Autonomous flying: a must for the future

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Abstract

The air transport sector is constantly looking for ways to reduce airfares. Much focus today is on reducing fuel cost. But new technologies offer another opportunity for the long term to reduce cost of flying by replacing the cockpit crew using autonomous aircraft and using autonomous ATM (Air Traffic Management) services. It is obvious that current technologies would not allow this option to be implemented.

New technologies, rules and certification would be needed to implement such a step change. However these changes seem feasible given the experiences so far. In order to investigate the possibilities for autonomous flight and ATM, also in combination with the traditional flight and ATM during a long transition period, research should start now to develop concepts of operation, technologies and regulation for the 2050 timeframe. However too little money is assigned today to enable such long term research in Europe. This will allow “new” aviation countries to take the lead and Europe may become a technology follower rather than a world leader in air transport in the long term.

Introduction

The demand for air transport has been growing in a spectacular way since the 1950s when the airline industry adopted new business models like the introduction of the economy class fares and jet engines were introduced. In 2014 more than 3.3 billion passengers were using air travel globally. The segment of aircraft bigger than 100 seats represented a market of 6.2 trillion Revenue Passenger Km (RPK).

In its 2015 global market forecast Airbus predicts an average annual growth of 4.6% in RPK resulting in 15.2 trillion RPK in 2034. [1] The biggest growth rate is expected to be in the Asia-Pacific region (5.7% annual growth). As a result Airbus expects the world fleet of aircraft bigger than 100 seats to increase from 17,354 to 35,749 aircraft. Dedicated freighters would increase from 1,633 aircraft to 2,687. The market for newly delivered aircraft would be 31,781 passenger and 804 dedicated freighter aircraft. Out of this total of 32,600 new aircraft, in total 22,927 would be single–aisle aircraft.

Boeing has made similar predictions in their 2015 market outlook. [2] Boeing predicted that the global RPK for jet aircraft (30 seats and above, no turbo props and business jets) will increase by 4.9% annually in the next 20 years. This would call for 38,050 new passenger airplanes (of which 26,730 larger single-aisle aircraft and 2,490 regional jets) and 920 new dedicated freighters.

These are all impressive figures. The demand for air travel is a function of the development in the GDP (Gross Domestic product), price to travel and frequency of service. In simple terms:

Fig 1: Demand for air travel (Source author)

There are other contributing factors that determine the demand for air transport like the runway availability especially in Europe, regulation and alternatives for air travel like fast trains (up to a distance of 700km) and new IT systems. But the principal factors are still GDP, frequency and price.

The elasticities associated with these principal determining factors (GDP, Frequency and Price) can change over time. We have seen a low elasticity for *GDP* during the last economic crisis but elasticity seems to be back at 1.5. Boeing analysed the effect of *frequency* of service on air travel demand. It concluded that the air travel growth in 2013 and 2014 was mainly due to the increase in frequencies of service.

The *price* of flying or airfare has steadily been reduced due to the increase in productivity of aircraft, lower cost of flying and high load factors. Figure 2 shows the effect on passenger fares since 1970.

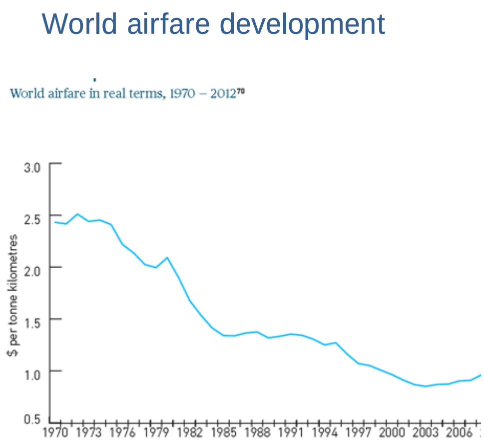

Figure 2 : Development airfares (Source: ATAG: Aviation benefits beyond borders).

The airfare issue can be illustrated by this simple formula:

Fare = profit percentage x load factor x { (DOC + IOC)/ Productivity)}, where DOC is Direct Operating Cost, IOC is Indirect Operating Cost and productivity is the product of speed x capacity x utilization.

Profits in the airline industry are small due to fierce competition. The *load factor* in the airline industry is very high however. Over the past years, load factors of above 80% have been achieved. Compared to public ground transport modes this high load factor is one of the reasons why flying is cheap. In general, public ground transportation experiences load factors of 20% or less.

The *productivity* of aircraft is dependent on speed, capacity and aircraft utilization. Up to the early 1970's the increase of *speed* was the most important factor to increase productivity of successive generations of aircraft types and thus lower airfares. Based on military technology, the engines of airliners became more powerful and better aerodynamics reduced drag and increased lift whilst improved structures reduced weight. As a result speed of flying increased. Aircraft also became *bigger* which reduced fixed cost per passenger. Aircraft *utilization* was increased thanks to reduced maintenance needs, short turn-around times and airline business models that supported high daily aircraft utilization rates.

Since the oil crisis in the early 1970's, when oil prices rapidly increased from $20 per barrel to $40 per barrel, a further increase in speed into the supersonic domain became too costly. And the oil prices have increased ever since the early 1970's in a volatile way.

The maximum seize of aircraft is restricted by airport regulations (the 80x80 meter box), so it is unlikely that we will see bigger aircraft than the A 380 in future (unless wings and fuselages can be folded). However we have seen an increase in capacity of regional airliners over the years thanks to larger aircraft often based on family concepts. Utilization has increased but restrictions on airport usage at night will limit future options.

The limited possibilities to increase productivity led airlines and the aircraft industry to focus on cost.

New business models were introduced to cut *Indirect Operating Cost*. Low Cost Carriers started by introducing internet booking saving on cost for travel agents. Advertising and promotion was basically restricted to adopting the paint scheme on aircraft etc. Young staff reduced staffing cost. They made flying a normal way of transport rather than something special.

The aircraft industry developed products with lower *Direct Operating Cost*. To cut the *kerosene fuel* cost of aircraft, more efficient aero-engines were developed, light weight structures were introduced and aircraft aerodynamics were further improved. Airlines are also active in fuel hedging to reduce fuel cost.

The fuel reduction efforts had a nice side effect: Less fuel also means less CO_2 emissions. (1kg of kerosene burned with 3.4 kg of oxygen equals 3.16kg of CO_2). Reduction of CO_2 became a political must for the airline industry (although only 2% of man-made CO2 emissions is due to air traffic). IATA set itself a goal to reduce CO_2 emissions from airline operations by an absolute 50% in 2050 compared to 2005, despite a 5% annual growth in traffic.

In the IATA Technology Roadmap 2013 [3], IATA listed several options to reduce CO_2 emissions mainly by reducing fuel burn. IATA concluded that the most effective technical means currently in development to reduce emissions would be the application of natural laminar flow to reduce drag (note that much effort is still devoted to hybrid laminar flow although Boeing has decided that it will not apply the technology for the B777x due to limited cost benefits), composite primary structures to reduce weight, winglets, advanced turbofans, fuel cells to replace APU's and riblets.

But IATA also concluded that the CO_2 goal for 2050 could not be reached with these incremental improvements in technologies. Studies have already shown that step changes are needed to achieve the CO2 goal whilst reducing Direct Operating Cost like the introduction of Blended Wing Body aircraft configurations, the use of cheap LNG to replace kerosene, the use of cheap ground power to launch aircraft on Maglev tracks, aerial refuelling etc. Electric propulsion or hybrid propulsion is not likely to be introduced for larger aircraft unless new types of efficient batteries can be introduced in future.

Other measures to reduce DOC included the reduction of *maintenance cost* (line replaceable parts, maintenance free parts etc.) and the reduction of *crew training and salary cost*. The *depreciation* and interest cost could be lowered by reducing acquisition cost of aircraft. The aircraft industry is therefore actively looking to reduce development and manufacturing cost. New aircraft are based on a family concept to reduce development cost and certification costs even further.

Passenger services are offered in a more tailor-made fashion to reduce cost as well.

But airlines have little influence on the *other DOC elements* like ATC cost, airport charges and airport handling cost. When the European Commission started its Single European Sky initiative in 2001 [4], the aim was to create one single European airspace to be used by both civil and military operators, thus avoiding a segregated airspace where parts are reserved for the military and making airways between no fly zones needed. If no segregation exists, civil airliners do no longer need to fly along predetermined airways that stem from the time aviation was depending on radio beacons on the ground for navigation. It would enable direct flight tracks from A to B without flying around restricted airspace using modern navigation equipment.

Figure 3: Flying around segregated airspace is costly (Source KLM)

In order to make a single sky, the national control areas would need to be merged into a single control area via a number of intermediate steps by creating Functional Airspace Blocks. Experience has shown however that this is a very slow process as national states and the military do not want to give up their authority over “their” airspace.

When the Commission stared to support new developments in *ATM* by enabling 4D gate to gate planning and execution via the SESAR program, the airlines were promised a 50% reduction in ATC cost. However the current status is that airlines are not to expect a substantial reduction of ATC cost. Rather airlines and ATC service providers are requested to make huge investments for example in their fleet of aircraft by installing datalinks (CPDLC), ADS-B transponders , SBAS, novel FMS systems, possibly EVS etc. whilst the benefits of the envisaged ATM system (while maintaining a segregated airspace) are still unknown but expected to be marginal.

Airport charges are high (the HUB-airports are the only stakeholder in the air transport business that make a decent profit) despite the fact that larger airports have substantial income from car parks and retail shops at the airports. By introducing competition in *ground handling* the European Commission has tried to reduce ground handling cost for airlines. One might expect that robotics would be used in future to serve the needs of ground handling and cabin crews can be replaced by robots but there is little evidence that the airline community is addressing this issue.

So how can airlines further reduce cost? The obvious answer is to **delete the cockpit crew and fly unpiloted vehicles in combination with fully automated ATM**. The deletion of the cockpit crew and ATC controllers would save as much as 20% of the DOC and would also solve the potential problem of a pilot- and controller shortage due to the growth in air travel. (Keep in mind that crew cost and ATC/airport charges constitute between 40% and 26% of the DOC of European airline operations [5].)

Military experience

Military aviation has a rich experience operating non piloted aerial devices. It all started with guided bombs (radio, radar, electro-optical, infrared, laser, GPS/satellite guidance) that fly to their target and detonate. Then came the cruise missiles, that are self navigating to their target (autopilot, gyroscope guidance, inertial and satellite guidance, automatic terrain contour matching, target recognition etc). But these devices are not designed to be reused.

Reusable vehicles are known as Unmanned Aerial Vehicles (Uninhabited Aerial Vehicles) or UAV's. It is an aircraft without a pilot on board. These vehicles are Remotely Piloted Aircraft (RPA). ICAO (Circular 328 AN/190) makes a distinction between RPA and autonomous aircraft.

Currently no autonomous aircraft are in operation. *An autonomous flight is defined by the author as a flight executed by a device able to perform complete complex flying missions safely and very efficiently without human interference. Such a system will perform all pilot functions (flying, navigation, emergency control, hazard mitigation, collision avoidance) including communication with other air transport system elements.*

RPA systems (RPAS) can be remotely flown via a command and control data link. This can be done in 4 ways:

- Line of sight (maximum about 110Km)
- Forward pass where the control of the vehicle is enabled by several ground stations along the flight track of the vehicle
- Airborne relay where the control is executed from another aircraft or RPAS
- Satellite relay where control is executed by satellite link

If the control signal is lost these RPAS normally either return automatically to their starting location or land on their own. Some military RPAS fly pre-programmed flight profiles. Non fly fully autonomous however.

Military operators are using RPAS for different roles like:

- Surveillance and reconnaissance
- Aerial targets (drones)
- Decoys
- Combat
- Logistics
- Counter UAS warfare

Military operators fly these PRAS basically in segregated (closed) airspace. Several classes of RPAS exist ranging from small hand-held devices up to HALE (high altitude RPAS flying above 30.000 ft) and orbital vehicles.

Civil experience

RPAS have also found their way in the civil domain. Using the same guidance and control methods as the military, civil operators use RPAS for survey, search and rescue, inspections, border patrol, crowd monitoring, law enforcement, newsgathering etc. The small quadcopter became very popular as it allows private persons to enjoy recreational flying and photography. A new function may be package delivery as promoted by Amazon and DHL for example. These small RPAS are operated by a pilot on the ground using line of sight control. Strict rules are being made to ensure safe operations and avoid accidents including interference with normal air traffic.

Regulation for small RPAS and for bigger unmanned remotely piloted systems receives a lot of attention today. Several issues like pilot licensing, safe operating limits, etc. will be regulated in 2017. According to EASA there are 2495 operators and 114 RPAS manufacturers of small RPAS up to a maximum take-off weight of 150kg in Europe. For mini RPAS (up to 4kg), for which operators do not need a pilot license, limitations are set for maximum operational altitude of 50 meters and maximum range of 100 meters. [6] For RPAS weighting 4-150kg a pilot license is required and regulations are implemented by individual Member States of the European Union. [6] Member State regulations for RPAS above 150kg are related to operations of model airplanes to be used on dedicated model airplane areas. Other RPAS operations above 150kg will need to adhere to EASA regulations in Europe.

In the USA there is a lot of pressure on FAA to allow small RPAS to be flown without exemptions. [7,8] Governments are also concerned about the privacy issues although normal privacy rules seem to be sufficient but adherence of these rules is difficult to check. We have seen cases in the US where citizens shoot at mini RPAS to ensure their privacy.

The current control methods seem not to be suitable for commercial air traffic. In the UK, an industry-led program started in 2012 to test unpiloted flights using a Bae Jetstream. The equipment on board already had some elements of autonomous flight like the automated detection and avoidance of bad weather (clouds), a sense and avoid capability and infra-red sensors to find a safe place to land in the event of an emergency. The Astraea project flew the aircraft in regular IFR airspace controlled from the ground. [9]. According to Bae the ground station used commercial satellite data link connections to relay messages to the aircraft. It was stated that there was a 4-6 seconds time delay between a controller input and a response from the aircraft. Such a *time delay* would be unacceptable in commercial aviation in my view.

ATM trials are being conducted both in Europe and the USA to integrate RPAS in the ATM environment. Trials in Spain were conducted in 2014 where a MALE unmanned aircraft was inserted in class C civil airspace and controlled by AENA. The SESAR sponsored CLAIRE project will use a Thales Watchkeeper RPAS that is remotely flown along a number of waypoints in Wales. [10] In the US for example, General Atomics is working with NASA and FAA on ground pilot in the loop separation using TCAS II/ ACAS XU and ADS-B [11]

In conclusion, the future for unpiloted RPAS vehicles is just starting. However many believe that autonomous flight for passenger or cargo aircraft in non-segregated airspace is not possible due to ICAO. Article 8 of the ICAO convention states that “no aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting state without special authorization by that state and in accordance with the terms of such authorization. All UA, whether remotely-piloted, fully autonomous or a combination, are subject of Article 8.” I disagree with those who think this article will prevent future autonomous flight as technology will advance. In my view the article 8 should be changed as soon as autonomous flight can be used safely in the air transport environment.

Autonomous flight

Many experts in aviation predict that in future single pilot operations for commercial flights would be feasible. They argue that the public opinion demands that at least one pilot should be on board as a safety measure. (Recent events show that airlines demand 2 people to be in the cockpit at all times and a stewardess is requested to be present if one of the pilots is absent in the cockpit of airliners).

These experts implicitly say that the automation cannot be trusted and one needs a safety pilot in case automation fails. My conclusion is that such a solution is typical for the traditional aviation business. People are afraid of change and do not dare to accept disruptive technology. Apart from the fact that such a half way solution would be costly one may question the effectiveness of such a solution. In recent times we have seen many fatal accidents where aircraft systems failed but pilots were not able to respond properly. And with catastrophic results (AF 447, TK 1951 for example). The software in flight control systems is very comprehensive and complicated and sometimes pilots do not understand what the aircraft is doing. The conclusion is “pilot error” but the underlying cause may be different. How can we expect a safety pilot to stay alert, understand problems in a split second and act appropriately when experience shows that in some cases a number of pilots in a cockpit cannot solve a problem together. The obvious solution would be to create a pilot advisory device that would alert the pilot in case of non-normal flight conditions and would suggest corrective actions. But if the system already understands the problem and knows how to solve a problem why wait for a safety pilot to take actions?

Let me stress that I am not against pilots, having been trained as a private pilot myself. Every day there are numerous incidents where something in the automated flight control systems fails and pilots act to prevent disaster. It only shows that current automated systems and the software are not good and clever enough. There are bugs in the software and there are functionalities built in that pilots are not aware of or do not understand. If autonomous flying could be adopted in future, higher quality software and several improvements as well as additional functionalities for avionics are needed.

Aircraft control needs to robust, reliable and redundant. In a number of cases present automated control systems rely on a single source of input, like a pitot tube. If that device is malfunctioning, iced up or blocked by tape, the autopilot is confused with sometimes disastrous results. The control systems therefore need to rely on different inputs from different sources and calculate the most probable outcome by sensor fusion. Information to feed these sensors can come from the aircraft systems, from satellite information or from ground based stations. Control software needs to be more intelligent. Aircraft control is to be fail safe as there is no longer a pilot that may intervene if something goes wrong.

Autoland systems were developed already a long time ago and have a good safety track record. But dependence on ground systems needs to be merged with other data sources like satellite based landing capabilities (GBAS) to make autonomous operations redundant.

Automated systems need to avoid hazards by predicting, perceiving, understanding, anticipating and avoiding. Hazards can be in the air where self-separation is needed. Mid-air collision avoidance should not only be accomplished with flying objects that use different types of transponders (ADS-B, Mode S, IFF/Mode5 etc.) but also with flying objects that do not have these devices. TCAS is just a last resource option but should still be used in autonomous aircraft. Better systems need to be developed to counter the danger of bird strikes. The danger of Controlled Flight into Terrain has already been mitigated by advanced Ground Proximity Warning Systems. Avoiding bad weather conditions is another issue that needs attention especially since global warming may lead to more severe weather conditions for flying and aircraft need to avoid danger areas and recalculate their flight path to reach their destination in the shortest possible way.

Over the past years good progress has been made with Sense and Avoid systems. Several universities have developed systems incorporating new devices like ultrasonic range finders that ensure self separation for small RPAS vehicles, including the TU Delft. The MIDCAS project sponsored by the European Defence Agency (EDA) was recently tested to validate advanced sense and avoid systems to enable RPAS to fly in non-segregated airspace.[12] And there are more examples. But there is still a long way to go before these systems can be deployed in commercial aviation.

Navigation in aviation is still basically relying on ground based beacons and inertial navigation. Satellite based navigation (GNSS) should be incorporated in future autonomous aircraft systems. Again it calls for data fusion options. New on-board systems need to designed with autonomous flight in mind from the start to ensure that these systems are both adequate and affordable.

Datalinks are essential for unmanned autonomous flight. These datalinks need to be secure and hardened to avoid hacking. And datalink connections need to become less costly. Aircraft tracking needs to be assured. Systems to protect aircraft from manpads attacks should be standard.

If aircraft could fly autonomously there is no reason to use traditional ATC services (Air Traffic Control). ATC services normally ensure separation during the en-route flight phase and provide navigation advice when aircraft fly over long distances or pilots get lost in the air. ATC is responsible for tracking the aircraft and alerting SAR (Search and Rescue) forces if need be. ATC is also responsible for sequencing aircraft for approach and landing as well as take-off and departure. Ground movements and gate allocation functions are becoming part of an integrated ATM approach. With the 4D-gate-to-gate concept new planning is possible avoiding holding patterns at crowded airports. However unexpected circumstances will happen also because priorities may change as a result of Collaborative Decision Making actions (CDM).

Question is why automated ATC systems cannot cope with these situations as good as or even better than humans. The policy over the last 40 years has been to provide controllers with more and more tools to deal with both normal and abnormal situations. Experience has shown that some of these tools are not used by controllers when working in a high stress environment. As controllers often introduce extra safety margins for instance during approach and landing, the capacity of busy airports is often not used to the optimum. For example different wind conditions may influence the decay of wake vortexes of aircraft and may allow a different than standard separation between aircraft during landing. Already experiments are done to see how this separation on landing can be reduced compared to the ICAO standard separation minima. If that kind of information could be merged with other data on the landing conditions, airport ATC could be more effective. I am quite sure that an IBM's WATSON type of solution could perform as good as or better than controllers, assuming programming has been done right.

First steps in the direction of more automation are already introduced by installing remote tower ATC. But we are still a long way from autonomous ATM. It would require a new design philosophy for ATM which would mean a step change in ATM as ATM has not fundamentally changed since the 1930's. One may expect that some sort of safety oversight may still be wanted by controllers to make sure that automated systems perform as advised.

There will be a long transition period where autonomous vehicles guided by autonomous ATM will share the airspace with traditional aircraft relying on traditional ATC services. Such a situation needs careful consideration.

But autonomous ATM opens up new business opportunities where national ATC service providers could be incorporated in the airport organisation which would simplify the aviation business by reducing the number of players responsible.

This touches on the important issue of accountability and liability. Who will be liable if something fails and the autonomous aircraft would be involved in an incident or even crash. There we need a clear set of rules. Otherwise we will end up in endless discussions between lawyers that will ultimately prevent new technologies to be introduced. If we could arrive at world standards for these issues autonomous flying should be accepted.

Certification is another issue that needs attention. The process of certification is under review in Europe at the moment. This new approach should make certification 50% cheaper and 50% quicker as demanded by the European air transport stakeholders in ACARE [13]. No rules exist to certify an autonomous flying aircraft. This calls for new regulation rather than adopting existing rules. In order to develop this new regulation EASA should be involved in the development of autonomous systems right from the start of the development.

As already mentioned public acceptance is used as an argument against autonomous flight. Indeed there needs to be proof that autonomous flight is safe. Therefore one may expect that the first applications of autonomous flight will be in the domain of cargo aircraft and small personal transport planes. Then airliners will follow. However one should not underestimate the ability of the citizen to accept change. People drive cars that are made by robots. 30 years ago there were no cell phones. Ebay did not exist etc. Cars now have functions like “park assist” that people are using. Automation is everywhere. Trains are running without a driver. The google car is about to be introduced in the market. So it is safe to say that by the time autonomous flying is feasible and proven, let us say in 2050, the passenger will have got accustomed to more automation and autonomous systems.

Figure 4: Flying autonomously (Source author)

Also protection against cyber war was already mentioned. The success of autonomous flight and ATM will largely depend on the capability of the airlines and ATM organisations to counter cyber-attacks. This is already an issue in aviation today and will become more important in future. There is a challenge for designers to make systems resilient to these attacks. But cyber-crime should be a design parameter right from the start of autonomous flight development.

Next steps

Technology development in aviation takes a long time to mature. IATA illustrated this in their Technology Roadmap 2013 [3]:

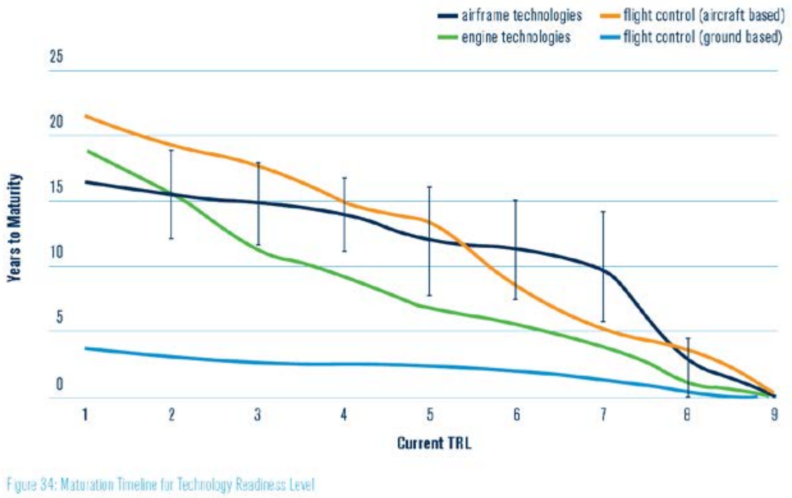

Figure 5: Time to mature technologies (Source IATA Roadmap 2013)

If we want autonomous flight to happen after 2035 we need to start the research today. Some system elements are already available but some need to be created from scratch. It will take a long time to develop and test the concept of autonomous flight/ATM and the contributing technologies and rules.

As airlines, the ATM community and the manufacturing industry are focused on near term incremental improvements one would expect public funding for new long term developments to be available. Some funding is available in the military domain but substantial public funding in the civil domain seems to be lacking. The European Commission is spending a lot of money on short term incremental improvements for projects in Clean Sky and SESAR, but very little money is available for new developments. If we are not careful and continue in this way to spend taxpayer money, the new world will soon be ahead of Europe. One may expect initiatives in China to address the issue of autonomous flight in view of the traffic growth in the Asia Pacific region and the substantial numbers of pilots and controllers needed. These countries are well acquainted with new developments in IT technologies and one may expect them to be in the lead in a couple of years.

So it is time that Europe wakes up and addresses the long term challenges and opportunities that lay ahead. For sure autonomous flight is one of them and will prove to be a must in the future.

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