



# EREA

vision for the future –  
Towards the future  
generation of Air  
Transport System

Study performed by ONERA, CIRA and DLR,  
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# Executive summary

## EREA ATS Study

**W**hat research is needed to pave the way for the future of Air Transport System (ATS) in 2050? This is the question EREA tried to answer to define its research agenda.

Four 2050 aviation scenarios have been investigated describing the associated technology challenges and choices as well as recommendations where more research is needed.

The scenario “Unlimited Skies” (ULS) represents a world that is not fundamentally constrained by energy availability. This doesn’t mean that people don’t need to save energy, but that the world is not governed by shortages. In consequence, aviation undergoes explosive growth, with the development of many different types of aircraft.

The scenario “Regulatory Push & Pull” (RPP) places emphasis on the public interest through a series of constraints and regulations. These constraints are primarily in terms of energy (both the cost and availability of fossil fuels becomes a deterrent) and the environment. This is a world dominated by electricity largely produced by nuclear plants but also by wind and solar power and any other technology using a natural resource in ecological fashion.

The third scenario “Down to Earth” (DTE) presents a radical situation, reflecting a political commitment to eliminate fossil fuels usage. These fuels are not necessarily depleted, but society has decided to stop tapping nature, and to freeze the remaining reserves as they are.

The last scenario, Fractured World (FW), offers a brand-new geopolitical vision. The world has been divided into very distinct blocs following major political and economic crises, partly caused by inequality in relation to the consequences of global warming and access to energy.

Along the four scenarios, the research priorities should be focused on technologies leading to a safer, greener and more efficient air transport system in a smooth evolution taking into account transition phases and legacy systems:

- > rethinking **Aircraft** architectures through all-out developments of cross-disciplinary technological building blocks;
- > migrating to a new Air Traffic Management (ATM) paradigm encompassing **4D contract and automation**;
- > optimizing **Airport infrastructures and logistics**;
- > developing multidisciplinary and multicriteria **design and evaluation** tools.

Five large areas have been identified as demanding research: electric aircraft, innovative aircraft configurations, carbon-neutral propulsion, carbon-neutral airports and the complete automation of air traffic.

In complement, the institutional aspects of European aviation have been investigated to analyze mechanisms that are needed to implement appropriate long term aeronautical research activities. Present boundary conditions and the role of the Research establishments have been reviewed to define the possible role that EREA and the Research Establishments should play in the preparation of the future generation ATS.

In conclusion from the institutional analysis, **EREA** should be the core of a Joint Research Initiative “ATS 2050” in the European Aeronautical research program. As such, it should coordinate the harmonization and standardization process relative to new business models, focusing on intellectual property protection, spin-off creation from research and technology transfer.

More funding is required for upstream research, continuing support for downstream research. EREA should be the coordinator at a European level for harmonization of a long term research strategy in coherence with the strategic directions provided in strategic research agendas.

# Introduction and scope

The future of any leading-edge sector depends on decisions made decades earlier in research centers and laboratories. In key technology areas such as energy, materials, design, onboard systems, infrastructure and environmental protection, making correct and timely decisions is crucial. The entire air traffic environment will have changed significantly by 2050. But to what degree will it actually change, and what resources will it need to support these changes? Whether the dominant scenario turns out to be unlimited development, drastic regulation, the virtual disappearance of the sector, or a combination of all three, the enabling technologies will undoubtedly not be the same.

<sup>1</sup>A study carried out from September 2002 to July 2005 by a consortium of DLH, DLR, NLR, QinetiQ, IIASA, MVA and Airbus, on behalf of the European Union (<http://www.dlr.de/consave/index.html>)

Several factors will have a considerable short-term impact on our society, including the depletion of oil resources, global warming and growing equality gaps worldwide. In fact, their effects are already perceptible. The air transport sector and its stakeholders are especially vulnerable to these factors, not only because the sector consumes resources and generates polluting emissions, but because its very raison d'être is in fact to support national and international travel and trade.

We must therefore ask certain vital questions, starting now. Will mass air travel still exist in 40 years? Will passengers still be boarding conventional, but ever-larger airplanes, or will they be in brand-new aerial vehicles based on disruptive technologies? Will aviation offer an alternative to private cars? And in that case how will we define air travel? Will we have made the transition from fossil to alternative fuels? Will we have invested in the air traffic control systems needed to unlock our airports, or will we run into the limits of a system that is already saturated?

These are not just theoretical questions. In fact, they clearly reflect how our society sees its future, and how it mobilizes its research resources. There are already paths indicating how we can shape a different world, but one in which air transport will still play a role. Moving forward will depend on the technological and organizational decisions that we must make in the near future.

**Chapter 1** gives an overview on the technical aspects related to the long term future of the air transport system. We have sought to imagine the role of air transport in 2050, based on the four scenarios defined by the Consave<sup>1</sup> study, and provide a comprehensive picture to support the decision-making process. We have used these contexts and backgrounds to build an organizational substrate based on pertinent technology options, capable of offering a comprehensive, "system" vision.

In **chapter 2** we give an overview on the major technical challenges resulting along these 4 scenarios and conclude on some prioritization. Additionally we provide a (non exhaustive) selection of innovative long term technical options for aviation.

**Chapter 3** provides an overview on the present institutional boundary conditions and describes the challenges and possible funding mechanisms that could be imagined to implement appropriate aeronautical research activities in order to reach the long term sustainable air transport system of the future.



# Research paths for a viable air transport system in 2050

Chapter one gives an overview on the four scenarios describing the associated technology challenges and choices as well as recommendations where more research is needed.



## 1.1 Unlimited Skies

Explosive growth,  
automated control systems

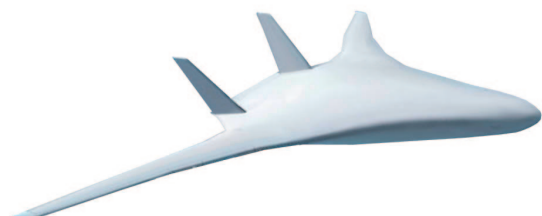
**T**he first scenario is called Unlimited Skies (ULS). It represents a world that is not fundamentally constrained by energy availability. This doesn't mean that people don't need to save energy, but that the world is not governed by shortages. In consequence, aviation undergoes explosive growth, with the development of many different types of aircraft.

Conventional large commercial jets, already very close to the optimum, have decreased weight by calling on advances in materials. This means that aircraft can carry more payload, increasing their profitability. Super-jumbo jets with 1,000 seats, but about the same size as an Airbus A380, are in widespread use. Existing airports are able to handle these super-jumbos without any problem. Advanced aerodynamic design has reduced drag, thus reducing their fuel burn – an extremely important point since fossil-based fuels are increasingly expensive. In fact, that is one of the key factors in this scenario.



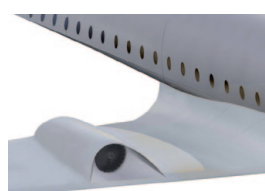
*The unlimited skies scenario*

There is also a role for alternative concepts such as the Blended Wing Body (BWB), an evolution of the old “flying wing” lifting body, because of the enhanced efficiency of this type of design. The development of artificial stabilization (computerized flight controls) has removed the major drawback of this configuration, which was the difficulty of combining controllability and performance. This applies even more because boundary layer air control devices are now capable of generating extra lift, while diminishing the aerodynamic penalty. The upshot is that we will be able to exploit the advantages of this concept, in particular increasing carrying capacity without decreasing efficiency. We can therefore design large-capacity aircraft with reasonable outer dimensions, by making widespread use of composite materials offering high specific strength. We can now fully control the design and qualification of these materials, which are partially recyclable, as well as their behavior over time due to integrated health monitoring systems.



*Blended Wing Body*

Because of their large available volume, Blended Wing Body aircraft will also enable the use of certain innovative propulsion concepts, such as buried engines, in which the engines are placed inside the structure. This has the dual advantage of reduced drag (and therefore lower fuel burn) and a smaller acoustic footprint. These advantages are all the more important since traffic is growing by leaps and bounds, and we have to address the problem of disturbances, especially around airports.



*Buried engines*

Another innovative technology is the distributed propulsion configuration, which would increase overall energy efficiency, while at the same time decreasing

acoustic impact. The idea here is to distribute the propulsive effect on the airframe, and therefore “fill in” the wake to prevent boundary layer separation. This solution may also result in decoupling electrical generation and the propulsive effect. Drag reduction is also reflected in the infinite aspect ratio of the rhombohedral wing; the structural rigidity inherent in this form combined with the use of modern materials would reduce weight. We will also see tiltrotors, combining vertical takeoff and landing with conventional lift for forward flight. All of these aircraft use internal combustion engines, and one of the top research objectives is to reduce their emissions.



*Rhombohedral wing*

Likewise, the use of propellers on either piston or turbine-powered planes, instead of jet engines, cuts fuel consumption on certain types of routes. This is not necessarily synonymous with reducing speed. For example, the Contra-Rotating Open Rotor engine, or CROR, which involves even greater airflow than a conventional layout and generates an exhaust nearly as fast as cruise airspeed, provides excellent performance. However, because these contra-rotating blades are unshrouded, noise is still significant in the low-frequency band. But they still generate economic savings sufficient to support the massive use of this type of engine in the Unlimited Skies concept.



*Contra Rotating Open Rotor*

The airport environment in this scenario is very similar to the current situation, in which hub and spoke networks operate alongside a network of secondary airports supporting point-to-point service, for example to link secondary

cities without transferring via capital cities. The number of airports is not significantly larger. But since the number of aircraft in service is booming, air traffic control has to be entirely revamped to avoid saturation. With only a few exceptions, the notion of conventional piloting will be replaced by a “full automation” concept, along with the “4D contract”. In constant contact with a complete ground control and command system, cockpit-less aircraft automatically follow flight paths adjusted to avoid major cities and decrease the distance flown for lower fuel consumption, without waiting, delays or conflicts. These flight paths include descent profiles into approach zones with significant glide slopes, flown with engines at idle to limit consumption and noise.



*Hub&Spoke airport*

The 4D contract incorporates the notion of time in addition to the usual three physical dimensions. Aircraft that are automatically guided along their entire flight path follow a strict schedule to be at predefined waypoints at given times. This is designed to optimize aircraft spacing (in order to further reduce wake vortices, already minimized by active aerodynamic devices in both the lead and trailing aircraft), and also helps decrease the width of the air corridors reserved for these aircraft. The air traffic control system operated and updated in real time, can therefore make use of the airspace before and after the passage of the aircraft. In case of an event that disturbs this process, such as weather conditions that make the initial route unusable, or technical incidents, a new “contract” between plane and system is negotiated in real time, enabling the plane to take a safe new route, i.e., one that avoids conflicts with other traffic.

Aircraft also communicate among each other and, if an immediate change in the trajectory is necessary (due to an engine failure for instance), they are capable of locally negotiating temporary “contracts”, enabling them to take a new conflict-free flight path.

Given the complexity and quantity of variables involved, which over-saturate human capabilities, this type of air traffic management can only be handled by a computerized system. Aircraft still carry passengers, but no longer have a pilot aboard. The pilot’s role has disappeared with the maturity of the automated control system. However, people are still in the loop through two distinct functions: a supervisor in the airplane (successor to the captain, who represents the airline and maintains onboard authority); and a ground captain (transition of the controller’s role to a supervisor tasked with managing emergency situations not provided for in the system). The ground captain can make strategic decisions (as opposed to tactical, local actions, such as the real-time control of an aircraft), insofar as human reaction time is compatible with the type of decision needed. Typical situations include the choice of routes, types of approach, or choosing an alternate destination in case of diversions. For a given aircraft during a flight, this role can be shared by as many ground captains as there are ground control centers along the route.

The concept of “full automation” is diametrically opposed to that of “free flight”, in which airlines are free to choose their routes to make optimum use of the airspace in their own interest. In the case of full automation, the notion of a comprehensive system is predominant, and all players are subservient to this system. This presumes that airlines have previously negotiated their departure and destination points with the air traffic control authority, as well as the time slots they want to offer their passengers. The system is in charge of integrating all these elements in the general traffic pattern, first in terms of planning, then in real time when the plane departs (allocation of a take-off slot), and then en route. Automated piloting concerns not only commercial transport, but also



business trips and Personal Air Transport. The PAT is a very-short or vertical takeoff and landing aircraft, whose large-scale development will require a major breakthrough in terms of lift and propulsion. It could also be a helicopter or a tiltrotor. In any of these cases, the PAT would be a private vehicle like a car, except that its “pilot” would simply enter the departure and arrival points, and perhaps several waypoints between the two.



*Electric Propulsion with fuel cells*

Civil and military drones would also be subject to this full automation system. Their flight paths (“loitering” surveillance circuits for example) are compatible with the 4D contract concept. The remaining categories include military, emergency and light aircraft, which are generally manned. In the case of military aircraft, as for police, medical, fire-fighting and similar missions, flight paths are requisitioned on demand (although with major constraints, since business concerns generally take precedence in this scenario), and Air Traffic Control (ATC) “clears the airspace” the time needed for a fighter patrol or emergency medical helicopter to pass. Real-time control minimizes the impact of this type of disturbance. So there are no longer any airspaces strictly reserved for military flights, as we see today.

Concerning light aviation (gliders, microlights, etc.), this must remain under pilot control, provided that these flights can be integrated in the rest of the automated traffic. Most of these aircraft use electric propulsion, and benefit from the ongoing improvements in this type of motor, tending towards increased specific power and lighter energy storage systems, taking advantage of technology developments in other sectors, particularly the auto industry. These aircraft remain very small and light. They operate on a cooperative basis, sending their position to the central system and to other aircraft in real time. Furthermore, their pilots have a 3D display (such as a head-up display) of the surrounding sky, using color coding to show what areas are free, prohibited (because they are occupied at a given moment), or if the area will be prohibited within a given period of time. This allows them to integrate the system naturally and smoothly.

### 1.1.1 Technology choices

The cornerstone of Unlimited Skies is the combination of full automation and the 4D contract, the only way to prevent the saturation of growing air traffic. This goes hand in hand with the development of “green” procedures, designed to limit impact on the environment and surrounding populations. Since the focus is on growing the aviation business, it is also essential, in a world where energy is expensive, to develop solutions that reduce fuel consumption and make air transport more cost-effective. From this perspective, we have to emphasize revolutionary aircraft concepts (flying wings in particular) and lightweight materials. The PAT is also an option that should be considered very seriously, since it will help shift some traffic from our jammed roads to individual aerial vehicles.

### 1.1.2 Our recommendations

Efforts concerning this scenario should primarily focus on the full automation concept; as for the 4D contract, the technology involved is relatively advanced. Even though the underlying organizational strategy requires more work, a number of technological building blocks are already available. Implementing the concept is only a question of financial resources, political will and social acceptability. The revolutionary aircraft concepts and configurations (BWB included), already well advanced in terms of Research & Development, also require an effort on the production level. At the same time, we have to maintain broad-based research on lightweight materials, green procedures and the use of electrical propulsion techniques from the auto industry. However, for Personal Air Transport (PAT), we are starting from scratch.

## 1.2 Regulatory Push & Pull

Regulations to benefit a comprehensive environmental protection approach

**T**he second scenario, dubbed Regulatory Push & Pull, or RPP, shares the “full automation” and “4D contract” concepts with Unlimited Skies (ULS). But whereas in the ULS scenario, these concepts were used to smooth out boom-

ing traffic growth, this concern no longer has the same crucial character in the case of RPP. This is quite simply because, with development being largely limited by an array of regulations, we don’t run the same risk of extreme saturation. The world illustrated by this scenario in fact places far more emphasis on the public interest, and is more concerned with its long-term viability and conscious of its fragility, due mainly to a series of heavy constraints. These constraints are primarily in terms of energy (both the cost and availability of fossil fuels becomes a deterrent) and the environment. This is a world dominated by electricity, largely



*The regulatory Push and Pull scenario*

produced by nuclear plants, but also by wind and solar power, and any other technology using a natural resource in ecological fashion.

We still face the issue of transport regulations, but it is now considered from the angle of a comprehensive, “system” approach: the only one that allows us to achieve an optimum tradeoff between all factors leading to the best specific fuel consumption. There are two main types of pollution: emissions and noise. From this perspective, the automation of air traffic (full automation and 4D contract) is tasked with guaranteeing the systematic adoption of green procedures, including anti-noise approach profiles and flight paths, engines at full idle without go-arounds. It isn't easy for pilots to comply with all these conditions under highly variable weather conditions, especially in terms of wind. That partly explains why a large majority of aircraft do not use these procedures. They are therefore subject to very strict flight path instructions, issued by the comprehensive system. This system minimizes environmental impact by using refined, real-time calculations of glide slopes adapted to each aircraft according to its weight at any given moment. Likewise, the automation of flight enables a vertical shift in all traffic, depending on atmospheric conditions (humidity, temperature), to remove traffic from the altitudes favoring the formation of contrails; since these trails are clouds of ice particles, they act as a screen to terrestrial radiation, thus contributing to the greenhouse effect and global warming.



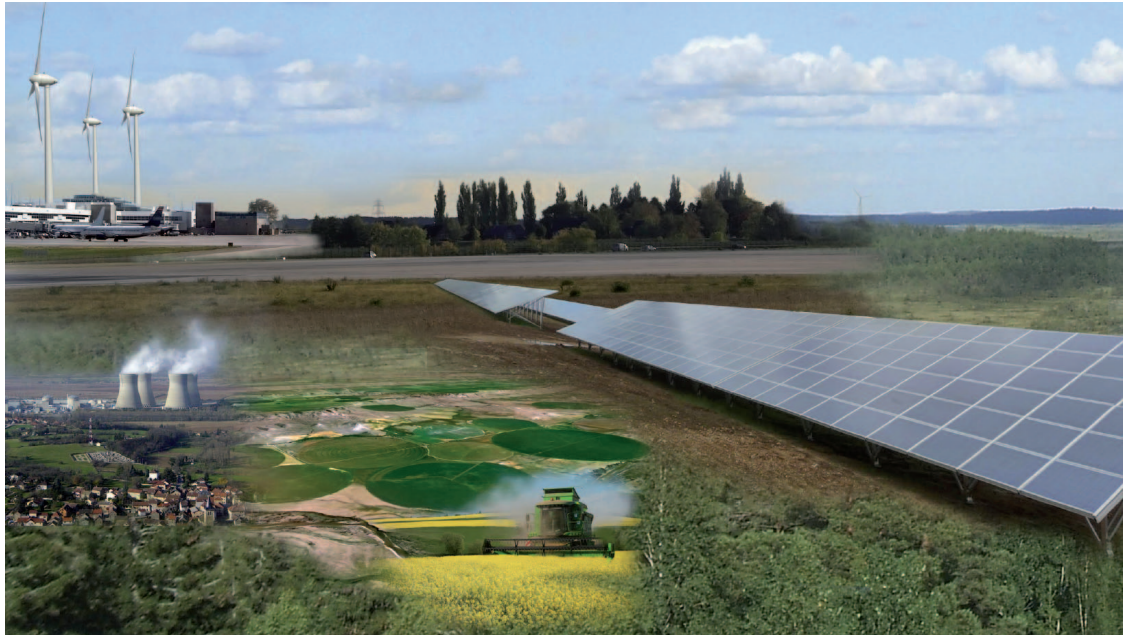
*Contrails avoidance systems*

As in the case of the ULS scenario, this regulation excludes the contrary concept, free flight, which

can only be envisaged within a context involving the absence of environmental restrictions and low traffic density. Logically, this is a world in which infrastructures have to prove they are carbon neutral. Airports, for example, must show they produce less pollution and noise, but also that they actively contribute to the overall ecological budget by using energy sources for their own operations that don't produce any CO<sub>2</sub>, or, if this is not possible, by offsetting their emissions by setting up carbon sinks, planting trees for example. There are fewer hub & spoke systems and more airports operated point-to-point. Some of these points are connected with each other or to the hub via rail (electric trains). Depending on distances and environmental conditions, rail travel can provide a better tradeoff than air travel in relation to the environmental priorities in this scenario. Air travel itself is reconsidered by society from a comprehensive perspective, with passengers paying not only their ticket, but also offsetting the environmental cost of their trip by contributing, for example, to reforestation. This type of “CO<sub>2</sub> solidarity” approach, long limited to the most committed environmentalists, has become one of the fundamental aspects of society in this scenario.

Air transport in general has to demonstrate its pertinence in relation to other means of travel. Faced with these constraints, aircraft change. There are far fewer of them, because of lower demand, and they are also smaller than in the ULS scenario. Less obviously, they also reflect the breadth of possible solutions. The strong constraints imposed by society favor the emergence of more innovative concepts. The focus is on limiting emissions and saving energy, not only during operation, but also throughout the life cycle of the vehicle, expressed in the “green aircraft” concept. We therefore scrap the older aircraft with less energy-efficient jet engines, and support the massive expansion of electricity, produced by diverse sources. This change is greatly facilitated by the development of non-conventional superconducting materials, which offer virtually no internal resistance for highly efficient current transmission. Progress lies in the temperature at which materials become superconducting: raising the temperature range makes this technology far more accessible (for example, well





*Greener airports*

above  $-170^{\circ}\text{C}$ ), thus minimizing the complexity and weight of cooling systems installed on aircraft. The Blended Wing Body (BWB), an evolution of the flying wing, is well suited to a wide range of propulsion concepts. The large internal volume offered by these aircraft (ideal for freight, or a combination of passengers and freight) also means that there is room for “buried” engines, thus generating less noise and enabling conventional internal combustion engines to once again justify their use. This type of aircraft could just as well be fitted with an electric propulsion system using energy from a small nuclear reactor in the fuselage, or from solar cells that could easily be distributed over the upper surface of the aircraft’s body.



*Blended Wing Body with Nuclear propulsion*

The regenerative fuel cell is another option. Biofuels are only considered a good solution if they offer a favorable overall energy budget, once again reflecting the system approach. It’s not worth using so-called “green” energy, if we have to use so much water and diesel fuel (for tractors) and release so much gas in the atmosphere to produce the required feedstock that we are unbalancing the system in other areas. Not to mention that the land used to produce this energy source is no longer available for food. This type of intellectual approach is typical of the RPP scenario. I

Propeller-based propulsion systems become more widespread. Contra-rotating layouts tend to be noisier, and are therefore mainly used on flights over unpopulated areas, for example intercontinental flights. In general, this scenario involves flights at lower speeds, as reflected in less swept wings and larger aspect ratios. Long routes are divided into more legs, mainly to limit consumption. Trials of different refueling solutions are carried out, either in-flight or via ocean platforms (also used for passenger transfers); when they generate fuel savings, these solutions will be used. How-



ever, this is not always the case, since after being refueled, the aircraft obviously have to climb back to their cruise altitude, which takes energy. That's why the concept of "tractors" is also being studied, to bring aircraft up to cruising altitude with their tanks still full. Likewise, commercial aerial tankers are being considered. In consequence, passenger aircraft will not fly as high, exposing these aircraft and their passengers to bad weather and turbulence over longer periods. This is partially offset by designing more flexible wings (damping), and by using turbulence detection devices, or controlling the effect of turbulence on the aircraft if it can't avoid it, by using MEMS (microelectromechanical system) type devices.

One very important research path is "morphing", for instance via the "active aeroelastic" concept. This seeks to duplicate the control effects of traditional lift augmentation devices, such as slats and flaps, with their weight and drag penalties, by using real-time changes in airflow over the wing, either by deforming the wing (via the actuation of minuscule, efficiently located control surfaces), or using a fan and duct system to locally reposition air streams within the boundary layers. These mechanisms will also improve aerodynamics during all phases of the flight. These two approaches, both using powerful onboard computers, could also be combined. However, they will not exist without the development of materials with the requisite elasticity, or shape memory materials, which would naturally retain their recyclability.

If point-to-point connections were to become widespread, this would of course favor the use of Personal Air Transport (PAT) systems. Offering short or vertical takeoff and landing, plus all-electric propulsion, these systems could be easily integrated in urban environments, similar to private cars. Along the same lines, a complete family of vehicles would be offered, from a single-seater to the equivalent of a minibus.

Military flights and emergency services (medical, police, fire) would integrate the airspace as in the ULS scenario, namely by requisitioning flight

paths that Air Traffic Control (ATC), in charge of managing priorities, would make available for the time needed. Private planes and trainers, instrumented to offer collaborative capability, would also retain a spot in this scenario, largely due to electric propulsion. This type of propulsion will have considerably improved its effectiveness due to the progress made on other types of vehicles, in particular cars.

### 1.2.1 Technology choices

Because the older technologies are no longer appropriate, Regulatory Push & Pull is the richest scenario in terms of key enabling technologies. It encompasses a wide array of solutions that help reduce pollution of all types, as well as the consumption of fossil fuels. In particular, it involves the widespread use of electrically-powered aircraft and, in general, innovative concepts and configurations, such as the Blended Wing Body, active airflow control and smart materials and sensors. Worth noting in terms of a comprehensive vision is the concept of "carbon neutral" that would apply to airports as well as propulsion systems. From the organizational standpoint, this scenario is dominated by the concepts of full automation and 4D contract, applied within the scope of green procedures to meet critical energy savings and traffic control criteria.

### 1.2.2 Our recommendations

The focus should be on five key technology domains. Four of them are still at the nascent stage, and require sustained efforts in terms of research, development and production: electric aircraft; carbon-neutral propulsion modes; complete traffic automation; and aircraft concepts based on disruptive technologies (the only one for the moment to benefit from significant R&D). The fifth technology domain is the carbon-neutral airport, and all that remains to do in this area is the actual implementation. Other technologies are less crucial, except for green procedures, which are important from the standpoint of the RPP scenario. Since this scenario requires all different types of technologies, it is probably the scenario that demands the most massive support for research.

## 1.3 Down to Earth

A world that functions with virtually no fossil fuels and generates no emissions

**T**he third scenario presents a radical situation, reflecting a political commitment to eliminating fossil fuels. These fuels are not necessarily depleted, but society has decided to

stop tapping nature, and to freeze the remaining reserves as they are. Furthermore, we no longer release polluting substances. This situation is not necessarily the catastrophic result of a period of hyper-consumption and all-out development as shown in the Unlimited Skies scenario, in which we are down to our last drop of oil. Instead, it is the result of a conscious and purposeful choice: we as a society decide that we have to stop negatively impacting our planet. Business activity is wholly subordinated to protecting our planet. Electricity (generated by nuclear, solar, wind and



*The Down to Earth scenario*

water power) will therefore be the predominant energy source for human activities, necessarily green.

Given this context, commercial air traffic, along with similar industries, is completely called into question, not only because it consumes energy, but also because it generates emissions and therefore contributes to the greenhouse effect. For travel within each continent, electrically-powered trains therefore become the primary mass transportation system. Intercontinental travel will call on ships with very large sails, using solar cells to provide energy for all onboard systems.



*Changed Intercontinental travel*

In general, however, instead of business travel, people will “meet” via videoconferences, either from their office or from home where they are teleworking. Virtual reality will meet some communications needs in a world where we can no longer travel as quickly or easily across the planet. Of course, airports no longer exist, since commercial air traffic has disappeared. The only acceptable flights are those in the public interest, or a few marginal operations that can prove they are neutral to the environment, starting with military activity.



*Videoconferencing*

States will still be as they are today, with defined borders and exercising sovereignty over their territory. So there are still jet- or turboprop powered military aircraft piloted by humans, for routine missions, operating alongside unmanned aircraft. These drones have changed very little from current models, except that they are fitted with regenerative fuel cells or solar cells to power small electric motors. Also considered acceptable are flights from small airfields or heliports by emergency units, for police, medical, search & rescue or fire-fighting missions. These units will make use of conventional aircraft, such as turbine-powered helicopters, for emergency medical evacuation and police missions, and water-bombers to fight forest fires. While these aircraft emit CO<sub>2</sub>, there are so few of them that they have a negligible impact on the environment. So this “exception to the rule” becomes acceptable, especially in light of the tremendous benefits for society.



*“Exception to the rule” missions*

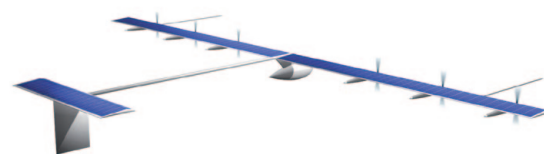


Furthermore, these aircraft could possibly use bio-fuels instead of oil, but only if the production of these alternative fuels does not upset the fragile ecological balance. If these fuels deplete our water resources, because of the need to water crops, then it would be better to use fossil fuels. In fact, at the rate of use according to this scenario, our fossil fuel resources could be considered virtually inexhaustible.

Automated systems will be developed to handle surveillance, observation or dangerous missions, those considered “Dirty, Dull & Dangerous” – the D3 concept. As for military drones, these systems would generally be unmanned and electrically-powered, since the principle of environmental protection also extends to human lives. Society’s tolerance for exposing people to danger has in fact become very limited. In general, although they have a specific status, soldiers, policemen, doctors and firefighters are subject to the same environmental logic prevalent throughout our society. Air force bases, for instance, will have to show that they are carbon neutral. Their emissions will be considered in the light of a holistic environmental approach, and must therefore be offset by planting trees (or other carbon sinks).

Light aviation only has a role to play in this context if it is totally environmentally neutral. However, it is only natural to believe that fallout from technological progress in other sectors would help maintain aviation for sports flying and flight training purposes. For instance, electric propulsion – especially the miniaturization and performance enhancement achieved in the auto industry (not to mention the ability to recycle batteries without polluting) – could support the design of very light aircraft that do not generate any emissions and whose energy source is environmentally neutral. Gliders launched by an electric winch, or electric motor-powered gliders would be totally le-

gitimate. All these manned or remotely-controlled aircraft (military, public interest or leisure) would operate in free flight; i.e., their operators choose their routes freely, with minimal contact with Air Traffic Control (ATC). There would be very few of these aircraft, and they would only be flying alongside highly automated aircraft, able to collaborate within a sophisticated local loop.



*Solar gliders*

### 1.3.1 Technology choices

The focus here is on enabling technologies for electric propulsion and carbon-neutral propulsion. There will be no aviation without them, because the most urgent goal is to stop pollution and use fossil fuels as little as possible. The logical complementary factor would be infrastructures that offset their releases by using carbon sinks. Since noise is also a type of pollution, reducing noise and using green procedures are also very important. Lastly, since air traffic in the Down to Earth scenario is very slight, this would be the natural environment to develop “free flight”.

### 1.3.2 Our recommendations

The priority investment must be in electric aircraft, along with carbon-neutral propulsion and air bases. While the latter are nearly feasible already, this is not true for electric aircraft and carbon-neutral propulsion technologies, and a massive effort is needed in R&D and other areas. Efforts to reduce noise and apply green procedures should be continued, while free flight and a “minimal” Air Transport System are considered as less fundamental, given the expected volume of air traffic.

## 1.4 Fractured World

A juxtaposition of independent worlds, developing at very different paces

**T**he fourth and last scenario, Fractured World (FW), offers a brand-new geopolitical vision. The world has been divided into very distinct blocs following major political and economic crises, partly caused by inequality in relation to the

consequences of global warming and access to energy. Other factors include the sometimes contradictory aspirations of different peoples, depending on their history and world view. At a moment when China embarked on a policy of accelerated production, along with a consumer appetite that was all the stronger because so long repressed, countries in Western Europe, united by common interests and having long trod the same path, were beginning to realize that they had to stop this same headlong pursuit. Each bloc therefore drew back into its shell, and chose its own solutions according to what it considered its basic values.



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*The fractured world scenario*

These groups of nations, relatively homogenous in geographical terms, are each roughly on a continental scale. The atmosphere is largely paranoid, and while a few resources seem to remain, notably fossil fuels, they won't last much longer, and above all there won't be enough for everybody – even those who live in a favored zone.

So the different blocs keep a wary eye on each other, ready to leverage the slightest competitive edge. The resulting tensions lead to an increase in military air traffic (among other reflections of sovereignty) within and at the edges of the different blocs. It is of primary importance for the states comprising these blocs to ensure their security in relation to other blocs, as well as in relation to their immediate neighbors. Trade between these now independent zones is now only marginal, which effectively eliminates long-haul air transport. Instead, various long-range communications solutions have been developed, and citizens no longer fly to the other side of the world on vacation – except virtually. A regional aviation industry still exists within the blocs in the best of cases, because not all of these groupings have developed equally.

Some, comprising very rich countries with natural resources and continuing political influence, still have the means to allow their economies to move forward. So they are operating according to the first scenario, Unlimited Skies (ULS). In this type of zone, air traffic has been allowed to expand without hindering it with restrictive environmental regulations. It is also worth noting that this case involves a vast land area, not overcrowded, with non-negligible fossil fuel resources. The priority is therefore still on economic and industrial growth, without the sustained social and political will to limit growth. This situation could continue as long as citizens are not subjected to unacceptable living conditions, forcing political authorities to pass laws. Among these conditions are the increasingly expensive access to energy and the pollution inherent in expanding air traffic. The only real constraint is to avoid saturation. That's why efforts focus on making traffic flows smoother by control systems making massive use of automation (full

automation and 4D contract). Long-haul jets have disappeared, replaced at the summit of the mass transport pyramid by unmanned medium-haul aircraft. As a result, international airports have also disappeared. The infrastructure network is still organized in dual fashion, combining hub & spoke operations (but without their current international scope) and point-to-point routes. Also characteristic of this scenario are a very wide range of business aircraft (all the way to supersonic jets), and Personal Air Transport vehicles, which tend to replace private cars.

This comparatively rich world, or worlds, exists alongside poorer zones, which have neither the same resources, nor the same influence. Their inhabitants are more conscious of the limits of their lifestyles, and of its fragility in relation to the upcoming depletion of fossil fuels. Without sounding the death knell of its industry, these blocs regulate their activities, with a priority objective being to reduce environmental impact. This has become a major political concern, supported by all of society. So these blocs naturally adopt the Regulatory Push & Pull (RPP) scenario, which no longer subordinates its political choices to the interests of the market, and capitalizes on automated traffic management to meet the objectives of environmental protection and drastically limit pollution's impact on people.

The full automation and 4D contract concepts are used to meet this specific goal, while the spotlight is resolutely on green technologies that will minimize consumption and emissions: electric propulsion, high or even infinite aspect ratio wings, lightweight materials, innovative configurations such as Blended Wing Bodies and PAT. The most innovative technologies will be implemented in these blocs, quite simply because the required tradeoff is the most difficult to achieve: produce and consume more, but while integrating the consequences. A comprehensive approach will be used. This type of zone is smaller than the other zones, which will foster the use of smaller aircraft sized for regional transport, with limited speeds and altitudes.



*Increased usage of regional aircraft*

There are other zones as well, which have decided to change their approach, either by necessity, or by choice. Instead of consumption that draws on natural resources, and human activities that pollute the environment, the inhabitants of these zones have decided to freeze natural energy resources as they are, and to use only renewable energy sources. A bloc of this type would operate according to the Down to Earth (DTE) scenario. Commercial air traffic no longer exists. Aviation is therefore limited to military and public interest missions, which means it is so widely scattered that it can operate in free flight mode without any problem.

The fact that these zones have withdrawn into themselves does not mean that they do not influence each other. In particular, it is hard to imagine that a country operating according to DTE logic would easily tolerate the headlong growth typical of ULS. While the political organization and strate-

gic decisions have resulted in a fragmentation into blocs of countries, the borderless air and ocean currents would tend to convey the emissions generated by certain blocs towards the natural sanctuaries set up by others. But does this mean that such differences in lifestyles are destined to be reduced in the case of a major crisis that would terminate the Fractured World scenario? Not necessarily, because, if entire areas of the world operated according to RPP, or even better DTE, that would enable, through a balancing effect, other blocs to remain in ULS mode for a longer time – exactly as though a global offset was occurring. However, it is also possible that things would not evolve like this. Rather, under international pressure, countries worldwide would collectively decide to adopt more or less the same lifestyle, but modulated according to the resources at their disposal. At this point, fragmentation would mean that each zone is drawing back into itself in order to organize the living conditions that reflect the effort that each society is ready to make.

#### 1.4.1 Technology choices

These choices vary according to the situation in each separate bloc, and the approach each has chosen.

#### 1.4.2 Our recommendations

The decisions to be made depend on the scenario and overlap with those given at the end of the three previous scenarios.

# Research: investment paths for a viable air transport system in 2050

Chapter two gives an overview on the major technical challenges resulting along the 4 scenarios and concludes on some prioritization. Additionally we provide a (non exhaustive) selection of innovative long term technical options for aviation (See annex 5.1, list of technological concepts).





The four scenarios described in the preceding pages are designed to support further analysis. They are rough sketches that describe highly contrasted situations, clearly bringing out their organizational foundations and their research requirements. Because the actual situation and trends are always more subtle and complex than this type of exercise can show, it is doubtful that the air transport industry in 2050 will correspond totally to these scenarios.

This study does not pretend to be a crystal ball. Its aim is instead to foster the development of a road map. The infinite variables at play, the fine balances possible, and the way in which history will shape the next 40 years mean that at least certain characteristics of the world of 2050 will be brand new. However, we will still find a preponderant share of the characteristics described in these four scenarios, and in consequence, the associated technologies, concepts and systems. These solutions are basically designed to allow people to use air transport to maintain their mobility, without at the same time sawing off the branch they're sitting on. In turn, this implies betting on certain areas of research, including new aircraft concepts and technologies, automation and traffic management, airport infrastructures and of course critical design and testing tools. Any decisions made in these areas have to address a two-pronged concern: to protect the environment and reduce the consumption of energy. This must be considered from a holistic "system" approach, the only one that takes into account the actual impact of applying any type of solution, from production to operation to recycling, and spanning all interactions with the environment.

## 2.1 Aircraft: rethinking the architecture and all-out development of cross-disciplinary technological building blocks

Two research paths in aircraft design must be pursued concurrently: the development of new technologies that could be integrated on all types of aircraft, and rethinking aircraft architectures. The conventional configuration of transport aircraft is dictated by the principle of separating the three main functions of payload (fuselage), lift (wing) and propulsion (engines), enabling each of these subsystems to be treated virtually individually in order to maximize benefits. Since this configuration has probably reached nearly optimum performance, it offers only very limited room for progress. It is therefore necessary to rethink the problem as a whole, enhancing efficiency by integrating all functions. A change in approach of this type naturally calls into question the current production organization, in which each sector (airframers, engine-makers, equipment suppliers) enjoys relative autonomy. This means that the industrial landscape and its balances of power will have considerably changed by 2050.

The significant advances in a known concept, the Blended Wing Body, or BWB, perfectly illustrate the need to move forward in step – and across the board – in terms of new architectures and innovative technologies. Of course, this configuration enables an advantageous increase in carrying capacity at lower energy cost (assuming that a need for large capacity aircraft still exists). The BWB's aerodynamic advantages, coupled with an intrinsically low structural weight, holds out promise of a significant reduction in fuel consumption. The large interior volume could be used for a better mix of passengers and freight, as well as to "bury" engines in the airframe. Although this type of propulsion layout could make maintenance a bit harder, it would also decrease drag and noise (a decisive

factor in people's awareness of the disturbances of air traffic). Decreasing the noise footprint also depends on the integration of generally passive noise-absorbent materials, greatly facilitated on a BWB. However, efforts are needed to ensure that these materials do not penalize energy efficiency, are stable over time, and do not make maintenance operations prohibitively complex. Active noise attenuation devices also have excellent potential to reduce cabin noise, particularly in narrow frequency bands. Here too, the focus is on mastering robustness and aging.

By pushing the BWB concept a bit further, it is also possible to rethink propulsion, in successive stages. A first step would be decoupling the power generation and propulsive functions, possibly leading to the development of a distributed propulsion system that would provide additional aerodynamic benefits. Individual engine control would contribute to flight control, instead of or in conjunction with conventional control surfaces, along with jet deflection or active airflow control devices. Another way of optimizing the energy budget during different flight phases would be controlling surface geometry, achieving small deformations via MEMS (microelectromechanical mechanisms), or using elastic, aging-tolerant materials. These solutions also bring potential benefits in terms of decreasing acoustic sources. However, this would require more extensive research on smart materials, the aging of materials in general, sensors and information processing (large, high-rate data streams), as well as distributed actuators for flight control surfaces. At the same time, we will have to ensure the dependability of these systems. All of these efforts will have to achieve a degree of maturity, based on the study of concepts drawing on these technologies, that achieves an optimum tradeoff between the total weight of these devices, their aerodynamic improvements and their complexity.

We could go even further in terms of propulsion, in fact, all the way to new energy sources. Our ongoing aim, of carbon neutrality, is feasible, and there are several ways of meeting this goal: either by calling on an intrinsically carbon-neutral energy, such as solar or nuclear power, or by using

an intermediate source that does not release CO<sub>2</sub> in operation, namely hydrogen. The development of production technologies for this gas, capable of limiting releases – and also easily capturable – would achieve an ecological balance. We must therefore develop production solutions, and in particular pursue our efforts on all technologies enabling the use of hydrogen-based fuel on aircraft: chilldown, maintenance at low temperatures, lightweight, insulating structural tanks. Last but not least, a carbon-neutral solution should not also involve a significant increase in the release of other pollutants, such as sulfur compounds.

An electrical generator driven by a hydrogen-powered turbine could supply power for a large number of high-efficiency electric motors. However, superconductor connections would be needed to ensure the overall efficiency of the system. By reducing losses, these superconductors would in effect increase the power-to-weight ratio of the engines and the capabilities of the associated electronic power controllers. Research efforts should also therefore focus on these materials. The use of electric motors should obviously be considered in terms of a tradeoff between energy and the environment, implying that the initial application would be on small aircraft. However, advances in this type of propulsion will only be advantageous if the total energy budget over the entire life cycle (including the aircraft seen as a whole) meets the objectives stipulated in each scenario. That would include energy storage devices combining high efficiency and recyclability.

The Blended Wing Body is not the only configuration we should be considering. We could also consider trisurface airfoils, aircraft using braced wings, or infinite aspect ratio wings. For example, in an architecture that separates functions, a rhombohedral wing could offer non-negligible aerodynamic gains by eliminating marginal vortices. However, the resulting internal structure would be complex. At the same time, we would have to focus on developing certain innovative technologies to better manage loads, in terms of controlling the elasticity of structural parts such as the wing. This would reduce the necessary design margins, which in turn means lower empty weight.

From this standpoint, it's worth taking a close look at composite materials. Their resistance to local degradation is a major concern, in relation to flight safety and therefore the resulting design margins. Miniature sensors must be integrated to better monitor these structures. It would also be a good idea to conduct more basic research on wood fiber-based composites.

Other new-generation propulsion concepts are based on high-speed propellers, possibly in a contra-rotating layout. In this case as well, their energy benefits must be seen in light of their environmental and societal benefits. Progress in these areas is also possible on essential subsystems, such as the landing gear. Only a multidisciplinary analysis could confirm the advantages of these technologies, by properly estimating the tradeoffs that they would necessarily have with aircraft performance in terms of fuel consumption and polluting emissions.

Innovative solutions will also be generated by exploring paths that are known, but of still limited interest. Achieving several key technological breakthroughs would enhance their operability, even if applications remain limited to a niche market. Airships, for instance, could hover over an area of interest – like satellites, but at a much lower altitude – for use as a communications relay, or to conduct surveillance from the troposphere or stratosphere.

Nor is it out of the question for disruptive technologies to come along at the right moment, providing the opportunity to reconsider the problem of flight from a brand-new angle. For example, we have to develop alternative lift solutions that would give definitive impetus to the Personal Air Transport (PAT) concept. If not, it is also perfectly possible that this type of individual vehicle would continue to use a conventional aerodynamic design, provided that its propulsion system limits the noise generated within cities, and that it limits energy consumption; i.e., is electric. Furthermore, based on previous technology trends, the PAT could well be the first vehicle to benefit from advances in this type of propulsion well before the large airplanes that are the primary target, but for

which the feasibility of all-electric propulsion will be very hard to prove.

Another important aspect, for any type of flight, is to protect our aircraft, and not necessarily by direct military action. Depending on the threats involved (such as terrorism), transportation safety must be able to count on self-protection devices developed for military applications.

This multitude of technologies demands a multidisciplinary, multicriteria approach. The necessary new tradeoffs, combined with the asymptotic effects seen today on some of these configurations, mean that all the reappearing coupled phenomena have to be integrated and modeled. Only by thoroughly understanding them can we draw the utmost from these concepts.

## 2.2 4D contract and automation: powerful algorithms and resources to enhance system reliability

**W**e still have a long way to go in developing green flight paths and the 4D contract. This is especially true in a world that is increasingly sensitive to the environment, where air traffic saturation is becoming a real problem and where energy is expensive. Under these conditions, there is a clear necessity for aircraft to follow optimized flight paths, since they generate significant energy savings and limit pollution, as well as maintaining safety at an acceptable level – except of course if commercial air transport collapses. More precise flight paths would also enable reducing separation distances between aircraft, to increase traffic flows. This is perfectly feasible with the technology at our disposal today. Simulation systems enabling us to evaluate flight path plans (4D contracts) are already within our grasp. However we still need a major effort to validate these calculations, so that the results convince

airlines and other operators that it is worth it. They would have to adapt to these procedures, in terms of fleet management and flight schedules. Several obstacles remain, including the classic one in this sector of having to produce equipment to handle the new procedures. Furthermore, we would have to prove the robustness of the system itself (tolerance of software, hardware or system failures), and show that it meets specific performance objectives, especially the Key Performance Areas defined by Eurocontrol: safety, punctuality & predictability, capacity & delays, flight efficiency, cost-effectiveness and environmental impact. From the technical standpoint, the most challenging research needed is the development of certifiable algorithms capable of carrying out high-speed calculations for 4D contracts.

From the standpoint of the aircraft itself, meeting constraints of this type will depend on the refined integration of aircraft performance, weather conditions and surrounding traffic. Because of its size and the number of parameters involved, this data is especially complex. We will have to automate calculations for a flight plan, adjusted to conditions at a given moment, and optimized according to the general or possibly specific criteria of each operator. Each aircraft will have to be capable of re-evaluating its flight path “on the fly”, to deal with unexpected (and unforeseeable at the scales in question) changes in weather conditions and the flight paths of other aircraft. A human pilot would have great difficulty in reacting quickly and accurately enough to evaluate conditions and track the flight path at any given moment. Aircraft must therefore be automated, transferring to this system some of the tasks previously handled by people. That means actually flying the aircraft, of course, but also communications with the traffic management system, navigation and handling unplanned events. One resulting advantage is an increase in safety because of the elimination of accidents due to pilot error. Likewise, traffic will be far more predictable, and organizational changes could generate savings.

It will also be simpler to design aircraft that don't have cockpits. On the aircraft itself, automation will depend on the use of a Flight Management

System, or FMS, capable of taking charge of the entire mission: from push back to parking on arrival, along with taxiing, takeoff, climb, cruise, descent and landing. Furthermore, various digital communications links will have to be installed to connect the traffic management system (the ground segment in particular, also automated) and the aircraft. In relation to the situation today, the implementation of these two elements will require certain major advances, particularly the development and validation of software controlling all aspects of a flight. This software will have to be capable of automatically managing emergency situations, communicating with the traffic management system, and even interacting with surrounding aircraft. An additional imperative is the validation of this software, which will obviously have to offer superior reliability.

Data links are the other essential pillar of automation. They will have to offer very high performance, not only between the various aircraft sharing a given part of the airspace, but also between aircraft and ground segment. In addition, we have to provide initial and in-service staff training, since people are still part of the equation. The presence of a technical flight crew on the aircraft will probably still be necessary, in particular to check system integrity, carry out certain non-critical repairs, etc.

In addition to these technical efforts, the application of automation also depends on resolving certain technical and societal issues. Among the former are the transition between the current system and an automated system, a critical period during which not all aircraft will be equipped to the ultimate standard. This is undoubtedly the most crucial aspect of the changeover.

We will also have to cope with a considerable cultural upheaval: passengers will have to accept traveling on a plane without a human pilot aboard. But will this still be an obstacle once the system has demonstrated its reliability? We will have to deploy the resources needed to achieve this, including proving the system's capability under all possible situations. And we will also have to determine all related legal responsibilities.

## 2.3 Airport infrastructures: optimized logistics, taking into account transition phases

Our airports must also be emissions-neutral, especially for CO<sub>2</sub>. Achieving this goal assumes that sustainable development principles will be integrated right from the design stage, in terms of cost, energy, pollution and of course recycling. A significant part of the challenge overlaps the situation in urban and industrial architecture, especially construction without using “dirty” techniques or materials. But this approach also encompasses the idea of airports within a multimodal transport network including roads and railways.

At the same time, we have to resolve the problem of operating and supplying these huge infrastructures, including heating, ventilation and air-conditioning (insulation), electricity, air, water and goods. It is possible to consider local energy production for the entire platform, taking advantage of the vast surface area available, and its location away from city centers. Electricity could be produced by wind or geothermal power, or transmitted from distant power stations. The distribution of passenger gates according to airlines and destinations must also be optimized at large airports. Unlike the situation today, airplanes should no longer have to taxi for a dozen kilometers to get to the runway. We could also design more user-friendly solutions for the aircraft, such as boarding via integral passenger modules, or, in particular with the BWB type plane, a more efficient distribution of payload between passengers and freight.

All of this will require modifying the terminals as well. Automated tractors could be used to bring the aircraft up to the runway threshold, to reduce the time that engines operate at idle, which generates a large amount of pollution, as well as increasing the amount of fuel planes have to carry. For the same reason, we should study takeoff assistance systems, such as catapults or downhill takeoffs. The

ultimate aim is to decrease dead weight and augment the payload (and/or lighten the airplane), as well as making more rational use of energy. Current research on alternatives to fossil fuels show significant restrictions on having fuels in a form that can be carried on airplanes. Storage, as well as thermal, mechanical and electrical processing, is much simpler on the ground, where the size and weight of the equipment needed is far less of a problem.

None of these possibilities represents a technological revolution: the required research will concern the design of the overall system, and enhancing its logistic efficiency. The use of advanced simulation methods will be decisive. The investments needed to start production and deployment are in fact way too high to be undertaken without a convincing demonstration of the actual advantages to be gained.

Another obstacle is fleet standardization. For example, any taxiing or takeoff assistance system would require a modification to aircraft (as well as to procedures and pilot training). Outfitting an entire fleet in one fell swoop would not be realistic. So we have to support the concurrent operation of the new and old models, allowing time to gradually replace the latter.

There is also the question of which system will emerge triumphant: point-to-point or hub & spoke? In Europe, the future seems to point to a mixed system, relatively close to the latter option. Because of the medium distances between major cities, trains are often faster door-to-door, and cost less. Another factor is that airports cannot be located closer to cities because of the disturbances they generate (environment, safety). The issue of energy – and therefore the cost of the trip for the user – also argues in favor of multimodal transport. Research into the optimum solutions will primarily call on models and simulations of “systems of systems” in this area. The optimum organization in fact depends very little on the actual technologies of the transport modes in question. Over and above the usual economic constraints, managed by the players involved (local communities for airports, operators for fleets and routes), the new global constraints (energy, environment) may require



a more conceptual approach on the continental level, rather than the relatively self-organizing approach used until now.

## 2.4 Design and testing tools: a multidisciplinary, multicriteria approach

**D**esign tools offer immense scope for development, because of ongoing improvements in technologies, which are increasingly sophisticated and interrelated, meaning they have to be considered from a “holistic” perspective. In addition, we have to integrate more and more operational, regulatory and societal constraints, in configurations whose components interact more strongly than ever.

No matter which scientific discipline is involved, aerodynamics, structural mechanics, aero-acoustics, etc., the expected gains are now subordinated to the integration of complex phenomena, demanding extremely refined modeling and powerful computation. Modeling presumes an understanding of the phenomena involved, which in turn demands extensive basic research efforts, combining theory and experimentation. Being able to integrate these phenomena in digital modeling approaches – critical if they are to be widely used in the analysis of complex systems – assumes the development of powerful distributed and parallel processing system.

But we also have to develop analysis and investigation methods to help experts understand the quintessence of these new models. In addition to this targeted vision of design, there is also the notion of interaction between disciplines because optimum solutions depend on phenomena which are increasingly coupled and hard to observe. This implies systematically embracing all the disciplines involved, at a suitably high level of complexity to fully represent the richness of actual situations, to develop the models which alone are capable of meeting the required performance objectives.

However, in our current organizations, the competencies and modeling processes available in each discipline or subsystem are controlled by individual departments which have trouble collaborating closely with the others. This is simply because the cultures are very different, and people in each discipline are unfamiliar with the constraints and complexity faced by their counterparts. We have to break with this way of doing things, and offer methods and tools that enable us to successfully apply this multidisciplinary design and optimization approach.

There is still vast room for progress. From the theoretical standpoint, for instance, we must define strategies for robust and reliable design, in order to manage the uncertainties of models and their input data. Another objective is the ability to calculate stable optimized solutions as a whole, largely unaffected by the natural range of conditions of use, whether operational or environmental. These processes will continue to demand heavy computing power, as well as storage and post-processing analysis to support decision-making. They will call even more widely on distributed processing for significant data throughput, as well as virtual reality applications, the development of which thus becomes a priority.

We will only be able to use a number of technological building blocks once we have proven their validity. Whether they concern new aircraft, a re-organized air traffic control system or new flight procedures, these blocks will have to be validated within the overall air transport system. Unfortunately, given the complexity of this system and its governing regulations, it is generally impossible to carry out a full-scale exercise of this type under real conditions, except for technologies that can be tested in flight (development of an open rotor, avionics, etc.). Simulation is therefore the only means of measuring the benefits of these new concepts. But the only off-the-shelf test tools of this type are generally each dedicated to a single performance criterion, such as noise around an airport, overall noise footprint of a continent, local and global chemical emissions, the cost of air traffic, etc. They are based on measured data, statistics, or semi-empirical laws, which means they call on our historical knowledge of aeronautics. This is in fact a legacy

of the way this sector has always developed over time, in small steps, or case by case, largely based on reactions to specific accidents.

However, the current trend is to consolidate the existing evaluation tools, grouping them within a single infrastructure. This is the case, for instance, of the Clean Sky Technology Evaluator, the French project IESTA (“air transport system evaluation infrastructure”) or the European project SPADE (Supporting Platform for Airport Decision-making and Efficiency analysis). These are simulation tools operating in time-accelerated or time-constrained mode. On the other hand, when we study the real operation of the system, especially to know how it is impacted by human factors, we use real-time simulators that call on people whose role is to reproduce the behavior of the actual system actors (controllers, pilots). Today, there is a dichotomy between these two types of simulation, which are complementary, although generally not linked. If the air transport sector evolves towards a more automated, and therefore more deterministic system, we could focus on simpler behavioral models, while still remaining representative, which would give us a broader and more flexible scope for modeling. Furthermore, networked gaming applications offer simulations of virtual societies that model a large number of agents with personalized behaviors based on artificial intelligence. Eventually we could use universal simulations of a complete, complex system, as for air traffic seen as a whole.

With the advent of revolutionary technologies, evaluation tools must be capable of integrating innovations which are still largely unknown. We must therefore totally revamp the way in which we design these devices, using models that are primarily based on laws of physics, rather than capitalizing on historical data and statistics. This presumes not only that we are capable of modeling all these innovations, but that we can do so at several levels of complexity, depending where we are situated in the process.

In general, we can consider three levels: the airplane itself, traffic around the airport, and traffic on a continental or global basis. This was the approach chosen for the Technology Evaluator platform to

evaluate new green concepts and vehicles within the scope of the European program Clean Sky.

One of the critical areas where investment will prove decisive is safety. This is obviously the first performance criteria to be considered in aviation. Paradoxically, however, it is the criterion that we are least able to evaluate at the air transport system level. Today, we do this “after the fact”, based on incident and Airprox. reports. Some of this research is designed to provide a preliminary evaluation of safety based on traffic complexity indices. Unfortunately, we do not yet have a method capable of integrating not only traffic characteristics but also all the other parameters that could impact safety, namely weather conditions and above all human factors – the most difficult.

As recent events have shown, air transport is highly vulnerable to malicious acts. This is true to such a degree that repeated acts of this nature could even lead to the disappearance of the sector. It is therefore essential that a massive effort be made to model the operation of the system, prioritize the possible failure modes and define an approach that would reduce them over the long term. Large-scale simulation systems will play a role in this area, to test various crisis situations, starting with terrorist attacks, or even predict behaviors and situations that we hadn’t considered.

## 2.5 Conclusion: technical priorities as we see them

**T**he number of areas in which research efforts are needed in the coming years is large indeed. All the underlying technological building blocks are important, but there are five in particular where an effort is fundamental, quite simply because their current state of development is still rather weak. These five areas are: the electric aircraft, innovative aircraft configurations, towards carbon-neutral propulsion, towards carbon-neutral and emission friendly airports, and the complete automation of air traffic.

# Institutional aspects: Present and future research opportunities

Chapter three has the objective to investigate mechanisms that are needed in order to implement appropriate long term aeronautical research activities. To that aim present boundary conditions, the institutional frame and research funding mechanisms for the preparation of the future generation ATS and the possible role of EREA and the Research Establishments in that context are investigated.





## 3.1 Present boundary conditions

The European Air Transport System (ATS) is intended as a complex architecture which includes four macro-areas: manufacture (airframe, engine, and equipment), airports, airlines, and Air Traffic Management (ATM). Beside aeronautical companies (users, developers and suppliers of advanced innovative technologies), the other main stakeholders are: policy-makers (European Commission, governments of Member States, European Institutions), airlines, airports, research institutions and universities, regulators and other institutions. The preparation of future generation ATS is necessarily correlated to the boundary conditions set by the European Union's policy guiding strategic documents published in the last decade which define the areas of intervention and the main mechanisms for the economic growth and environmentally sustainable future of all the member countries. Air Transport and Aeronautics, identified as key assets due to their significant contribution to European wealth, evolve in the general European frame interacting with the national and regional level. Initiatives across national European borders include GARTEUR, Air Transport Net and EREA.

**GARTEUR**<sup>2</sup>, the Group for Aeronautical Research and Technology in Europe (a government-to-government agreement between France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom) was set up in 1973 to strengthen R&T co-operation in aeronautics, covering both the civil and the military applications. Since its creation GARTEUR has conducted numerous collaborative projects for defence, dual use and civil applications, interfacing with EU, EREA, ASD and EDA.

**Air Transport Net** (ERA-NET AirTN)<sup>3</sup> is a project funded through the ERA-NET scheme of the 6<sup>th</sup> Framework Programme to be continuing under FP7. It covers aeronautical research and air traffic management issues and thus the whole ATS. AirTN consortium consists of 27 partners (ministries and agencies managing either civil aeronautics or technology innovation programmes) from 18 countries along with the asso-

ciated partner Eurocontrol. The partners fund aeronautical research projects. Programmes with a thematic focus are defined vertical; while those across boundaries are defined horizontal programmes. The funding schemes are divided into three categories: a) specific aeronautics programmes, b) programmes including topic aeronautics, and c) programme like activities. Partner countries with a specific Aeronautics Programme are: Austria, France, Germany, Spain, Sweden, and the Netherlands. Partner countries with horizontal programmes which include topics relevant to aeronautics are: Greece, Italy, Ireland, Poland, Portugal, Romania, and UK. Partner countries which do not have a programme, but support activities relevant to aeronautics are: Belgium, Czech Republic, Slovakia, and Switzerland.<sup>4</sup>

In the field of aeronautical research, **EREA**, the Association of European Research Establishments in Aeronautics is a non-profit association created in 1994 with the objectives of: intensifying the co-operation between its members, increasing integration activities in the field of civil, military and space-related aeronautics; improving co-operation with third parties in the field of aeronautics; and facilitating an integrated management of joint activities, thereby contributing to Europe's role as a global player in aeronautics. Presently EREA full members are: CIRA (Italy), DLR (Germany), ILOT (Poland), FOI (Sweden), INTA (Spain), NLR (The Netherlands), ONERA (France), INCAS (Romania), VZLU (Czech Republic) in addition to four associate members.

The general frame of the strategic high-level objectives has been set out in the **Lisbon Agenda** by the European Council in 2000 with the aim of making the EU "the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010", and refocused in 2005 on actions that promote growth and jobs in a manner that is fully consistent with the objective of sustainable development. According to the Lisbon Review published by the World Economic Forum on a biannual basis to measure Europe's progress towards meeting its own criteria, EU-27 competitiveness average score is 4.73 versus the United States 5.44 and East Asia 5.26.<sup>5</sup>

<sup>2</sup><http://www.garteur.eu>

<sup>3</sup><http://www.airtn.eu>

<sup>4</sup>AirTN (2009) ERA-NET AirTN Aeronautics research Funding in the Partner Countries. Vienna. 67p.

<sup>5</sup>World Economic Forum (2008) The Lisbon Review 2008. Measuring Europe's Progress in Reform.

<sup>6</sup>European Commission (2005) European Charter for Researchers. The Code of Conduct for the Recruitment of Researchers. Directorate-General for Research. Human resources and mobility. Luxembourg.

<sup>6</sup>European Commission (2005)  
European Charter for Research-  
ers. The Code of Conduct for  
the Recruitment of Researchers.  
Directorate-General for Research.  
Human resources and mobility.  
Luxembourg.

<sup>7</sup>European Commission (2001)  
European Aeronautics: A Vision  
for 2020. Meeting society's needs  
and innving global leadership. Re-  
port of the Group of Personalities.  
Office for Official Publications  
of the European Communities.  
Luxembourg.

<sup>8</sup>ACARE (2002) Strategic Research  
Agenda 1. Volume 1 and Volume 2.

<sup>9</sup>ACARE (2004) Strategic Research  
Agenda 2. Volume 1 and Volume 2.

In order to prevent potential shortage of researchers as a threat to the Europe's innovative strength, knowledge capacity and productivity growth in the near future, the **European Charter for Researchers and Code of Conduct for the Recruitment of Researchers**<sup>6</sup> are key documents in the EU's innovation and economic policy to make the best of its scientific potential, contributing to the development of an attractive, open and sustainable labor market for researchers. The Charter and Code of Conduct aim at giving individual researchers the same rights and obligations wherever they work throughout Europe contributing to overcome the fragmentation of research careers at a local, regional, national or sectoral level and to valorize scientific potential.

The **Bologna Process** is the process of creating the European Higher Education Area (EHEA) and is based on cooperation between ministries, higher education institutions, students and staff from 46 countries, with the participation of international organisations.

Present and future ATS is central in this socio-economic and environmental challenge. It contributes directly to economic prosperity in pioneering the 'knowledge society' (advanced innovative technologies). As for the future of ATS, the Advisory Council for Aeronautics research in Europe (ACARE) organized a pan-European working team which started with the definition of top level objectives reported in the **Vision for 2020**<sup>7</sup>. The role of ACARE is to define and prepare the implementation of the 'Strategic Research Agenda' (SRA), acting as an advisory body to the EC and for the aeronautical stakeholders for the definition of research needs. The Vision outlined in 2001 the upcoming market requirements in order to strengthen competitiveness of European ATS in an increasingly integrated economy: safety, quality and affordability, environment-friendly through more effective and efficient research.

Subsequently, ACARE European **Strategic Research Agenda 1**<sup>8</sup> (SRA1) and **Strategic Research Agenda 2**<sup>9</sup> (SRA2), the strategic documents looking beyond 2020 for RTD activities in aeronautics and ATS (and also regarded as the official reference documents

in the formulation of national proposed guidelines and of institutional bodies for establishing their policy) define the 'challenges. SRAs pursue two crucial macro-objectives: fulfill the needs of society and of aircraft users and bestow global leadership in the aeronautical sector in Europe.

The SRA 1 (2002) is the basis of all aeronautical research programmes in Europe (National Programmes, Stakeholders Programmes, EC Framework Programme). It is built around 5 challenges for technology development: Quality and affordability, Environment, Safety, Efficiency of the Air Transport System, Security.

The SRA 2 (2004) addresses six high level target concepts (HLTCs) of European aeronautical research driven by the defined five interacting challenges: 1) a highly customer oriented air transport system, 2) a highly efficient air transport system, 3) a highly cost efficient air transport system, 4) an ultra green air transportation system, 5) an ultra secure air transport system; 6) 22<sup>nd</sup> century; and six key-technologies for further improvements: propulsion, lifting force, guidance and control, passengers' comfort, life cycle and the general air transport system.

Coherently with the 'Cooperation' programme-Transport of EC FP7, the objectives defined are: the development of 'greener' and 'smarter' pan-European transport systems and securing the leading role of European industries in the global market. Therefore, the specific activities defined in order to achieve the objectives in Aeronautics and Air Transport aim at: the development of more environmentally friendly air transport, increasing time efficiency, ensuring customer satisfaction and safety, improving cost efficiency, the protection of the aircraft and passengers, and pioneering the air transport of the future.

Strategic Research Agendas 1 and 2 provide the challenges, the top-level objectives, and some of the enabling factors that will be needed to ensure a successful outcome in Aeronautics and ATS. The strategic directions set out in the SRA necessarily look beyond 2020 since it will only be in later years that the results of some of the ongoing re-

search will have their impact. In addition the SRA addresses additional enabling mechanisms to be implemented in five areas: the European Research infrastructure, the Supply chain, Certification and qualification, Education and Trans-European synergy of research. The SRA also points the way toward actions in other fields where equally important changes will be needed; in public policy, in regulation, and in areas of international co-operation.

Beside the statements on the importance of evolutionary and incremental developments in air transport, ACARE has expressed the awareness of the need for radical and revolutionary innovation for the future ATS. Research institutions should be stimulated to play a major role in the development of ground-breaking technologies along with the mainstream of evolutionary research.<sup>10</sup>

In a rapidly evolving context, in the ACARE **2008 Addendum to the Strategic Research Agenda**<sup>11</sup>, besides readjustments concerning technical issues, institutional issues are tackled with focus on: the necessity of new business models enabled by the available technologies, international collaboration in the commercial, 'context and commodity' and strategic areas, a further rationalization of research infrastructures, and the harmonization of the education and training system.

**The Green Paper**<sup>12</sup> assesses the progress made by the European Research Area (ERA) and stimulates the discussion on future orientations of raising questions on a single labour market for researchers, the development of world-class infrastructures, strengthening research institutions as a source of fundamental research as well as a provider of applied research (important to underpin business research and innovation), knowledge sharing, coordination of research programmes and international cooperation. Therefore key factors affecting the performance of research systems in Europe pertain:

> Researchers mobility: with the aim of ensuring that Europe makes the most of globalization in science and technology, researchers are to be stimulated by a single labour market offering equal opportunities and by the absence of financial/administrative obstacles to trans-national mobility.

- > Infrastructure: integrated and networked research infrastructures are to be built and better exploited in the form of joint European ventures.
- > Intellectual Property charter: REs are to be more competing and cooperative interacting routinely in the world of business and being engaged in durable public-private partnerships and clusters. A simple and harmonized regime for Intellectual Property Rights (IPRs) which includes cost-efficient patenting system and shared principles for knowledge sharing and cooperation between public research and industry.
- > Joint programming: well-coordinated research programmes and definition of common priorities through joint-foresight.
- > International cooperation: S&T cooperation with neighboring countries, developing countries and industrialized and emerging economies to jointly address global issues, particularly in multilateral frameworks (e.g. UN Framework on Climate Change).

This new approach oriented to a more efficient use of European R&D funds aims at making joint programming operational. **Joint Programming** in research (public-public partnerships) has therefore been identified as a necessary framework condition for the upcoming public programmes<sup>13</sup>. The basic measures to be adopted to facilitate joint programming in research aim at the definition of common principles and procedures, common methodologies, common principles for cross-border funding of research and effective measures for the protection of Intellectual property rights (IPR) and to facilitate the dissemination and optimal use of research outputs.

**European Technology Platforms (ETPs)** provide a framework for stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues where achieving Europe's future growth, competitiveness and sustainability objectives is dependent upon major research and technological advances in the medium to long term. ETPs play a key role in ensuring an adequate focus of research funding on areas with a high degree of industrial relevance, by covering the whole economic value chain and by mobilising public authorities at national and regional levels. In fostering effective

<sup>10</sup>European Commission, ACARE (2007) *Out of the box. Ideas about the future of Air Transport. Part 2.*

<sup>11</sup>ACARE (2008) *2008 Addendum to the Strategic Research Agenda.*

<sup>12</sup>European Commission (2007) *The European Research Area: New Perspectives. Green Paper. 04.04.2007. Luxembourg.*

<sup>13</sup>Commission of the European Communities (2008) *Communication from the Commission to the European parliament, the Council, the European economic and Social Committee and the Committee of the Regions. Towards Joint Programming in Research: Working together to tackle common challenges more effectively. Brussels. 12p.*

public-private partnerships, technology platforms have the potential to contribute significantly to the renewed Lisbon strategy and to the development of a European Research Area (ERA) of knowledge for growth. As such, they are proving to be powerful actors in the development of European research policy, in particular in orienting the FP7 to better meet the needs of industry. Address technological challenges that can potentially contribute to a number of key policy objectives which are essential for Europe's future competitiveness, including the timely development and deployment of new technologies, technology development with a view to sustainable development, new technology-based public goods and services, technological breakthroughs necessary to remain at the leading edge in high technology sectors and the restructuring of traditional industrial sectors. The EU's new 'technology platforms' have been major contributors to defining the Union's future transport research strategies.

The Lisbon Strategy goals to keep technological advance of Europe are translated into two concrete measures: the Framework Programmes for Research and Technological Development (FPs RTD) and the joint multi-national initiatives.

**The Framework Programme for Research and Technological Development** is the funding programme created by the European Union to support and encourage research in the European Research Area (ERA). Trans-national cooperation within the FP7 is implemented through:

- > Collaborative research
- > Coordination of national research programmes (in particular through the ERA-NET scheme)
- > Joint Technology Initiatives
- > Technology Platforms

The total indicative budget for FP7 2007-2013 is Euro 50.5 billion. Co-financing is the basic principle of funding in FP7. The Commission gives grants to RTD projects contributing with a 50% percentage to the overall eligible costs. Therefore, the maximum reimbursement rates can vary depending on the funding scheme, the legal status of the participants and the type of activity. Non-profit public bodies, Small and Medium Enterprises (SMEs), research organisations and higher educa-

tion establishments can receive up to 75%. For demonstration activities, the reimbursement rate may reach 50%, while for other activities (consortium management, networking, training, coordination, dissemination), the reimbursement can be up to 100% of the eligible costs. The 100% rate applies also to frontier research actions under the European Research Council.

Funding schemes, the types of projects by which FP7 is implemented are:

- > *Collaborative projects*: focused research projects with scientific-technological objectives and specific expected results (e.g. knowledge or technology development) carried out by consortia made up of industrial and academic participants throughout different countries;
- > *Networks of Excellence*: designed for research institutions willing to combine and functionally integrate a substantial part of their activities and capacities, in order to create a European „virtual research centre“ in a given field through a „Joint Programme of Activities“ based on the integrated and complementary use of resources (human and infrastructural).
- > *Coordination and support actions*: actions covering the coordination and networking of projects, programmes and policies (e.g. activities for dissemination and use of knowledge, actions to stimulate the participation of SMEs, „frontier research“);
- > *Individual projects*: Projects carried out by individual national or multinational research teams, lead by a „principal investigator“, funded by the European Research Council (ERC);
- > *Support for training and career development of researchers*: actions named after Marie Curie
- > *Research for the benefit of specific groups* – in particular SMEs.

The budget for 'Transport (including Aeronautics)' is Euro 4.16 billion over 7 years. As far as transport is concerned, the European Commission under the FP7 is funding RTD specific activities in the aeronautical and air transport sectors for a 'greener' and 'smarter' pan-European transport system, such as: reduction of emissions; research and development for engines and alternative fuels; air traffic management; air transport safety and reliability; eco-sustainable aviation.



Furthermore, as part of the FP7, in 2007 the Commission adopted a special instrument called the **“Joint Technology Initiative”** (JTI) set up for the cooperation between the public and private sectors at a European level, for the funding of specific research programs in a limited number of ETPs including the transport sector. A JTI is a long-term public-private partnership (PPP) using the ‘Joint Undertaking’ model. The European Commission has identified JTIs as a new strategy of implementing the Seventh Framework Programme (FP7) according to the goals of the Lisbon Strategy to support, in a limited number of cases, large scale initiatives that could not be implemented efficiently, using the other R&D funding mechanisms. A JTI focuses on one specific industrial area, has a well defined objective, addresses a market failure and is funded by a combination of private and public investments. In the light of the stage of development of the Strategic Research Agendas of European Technology Platforms at the time of the FP7 proposals, six areas were identified where a JTI could have particular relevance: hydrogen and fuel cells, aeronautics and air transport, innovative medicines, nanoelectronics (ENIAC), embedded systems (ARTEMIS) and global monitoring for environment and security. Each JTI organises open calls for proposals. The principles of openness, transparency, competition and excellence should be reflected in the governance structures and the project selection procedures. JTIs facilitate the creation of critical mass in the areas concerned by developing a coordinated approach to research across Europe. In doing so, they strengthen the competitive position of European industry, consequently making Europe a more attractive location for inward investment in research.

In particular, two ‘joint’ initiatives have been defined in the air transport sector: SESAR and Clean Sky. The ‘SESAR’ Programme aims at the realization of the Single European Sky over Europe, through the introduction of technologies and procedures which are highly innovative compared to the current air traffic management system. ‘Clean Sky’, on the other hand, is an answer to the necessity of accelerating the development in Europe, of advanced technologies aimed at reducing the emissions produced by aircraft, as well as speeding up their introduction into the market.

**Single European Sky ATM Research (SESAR)**<sup>14</sup> was launched by the European Commission to organise airspace and air navigation following the logic of the single European market created in 1985 and of the economic and monetary union in 1990. SESAR follows a legislative approach, entered in force in 2004, to solve issues affecting air transport and Air Traffic Management (ATM), particularly related to the forecast of the congestion of airspace and the increase of air traffic. The objectives of SESAR re-engineering of European ATM network is the achievement of environment sustainability, efficiency, full integration and cost-efficiency through the production of technology, standards and procedures. European Commission (through TEN-T) and Eurocontrol have co-financed a contract which has lead to a Consortium - composed of 30 members associated to over 20 subcontractors and project associates - including the representatives of all relevant sectors of the aviation industry. The SESAR Joint Undertaking was created in 2007 to federate R&D efforts in the Community. The three main phases and relative costs are defined in the ATM Masterplan : definition phase (2005-2008) with 60 million euros funded in equal percentage by the Commission and Eurocontrol; development phase (2008-2016) with 2.1 billion euros funded in equal parts by the Commission, Eurocontrol and Industries; deployment phase (2014-2020) with Euro 20 billion paid by the Industry 100%.

**Clean Sky**<sup>16</sup> will develop breakthrough technologies necessary to make major steps towards the environmental goals sets by ACARE to be reached in 2020: the reduction of the impact of the air transport on the environment. Clean Sky will contribute to meeting two of the ACARE HLTCs: Ultra Green Air Transport System, i.e. reducing the impact of air transport on the environment and Highly cost efficient Air Transport System. The Clean Sky JTI is made up of 6 Integrated Technology Demonstrators (Smart Fixed Wing Aircraft, Green Regional Aircraft, Green Rotorcraft, Sustainable and Green Engines, Systems for Green Operations and Eco-Design). In order to assess the main benefits of technologies demonstrated, a Technology Evaluator is also included in this Initiative. The Members of Clean Sky represent 86 organisations in 16 countries, among which: 54 industries, (including 20 SMEs), 15 Re-

<sup>14</sup><http://www.sesarju.eu>

<sup>15</sup>SESAR Joint Undertaking (2009) European Air Traffic Management Master Plan.

<sup>16</sup>[www.cleansky.it](http://www.cleansky.it)

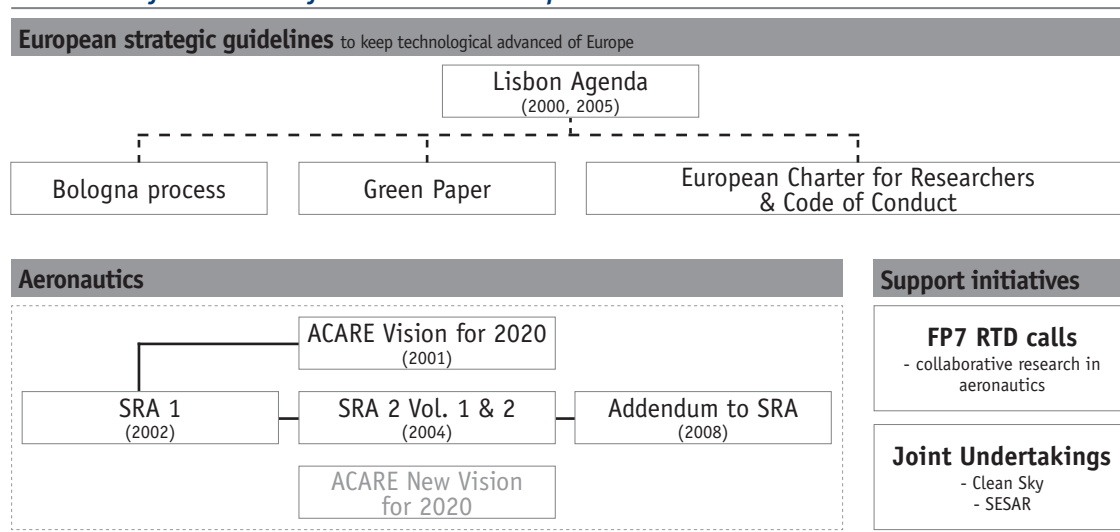
search Centres, 17 Universities. Clean Sky runs for 7 years as part of the FP7. A significant part of the Clean Sky programme will be performed by Partners selected through Calls for Proposals and Subcontractors selected through Calls for Tender.

The calls published within the four main blocks of FP7 RTD (Cooperation, Capacities, Ideas and People) along with the multi-national Joint Undertakings facilitate and support researchers' mobility and international cooperation, in coherence with the Lisbon Strategy.

## *Aeronautics and Air Transport work programme.* Source: EC (2007).

	The greening of air transport	Increasing time efficiency	Ensuring customer satisfaction & safety	Improving cost efficiency	Protection of aircraft passengers	Pioneering the Air Transport of the Future
Level 1						
Level 2						
Level 3		Clean Sky JTI				
		SESAR JU				
Structuring Aeronautics Research						
Supporting Programme Implementation						

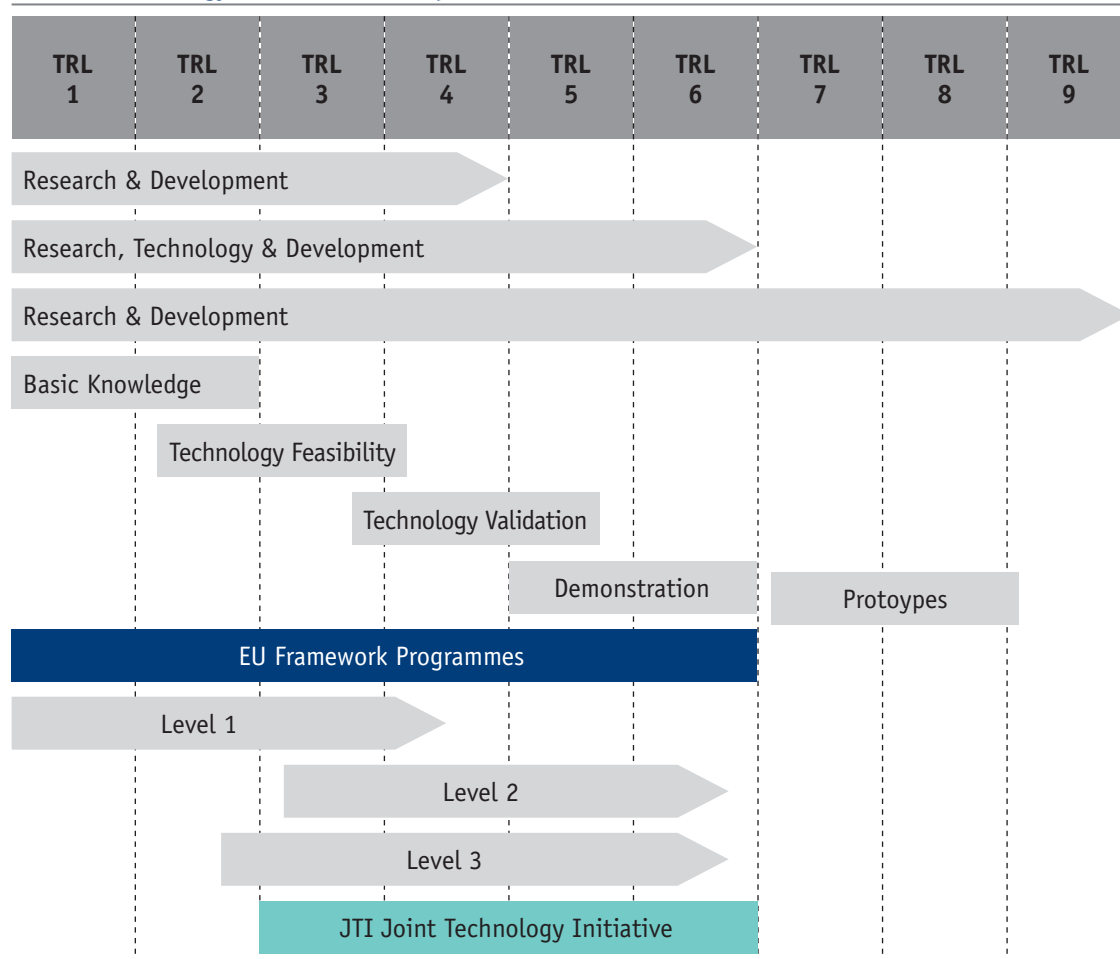
## *Institutional frame relevant for Aeronautics in Europe.* Source: our elaboration.



The aim and scope of the Aeronautics and Air Transport work programme concerns: technologies, services and operations of all components of the air transport system from airport kerbside to airport kerbside (i.e aircraft, airport, and air traffic management). Level 1 includes upstream R&T activities from basic research to validation at component or subsystem level through analytical and/or experimentation. Level 2 refers to downstream research and technology development activities up

to higher technology readiness levels (TRLs) focusing on multidisciplinary integration and validation of technologies and operations at a system level in the appropriate environment (large scale flights, ground test beds/simulators). Level 3 comprises RTD activities up to the highest TRLs, focusing on the combination of systems and the final proof of the comprised technologies in fully integrated system of systems in the appropriate operational environment (JTI, JU).

**Research, Technology and Product Development.** *Source: our elaboration.*



## 3.2 Preparation of the next generation ATS

Despite the recent economic downturn, air traffic in the emerging economic nations are expected to continue growing over the next 20 years, as also outlined in Airbus Global Market Forecast<sup>17</sup>. The Airbus forecast continues to predict that traffic demand will nearly triple and airlines will more than double their fleets of passenger aircraft. Passenger traffic is expected to grow by 4.7%, per annum while freight traffic is expected to grow at by 5.2% per annum. This means that over the 2009-2028 period, the number of frequencies on passenger routes will more than double while the world fleet will grow from 15,750 to nearly 32,000. Airbus statistics predict that the largest demand for passenger aircraft will come from the United States, the People's Republic of China and the United Kingdom which will be satisfied by a mix of global, low-cost and charter airlines.

The present difficult economic environment accentuates the importance of not losing sight of long-term competitiveness fundamentals amid short-term urgencies. The volatility euro-dollar and the increase of the price of oil have influenced the dynamics of air transport as seen in the rise of low-cost flights.

It is widely agreed upon that **new concepts and breakthrough technologies** will be needed to bring a new age of air flight. Both upstream research to further improve the technology base and develop innovative concepts and breakthrough technologies, and downstream research to achieve ambitious objectives integrating a critical mass of technical fields are to be supported. This means that sufficient funding for the entire innovation chain from breakthrough technologies (the most promising technology options selected using technical and economic success criteria for further research and development) to A/C demonstrator for revolutionary technologies to show that these breakthroughs are feasible.

The preparation of the next generation ATS the associated breakthrough technologies need to be seriously investigated in order to enable Research Establishments (REs) to plan their future technologies

development in an harmonized approach leading to common European demonstration programmes. Due the success of the JTI model (public-private partnership), in terms of integration of funds, mutuality requisites, optimization of resources, integration of national programmes, a JRI, Joint Research Initiative (public-public partnership) could be developed with the aim of facilitating the harmonization of RTD activities in the field of aeronautics in Europe, in line with recommendations underpinned in EC strategic documents and Aeronautical-specific requirements.

The civil aeronautical sector includes commercial, regional and general aviation businesses. The commercial aviation business consists of firms practicing commercial transport (public flights on request or scheduled flights). The regional aviation business consists of firms focusing on smaller equipment and shorter stage length. The general aviation business includes business aviation (private transport for business), various forms of aerial work (air taxi, aerial photography, publicity, light cargo, aerial agriculture) and public activities (tourism). The great variety of uses of the airplane, along with a large number of potential users entail a vast range of technological solutions. **Aeronautical technologies are transformed to other types of transport:** rail, automotive, marine. Aeronautics is a pilot case useful also for other transport sectors in terms of application of inter-sector breakthrough technologies (e.g. in propulsion).

The aeronautical sector is considered a driver of innovation for national industry on account of its technological significance and its role of catalyst. An example of **aeronautical technologies providing benefit in other industries** is given by the advances in aerodynamics leading to applications in other transport sectors such as automotive and rail, as well as in relatively remote industrial sectors, such as meteorology and wind energy systems. There are many technology transfers and spill-overs from aeronautics to numerous other sectors beside the very important applications in the fields of safety (e.g. anti-terrorism), environment and energy (e.g. fuel and solar cells), such as: monitoring and surveillance, agriculture, healthcare (e.g. orthopedic, biomedical), optical, new materials and structures, ICT, laser technology, construction, mechatronics, robotics, space, leisure.

<sup>17</sup>Airbus (2009) *Flying smart, thinking big. Global Market Forecast.*



### Examples of aeronautical technology providing benefit in other industries<sup>18</sup>

Aeronautical Technologies	Spin-offs for other industries
<b>Aerodynamics</b>	Automotive, Transportation systems (Trains) Meteorology, Ventilation systems Stability of structures (aerodynamic effects) Wind energy systems, Hydraulic systems
<b>Structures</b>	Structural design of buildings and bridges Shipbuilding Automotive and other vehicles
<b>Materials</b>	Power generation turbines, gear-boxes Free-time and Sport Equipment Chemical and Marine Industries Building and Agriculture
<b>Systems, Electronics</b>	Industrial control systems and motor industry Marine systems (Radar, Navigation, etc.) Simulators for trains, cars, ships, etc. General systems (servo-mechanism, batteries, clocks, etc.)
<b>Production Systems</b>	Shipbuilding and Motor industry Control methods for other industries (Metallurgical, Atomic energy, Automotive, Motor, etc.) General engineering, etc.

<sup>18</sup>Domenico Ferreri (2003) *Marketing and Management in the High-Technology Sector. Strategies and Tactics in the Commercial Airplane Industry*. London: Praeger.

<sup>19</sup>Keith Pavitt (1991), *What makes basic research economically useful?* in "Research Policy", 20, p. 109-119

<sup>20</sup>ASD (2007) *Facts & Figures 2007*. Brussels.

Economists stress the **contribution of science to technology as a source of economic benefits**, arguing that scientific fields are more strategically important to technology than data on direct transfers of knowledge lead us to believe, and that 'unplanned applications' are important to achieve short-term technological objectives contributing to about 10% of the relevant knowledge inputs. Pavitt identified four dimensions for a better understanding of the complexity of the impact of science on technology: a) the intensity of direct transfers of knowledge from science to application is different amongst sectors; b) the nature of the impact of basic research on technology varies in time; c) the impact is also through access to skills, methods and instruments; d) knowledge transfers involve personal contacts, movements, participation in national and international networks (person-embodied).<sup>19</sup>

**Economies benefit from the growth of air travel.** Air transport drives employment, economic growth and global exports. In monetary terms, aviation contributes in over 20 countries to world Gross Domestic Product (GDP) benefiting trade (exports), investment (the presence of airports encourage the establishment of businesses), productivity and

tourism. In occupational terms, air transport will directly employ 8.5 million people contributing to \$1 trillion to world GDP in the next two decades.

Europe is one of the world's leading exporters of aeronautics-related products and services. The EU aeronautics and aerospace sectors represent multi-billion Euro industries in the European economy and supporting millions of jobs for European citizens. The air transport system in Europe can call on a fleet of around 5,000 aircraft and moves one billion passengers every year. Aeronautics, therefore, is an important economical factor in Europe and in the member states, especially the new member states. Europe will receive 25% of the world growing demand for passenger aircraft in the next 20 years (North America and Asia-Pacific taking 23% and 31% respectively).

Aeronautics is a key contributor to the 5% increased turnover of the European Aerospace Industry in 2007, with a Euro 94.5 turnover and a turnover growth of 4.4 %. This Euro 4 billion increase in turnover had an associated 4.16% of operating margin and a slight decrease by 1.5% in the level of employment.<sup>20</sup> European aeronautical industry

reinforced its position in 2007 as a global actor with exports accounting for 56% of the industry's turnover. The share of contracts with European governments was 22% share of turnover, with the private sector accounting for over two-thirds of the turnover representing 77.6%. In the US, the aerospace industry has benefited from far higher levels of defence expenditure.

#### European Aeronautical Industry key figures (2007)

Turnover	€ 94.5 billion
By Governments	22.4 %
By other customers	77.6 %
Civil	57.9 %
Military	42.1 %
Turnover growth (compared to 2006)	4.4 %
Turnover/Employment	€ 214 million
Labour productivity per employee	212,000
Employment	442,100
R&D Expenditure	€ 11.7 billion (12% of turnover)
Exports	56 % of turnover

Source: ASD (2007)

With reference to Pavitt's (1984) classification of manufacturing industries, the aerospace sector is "science-based", that is to say that innovation is directly linked to new technological paradigms as the output of scientific advances; innovative activities are formalized in R&D laboratories where investments in R&D are quite high; many of the product innovations enter a broad range of sectors as capital or intermediate inputs. More specifically, aerospace applications along with various military related activities share other with science-based sectors the importance of inputs from scientific progress and of formalized research, and share with the production-intensive sectors the importance of economies of scale and of an efficient organization of complex production systems. Furthermore, air transport-derived technological advances stimulate and accelerate knowledge acquisition, innovation and European integration.

One striking exception to Europe's low performance in innovative sectors is represented by the aero-

space industry, export-oriented R&D-intensive industry boasting growth in labour productivity. While the gross domestic expenditure on R&D of EU-27 is 1,84% (2006), which is below Lisbon objective and definitely low compared to Japan (3,32%) and the United States (2,61%) , R&D is a key driver of the aeronautics industry representing 12% of total turnover (2007).

Air transport, fundamental element of the Union's Lisbon strategy, has proven itself as a major contributor to the European economy, supporting industry as well as the research, academic and political communities. In innovation terms, studies have proven that the results of research have already led in the last 40 years to the reduction of aircraft fuel burn and emissions by 70% and noise by 75%. Innovation remains a key-target to improve CO<sub>2</sub> emissions as requested by the Kyoto Protocol signed and ratified by 183 states in February 2009 for sustainable development.

In terms of societal return, **air transport provides, in a global society, means of mobility facilitating integration.** International technological collaborations characterize the industry worldwide allowing scale economies, scope economies, cost and risk-sharing, the reduction in duplication of investments, and the creation of 'technological windows' to learn by collaborating and to broaden relationships with the scientific community. Joint European initiatives like SESAR and like Clean Sky are key-components in transforming public research into innovation through cross-fertilization which links technology demand and offer. Joint programming initiatives focus on the relationship and cooperation between the research community (research centres and university) and industry in order to connect the results of research with end-users. The collaboration between these three key-players creates a network supporting industrial collaborations in order to obtain broader macro-economic effects such as: the development of scientific and technological research activities and the creation of a culture of innovation; knowledge creation and competence strengthening of the territorial socio-economic system; the promotion of research and innovation integrated networks; and human capital valorization.

The intensity of the competition is heightened by five structural factors: the high fixed costs pushing firms to maximize their production capacities; the height of exit barriers due to the high costs of re-conversion and the high degree of specialization (in facilities, production modes, professional techniques, commercial abilities); government support in the excess of production capability; the differences in the competitor's strategies, the managerial approach, country of origin, cultural and political values; the strong dependency of the aeronautical sector on macroeconomic variables. Although limited due to the advantage of aircraft in terms of speed, the threat of substitute products could be represented (in the future) by high-speed trains, by fractional ownership programs and by the increasing use of videoconferencing.

These fundamental political arguments require the encouragement of new concepts and mechanisms to support future innovative research, to be applied for a comprehensive change in European ATS as well as to any strategic research- and technology-intensive area. The origin of European RTD strategy is the Lisbon Agenda which stresses 'knowledge' as a mean and the improvement of competitiveness as a result. So the question is: what are the pre-requisites for success? Recalling the main institutional issues outlined in the 2008 Addendum to the SRA, the necessary new competitive strategies and mechanisms pertain three areas: business models, international collaboration and infrastructure and education to be implemented within evolved framework conditions.

### 3.3 Role of Research Establishment

Pre-requisite for success:  
government support for  
enabling mechanisms

**T**he political and economic macro-environment plays an important role in aeronautics versus other transport mode. The aircraft industry operates in a world market and the industrial structure and position in global competition is influenced by government industrial policy (tax incentives, R&D funding, financing through banks, other forms of political leverage), particularly by trade barriers and boundaries to protect nations' industrial interests (protectionist measures, political guiding of demand, assistance for sales to foreign countries). The technological factor is vital to defining the characteristics of the sector, determined as well by direct or indirect government involvement, beginning with research activities which are very often located in **research establishments** (public or private), government agencies, bodies for certification and control, and universities.

Changes in the future ATS are to be prepared at both the technical level and institutional frame. The SRA is focused on technology since the great changes that are needed for preparing future European ATS will be impossible without new technologies in new applications. Simultaneously, preparing for future European ATS requires a comprehensive approach involving manufacture, operation, regulation, **research** and policy-makers.

The institutional environment is ranked by the World Economic Forum as the first of the twelve pillars of competitiveness, intended as 'the set of institutions, policies, and factors that determine the level of productivity of a country'.<sup>21</sup> The identified institutional issues in European ATS, business models, international collaboration, infrastructure and education are based on a key success common

<sup>21</sup>World Economic Forum (2009)  
The Global Competitiveness Report  
2009-2010.

factor: government support. Government support, based on a precise industrial policy and a clear vision of the evolution of the sector, is important in areas such as R&D, industrial investments and policy definition.

The capability to integrate and create synergies among government institutions, RTD organizations (universities, research centers) and companies, defined triple-helix, is particularly evident in science-based sectors, in which the capability to create technological innovations is strongly dependent on the availability of scientific knowledge.

#### Government support to increase competitiveness



<sup>22</sup>Janez Potočnik, European Commissioner for Science and Research, in: European Commission (2005), *European Technology Platforms. Knowledge for growth*. EC Publications Office.

Government support for a more innovation-friendly European environment (science-based, technology-oriented and business-competitive), create an enterprise environment more receptive of research and technology in-puts. It is also essential in establishing international alliances facilitating international partnerships aimed at technological innovation and the development of new programs.

Macroeconomic settings (the surrounding environment of institutions, legal arrangements) set the rules and range of opportunities for innovation and competitiveness. **A supportive public policy hereinafter basically refers to the legal framework** (legislation, regulations, procedures and operations of the air transport industry) **and to funding**.

#### Institutional issues and relative enabling mechanisms

*A more competitive ATS of the future is to be knowledge-intensive, technology-based and business-competitive.*

High level objectives are to be pursued by the policy makers in order to launch an even more robust “Triple Helix” in Aeronautics and ATS in Europe. The institutional issues identified in the 2008 Addendum to SRA for the implementation of the European air transport policy are: Business Models, Research Infrastructures and International Cooperation. These institutional issues require additional and significant Pan-European enabling mechanisms within the European Research Area to provide a more receptive environment, ensuring equal competitive footing with other countries (particularly the US).

#### Business models

*“The results of research can be commercialized, enabling Europe to increase its innovative capacity to transform excellence in science into economic value.”*

(Janez Potočnik, European Commissioner for Science and Research)<sup>22</sup>

‘Knowledge-based society’ entails investments in research, technology and innovation in order to lead to a more dynamic business market. Science enables Technology, technology enables Business. Public policy is fundamental in addressing research and to foster virtuous dynamics through European measure such as market surveys, legislation, regulation. Public R&D funding must finance both basic research (TRL 1-3) which leads to breakthrough technologies in the long term continuing support to applied research (TRL 4-7) closer to technological results. Science requires long-term vision, technology a medium term vision, while business entails a short term vision - a more dynamic business market. Surveys suggest that when investing in R&D, business primarily look for: favourable framework conditions for the commercialization of technologies, adequate numbers of well-trained and mobile researchers, responsive to the needs of industry and, an excellent public research base (REs and infrastructures).

Reforms are to be undertaken at national level with a European perspective and a transnational coherence. Enabling (missing-weak) Pan-European enabling mechanisms within ERA:

- > Intellectual property regime (legislation, rewarding system for patents)
- > Supportive policy for spin-off company creation (from research)
- > Technology transfer policy

**Intellectual property regime.** Intellectual property provides a link between innovation and the marketplace. Patent-intensity reflects the capacity of exploiting knowledge and transforming it into economic gain.<sup>24</sup> Patenting is a means to avoid the duplication of innovation in the airplane and components industry. The number of patents granted in the European Aeronautics and Aviation Industry between 1996 and 2002 has increased by 117 %. In 2002, three European countries held 80% of total patents: Germany (35%), France (31%) and UK (14%).<sup>25</sup> In 2005 1.3% of high-technology patent applications made to the European Patent Office (EPO) were in the field of aviation.<sup>26</sup>

In the US, since the 1980s there has been an increase in the number of NASA patents per dollar of research expenditure and ultimately reaching the level of other federal labs. Patent behavior is regarded as consistent with the effort to commercialize federal lab technology. Besides the importance given to publications which can shape a scientist's career, NASA researchers are also economically motivated to pursue commercialization as inventors and receive one-quarter of any royalties from licensed patents. Beside this, evidence on technology spillovers from federal labs in the US shows the relationships among patents, patent citations and technology spillovers. The technology of many firms is closely connected with the R&D of federal labs (for example aerospace firms cite NASA patents and are more likely to commercialize the technology).<sup>27</sup>

The gestation time of each technology, which is the time required for a firm to convert a patent to a commercial product, is firstly, product-specific and second, it tends to shrink over time. The gestation time of pre-1970 technologies is 25 years, whereas it reduces to 7.8. years for post-1970 technologies. Evidence reveals that the rate of technological change as well as the number of new technologies increases over time<sup>28</sup>.

Therefore, government policy and funding for the increase of competitiveness should aim at supporting the creation, the spreading and the strengthening of an industrial and research policy for intellectual property protection (patents) as an asset that will lead to the generation of income with a positive impact on the economic development of Europe and as an indicator of the scientific performance and innovation in the sector, with a positive impact in stimulating internationalization processes..

**Support for the research spinning-off.** In order to increase the international competitiveness, as well as the return in terms of employment, public policy should stimulate the creation of new businesses in the sector also through research spinning-off and public policy should, for example, steer scientific research toward exploring/reinforcing the presence of small enterprises in new, profitable niches of the international market;

**Technology transfer.** Pro-technology transfer government policies play an essential role in encouraging both research organizations and enterprises to transfer knowledge and technologies. The OECD Oslo Manual, highlights the governments' function in technological change resulting from innovative activities, including investments such as R&D, and thus leading to job creation and increased income through increasing investment opportunities and productivity. This naturally depends on the conditions offered that induce firms to engage in the investment and the innovative activities required for enhancing technical change.

<sup>24</sup>Patents have been rated (on a scale from 1= ineffective to 7= very effective) 3.14 for new processes and 3.79 for new products; while lead time for both process and product innovation is valued as the most appropriate Intellectual Property (IP) tool for the protection of the profits from innovation. S. G. Winter (1987), *Knowledge and Competence as Strategic Assets*, in D.J. Teece, "The Competitive Challenge", Ballinger, Cambridge, MA.

<sup>25</sup>SRM (2006), *L'Industria Aeronautica. Struttura e prospettive di crescita*. Napoli: Giannini Editore, p. 132.

<sup>26</sup>Eurostat, European Commission (2009) *Europe in figures. Eurostat Yearbook 2009*. Luxembourg.

<sup>27</sup>Jaffe et al (1998) *Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation*, in "The Journal of Industrial Economics", 46(2), pp. 193-204.

<sup>28</sup>Sood, A., Tellis, G. J. (2005), *Technological Evolution and Radical Innovation*, in "Journal of Marketing", 69, 152-168.

Successful technology transfer from research organizations to companies: the supportive role of national government policies (through legislative issues, the creation of technology transfer infrastructures, research, technology and innovation funding programs), the strategic importance of intellectual property protection, and commercialization or the conversion of an idea from research into a product or service for sale in the marketplace.

Public policy (through tax codes, patent laws, industrial and research policies, public procurement) should maximize the positive spin-out effects to and from the other hi-tech sectors (e.g. ICT). impacting on the opportunities, incentives and capabilities of innovating and transferring technology.

### Research Infrastructures & Education

The technological capability is embedded in labor force (skilled worker, engineers, as well as salespeople, managers) and facilities (research and testing laboratories, departments) and depends on

the (complementary) characteristics of organizations such as financial structure, marketing strategy, competitors, alliances with industrial and research partners, and internal organization.

The science and engineering base includes the accumulated knowledge and the science and technology institutions that underpin business innovation also by providing technological training and scientific knowledge: specialized technical training system, university system, support system for basic research, public R&D activities, strategic R&D activities, non-appropriable innovation support.

Public policy should increase the initiatives for the training of specialized staff with joint training projects defined by research centers, training organizations and firms and training agreements for young researchers (graduates and post-graduates), technicians and professionals/managers of the present and of the future.

# Conclusion: the role of EREA

The role of EREA as  
contributor to European  
ATS RTD harmonization  
programmes to strengthen  
Competence and Cooperation.





**H**ow can research establishments contribute in a real comprehensive long-term and strategic process of the restructuring European ATS?

As outlined in the Green Paper (2007), fragmentation of public research diminishes Europe's attractiveness for business for R&D investment. Consideration of statistics shows that 83% consider that there should be more coordination of research activities between the Member States of the European Union<sup>29</sup>. Uncoordinated research leads to dispersion of resources, duplication, unrealised benefits from spill-overs. EREA which groups the largest research establishments in aeronautics in Europe should cover a major role in the harmonization process comprehending and contributing to the implementation of the prerequisites for success: competition, competence and cooperation (3 Cs).

Since years, in order to achieve the expected transfer of technologies from research to industry, the current European research has becoming more and more industry led and oriented. Consequently, as many industries are competitors in aeronautics, the research programs are generally defined in order to cope with:

- > Short term business for any of the industry partners;
- > Employment pressure in the various European countries;
- > Industry proprietary rights competition.

The resulting situation is that the long term research suffers from this orientation and that many projects and researches initiatives are distorted, the number 1 priority being that the budget is distributed "fairly" among the European industry partners. Once this is done, some kind of self neutralization appears among the industry partners: any of them tries to enhance its own business situation rather than looking far in the future.

Another questionable issue is that the tax payer money is used, at least partially, to build valuable results that are the property of a particular indus-

try instead of being open for any European industry. A public funded research that would benefit from a real common effort to serve globally the European industry would probably be more efficient.

A relevant piece of evidence of this industry ruled situation is that only one of the four scenarios that have been described in this paper is considered today for the future plans of the R&D in aeronautics. It is the "UnLimited Skies", the one that does not change too much the current industry structure. Indeed, none of the three other scenarios offers an attractive opportunity to the current aviation industry!

Though, a better open-mindedness is needed to cover a wider scope of customer needs in the future, even if some businesses have to adapt drastically.

The definition of the high-level objectives for the future generation of ATS sets out, therefore, from the intersection of: vertical inputs, originating from the national and European guidelines; and horizontal inputs, determined at every single national level by the synergies that should be established by players in the field of ATS.

The role of research establishments in this respect, through EREA, the Association of European Research Establishment in Aeronautics should be to carry out in improving the coherence and coordination of aeronautical research and innovation activities conducted at national and European levels through:

- > Lead to the European Strategic Forum on Research Infrastructures (ESFRI) contributing to establishing a European 'roadmap' for new and upgraded pan-European ATS research infrastructures;
- > Generate/coordinate/participate in Joint Research Initiative (JRI) for the implementation of technical and institutional issues;
- > Secure the complementarity of European-national Aeronautics R&T policies;
- > Contribute to EU environmental technology action plan (ETAP).

<sup>29</sup>[http://ec.europa.eu/public\\_opinion](http://ec.europa.eu/public_opinion)  
 European Commission, (2005)  
 Eurobarometer Europeans, Science  
 and Technology.

EREA should coordinate the harmonization and standardization process relative to new business models focussing on intellectual property protection, spin-off creation from research and technology transfer. Within each single RE, transfer from the R&D organization to industry leading to superior technological and economic results will require a detailed technology transfer 'protocol' which describes the technological trajectories in terms of research topics, staff responsible, legal aspects, and economic contributions, in coherence with European guidelines.

The harmonization for future of ATS means to synchronize aeronautical research and innovation agendas at European and national levels in order to multiply and optimize investments and avoid the overlapping and wasting of resources. This synchronization will occur through:

- > the description of the state of the art of the ATS national system, with particular focus on the areas of excellence,
- > R&D trends and possible synergies with other international players,
- > the identification of the areas of critical intervention in order to contribute to the choices made by policy makers, with regard to the upcoming allocation of funding for research into the most strategic technologies for the sector.

EREA should be the mean for Joint Programming in European Aeronautical research if necessary framework conditions (e.g. shared principles and

procedures, common methodologies protection of IPRs) are put in place. New technologies leading to radical change in ATS are possible if developed and deployed appropriately and in time. Institutional measures encompass the funding of a Joint Research Initiative (JRI), a public-public partnership, a research equivalent of JTI with a research leadership to increase investment in 1-3 TRL and stimulate breakthroughs, in both technology and concepts of systems, sub-systems and operation. International cooperation strengthens the integration of funds, and therefore to an 'integrated funding policy', rather than simple availability of funds along with integration of plans is necessary.

Innovation implies wide-ranging co-operation of government bodies, research organizations, firms, individuals. It is the result of the interaction between economy and technology. The centrality of government support: intended as both public-funded research to addressing the challenge and institutional issues capable of overcoming present legal and practical barriers to superior economic results. As outlined in SRAs, more investment from both public and private sources will be needed. The preliminary estimate as mentioned in Vision 2020 "possibly in excess of 100 billion euro over 20 years" has been confirmed. More funding is required for upstream research, continuing support for downstream research. EREA should be the coordinator at a European level for harmonization in coherence with the strategic directions provided in SRAs that should be generated through a common effort of EREA and industry.

EREA

vision for the future –  
Towards the future  
generation of Air  
Transport System

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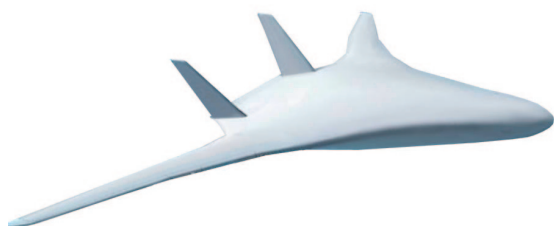
# Annexes

5

## 5.1 List of technological concepts

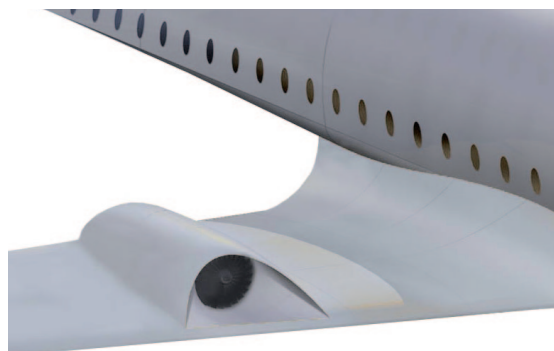
### Blended Wing Body (BWB)

The BWB is an extension of the well-known flying wing concept, in that the fuselage plays a significant role in providing lift. Both wings and the tail assembly are merely stumps. This means that the volume left for passengers and freight is maximized. It also provides the space needed to “bury” the engines in the airframe, which significantly masks any noise generated. However, this configuration does not only offer advantages. Boarding and evacuating passengers is more complex, and they do not necessarily enjoy maximum comfort. Passengers placed near the center of the structure will not have any external visibility, while those seated farthest away from the centerline may be disturbed by the aircraft’s rolling motion.

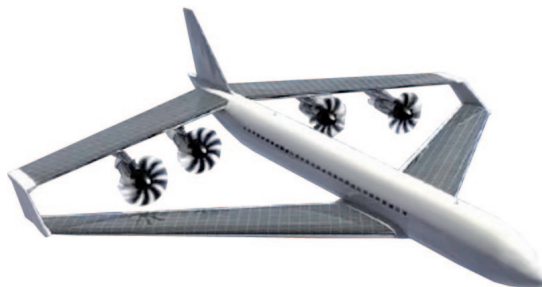


### Buried engines

As the term implies this is a configuration that “buries” the engines in the airframe. This concept is particularly suited to a Blended Wing Body, or BWB type aircraft, which offers considerable internal volume.



### Infinite aspect ratio (rhombohedral wing)



### CROR – Contra-Rotating Open Rotor



### Hub & Spoke / Point-to-Point

Two basic ways of organizing service between airports as part of an overall air transport system. As indicated by its name, the Hub & Spoke system comprises a major airport, or hub, linked by spokes to smaller, regional airports, which funnel passengers to the hub. Long-haul flights leave from the hub to other hubs.

The Point-to-Point network can be summarized as a set of regional airports, in which planes fly directly between these points

In practice, actual networks are most often a combination of the two concepts. A Point-to-Point system would have a larger number of flights for the same number of passengers, along with shorter flights and smaller aircraft. It is also less vulnerable (in terms of technical failures, climate and safety), and has fewer constraints in terms of control capabilities. From the economic standpoint, the Point-to-Point network offers advantages for a segmented market (with its regional airlines and mini-hubs). However, for major airlines, it implies more complicated, more costly logistics.

In general, aviation is less dependent on other transport modes in this type of organization, because it is less integrated in an overall modular (or multimodal) design. A Point-to-Point organization would be necessary with Personal Air Transport (PAT) vehicles, that may exist in the ULS scenario. On the contrary, major hubs obviously demand very high-capacity airport complexes, in terms of runways, gates and terminals, as well as approach ATC (Air Traffic Control). For instance, air traffic growth in London is hindered by the small size of the five local airports, which already cause delays and waits.

## 4D contract

A 4D contract refers to a precise and negotiated scheduling of flights (prior to the flight, as well as en route in real time), along with rigorous tracking of flight paths and times at each waypoint. This is all designed to develop itineraries that avoid conflicts between airplanes, limiting downtime and maximizing the use of airspace assigned to air traffic. It also allows placing more aircraft in the sky without the risk of saturation, using optimized, complex flight paths that will save fuel, limit emissions and reduce noise. “4D” means that tracking is done not only in the three dimensions of space, but also in time. In practice, each aircraft negotiates with ATC a 4D flight plan, for which it then “signs” a contract with the system. As long as the aircraft does not signal anything out of the ordinary, the control authority is assured that the aircraft will respect its contract. The aircraft itself is assured by ATC that no conflict will occur. The situation can change in real time in case of an

incident, following which a new contract is negotiated and applied. Rescheduling in real time obviously presumes that air-to-air and air-to-ground links will always be reliable and available (cooperative communications capabilities between all aircraft). A 4D contract can only be considered feasible within the scope of a redesigned traffic management system, based on the full automation concept. In effect a controller could no more verbally express an instruction in the 4D contract, than a pilot could manually enter the instruction in his or her FMS. Excluding the purely technological aspects, the main obstacle to the 4D contract is its acceptance by the various professional associations involved, in particular pilots and air traffic controllers. Adopting this concept also assumes that airlines agree to no longer choose their routes and flight times according to their own interests, but rather negotiate with the system to determine slots – and the system would have final decision authority. In this case, traffic control is in fact the top priority, either to avoid saturation, or to limit the disturbances it causes, all while ensuring the highest possible level of safety.





## Full automation

Automation means that a system depends only marginally on human intervention in real time. All procedures are implemented by automated systems, which merge the functions of pilots and ground controllers into a new function carried out on the ground, whose precise scope must still be defined. In this case, each aircraft, either linked by a 4D contract with the control authority, or even in free flight, is controlled by an automated system. It has collaborative capabilities in a local loop, enabling it to resolve local conflicts; i.e., those limited to the immediate section of the sky where it is at any given moment. This would enable it, for example, to manage unforeseen situations, particularly in cases where the communications links with the ground are degraded. In this case, aircraft that momentarily no longer receive instructions from the system, can work out how to avoid colliding with each other, and continue their flight. Full automation does not mean that people are totally out of the loop. There will no longer be pilots in commercial airplanes, of course, but an airline representative will have onboard authority (an evolution from the traditional captain on the flight deck). Likewise, on the ground, while air traffic control is handled by the system, this system assigns flight supervision to ground captains, who can strategically modify certain parts of the flight path if needed, such as choosing a diversionary airport, changing the approach, etc. For a given flight, there may be as many ground captains as there are ground control centers under the airplane's route.

## Continuous descent, engines at idle

Within the scope of the 4D contract, especially as used in the Regulatory Push & Pull (RPP) scenario, air traffic must limit environmental impact as much as possible, particularly gaseous emissions and noise. One way of meeting this dual objective is for aircraft to use continuous descent arrivals, with their engines throttled back to idle. A continuous descent towards the final approach zone and the airfield limits – or even eliminates – the time previously spent at low speed and low altitude in a stair-step flight path, situations where jet engines are both fuel-hungry and noisy. Furthermore, if this procedure is applied within the scope of 4D

contracts, it would drastically reduce the airspace volume assigned to this phase of flight, which would in turn unclog airports and speed up traffic, eliminate many waiting periods, etc. Aircraft are in the air for shorter periods, thus reducing noise around airports, especially since with the engines at idle, approaches generate much less noise. In short, this is a win-win situation. The only drawback is that it is very difficult for a pilot to carry out this type of descent while fully complying with the terms of the 4D contract, under any conditions of wind, temperature, etc. Mastering a continuous descent with engines at idle depends on integrating the aircraft's weight in real time, along with atmospheric conditions, and applying a complex trajectory without allowing oneself the liberty to use a possible go-around (if not, what good would the concept be?). Therefore, this type of approach, linked to the 4D contract concept, is only possible in the case of full automation, because a human pilot would be unable to manage so many variables at once, every time, without risking an error.

## Free flight

The concept of free flight does not mean that flights are free of all air traffic control authority. It is in fact perfectly manageable within the scope of a system based on full automation. "Free flight" as used here is just in opposition to a 4D contract. Operators (airlines, aerial services firms, private owners, etc.) can choose their flight paths and time slots without these being regulated. Drones could very well fly on a free flight basis.

## Superconducting materials

Materials that transmit electrical current without energy losses. The growing importance of electrical propulsion makes this a fundamental technology. Superconducting materials already exist, but are still limited to operation at very low temperatures, which entail major technological challenges.

## Regenerative fuel cell

A fuel cell that converts hydrogen and oxygen into electricity, combined with an electrolysis device that converts the water byproduct into oxygen and hydrogen, which can be reused in the fuel cell. The energy needed for electrolysis can be generated



by solar panels. This type of system is capable of operating day and night, and reduces the weight needed for fuel storage (hydrogen) and electrical energy storage (batteries).

### Morphing

This broad concept encompasses both “smart materials”, and real-time changes in the shape of wings and or aircraft. Smart materials react to various stimuli to change their properties, including mechanical, such as deformation, elasticity, etc. This is a major focus of research, in particular leading to the active elasticity concept. The latter case refers to devices (sometimes these same smart materials) that can change the airfoil of a wing, for instance. The underlying aim is to eliminate lift augmentation devices such as slats and flaps, which are heavy and cause excessive drag. To replace them, we generate real-time changes in the airflows over the wing, either by deforming the wing itself (via the actuation of minuscule control surfaces), or by using blowers and ducts to generate local phenomena capable of maintaining the boundary layer. This enhances aerodynamic efficiency in all phases of flight, thereby improving fuel consumption and/or controllability. These techniques are used in conjunction with smart sensors, used to monitor in real time the shape and condition of the wing, and its constituent materials, which have to be changed

to adapt the wing shape to each flight phase; at the same time, these sensors keep an eye on aging, and check whether deformation has not exceeded a safe threshold. This concept is known as Structural Health Monitoring (SHM). Applying these technologies assumes that we can develop the complex computation methods capable of providing a clear idea of the strength, flexibility and aging cycles of a structure made of different materials, in which a large number of sensors have been embedded.

### PAT – Personal Air Transport

PAT is the aerial version of the private car. It also represents a complete range of vehicles, from single-seater to the equivalent of a minibus. The major difference is that the notion of “driving” is eliminated completely, replaced by full automation type management. Occupants merely choose a destination, and perhaps several waypoints.

### D3 – Dirty, Dull and Dangerous

The D3 concept applies to missions that are assigned to automated aircraft, because they are carried out under conditions that would not be tolerated by humans. Typical cases include observation aircraft remaining in the air for several days at a time, as well as aircraft carrying out monitoring missions in areas having experienced natural disasters.

## 5.2 List of abbreviations

<b>ACARE</b>	Advisory Council for Aeronautics Research in Europe
<b>AirTN</b>	Air Transport Net
<b>ASD</b>	AeroSpace & Defence Industries Association of Europe
<b>ATM</b>	Air Traffic Management
<b>ATS</b>	Air Traffic System
<b>EDA</b>	European Defence Agency
<b>EPO</b>	European Patent Office
<b>ERA</b>	European Research Area
<b>EREA</b>	Association of European Research Establishment in Aeronautics
<b>EHEA</b>	European Higher Education Area
<b>ESFRI</b>	European Strategic Forum on Research Infrastructures
<b>ETAP</b>	Environmental Technology Action Plan
<b>ETP</b>	European Technology Platform
<b>EC</b>	European Commission
<b>EU</b>	European Union
<b>FP</b>	Framework Programme
<b>GARTEUR</b>	Group for Aeronautical Research and Technology in Europe
<b>GDP</b>	Gross Domestic Product
<b>HLTC</b>	High Level Target Concept
<b>IPR</b>	Intellectual Property Right
<b>JRI</b>	Joint Research Initiative
<b>JTI</b>	Joint Technology Initiative
<b>JU</b>	Joint Undertaking
<b>PPP</b>	Public-Private Partnership
<b>RE</b>	Research Establishment
<b>R&amp;D</b>	Research and development
<b>R&amp;T</b>	Research and Technology
<b>RTD</b>	Research and Technological Development
<b>SESAR</b>	Single European Sky ATM Research
<b>SME</b>	Small and Medium Enterprise
<b>SRA</b>	Strategic Research Agenda
<b>TRL</b>	Technology Readiness Level

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