well understood ; thus this memory builds up his experience, his discernment, his intuition so essential for him to make rapid and sensible decisions. This is usually called in aviation "airmanship".

Human beings are also reacting with their instinct, and when facing a new environment they are able to adapt. But human beings have their own weaknesses; not to mention all of them, it is clear that mans in slow to act : when facing an unpredictable situation , his mind reacts rapidly, but the physical reaction comes up with a certain delay.

Man, as a manipulator, is very inaccurate so that he needs a certain training to build up his skills and become more performant, more accurate.

Man is a non- repetitive manipulator, his performance being affected by fatigue, stress, and time pressure.
Man is a slow computer, an while computing he has great difficulties to achieve other tasks simultaneously.

Thus last but not least, man is unpredictable, potentially undisciplined…

The implementation of automation in the aircraft had to take into consideration all these human factors, since the automation has been designed as a complement to man, to the pilot.
Therefore automation has been applied for tactical tasks

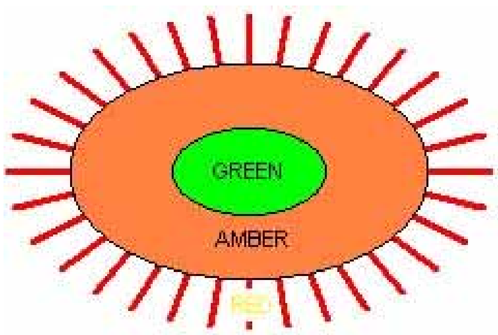
- Consistent and accurate aircraft handling (operate)
- Fast computations (navigate)
- Situational awareness enhancement (manage systems).

The 3 loops of automation existing on the Airbuses are associated to those 3 tactical tasks.

It is clear that, in an aircraft, automation is not there to challenge pilot's role and responsibility: he is the decision maker and has the strategic role in the aircraft.

2.2.3 How to automate each field of application?

The aircraft and its main systems are meant to be operated according to certain established rules and principles, applied by the pilots, which I call the 3 coloured domains principle. The automated systems have to work consistently with this 3 coloured domains principle – What is it?



The 3 coloured domains principle

- The Green domain is the Normal flight envelope of the aircraft or the normal field of variation of the main parameters, which control a system.

The role and responsibility of the pilot is to keep the aircraft flying in the green domain and to keep its system working in the green domain.

- The amber domain, peripheral to the green one, represents a potential risk for the aircraft or a system if a major driving parameter drifts into it, or if a failure occurs.

The role and responsibility of the pilot is to minimise the excursions in the amber domain ; should this happen the pilot must do its utmost to fly the aircraft or the system back into the green domain.
The aircraft and its systems are fully controllable within the amber domain, but the pilot must be made aware of the growing risks when nearing the red/amber domains boundary.

- The red domain is out of the limits of the flight envelope or of the safe field of variation of the parameters driving a system. In the red domain, the aircraft and its systems exhibit discontinuous and non linear phenomena unexpectedly, which jeopardizes the aircraft and its systems performances and makes their operation extremely difficult, if not impossible.

The role and responsibility of the pilot is to prevent any excursions in the red domain: should this happen, he is the only one able to take the decision on how best to fly back into the green domain.
The automated systems have been designed to comply with this 3 coloured domains principle:

- The automated system strive to keep the aircraft or its associated systems within the green system, despite outside perturbations or some potential mishandling errors by the pilot. The automation in error resistant in the Green domain.

- The automated system does its utmost to bring the aircraft or its system back into the green domain, should these have drifted into the amber domain due to severe circumstances or due to a failure. The automated system advises the pilot of this excessive drift for his situational awareness. The automation is error tolerant in the Amber domain.
- The automated systems warns the pilot that the aircraft or some of its systems get into the red domain ; but the automation hands it over to the pilot, who is the only one able to take the adequate decision on how best to fly back into the green domain. The automation is error warning in the Red domain

2.2.4 Lest us review the 3 loops of automation

- First loop of automation : the Flight Control Loop

Automation has been first applied to assist pilots to hand fly the aircraft.
In 1987, the A320 Fly By Wire system has been a revolutionary step forward in flight control design. The Fly By Wire system is actually the First loop of automation, the Flight Control Loop.

On a Fly By Wire aircraft, the pilot gives flying orders to the Fly By Wire computers (e.g.: g load, roll rate…), when he acts on the stick (or yoke). The computers translate those orders into flight surfaces deflections (elevators, ailerons…). The relation between the stick deflection and the aircraft expected reactions is called "control laws".

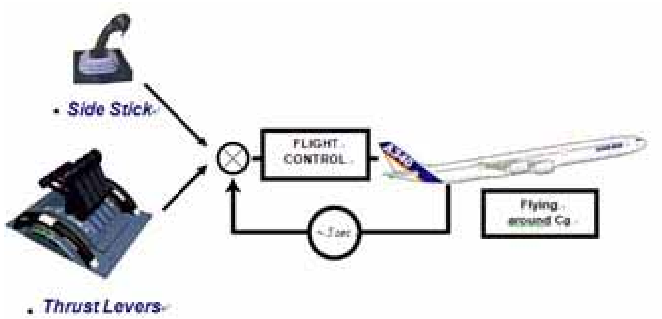


Fig 1 : First automation loop called "Inner" flight control loop

The control laws programmed in the A320 Fly By Wire computers actually determine the handling characteristics of the airplane ; those handling characteristics are actually outstanding, indeed :

- The aircraft is simultaneously stable and manoeuvrable regardless of aircraft Cg, speed, configuration.

- The aircraft responses to pilot's inputs on the stick are consistent on all its axis whereas the pilot efforts on the controls are always balanced.

- The aircraft is "protected" against excursions out the safe flight envelope (high angle of attack, high g level, high pitch, high speed, high bank angle…). Such protections give full authority to the pilot to get consistently the best achievable performance of the aircraft when required, with an instinctive and immediate action on the stick, while minimizing the risks to over control or overstress the airplane; such protections are most effective in case of windshears, risks of collision with terrain and/or other traffic.

Such Fly By Wire control laws have significantly improved the safety level of those airplanes, and have allowed Airbus to create the first real and realistic family of Airplanes, with quite similar handling characteristics; this family of airplanes ranges from the A318 (twin engine, short to medium range 100-seater), to the A340-600 (4 engine, ultra long range 400-seater) and even to the A380…

The aircraft family concept has become even more beneficial to day, in terms of flight safety and in terms of operational efficiency, because of the rapidly growing number of airplanes: indeed the flying experience acquired on one airplane of the family is most valuable and fully applicable on any other airplane of the family, which is a tremendous safety benefit. As for the Airlines, this concept allows to safely and reasonably decrease the transition training time required between 2 airplanes of the family, and to consider Mixed Fleet Flying operation (MFF) of 2 or 3 airplanes of the family without any additional recurrent training required, which is a tremendous operating cost benefit.

Additionally such Fly By Wire control laws extend artificially the stability domain of the airplane: thus it can fly with a very aft Cg, hence with reduced drag ; it allows also to envisage flight controls with reduced surfaces, hence with lower gross weights. Such control laws do significantly participate to operating cost reductions.

- The second loop is the "outer" guidance or autopilot loop:

it consists in guiding the aircraft on basic trajectory defined parameters such as heading or track, such as vertical speed or flight path angle, such as speed etc… It is therefore the aircraft Centre of Gravity that is somehow servo looped or guided to those parameters. This loop is achieved by the Autopilot system as well as the Autothrust system regarding the control of the engines.

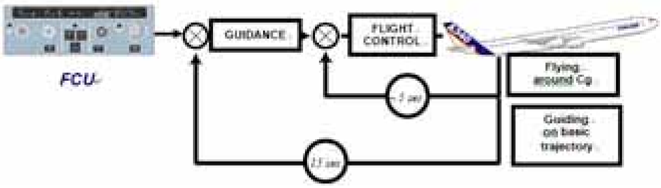


Fig 2 : Second loop called "outer" guidance loop

Autopilot and autothrust systems operate according to various guidance modes, which are activated by the pilots on specific interfaces depending upon the tasks they have to achieve ; indeed, manufacturers have defined those various modes as a function of the missions of the aircraft. On commercial transport airplanes, those modes are associated to the most common Air Traffic Control (ATC) clearances used en route, in terminal and approach areas : fly a given heading (HDG mode), climb or descent to a given altitude (OPEN CLB or DES modes), maintain an altitude (ALT mode) etc…

The evolutions of the aeronautical environment have led to more constraints, to a more demanding operation : additional modes more complex have been developed such as the LAND mode which enables the autopilot to guide the aircraft along an ILS beam during the final approach down to the ground, to ensure the flare, the align and the roll out of the aircraft, in other words to land the aircraft on the runway (LOC – GLIDE SLOPE ; LAND ; FLARE ; ROLL OUT modes…).

The airplanes certified with such a LAND mode may fly into airfields properly equipped (ILS
CAT 3, proper lighting, acceptable obstacles in the approach path…), in most foggy conditions, in other words with extremely reduced visibility ; they can safely fly the final approach and land automatically with the autopilot. All Airbuses are CAT 3B certified which allows them to fly to CAT 3 airfields with visibility down to 125m (RVR = 125m), the associated Decision Height being equal to 0.

The rate of success of such automated approaches is higher than 99,6%, regardless of the circumstances (weather, aircraft failures, crew fatigue or psychological stress…) ; such a rate of success is by far higher than the one you would get without the automatic approach mode ! And yet the presence of the aircrew is essential for the safety of such approaches, since the pilots are the one meant to take over in case a major problem occurs.

- The third loop in the navigation loop :

it consists in guiding the aircraft along a flight plan, or more precisely on the active leg of a flight plan. On older generation airplanes, pilots used to achieve this task using the basic modes of the autopilot such as heading mode: they used to periodically adjust the target heading of the autopilot to capture and track a course cleared by ATC. This method is today incompatible with the accuracy and performance criteria set by the Air Traffic Control, as well as with the constraints of many complex trajectories to be flown in terminal areas.

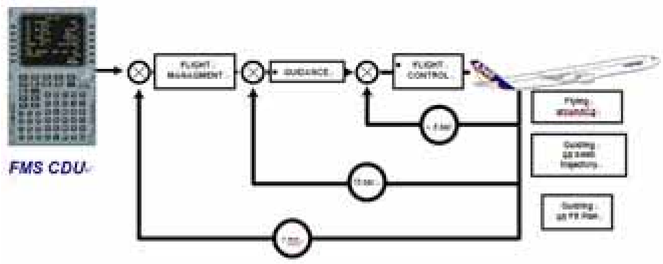


Fig 3 : Third loop called Navigation Loop

The essential computer for this 3rd loop is the Flight Management System (FMS) : its first and essential task is to compute the most accurate aircraft position using the best available navigation sensors (IRS, GPS, and DME….). The FMS carries two data base: a navigation data base (with waypoints, navaids, airports, Standard Instrument Departure and Arrival trajectories - SID and STAR -, approach trajectories, airways, as well as "Company Routes" between origin and destination airfields…) ; it also carries a performance data base (aircraft performance models). Those two databases are used to achieve the various required flight management functions.

The interface between the pilot and the FMS is called Control Display Unit (CDU); it allows the pilot to define a 3D or 4D flight plan in between origin and destination, to select certain performance parameters and a sector cost factor ; the FMS is then able to process the resulting 3D or 4D trajectory, the predictions associated to each point of the flight plan (time, altitude, speed, fuel), the optimum parameters of the flight (optimum altitude, optimum speed or mach…).

The FMS sends the trajectory data to the autopilot, which can guide the aircraft along the lateral, and vertical active flight plan leg, at the optimum speed as computed by the FMS, provided the pilot has selected the associated guidance modes on the autopilot interface (Flight Control Unit – FCU), those modes being named "managed modes".

* Those 3 automation loops have to be closely monitored by the pilots who are provided with a set of instruments displaying the required information properly formatted. The set of adjacent dials offered on older generation airplanes is actually inadequate for such a monitoring task. They have been replaced by a set of large display units (DUs, CRT or LCD), which provide in a very realistic and synthetic way, all the data associated to a major task : for the "operate or fly" task, it is the Primary Flight Display (PFD), for the "navigation" task, it is the Navigation Display (ND). The PFD and ND allow the aircrews to monitor the 3 automation loops efficiently, because they provide a realistic, complete but not overloaded picture of the situation, because they effectively enhance pilot situational awareness.

2.2.5 How is the 3 coloured domains principle effectively applied in the 3 loops of automation?

Let us consider the first essential task of the pilot: "operate the aircraft".

The operation tasks of the pilot consists in controlling the aircraft on a long term defined trajectory assigned by the ATC, or flying it to a basic trajectory defined parameter (e.g: heading, vertical spedd,…), while always keeping the airplane within its green domain.

In a standard airline flight, the pilot uses the autopilot and auto thrust systems (also called Autoflight systems) in order to operate the aircraft in most flight phases.

Should an unexpected event occur, those systems will do their best to keep the airplane within the Green domain (e.g: in case of windshear, heavy turbulences, avoidance manoeuvres…).

If the situation gets too severe and some aircraft parameters drift and reach the amber domain, a caution is triggered to raise pilot's situational awareness of the growing risks, whereas the Autoflight systems strive to bring the aircraft back into the Green domain.

If the situation still aggravates and some parameters get into the Red domain, the Autoflight systems trigger a Red warning and trip off, so as to give the hand over to the pilot, who is the only one able to take the appropriate decision on how to fly the aircraft back into the Green domain.

The First loop of automation, the Flight control loop, then assists the pilot to best achieve this task; in such situations, an instinctive, intuitive and simple procedure allows the pilot to get maximum performance from the aircraft and its engines to recover the situation and go back into the Green domain, while minimizing the risks of losing control of the aircraft.

The following diagram materializes how the Flight Control loop assists the pilot to best recover from a dangerous situation, called CFIT (Controlled Flight Into Terrain).

If for any reason during an approach, the airplane gets too close from a hill or from an obstacle, an aural warning is triggered telling him "Terrain, Terrain, Pull up".

On a Fly by Wire Protected aircraft, the pilot has merely to react by pulling his stick fully aft; such an instinctive reaction automatically commands:

- maximum Angle of attack of the aircraft, in other words maximum lift
- maximum thrust from the engines
- minimum drag

On a non protected aircraft, the required manoeuvre from the pilot is by far less instinctive, and somehow prone to errors leading to the potential loss of control of the airplane by the pilot.

Obviously the CFIT escape trajectories are by far safer on Fly by Wire protected airplanes than on non protected ones, as outlined on the below schematic.

CFIT Escape Manoeuvre on Protected versus Non protected Aircraft

2.3. Two Examples of the tuning of control laws on various aircraft types

As mentioned here above, the relation between the stick deflection and the aircraft expected reactions around its centre of gravity is called “control laws” which actually define the handling characteristics of the airplane. Let us review two examples on how such control laws are tuned to suite best the characteristics of an airplane type for a given manoeuvre.

2.2.1 Take off control law

What are the objectives to be considered in the design of the “Take off rotation” law?
When a pilot pulls on the stick during the take off roll, at the required speed (called rotation speed), he wishes that, for a standard action on the stick :

- the aircraft reacts with a consistent Pitch Rate, ensuring a proper aircraft lift off performance, in all combinations of aircraft GW and allowed Centre of gravity.
- the risks of tailstrike, or APU cone strike be minimum. This is more particularly true on so called “geometry limited” airplanes such as A321, A340-600 or A380.

However the pilot must always keep full authority on the elevator deflection, by pulling full aft stick, should circumstances so dictate.
Considering those goals, here are 2 examples of the take off control laws as implemented on A320, A340 and A380.

Tailstrike margins on a “geometry limited” aircraft

- On A320

The control law is extremely simple: there is a Direct Relation between the stick deflection and the resulting elevator deflection via a given kinematics, adapted to the aircraft configuration. This is called “Direct law”.

- On A330/A340/A321

The control law is a bit more complex, because those aircraft are“geometry limited” which means that in case of an outside perturbation or of a pilot non-standard stick application, a potential risk of damageable tailstrike exists.

Thus a so-called “pitch rate damping” lane is additionally introduced in order to minimise the risks of a destructive tailstrike: should the pilot stick input deflection be too high, the aircraft will react with a high pitch rate sensed by dedicated sensors. The pitch rate feedback associated to the stick deflection order will command an elevator nose down order, which will damp the elevator nose up order given by the pilot on the direct lane.
However if deemed necessary, the pilot can always command full nose up elevator.

- On the A380/A340-600

Those aircraft are more prone to tailstrike and even to APU cone strike for the A380.
Consequently the take off control law has been adjusted so as to “avoid” an APU cone strike or a tailstrike, with a “standard” input on the stick from the pilot.

Thus, a “SOFT PROTECTION” lane against tailstrike/APU cone strike has been added to the other two lanes, direct & pitch rate damping lanes, this last one been enhanced

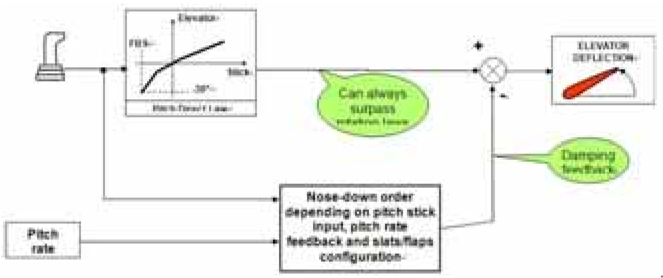
How are achieved both these features?

- Enhancement of the pitch rate damping lane :

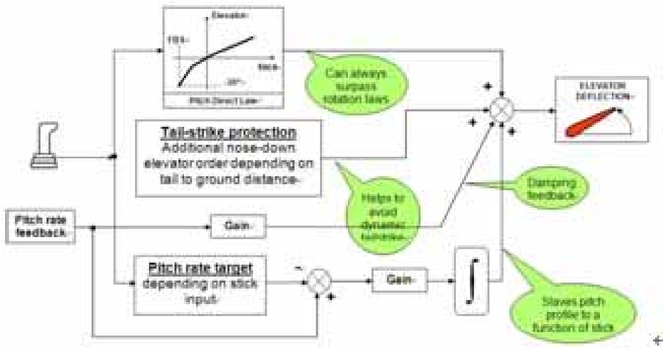
The Pitch rate sensed and fedback, associated to the stick input, commands a nose down elevator demand, if it is sensed too high, as on A340.
For each stick deflection is associated a “Pitch Rate Command” which is the expected pitch rate of the aircraft for that stick input. If (Pitch rate sensed – Pitch rate command 0) an elevator command is processed to adjust the aircraft pitch profile to the expected one.

- “Soft protection” against APU cone/Tail strike

The Fly by Wire computers process during the rotation of the aircraft, the height of the tail and of the APU cone and their respective variation rates, as a function of the aircraft pitch and radio altimeter outputs. Whenever the rates are too fast too fast and/or the heights become too low, this triggers an elevator nose down command that protects against a destructive strike.



A321/A330/A340 Take off control law



A340-600/A380 Take off control law

2.3.2 Aircraft yaw control law in the flare

What are the problems a pilot has to face in the lateral control of an aircraft during flare, more particularly in crosswind situations?

In crosswind approaches, the airplane flies on the extended runway centreline with a drift angle which depends upon the aircraft approach speed, and the crosswind component of the wind; typically the drift can go up to over 15°.

Consequently the pilot has to "Decrab" the airplane in the flare, in other words to zero the drift, so as to allow the airplane to land "straight" on the runway. Therefore, the pilot will act on the rudder pedals to align the airplane with the runway axis. By doing so, he commands a side slip from the aircraft which, by dihedral effect, induces a roll rate in the downwind direction. If stick is free, the lateral control law (roll rate law) zeroes the roll rate of the airplane; thus the airplane stabilizes with a small downwind bank angle.

The resulting downwind bank angle, added to the effect of the crosswind pushes the aircraft sideways, downwind of the runway. Thus the pilot has to react laterally on the stick, so as to gently zero the downwind bank angle; and in case of very strong crosswinds, he has even to slightly bank the airplane upwind in order to maintain it on the runway centreline.

This shows that an accurate control of the rudder and of ailerons/spoilers during a crosswind flare so as to somehow fly "sideways" is not simple.


Crosswind landing technique: downwind rudder and upwind stick

- On the A320 and A330/A340:

The rudder pedals are mechanically linked to the rudder surface; thus there is a direct relation in between rudder pedals and rudder deflections. The rudder is also deflected by various yaw demands processed by the Fly By Wire computer Lateral Control Laws such as the yaw demands of the yaw damping function which counters any dutch roll tendancy of the airplane, or of the turn coordination function; these yaw demands deflect the rudder and add to the rudder deflections mechanically commanded by the pilot acting on the rudder pedals.

Thus stick free, if rudder pedals are moved, the rudder is deflected by the mechanical link in a direct relationship to the pedals movements. Additionally a side slip demand (more precisely a yaw rate demand) proportional to the rudder pedals movement is sent into the Fly By Wire Lateral Control Law; this side slip demand equates to a yaw command which is combined to the other yaw commands sent to the rudder by the Fly By Wire computers.

At the same time, since the stick is free, the roll rate order of the lateral control law is a zero roll rate command which counters the roll rate induced by the side slip; thus the airplane soon stabilizes with a small downwind bank angle.

Therefore, the rudder pedal deflection results in a steady sideslip demand at constant bank angle, despite the fact that the link between rudder pedals and rudder is a mechanical link.

- On A380:

there is no mechanical link from the pedals to the rudder. The rudder pedals deflections are a flying order to the Fly by Wire computers, such as the stick deflections. A rudder pedal deflection is a side slip command to the airplane, the maximum pedal deflection giving a maximum side slip pending upon the aircraft speed and configuration.

When the aircraft flies in the flare, the rudder pedal deflection sends also an order to the ailerons (aileron precommand) via the Fly By Wire computers, in order to reduce the roll rate induced by the side slip; additionally, the gains of the lateral roll rate law are reinforced.

As a consequence, when the rudder pedals are applied during a crosswind flare, in order to decrab the aircraft, the roll and the resulting bank angle induced by the side slip is almost zero, which significantly assists the pilot in this touchy manœuvre.

3. SHORT TERM EVOLUTIONS 4th LOOP OF AUTOMATION

The short term evolutions in the aircraft design will take into account two major factors:

- first, the lessons learnt from the current in line operation of the latest generation airplanes (incidents or even accidents, in line feedback data, audits, pilot voluntary reports…),

- second, the predicted evolutions of the aeronautical environment which can be summed up by 2 items: saturation of the airspace, congestion of major airports.

3.1. Lessons learnt from in line operations

"La vérité de demain se nourrit des erreurs d'hier" said Antoine de Saint Exupéry ; which means, "tomorrow's truth is fed with yesterday's errors" !

As a general statement, most pilots are satisfied with the 3 integrated loops of automation functionally, since they answer to most of their existing needs. The Fly by Wire system with its control laws including protections, the Auto Flight System (AFS) including Autopilot (AP) and Autothrust (ATHR), and the FMS (Flight Management System) do achieve their intended functions. However several minor difficulties are still experienced by some aircrews in daily operations, mainly due to:

- The distrust of some pilots when operating those systems (either due to an experienced malfunction, or due to some incomprehension or misunderstanding).

- The overconfidence of some pilots in those systems (either due to the excellent reliability of the automation leading to complacency, lack of vigilance and over tolerance to errors, or due to intimidation of some crews leading them not to interfere with the systems).

- The lack of user f riendliness of certain interfaces (CDU too small, lack of certain information on Display Units (DUs) located on the main instrument panel …).
- The potential of auto flight system modes confusion by pilots (either due to some surprises, or due to the misuse and misunderstanding of some modes).

In other words, the origin of those minor difficulties is essentially linked to the various human machine interfaces (HMI) such as CDU, PFD, ND… The first short term evolutions are now provided with the upgrade of those interfaces on the A380 :

- The CDU, main interface to the FMS, is upgraded into a large display unit, interactive with a Keyboard Cursor Control Unit (KCCU) which allows to access to data, to modify and insert them easily, in a similar manner than the one widely used on PCs.

- The DUs (PFD & ND) are enlarged so as to allow to complete the display of all the information required to achieve a task, and thus to enhance pilot's situational awareness. E.g, slat/flap configuration, take off pitch trim setting, potential operation limitation associated to a failure, those information associated to the "flying" task of the pilots are added on the PFD; whereas a "Vertical flight plan" is added on the ND.

- The DUs, used to manage the aircraft systems and called ECAM (Electronic Centralized Aircraft Management system), are enlarged, and interactive with the ECAM control panel carrying a cursor as well, so that the handling of normal and failure related procedures be more user friendly, and so that the aircrews have access to some additional technical information enhancing their system situational awareness.

3.2. Answer to airspace saturation problems

There are various causes to airspace saturation and to airport congestion problems :

- Of course the continuous growth in the number of airplanes
- Of course the fact that airplanes operate mainly from a limited number of airfields
- But also the structure of the Air Traffic Control (ATC): the airspace is divided into sectors assigned to one controller, who ensures the traffic management, the separation in between aircraft as well as the prevention of collisions. One controller is able to handle some 20 to 25 airplanes per hour…

- The link in between the aircraft and the controllers is achieved by voice communication preferably via VHF radio communication means (at least in congested areas); but the number of VHF channels is limited…

Today, those problems are crucial in some congested airspaces. Consequently the industry has taken 3 measures :

- Increasing the number of sectors of airspace
- Increasing the number of VHF channels (the frequency difference between 2 channels has been reduced from 25 kHz down to 8.33 kHz thus multiplying by 3 the number of available channels).

- Implementing slowly, somehow shyly, automatic data transmission in between pilots and controllers.

Those measures are actually insufficient: indeed they do not address one root cause of all those problems, which is the airspace management. The airspace effectively available for the airplanes is too small relative to the growing number of airplanes. This airspace is too restricted amongst others because of the existing control methods:

- Either the control is "procedural" in non-radar covered areas. The controller "guesses" the aircraft present position from the periodical aircraft position reports, which are communicated by the aircrews when the aircraft over flies designated positions ; the controller assigns a volume of airspace to each aircraft and ensures that those volumes do not overlap.

- Or the control is "radar control" in radar covered areas. The controller knows the present position of the aircraft and "guesses" its future position. He also assigns a volume of airspace to each aircraft, but a restricted volume ; in order to ensure an adequate separation between the airplanes, the controller gives successive headings to each aircraft in his sector (radar vector method). This method is very heavy, time consuming, airspace consuming, transmission time consuming… It does not allow an efficient Air Traffic Management (ATM).

Those two methods are less and less adapted to the existing environment, and will be even less adapted to the predicted air traffic flow growth. Indeed they merely consist in ensuring that two volumes of airspace do not overlap. Consequently it is now time to shift from this "procedural" control, to a real control of the airplane trajectories, which will effectively allow an efficient management of the available airspace. This will require :
- The ATC to know accurately and continuously the present position of the aircraft
- The ATC to know accurately the aircraft predictions and intentions
- The ATC to know accurately the expected performances of all aircraft
- The aircraft to know accurately the ATC clearances and long term intentions
- The aircraft to be able to achieve the ATC clearances and intentions

The 4th automation loop is the "ATM" loop (Air Traffic Management): it consists in guiding the aircraft to the ATC clearances as processed by ground computers, from the data exchanged automatically in between the ground control and the aircraft systems. Those clearances are automatically transmitted to the aircraft systems, which can achieve their guidance tasks.

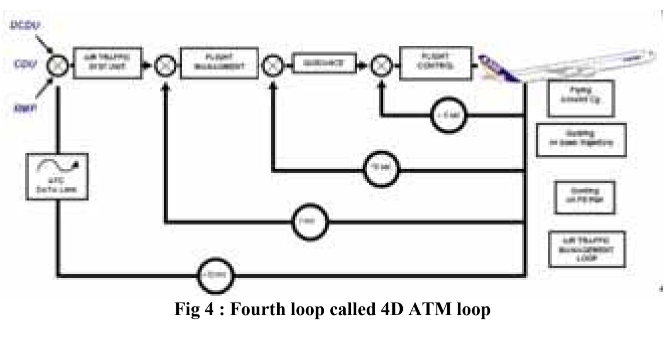


Fig 4 : Fourth loop called 4D ATM loop

This fourth loop requires the implementation of an automatic data transmission system in between the airplanes ant the ground control centres, also called Data Link ; such a data link communication system will allow periodic exchanges of data, as well as broadcast of some information required for traffic management and for surveillance.

In the future, a vast majority of aircraft will carry:
- An FMS processing the aircraft position with its associated accuracy called navigation performance, as well as all the predictions at all the waypoints of the active flight plan (time, speed, altitude, fuel). Additionally in saturated or in certain en route areas, flight plan segments defined by Navigation authorities will have specified Required Navigation Performance (RNP) criteria to be satisfied by the airplanes, in order to be granted less constraining separations between airplanes, or lower approach minima…The FMS and AFS of those aircraft will be capable of taking fully into account these RNP criteria and thus making them beneficiate from extended operational capabilities.

- A data link communication system, able to broadcast all the data processed by the FMS, or to transmit them periodically, also able to receive the data up-linked from the ground control systems, or broadcasted by the other airplanes flying in the vicinity, and finally able of Controller Pilot Data Link Communications (CPDLC) as well as of voice communications.

On the other hand, in the frame of the Future Air Navigation System (FANS) project, a global Aeronautic Telecommunications Network (ATN) is being implemented so as to safely and efficiently support all the communications media required for Air Traffic Control. ATN defines the performance, safety, integrity and reliability criteria necessary for ATC communications; ATN will allow to automate the management of air traffic and of airspace, and it will allow to automatically solve potential conflicts and even potential collisions between airplanes.

What are the latest foreseen Air Traffic Management (ATM) concepts and associated implementation steps?
As a first step, the concept is called "Airborne Spacing" (or "Station Keeping or Sequencing"). Its principle is for the ATC to designate an airplane as the target for other airplanes converging towards a waypoint of the terminal area, or towards the final approach fix of an approach to a destination airfield; the ATC then clears those airplanes to merge one behind the other, with an assigned longitudinal separation relative to the identified target aircraft from that given waypoint; those aircraft must then keep this longitudinal separation along the Flight Plan. With the "airborne spacing" concept, the responsibility of the execution of the task will be devoted to the aircrews, whereas the responsibility of maintaining the separation in between the airplanes will still be devoted to the controllers.

The next step will be called the "Airborne Separation" concept, where the responsibility of solving some potential conflicts with other aircraft will be delegated to the aircrews.

A further step called "Airborne Self Separation" will consist in a total delegation of aircraft separation to aircrews…

In a nearer future, "Airborne Spacing" method will be applied for two purposes; it will solve significantly the communication saturation problems, and it will decrease the workload of the controllers by suppressing some of their time consuming tactical tasks (such as radar vectors), so as to allow them to efficiently manage the air traffic flow.

Those new ATM concepts may only be applied if the aircrews are properly informed of the air traffic status around their own airplane. This implies that all the aircraft must be able to broadcast their position, their status vector, their predictions and intentions, and that each aircraft is able to automatically and continuously receive those data from all surrounding airplanes ; those data will then be processed in order to provide a comprehensive display of traffic information on dedicated display units such as ND. This is called Automatic Dependant Surveillance – Broadcast (ADS–B) and Cockpit Display of Traffic Information (CDTI), or Air Traffic Separation Awareness enhancement (ATSAW).

In other words, the implementation of the 4D ATM loop will require :

- On board the airplanes :

• Data link communication means : VDL, HFDL, SATCOM DL, Mode S.
• Most accurate navigation sensors : GPS, augmented GPS
• A unique time reference (GPS)
• A computer able to process the guidance orders resulting from the spacing/merging clearances uplinked by ATC.
• A system (typically FMS) able to format the messages required by the ADS-B, and able to receive the ATC guidance orders as processed on board
• A ND capable of CDTI
• An Auto Flight System with ATM adapted modes

- On ground :

• The ATN, in other words a communication network dedicated to ATC ; a worldwide, integrated and safe network able of data link, broadcast and voice communications.
• The definition and design of ATM concepts and methods accepted and applied worldwide.
• The integration of adequate algorithms associated to these ATM concepts, into the ground computers (and possibly into the airborne computers).

- On board and on ground :

• Controllers and pilots, in other words experts properly trained and qualified
• ATM procedures clearly defined
• A clear and seamless responsibility sharing between controllers and pilots
• A set of procedures adapted to a transitory period during which old generation aircraft will coexist with latest generation ones.

4 LONGER TERM POTENTIAL EVOLUTIONS

The evolutions in between 2 generations of aircraft are and will always be dictated by the same essential factors :

• Flight safety considerations
• Achievement of the assigned mission by an aircraft
• Answer to the new operational needs dictated by the changes of the aeronautical environment

What are the expected changes in the aeronautical environment ?

• More saturated airspaces
• More congested airports
due to the expected increasing number of aircraft
• Increased price of fuel due to the rarefication of
the kerosene feed stocks associated to the increase of fuel demand
• Increased environmental constraints (noise protected areas, enhanced noise regulations and criteria, limitation of noxious emissions…)
• Increasing manpower costs

Let us review the various axis of research major airframe manufacturers, amongst other Airbus, have launched today in various fields such as structure and materials, engines, aerodynamics, some airplane systems, and last but not the least automation.
It is clear that some of those items do address simultaneously several goals: for example any effort achieved to reduce the airplane gross weight favours the airplane economics (lesser fuel consumption), and the achievement of environmental targets (lower gas emissions).

4.1. Structure and materials

The research in structure and materials is a permanent effort done by all manufacturers in order to get airplane structures more and more resistant, corrosion free, resistant to fatigue, to loads… and last but not the least light! Weight reduction is an essential goal in the airplane design.
For example, here is the way the use of CFRP (Carbon Fiber Reinforced Plastic) has spread throughout the Airbus models :

- In the 1980s, on the A310, it has been used for the rudder, fin, speed brakes, radome
- In the late 80s, on the A320, it has been additionally used for the belly fairing, the horizontal tailplane and various fairings

- In the early 90s, on the A330/A340, some 15% of the structure was built in CFRP (same as above plus rear pressure bulkhead, ailerons, spoilers, elevators, flaps).
- In the late 90s, on the A340-600 and –500, the keel beam was additionally built in CFRP.
- And today, some 25% of the A380 structure is made of CFRP (same plus rear fuselage, wing ribs, centre wing box, flap track panels, floor crossbeams for upper deck), whereas glare is used for upper fuselage.

- Tomorrow, in 2013 range, on the A350, some 52% of the A350 structure will use composites (same as above plus outer wings, and fuselage).

Yes the extensive use of CFRP will significantly reduce operational costs and global environment impact, by fuel burn savings; it will reduce maintenance costs as well, since CFRP is fatigue and corrosion free.

However Aluminium-Lithium will participate to 20% of the structure, for cargo floor structure, for fuselage extruded frames, for crossbeam and seat rails, for wing-ribs, whereas Titanium will participate to some 14% of the structure for pylon primary structure and for essential parts of the landing gear.

Finally, as far as industrial maturity is concerned regarding CFRP, Airbus has gained its composite experience step by step since the 80s. However the extensive use of composites on A350 is an industrial challenge. For example a solution had to be designed for CFRP lightning protection, so as to enable a current flow in case of lightning strike :

The solution consists of an embedded metallic mesh in the CFRP as an addition to the network of existing metallic structure. Another challenge was the choice of the method applied to manufacture the fuselage either as an assembly of several cylindrical parts, or as an assembly of longitudinal panels, each panel optimized for its design case, the longitudinal joints participating in the fuselage bending strength. This last solution will be most probably retained.

The use of the right materials in the structure of an airplane such as the A350 is expected to provide a 5% fuel saving.

4.2. Engines

The engines are the essential component of the fuel savings and of gas emissions reduction efforts, both going in pair.

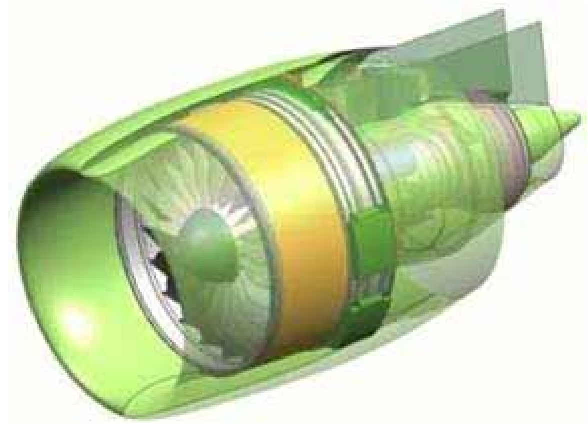
Each generation of turbo fan jet engines has made a step forward in fuel savings by, amongst others, increasing their bypass ratio. This is achieved, to day, by increasing the size of the fan of those engines; this method has a limiting factor which is the speed reached by the fan blades tips, which can be sonic, thus generating shock waves detrimental for the overall performance of the engines.

Two innovative engine architectures are envisaged for future programs such as the A30X, in order to increase the by-pass ratio:

- The Geared Turbo Fan:

the principle of the geared Turbo Fan is to allow the increase of the diameter of the fan by properly shaping and sweeping its blades and by slowing down its rotation speed so as to slow down the speed of its fan blade tips and reducing the onset of compressibility effects. On present jet engines, the fan rotation speed is equal to the rotation speed of the low pressure turbine (e.g some 2000 Rpm). With the geared turbofan, the fan rotation speed will be significantly reduced by a dedicated gearbox, while the angle of attack of the fan blades will be regulated so as to keep up the required airflow. The great challenge of such an engine lies in the design of the Gear Box which must transmit a huge energy and be properly cooled down.

Such a technology should allow to increase the bypass ratio from 8 to a range close to15, and thus to improve the Specific Fuel Consumption (SFC) by some 10%.



The Geared Turbo fan

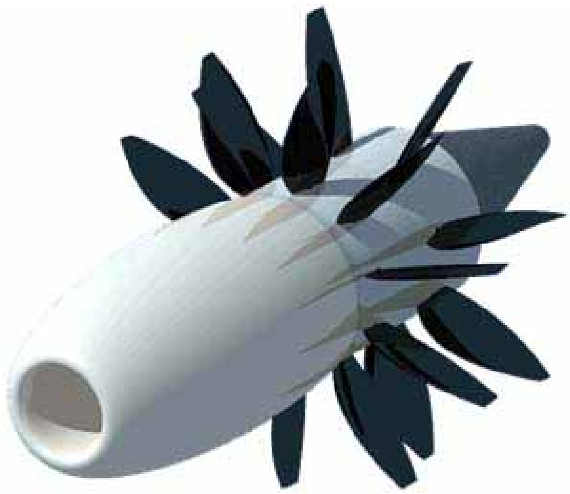
- The Unducted Fan or the Prop Fan engines:

it is an open rotor technology which will raise the bypass ratio up to 80. The fan will consist of one (or two counter rotating) wheels, each carrying some 15 fan blades, with an adequate shape and sweep so as to delay the onset of compressibility effects.

The expected gains in terms of SFC are close to 25% which is considerable; they will significantly reduce the CO2 and Nox emissions as well.

However there are some challenges with this technology:

- The noise level of such engines at take off is quite important
- The loss of a fan blade (which per nature is uncontained) must not cause a major damage to the structure, which leads to the definition a new wing/engine configuration, with engines located at the rear of the airplane.
- The Cruise Mach number with such engines will be limited to the .75 range (instead of .85).



Counter rotating Unducted Fan (or Prop Fan)

Obviously those new engines must be able to accommodate new types of fuel, such as Bio fuels, so as to reduce the CO2 and NOx emissions.

Today 3,3kg of C02 is emitted by 1kg of kerosene.
Standard Bio fuels do not emit C02 ; today they cannot be used on an aircraft, because they are chemically not compatible with airplane operation conditions (low thermal stability, high temperature freezing point…), because of their low efficiency (the calorific power of Bio diesel is some 10% lower than kerosene), and because of their cost (today some 130 $ to 150 $ / barrel).
The only viable solution would be Bio kerosene, with still lots of unknowns such as cost, and availability of feed stock…

In order to save fuel and reduce gas emissions, on board systems optimisation or some new operational concepts will offer some potential solutions, such as for example :

- Low pressure bleed ECS:

it is an integrated approach to improve bleed air supplied systems, towards lower pressure requirements. Consequently the air would be bled off from lower pressure engine stages, and at lower temperature so that pre-coolers be no more required. This would improve the SFC and reduce the weight of the bleed system.
This would reduce some 30 % of the energy consumed by ECS.

- Taxiing with engines stopped:

most of the time, taxiing with engines at idle necessitates the use of brakes and leads to a fuel consumption in between 400kg to 800kg on major airports (depending on aircraft type). Consequently various solutions of taxiing with engines stopped are currently studied :

* The motored gear which has lots of advantages such as autonomy or noise reduction, but which is not fuel efficient because of the induced weight increase which is penalizing throughout the whole flight.

* The high speed towing solution which is extremely fuel efficient because the tractor vehicle is by far more efficient than aircraft engines at idle. However the implementation of such a solution requires an harmonization with airport authorities. But an estimation indicates that high speed towing may save up to 10.000 ton of fuel per aircraft over a 20 year of A320 lifetime. Is such a solution operationally viable?

4.3. Aerodynamics

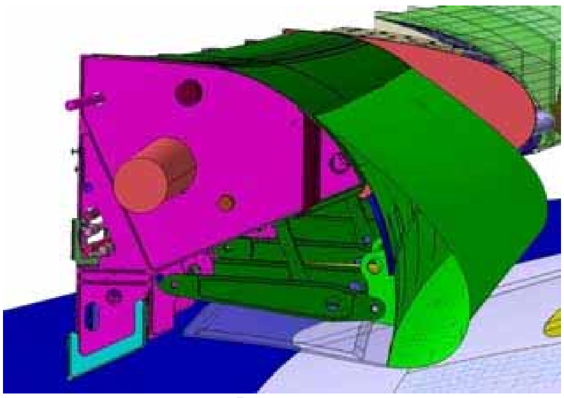
Aerodynamics improvements are a permanent field of research for all airframe manufacturers to improve the efficiency of their airplane. Here are mentioned some of them:

- Advanced Computation of Flight Dynamics:

Those computation methods allow to improve the understanding of High Reynolds/Mach aerodynamics of the wing, thus to create more realistic models. This additionally allows to reduce some 40% of wind tunnel tests days, thus to reduce the design costs while providing excellent performance prediction accuracies.

- Droop nose:

on the inboard wing, the droop nose technology allows to improve the Lift / Drag ratio of the wing more particularly at take off, and to reduce the drag at low speed. This improves significantly the performance of the wing, and allows to reduce the thrust requirements from the engines at take off, which somehow sizes them down. This technology has been applied on the A380, has demonstrated significant benefits, and thus will be used on future programs.

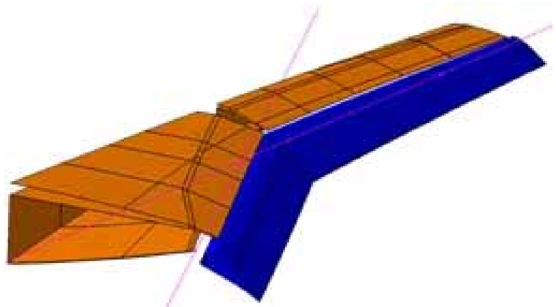


Droop nose

- Advanced Dropped Hinged Flaps:

Such flaps are actuated around one rotation axis, thus allowing to modify the camber and surface of the wing, while creating a slot on the trailing edge of the wing.
Such a technology simplifies the existing flap mechanism (weight reduction), makes the flap system more rigid (thus minimizing vibrations and buffet at low speed), and improves

the efficiency of the slots by eliminating some undue rotors. Additionally, with such flaps, it is
considered to adapt the camber of the wing in cruise flying conditions, for better efficiency.



Advanced Dropped Hinged Flaps

4.4. Extension of automation

Yes, there will be an extension of automation within the next generation airplanes and cockpits; indeed the aeronautical environment is predicted to be even more constrained and the need for increased safety, for improved efficiency and economics, as well as for increased cleanliness of airplanes, this need is already expressed today.

The starting point of this evolution will be the automated aircraft architectured around the 4 loops of automation described here above; all the automated systems provided in the flight deck will be defined as a complement to man, to the pilot, and most of those sytems will comply with the 3 coloured domains principle.

The levels of safety of most automated systems in the cockpit, their reliability (thus their architecture, their redundancy…) have always been defined considering the presence of the pilots (or of the controllers). The severity level of a system failure is always determined by the level of severity of the operational consequences of that failure as estimated by the pilots ; they are the ones able to assess their capability to recover the situation degraded by the failure. Thus the severity level of a system failure determines its performance, its reliability as the required failure probability level. This principle is used for most cockpit system failure analysis :

Major failure
Ops consequence estimated major
proba fail 10^{-5}/h

Hazardous failure
Ops consequence estimated hazardous
proba fail 10^{-7}/h

Catastrophic failure
Ops consequence estimated catastrophic
proba fail 10^{-9}/h

Obviously when the safety objective of an automated system, or of one of its mode of operation, is associated to a failure probability equal to 10-9/h or less, such an objective is very difficult to achieve; it requires a very safe system architecture, a high level of redundancy, and extreme precautions in the system design so as to make that failure extremely improbable.

The most probable long-term evolutions in terms of automation are dictated by in line operational feedback and incident analysis on one hand, and by the emergence of certain most promising technologies on the other hand. These considerations indicate that a further level of automation, another set of safety related systems in the cockpit, as well as a further integration of airborne and ground systems, are most probably expected.

Following probable applications are expected:

- Automatic taxi
- Automatic take off
- Automatic landing widely used due to availability of augmented GPS
- Automatic ground and obstacle collision avoidance (vertically and laterally) due to a more efficient, reliable and complete EGPWS
- Automatic in-flight collision avoidance due to ADS-B and to more efficient ACAS system
- Extension of RNP implementation towards a performance based airspace organisation, and towards a rationalisation of approaches: RNP-RNAV approaches and RNP-RNAV-LS approaches.
- Further enhancement of pilot situational awareness by providing an even more realistic representation of the aircraft status and environment, due to the availability of a preferment Enhanced Vision System (EVS using Infra Red or Millimetre Radar sensors), or of a Synthetic Vision System (SVS using a terrain and obstacle data base), or of an efficient 3D display format on PFD & ND.

This shows that the future aircraft will be most probably fully automated on longer term, which means that all the "operating" tasks in the cockpit will be achievable either by the pilots, or by automated systems (taxi, take off, climb, cruise, descent, approach, landing, go-around, any collision avoidance…), as well as the flight management, system management and communications tasks. All those automated systems will be designed crew centered; the essential task of the pilots will be to control and to monitor the automated systems so as to be ready to take the adequate decision in case of a major failure, and in case of an unpredicted or dangerous situation, and to readily react and take over whenever deemed necessary
Yes, automation will spread in the flight decks, fully complying with the existing fundamental automation principles.

4.5. Operation with one pilot – one cruise pilot!

On long-range airplanes, the flight duration varies in between 9 Flying hours (FH) to over 20 FH. Today 2 pilots are flying the airplane, regardless the flight phase, but regulations do impose a 3rd pilot on trips more than around 10 FH, and a 4th pilot (or 2 crews) on trips longer than around

14 FH.

Thus 3 or 4 pilots are somehow alternating in their operating seats, so that the actual operating crew is always fit while the other(s) are resting.

Yet on latest airplanes, the crew workload in the cruise phase is generally low and significantly reduced due to the 3 loops of automation.

Consequently it might be possibly considered to operate long range airplanes with only one cruise pilot in an operating seat, while the other goes to rest, thus reducing the number of on board staff.

The principle of such an operation could be as follows:

- During Takeoff, climb, descent, approach and landing phases, both pilots are in their operating seats
- Once the airplane reaches the cruising flight level (CRZ FL), one pilot remains in his operating seat (operating pilot), the other goes to rest (rest pilot).
- The rest period duration would be between 2FH and 4FH to be determined by airlines or authorities along with medical bodies
- Once a rest period is over, the rest pilot gets back to the cockpit, is briefed by the operating pilot on the flight progress (briefing contents provided in the Standard Operating Procedures)
- In certain emergency situations, the rest pilot is supposed to get back into the cockpit to assist the operating pilot.

For a pilot, flying 4 FH alone in the cockpit is not a problem; it already exists in the military aviation. However, in a commercial transport airplane, for obvious safety reasons, various physiological issues have to be considered:

- A system has to continuously monitor the status of alertness of the operating pilot who should not fall to sleep….
- A system must be able to detect any risk of pilot incapacitation.
- The operating pilot must have some means to go periodically to restrooms, to drink and eat…
- And obviously the operating pilot must have all required skills to fully operate the airplane by himself, during cruise.

Those general considerations have consequences in the design of the airplane, more particularly of the front part of the aircraft which should be divided into 3 zones :

- The cockpit with 2 operating seats.
- The rest compartment fully separated and properly isolated from the other zones. In this rest compartment, adequate means of communication as well as some information systems will be provided to the rest pilot.
- The toilets and possibly mini galleys.

The front part of the airplane should be secured with a reinforced door and a protected opening (unlocked in certain emergency situations such as aircraft depressurisation or pilot incapacitation).

The 3 loops of automation fully allow one operating pilot to achieve all his tasks ; however all the operating systems and information systems within a cockpit have been designed to day, considering a task sharing scheme between two pilots, as well as the application of Crew Resource Management (CRM) principles.
Consequently, various evolutions have to be considered in the avionics so as to achieve a high level of safety and efficiency with one operating pilot during cruise:

a) In the Guidance loop

The AFS (AP / ATHR) will need to be very robust in case of adverse environment (turbulence, shears, severe icing…), and in case of failures of systems or of engines (including engine bursts).
Modes such as APFD TCAS have to be available, to properly assist the operating pilot in case of risks of collision.
"Managed modes" (allowing the 3rd loop of automation), associated to severe failure cases must be developed (engine out with obstacle / ETOPS / Standard strategies…).
"Emergency descent mode", in case of cabin depressurisation, must be considered

Additionally it is extremely important to enhance the information provided to the operating pilot regarding the AFS operation, so as to ensure a high level of pilot situational awareness, which today is reached because of the presence of the 2 pilots.

b) In the Flight Management Loop

The flight management functions will have to be enhanced so as to allow the operating pilot to be rapidly provided with the required information during the flight progress, more particularly in abnormal situations:

- Efficient fuel management and potential fuel leak detection
- Performance based navigation with adequate alerts, in case of loss of the required performance
- "What if" functions, which are essentially prediction based functions; they assist the pilot to answer to questions such as "what if a diversion has to be envisaged".
- Effects of a major ATC clearance on the routing of the airplane.

Additionally, the management of the additional information necessary for the pilot to achieve his tasks will have tobe rationalized and optimized, so that any important data in a given situation be readily available to the operating pilot (charts, performance data, technical information…).

c) In Communications

2 types of communications have to be considered: the ATC & AOC communications, and the communications internal to the aircraft with a crew spread in 3 different areas.
ATC vocal communications on Long Range airplanes are a major task for one pilot, since these communications are often time consuming more particularly when HF transmitters have to be used. Furthermore, in case of incomprehension of an ATC message, the operating pilot, as

cruise pilot, is alone thus not assisted by the other pilot to solve this incomprehension.

- Therefore data link with CPDLC (Controller to Pilot Data Link Communication) has to be efficiently mechanised.
- Position reports via ADS (Automated Dependant System) must be implemented.
- In case of vocal messages, the latest ATC messages must be memorised, for possible replay purposes in case of misunderstanding for example.

For cabin communications, obviously interphones will have to be available in each part of those 3 areas.

Additionally specific calls from the operating pilot to the rest pilot will have to be available.
The rest pilot will have to be provided with a capability to be continuously informed on the flight progress, on the status of the aircraft, on certain serious alerts (fire/smoke, depressurisation, incapacitation of the pilot in command…).
Additionally, the Cabin Crew role in cruise will have to be somehow extended to take into consideration the loneliness of the operating pilot.

d) In Aircraft system management

In case of failure of certain aircraft systems, to day the workload of the crew increases a lot despite most actions required from the crew to manage the failure are achieved by the so called Pilot Non Flying (PNF) using the ECAM (Electronic Centralized Aircraft Monitor system)

A one pilot in cruise operation will require some evolutions in the ECAM system, to cope with the fact that the operating pilot will be alone and that the availability of the rest pilot, if necessary will not be instantaneous. Following evolutions should be considered amongst others:

- Limit the cautions to the only ones having an impact on the flight operation.
- In case of a failure, ensure an automatic system reconfiguration whenever safe and possible.
- Significantly improve the detection of smokes: zone affected by the smoke, most probable cause of the smoke proposed to the pilot to enhance his decision …

This will alleviate a lot the so-called “smoke procedure” which is quite complex and leads sometimes to unjustified pilot decisions.

- And finally fuel leaks, or excessive fuel consumption shall be detected.

Conclusion:

The long term future in Aviation, say the next two decades, may be summed up as follows:

- passenger and cargo demands will continue to grow
- a huge number of new airplanes are needed
- traffic will grow, might double, whereas airport capacity will not
- economics in terms of fuel and staff costs will be more and more demanding
- last but not least, environmental considerations will become paramount with the growing traffic

From now on, this is the aeronautical environment Commercial Transport Aviation industry has to consider.
As for airframe manufacturers, who will have to produce all those new airplanes, they will have to solve this equation, quite complex:

MORE (COSTLY FUEL/STAFF + AIRSPACE SATURATION + AIRPORT CONGESTION) =
AIRPLANES (SAFER + GREENER + QUIETER + MORE COST EFFECTIVE)

The solution to such an equation requires from airframe manufacturers new airplanes, integrating necessarily a significant technological step forward,
some of the evolutions described here above being possibly part of that step forward.