LES DOSSIERS

Académie de l'Air et de l'Espace
Air and Space Academy

Flying in 2050

Dossier 38 - 2013

ERRATUM

An error to be found in Figure 9, page 56, has been corrected in this version.

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FOREWORD

Aviation facilitates the mobility of people and goods and furthers education and training for research, development and production professionals as well as contributing substantially to Europe's balance of payments. It also has positive spin-offs in many other sectors, contributing to a higher standard of living, social progress and improved well-being in Europe.

However in the context of a free market and global economic uncertainty, this sector is a field for geopolitical rivalries which justify concerted efforts on the part of all Europe's actors and decision-makers. Given the challenges facing air transport, the Air and Space Academy (AAE) decided in 2009 to launch foresight studies into future prospects for the sector. The issue raised was that of "Flying in 2050". The Academy seeks to address this issue here and put forward recommendations enabling European aeronautics to preserve its leadership.

After studies and exchanges carried out in an international framework, the Academy is publishing the present dossier, No. 38, which summarises the results obtained in the past four years. Its originality lies in the fact that it takes into account aspects external to air transport such as demography, society and the global economic outlook, and examines their influence on the commercial aviation transport market, the quality of service, safety and security. Their impact on aircraft construction, energy resources, operating structures and ticket prices is then examined. Finally an assessment is made of their impact on the environment, air traffic navigation and the possible contribution of space. Vital recommendations emerge concerning institutional and industrial choices as well as research and training orientations. They are generating a great deal of interest on the part of the policymakers to whom they have already been presented.

The Academy is pursuing its work in the field and deepening specific issues highlighted by the present dossier. These aspects will be analysed in a later dossier.

Philippe Couillard

President of the Air and Space Academy (AAE)

1. APPROACH

Unique in providing fast, non-stop transport between distant cities, air transport is a major societal, social, and economic player worldwide, Europe included. Some figures[1] illustrate this universally acknowledged position: worldwide turnover $538 billion (Europe: $176 billion), 8.3 million operational employees (Europe: 1.86), $618 billion in goods and services purchased, with 9.3 million jobs (Europe $213 billion and 2.19 million jobs). Europe benefits from air transport, and also enjoys social, industrial and intellectual benefits. Aviation contributes substantially to Europe's balance of payments, facilitates the mobility of people and goods, and furthers education and training for research, development and production professionals, with effects in many other sectors. Aviation is essential in contributing to a higher standard of living, to social progress, and to improved well-being in Europe. With a free market and worldwide economic uncertainty, this sector is a field for commercial competition and for geopolitical rivalries which justify the mobilisation of all Europe's actors and decision-makers.

Given the challenges facing air transport, the Air and Space Academy (AAE) asked its Foresight Commission (FC) to gauge the risks in the 2050 period, and to deliver recommendations aimed at reducing them.

The members of this independent commission have recognised expertise and experience; they met in plenary sessions and in working groups on themes that interact with air transport: worldwide demographics, market volume changes, energy availability, environmental effects, expected quality of service, air navigation services, airline and airport operating structures, and use of space facilities, using a multidisciplinary, iterative approach.

Intentionally, the Foresight Commission did not use an approach of extreme, separate scenarios, but developed a vision based on a projection which it deemed consistent and probable. It considered that commercial passenger air transport, the predominant component of aerial activity, is the primary indicator for gauging change, and worked in depth on this component. Freight transport, business and

1 *Source: Aviation Benefits beyond borders: published by ATAG, March 2012*

general aviation, helicopters and drones are addressed marginally since the major identified issues are applicable to them to extents that the reader may judge.

The debate was extended during the "Flying in 2050" colloquium at Toulouse in May 2012. The Commission's work resulted in the present document. ***Chapter 2 presents the vision of air transport in 2050 and chapter 3 has the key recommendations for attaining it.*** *The following chapters contain the actions to be carried out, and all the recommendations.*

The table of Appendix 1 shows the key figures used. Appendix 2 lists the people who contributed to the work.

The complete report of the Foresight Commission, with more detailed appendices for each of the themes*, is on the Air and Space Academy's website*[2].

Note: The reader may judge for themself the high potential that air transport offers, with its many opportunities for social and technological development. This dossier identifies the actions that can release this potential.

Alain Garcia

President of the Foresight Commission

2 *www.academie-air-espace.com/upload/doc/ressources/CP-2050-VOLUME1.pdf*
www.academie-air-espace.com/upload/doc/ressources/CP-2050-VOLUME2.pdf

2. VISION OF AIR TRANSPORT IN 2050

2.1. SOCIETY, DEMOGRAPHICS AND THE ECONOMY

Using data published by the World Bank and France's CEPII (Research centre in international economics), the world's population is about 9.3 billion, with Europe in slow decline from 2020, and North America slowly growing. Asia peaks in 2050 at about 5 billion, and Africa continues its growth towards 2 billion. The growing, ageing, population is free to travel, but with increased needs for good quality travel. The well-to-do are booming, especially in Asia. These trends imply a higher demand for mobility.

Worldwide GDP is increasing by 2.8% per year between 2010 and 2050. Europe's share changes from 33% in 2010 to 17% in 2050, North America's from 29% to 22% and Asia-Pacific's from 26% to 42% respectively.

2.2. MARKET VOLUME

A new mathematical model has been developed, supported by university work, based on two findings:

- *the turnover of passenger air transport increases as a fixed proportion of GDP;*
- *the market share of turnover is inversely proportional to the square of the distance.*

This model produces a volume of traffic expressed in RPK[3], and allows the changes in the numbers of passengers, the number of flights and the average passenger load to be foreseen.

3 *Revenue Passenger Kilometres*

The model showed the following growth results:

- *traffic tripling, going from 5.1 to 15.4 trillion RPKs per year, growing 2.8% annually;*
- *passenger numbers tripling, going from 2.7 to 7.9 billion with a slight growth in average trip distance;*
- *the number of flights doubling, going from 28 to 61 million per year, thanks to increasing average aircraft size with better load factors.*

Europe's relative economic size is contracting (its share of worldwide GDP dropping from 32% to 17% between 2010 and 2050), so the projections have lower growth:

- *traffic RPKs up by a factor of 1.4;*
- *passenger numbers and numbers of flights up by a factor of 1.2 with higher estimated average flight length, because of expansion in high speed train services.*

These projections lead to only 1,200 estimated annual aircraft deliveries, lower than the numbers published by airframe manufacturers.

2.3. QUALITY OF SERVICE

In 2050 the quality of the service that the passenger experiences is significantly better, in terms of air travel convenience, safety and security.

Comfort has improved, making air travel even more attractive.

All the air transport players provide clear, comprehensive information with a personal touch, using automated people-to-people communication systems, especially important during a crisis.

***Flight safety has improved by a factor of four, compared with 2010**, along with increased traffic, with no continent having a safety level less than half the worldwide level.*

Accident technical investigations are carried out by internationally recognised organisations, which are independent from the regulators, and cover the same territory. Their results, which are publicly available, are used by the legal inquiry.

Security checks are more thorough. These checks operate in a framework of improved ethics and personal liberties. They are less penalising, less intrusive, and no longer the cause of boarding or transit delays. European and worldwide security regulations and practices have been harmonised.

Replacement (rail, road and sometimes marine) public transport services over short or medium distances offer redundancy, and are now considered to complement air travel rather than to compete with it. European air and ground transport networks have been optimised so as to allow switching mode as needed, when *problems arise with weather or when a mode of transport has labour problems, leading to a more resilient transport system.*

2.4. AIRCRAFT MANUFACTURING

Because the aircraft progressively replacing the in-service fleets were initially manufactured in the 2010's or thereabouts, and because of the poor maturity of alternative solutions, aircraft flying in 2050 are similar to recent aircraft flying in 2010, but with continuous improvements in aerodynamics, mass and propulsion efficiency. Consequently, improvements in aircraft performance, air traffic management and airline operations enable ***an estimated fleet average fuel consumption reduction of 35% per RPK****. This leads to twice the fuel burn for three times the RPK traffic, with the best aircraft in the fleet using 40% less fuel than aircraft using 2010 technology.* ***Alternative configurations*** *such as flying wings or rhomboidal aircraft, still without demonstrated advantages,* ***may exist only in marginal quantities****, and thus do not change the overall results, resulting in a family of aircraft with configurations like those of 2010.*

The European aeronautical industry is able to:

- ***design and manufacture competitive products, with acceptable production costs****;*
- *provide* ***attractive careers*** *for young people with quality education and training, and retain adequate strategic production capacity;*
- ***benefit from cutting-edge technologies*** *so as to obtain the above fuel burn improvements, while continuing to study new innovative configurations, including more efficient integrated propulsion;*
- ***use more automation to improve safety****,* ***with supervisory human inputs for exceptional circumstances*** *(a new form of piloting, for example: an engineer-pilot on board, with ground capacity to supervise and assist, and even take over control of flights);*
- *work with China in a fair way, preserving knowledge and know-how,* ***offshoring only as needed****.*

2.5. ENERGY

Because of its unique properties, aviation kerosene or jet fuel is still commercial air transport's fuel, but its availability is an issue*. Overall demand is up from 250 million tons a year (Mt/yr) in 2010 to at least 450-500 Mt/yr in 2050. Information available in 2012 on future production volumes show a shortage appearing around 2035-2045, even when allowing for an increase in aviation kerosene yield to 10%, up from today's 6-7%, leading to severe market stress for* *this product. About 100Mt of additional alternative drop-in fuel, with equivalent properties to 2010 jet fuel, need to be found, from this date, among the following:*

- *chemical synthesis using coal or natural gas feed-stocks (Coal to Liquid –CTL and Gas to Liquid-GTL) and,*
- *fuels from biological feed-stocks or biofuels, coming into use progressively.*

***Other energy sources such as hydrogen or electricity are often mentioned**, but the poor energy density of the total "propulsion system", comprising the fuel, its on-aircraft storage, distribution and combustion do not allow the manufacture and service entry of a passenger transport aircraft to be envisaged by 2050. It is to be noted that the use of hydrogen would require substantial measures to be applied, so as to mitigate its significant fire risks.*

In view of the expected imbalance in air transport fuel supply and demand in this timescale, the eventual added costs of production of non-petroleum solutions, with their heavy investment needs, and the effects of added taxes, it was deemed reasonable to use a market price of US$250 per barrel of petroleum (or equivalent). The effect of the recent shale gas production operations, with their uncertain development, will need to be evaluated.

2.6. FARES AND OPERATING STRUCTURES

Assuming a fuel price of US$250 per barrel, the average ticket price per kilometre increases by only 10% in real terms, because of improvements in aircraft energy efficiency (fuel burn down by 35%), productivity improvements for all other costs, including personnel, and unchanged or lower user charges. Fuel costs have proportionally near doubled, to half the ticket price, rising from 5.2 to 10.7USc/km.

International air law has changed, in a climate of fair competition.

***Most airports serving commercial traffic have invested to support growth and the demand for new services, especially security, baggage handling and land-side access. Around two hundred new airports have been built, mainly in developing countries** (outside Europe and the US), where the number of flights has tripled. All regions in the world are well served, but a major issue is lack of enough available land to continue good service to cities like London, Tokyo or Mumbai.*

The large hubs have continued to grow faster than other airports, because they unlock the better productivity and environmental efficiency offered by wide-bodies.

Airport cities (aerotropolises) have established themselves around these large airports. The airports and their communities now enjoy mutual trust: The airport is no longer just a place of passage and pollution for the benefit of outsiders, but has become a dynamic resource, a place of value and jobs, enabling it to be accepted.

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2.7. THE ENVIRONMENT

Noise *is much lower, and continues to go down because of newer aircraft entering the fleet, in spite of a higher number of flights, with the help of a constraining regulatory environment. The total acoustic energy is estimated to have been reduced by 15 to 20% between 2010 and 2050. Nevertheless noise remains a major issue for some heavily used airports; under watch with due regard to relevant psycho-acoustic effects studies.*

Total emissions *have been relatively stable between 2010 and 2050, with increased traffic mitigated by lower fuel burn per passenger kilometre, and lower gas emissions, along with technology and operational procedure improvements.*

Particulate emissions *are getting increasing attention, and nitrogen oxide emissions are relatively stable.*

Greenhouse effects and global warming, *concern mainly aviation's carbon dioxide emissions, with the continuing use of mainly kerosene fuel.*

In 2010 the aviation industry announced very ambitious objectives, which were in part adopted by ICAO[4]: 1.5% annual improvement in fuel consumption (ICAO: 2%), carbon-neutral growth from 2020, and total carbon dioxide emissions halved in 2050 compared with 2005 (industry only). Notwithstanding a considerably lower traffic growth estimate than the industry's, AAE considers that it would be unlikely that technical progress alone would compensate the effects of growth. ***Consequently an intensive research programme has been committed to this issue, and the community has been mobilised to produce new "emergent" solutions for standard use in 2050.***

2.8. AIR TRAFFIC MANAGEMENT

Traffic growth has substantially slowed in the US and Europe. The emphasis on increasing system capacity has changed to reducing fuel burn and environmental impacts, and reducing the costs of air traffic management. Nevertheless capacity remains an issue for large airports, principally in the US, Europe and China needing innovative solutions. The rest of the world's traffic durably continues its strong growth, with areas that are not using solutions as good as or better than the US's or Europe's suffering from inadequate capacity.

Institutional issues are the key to system improvement at the regional and world level. *2010's US-Europe comparison[5] is instructive: with 35,000 people, the US controls 70% more traffic than Europe, which employs 57,000 people at double the cost per flight. The main reasons are the US's use of a single air traffic control*

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4 *International Civil Aviation Organisation*

5 *Source : Performance Review Commission*

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organisation, the separation between the Federal Aviation Administration's (FAA) budgets and its revenue, and the flow management organisation having authority over the control centres.

Aware of the opportunity for substantial improvements, starting in 2000 the European Commission put in place two Single European Sky legislative packages, which had not yet been applied in 2012. ***In 2050 European sovereignty over airspace enables higher integration and the resolution of capacity and efficiency issues.***

When crises result in temporary airspace capacity reductions, a ***priority regulation mechanism which is not based on the first-come-first-served principle*** *is used to optimize capacity, such as approach flow management, whatever the systems and institutions in place.*

Improved efficiency and overall cost reductions for the operators in Europe have required ***accompanying measures for the organisations, with new service and system solutions****.*

2.9. SATELLITE SYSTEMS

Over the next few decades, Europe deploys its innovation and technology potentials to stay a leader in satellite infrastructures and services for aviation, with resulting economic advantages.

The following areas have benefited*:*

- *satellite based telecommunications;*
- *satellite based navigation;*
- *search and rescue.*

With an on-going exchange between aviation and space experts, efficient improvements have been made to ***aircraft surveillance, to terrain data gathering, to meteorological and environmental data gathering, to security, remote surveillance and aircraft control assistance****, and last but not least,* ***telemedicine*** *aboard aircraft.*

3. ESSENTIAL RECOMMENDATIONS

The Air and Space Academy recommends the following actions in four areas that are critical for air transport:

3.1. EFFICIENCY

R1-1: *A single authority for local territory and country planning, transport and energy, should coordinate these activities at the European level.*

R1-2: *Transfer of the sovereignty of Europe's airspace to a single European authority, merging together the civil air traffic management service providers in geographical areas which allow genuine optimisation of traffic, and their separation from the technical service providers.*

R1-3: *Improvement of satellite telecommunication safety, integrity, and availability, and information link security.*

R1-4: *Deployment of incident-resilient complementary transport networks with genuine co-modality.*

3.2. ECONOMY

R2-1: *Use of more realistic market forecast models by decision-makers for strategic planning, including the scale of industrial capacity investments.*

R2-2: *Monitoring compliance with ICAO safety arrangements should be transferred to supranational entities, on a continental or sub-continent scale.*

R2-3: *A European (or worldwide) entity, including all the air transport players concerned, should assure the availability of the required energy in due course.*

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3.3. SOCIETAL ACCEPTANCE

R3-1: *Develop a passenger service charter, addressing rights, and ground and in-flight service quality, and introduce compliance assurance by appropriate bodies.*

R3-2: *Consider the aggravating effects of the concentration and repetition of events linked to air traffic density variations over time, and not just the characteristics of the acoustic spectrum.*

R3-3: *Fix an objective of four times better worldwide safety by 2050, compared with the 2009 level, with no continent worse than half the worldwide average.*

R3-4: *Urgently open a wide-ranging ethical debate and deliberation process on security and individual liberties.*

3.4. AFFIRMING EUROPE'S POSITION

R4-1: *Ensure that, in a worldwide open market and with a shrinking share of GDP, Europe acts in a united way worldwide in the WTO and in ICAO to impose strict rules to raise the level of universal standards and prevent unfair competition worldwide.*

R4-2: *Ensure that its manufacturers may not sign away the future for the sake of immediate gains, by excessive transfers of technologies. Create a high-level advisory council to watch over retention of European aviation abilities, covering notably training, cooperation and offshoring.*

R4-3: *Encourage sensible, healthy, consolidation of the sector. Revise the overly-restrictive foreign-ownership laws of many countries, which hinder mergers between airlines of different nationalities, particularly by relaxing the overly restrictive clauses on the proportion of shares held by foreigners.*

R4-4: *Help European players to contribute to advanced R&D programmes, and to the definition of international safety and interoperability standards.*

R4-5: *Intensify research, and launch ambitious, motivational demonstrator programmes to rally the most able and attract the younger generations, such as a very silent inter-city transport aircraft, with a very small carbon footprint.*

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4. DEMOGRAPHICS, SOCIETY AND ECONOMICS [6]

4.1. GLOBAL AIR TRANSPORT

The development of air transport has benefited from a combination of favourable factors. The first is undoubtedly the "pax economica" which has reigned since the fifties: due to UN peace mechanisms, and under the protection of a "nuclear umbrella", open conflicts have tended to remain localised while the Western model has spread, supported by the extensive power of the United States and in particular the influence of organisations like the World Bank, the International Monetary Fund (IMF) and the WTO. The liberalisation of global exchanges called for an appropriate means of fast transport for high value products, business meetings and movements of labour.

The second factor is on one hand aircraft technical progress (weight, aerodynamics, guidance, and navigation together with very safe and more economical powerplants and with extended use of information and communication techniques) and on the other hand the availability of low-price fuel. A strict organisation of flight safety and air traffic management, together with enhanced standardisation, under the aegis in particular of ICAO, a UN agency, made the most of these factors.

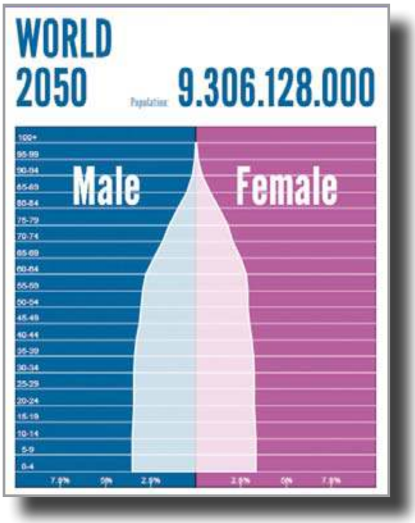

Figure 1: ***Age distribution of world population in 2050 by gender***

6 *This chapter has taken its data from public documents, accessible on the Internet. It did not seem necessary to mention them all.*

These technical advances have brought about a transformation in air transport: in the last five decades it has changed from being a service for businessmen and the wealthy, who are not particularly sensitive to cost, to a form of public transport accessible to almost everyone, with an eye on the price. With regard to the size of aircraft and the comfort provided, the very high number of air travellers confers on aviation the status of almost mass transportation. The size of the US territory and affluence of the population together with the comparative advantages offered by air transport made flying commonplace in this country. It allowed their manufacturers to consolidate into a quasi oligopoly. Now practically the whole world is following this model and, in parallel, other manufacturers have emerged. While western countries see their economic power diminishing, China will probably use all its capability to operate and produce aircraft to compete on western markets, and other emerging countries will follow suite. Soon Africa, with its dynamic demography and continental dimensions, will offer opportunities for building up a comprehensive air transport organisation.

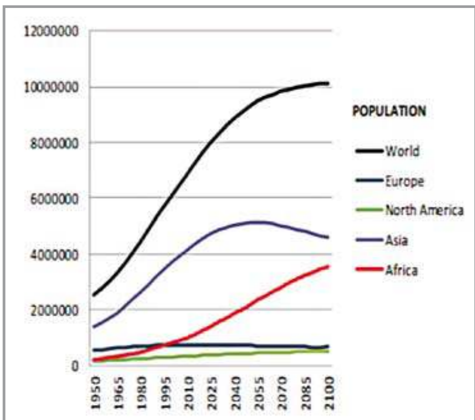

Figure 2 : ***World Population growth***

In a foresight approach, the questions that arise are those of the sustainability of this favourable environment and the share of benefits between countries. The problem is really a geopolitical one.

4.2. DEMOGRAPHY

The FC based itself on the demographic projections contained in the UN "2010 revision", and specifically its median variant. These projections point to a world population of 9.3 billion inhabitants in 2050. The period around 2050 is characterised by the beginning of a decrease in the Chinese population and the approach of a ceiling in the world population. Overall, the population will be marked by ageing, except for Africa which will still be in strong growth. Europe, having finished its cycle of transition, will be on the decline. The numerical prevalence of Asia will thus be high.

The decline in fertility is widely found almost everywhere, except in some

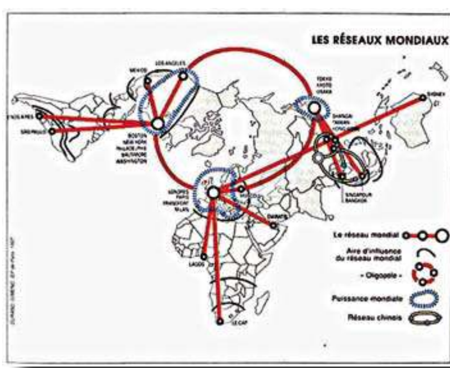

Figure 3: ***World networks***

often poorer countries, although its extrapolation is not always reliable, indeed neither is that of the increase in life expectancy which causes an aging population. However, an increase in world population of about one third cannot fail to raise issues of food, health, water and land use and availability of energy sources.

There will be widespread migration. The numbers quoted by the UN correspond to political objectives, but are and probably will continue to be outstripped in reality. The formation of diasporas of young people in ageing countries may leave a mark on society.

Worldwide, urbanisation will continue apace, to enable subsistence, or to attain higher levels of services. In addition to the creation of metropolises, several megalopolises will develop, relatively highly planned in China, and more spontaneous elsewhere; air routes and networks will develop around them. Serving the various needs of these megalopolises will create enormous challenges. A return to a semi-rural society is plausible, but on a limited scale.

4.3. SOCIETY

The FC considered that the global way of life would not radically change by 2050, in spite of an increase in disrupting episodes. Many area conflicts can be expected, caused by shortage of water, moving populations due to the effects of climate change, seizure of valuable resources (oil, rare metals), intercultural shocks with the migrant populations; the FC adopted the approach that they would remain localised and of limited duration. Overall stability is anticipated in line with large-scale models such as the United States of America, China and Europe heading in the direction of a form of federation. Africa, in line with its demographic and economic development, will continue its transition towards a more Western mode of living.

Humanity will not escape its contradictions, and with its desire for technological equipment and remote displacement, its propensity for speed and fast consumption will continue to fly in the face of ever greater environmental concerns.

As the consequences of climate change become more evident, the social requirement to reduce harmful effects and pollution should logically lead to more stringent standards and regulations. However the possibility remains that only the most extreme events would be taken into account as an immediate threat, while economic development would continue to use energy resources detrimental for the greenhouse gases.

UN programmes targeting the “Millennium Goals” appear to do little more than maintain current rates of poverty levels and access to hygiene and development, paving the way for frustration and resentment, which are sources of instability and violence.

Moreover the supposed stability will not be enough to avoid terrorist threats whose characteristic is to transpose local conflicts to a worldwide arena. In parallel, nongovernmental organisations (NGOs) will increase their capability vis-a-vis transnational corporations. The latter will nevertheless compensate by taking full advantage of global societal trends and of loopholes still open in the world organisation in 2050.

4.4. ECONOMY

The basic assumption is that the world economy will continue to function more or less in the same way, according to an essentially liberal model. Temptations for protectionism will be strong, in particular because of the increasing scarcity of raw material and energy resources, but will undoubtedly remain limited, even volatile, because of increasingly strong interdependence between states, due to this very context. Society will not turn its back on international trade, or tourism.

The strongest test will come from the increasing scarcity of fossil energy resources. Taking this problem and the impact of conflicts into account, the FC settled on an average growth rate in world nominal GDP of 2.8% per annum from 2010 to 2050, i.e. a tripling in constant economic conditions. Asia's share (China, India, Indonesia and Japan) will by then be very largely prevalent, although the US will maintain its strong position. Forecast GDP distribution between areas will be as is usually assumed, after the growth of the "BRICS" countries, extended to Mexico, Turkey and Indonesia. There exists a consensus (cf. various studies by the World Bank, IMF, Goldman-Sachs, PricewaterhouseCoopers and CEPII) that Europe's position

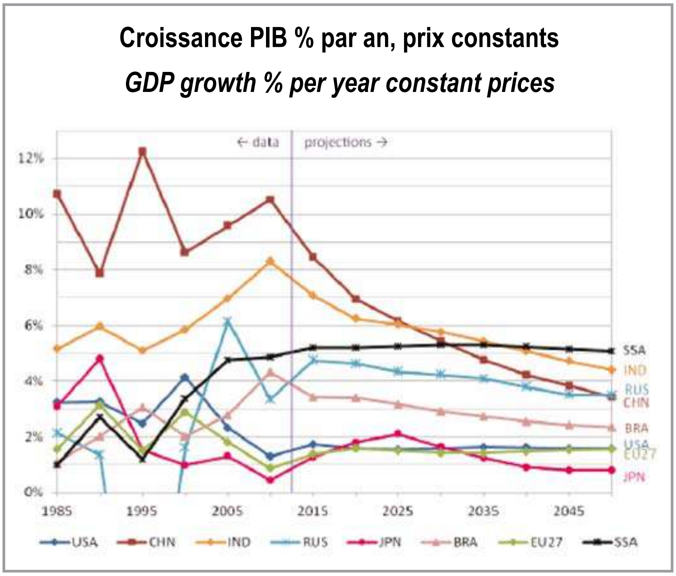

Figure 4 :

GDP Growth. Source: Fouré, Bénassy-Quéré and Fontagné (2012) CEPII

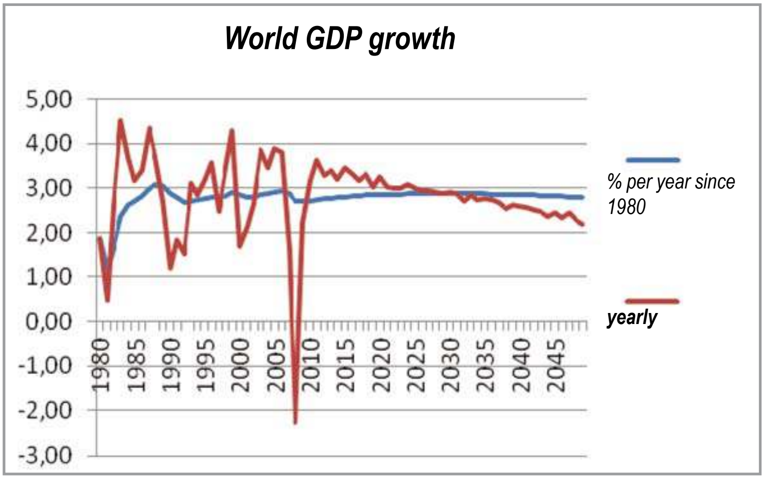

Figure 5: ***GDP growth since 1980***

in the world economy will fall; its share of global GDP is expected to drop by a factor of 2, and even 3 for some countries by 2050 (expressed in current currencies as for trade exchanges).

Average total growth can hide strong disparities between countries and high internal inequalities. The FC did not analyse these inequalities, factors of instability, but implicitly agreed that enrichment would reach a widened proportion of the population. The growth of a "middle class" in emerging and developing countries, a social category wealthy enough to afford air transport, a mode of transport which is anyway becoming more affordable, will procure a solid basis for the aviation industry.

This projection of 2.8% is more modest than other current projections, in particular by aircraft manufacturers; comparisons are made difficult by the use of varying definitions of GDP (nominal or purchasing power parity, in constant or current currencies). Taking into account the international nature of air transport it appeared more appropriate to stick to an assessment of nominal GDP with a constant US dollar rate of exchange.

On the whole, an increase in the use of air transport was assumed, both for passengers and freight. The entire set of assumptions is reflected in the ratio of the sales turnover of airline companies, with GDP taken into account to evaluate air traffic. The FC's observations apply to aviation globally, but attention is naturally centred on Europe. Although the definition of this space may vary in 2050, with regard to air transport, growth will be more moderate than the world average, for fairly obvious reasons: difficult social acceptance of new airports leading to saturation, stagnant or declining population, already dense, satisfactory access road networks, limited increase in wealth from an already high level, competition from other modes of fast surface transport.

Air transport's share of GDP includes a part directly related to this activity (employment, investment, consumption) and a part corresponding to activities which rely on air transport for their existence (long-distance tourism). It is customary to go further and allocate a part which benefits from the advantages of air transport for trade and industrial engineering, but the fuzzy limits of this category can give exaggerated results.

Within this framework, the economic future of air transport depends on its capacity to offer increasingly attractive services for a largely accessible price. This ticket price covers multiple components, a main one being fuel. The price of fuel will be affected by taxation, whereas the price of its raw material ("crude oil") will be aligned on that of synthetic products, themselves influenced by investment and profitability. Unit consumption will decrease further thanks to technology; personnel costs and user charges will evolve with a recasting of the industrial model and a reduction in their costs to compensate for other increases. Finally the propensity to travel could be impacted by cultural phenomena.

4.5. STANDARDS AND REGULATIONS

A very important field in air transport, standards translating society's requirements will be most probably marked by:

- *strengthening of existing standards and regulations or the appearance of new ones on pollutants, noise and even CO_2 emissions;*
- *reinforcement of safety requirements to keep the number of accidents under a threshold acceptable to society;*
- *maintenance of security measures, in more transparent forms, with careful supervision in order to keep them compatible with personal liberties;*
- *standardisation of energy vectors, in particular aircraft fuels, so that their production on a worldwide scale safeguards the economy, resource management and the environment (for example restriction of CTL production).*

4.6. INSTITUTIONS

The FC underlines the existence and work of the institutions which control, regulate and frame the practices of air transport, such as ICAO (and through ICAO, the United Nations Framework Convention on Climate Change - UNFCCC) and the WTO, with the EU and EASA for Europe. In fact the FC's reflexions tend rather towards a reinforcement or an expansion of such institutions: the emergence of a cost-effective single authority to manage a unified European airspace, an evolution towards supranational and international air safety entities (inquiries and analyses, establishment of standards), creation of a European entity responsible for the availability of kerosene and its substitutes.

4.7. CONCLUSION

The socio-economic system "Humanity on Earth", whose demography can be seen to be of significant size on a global scale, is an ecosystem for which air transport provides a certain exchange function. In this complex system all the components are heavily interdependent. Humanity is by nature established in the "Planet" system and interacts with it. The limited resources that the Planet can offer, the variability of the climate, with or without human action, events involving the earth's atmosphere or crust, erosion and the rising sea level are some of the many constraining features. Due to the force of its technical exploitation of the Planet, the changes caused by humanity are not easily reversible: deforestation, impoverishment of the soil, generalised pollution. Multiple types of feedback are appearing within the societies composing Humanity. The power of physical or virtual communications quickly spreads them to the whole of Humanity. At its heart, a form of way of life for the individual - the ultimate component of the system -, known as Western civilisation, is tending to spread, in spite of confrontation with other modes.

The prospects for the next half-century show that the pre-eminence of what is known as the Western world will give way in favour of the Eastern world around China and India.

Notwithstanding this evolution, the current socio-economic configuration gives air transport a fairly important role that is clearly essential to the proper operation of the system. However, the future of air transport is by no means clear. It is likely to be disrupted by conflicts of various origins, with a longer-term threat linked to the combined issues of energy provision and climate change. These two factors might well result in air transport being "rationed", with a parallel increase in costs if required to finance another fuel.

Air transport is not threatened with disappearing, but will probably have to weather some crises severe enough to significantly damage its key role in the balanced development of the Planet. The fundamental challenge facing the air transport sector and related services remains its capacity to face up to these crises. This will call for adaptability and a vital proactive approach.

*The **recommendation** at the end of this chapter is thus to set up a robust tool capable of adapting quickly to these threats when they present themselves, by accumulating financial reserves, conducting inventive research, implementing innovative training and encouraging civic behaviour.*

5. MARKET VOLUME

5.1. REASONS FOR THE NEW APPROACH TO TRAFFIC FORECASTING

First of all, why a new tool for assessing traffic volume when so many estimates have already been put forward by manufacturers, airlines and administrative bodies? There are three reasons behind this choice:

- *the hypothesis underpinning these estimates, based on a constant growth of 5% per year, seems optimistic when set against past trends, simplistic and not relevant to long-term forecasting (2050 horizon);*
- *it is important to take into account all limitations structuring the sector (technical, energy-related, environmental, economic and operational…) when attempting to forecast the development of air transport;*
- *air transport is part of a global transport network and cannot be dealt with independently of other modes of transport; the present approach draws on work by Professor Yves Crozet and his team at LET (Laboratoire d'Economie des Transports, Lyon, France).*

The present analysis, limited to passenger air transport worldwide and split into the classic six main regions (North America, Europe, Latin America, Asia-Pacific, Africa and the Middle East), covers a period of eighty years (1970 to 2010 as a basis for the model and 2010 to 2050 for its application).

The proposed model aims at answering the three following questions:

- *What proportion of their available resources are passengers ready to devote to their air transport needs?*
- *Which of the many air transport services will passengers choose to spend their money on?*
- *What operational answer is provided by the air transport system to satisfy these needs?*

5.2. RESOURCES DEVOTED TO AIR TRANSPORT

With regard to the first point, an analysis of the 1970 to 2010 period shows a strong correlation between airline passenger revenue (global resources devoted annually to passenger air transport) and GDP (Gross Domestic Product, i.e. total yearly resources): after continuous growth up to 1990, the volume of annual airline turnover measured in % of GDP has appeared to reach a ceiling of between 1 and 1.1 % of GDP. The same results are obtained at regional levels.

Independent sources confirm this aspect: Boeing, for instance, in its 20 year forecast states that the relationship between airline turnover and GDP will level out; the same correlation has been noted indirectly by Airbus and can be found in the LET publications for all transports.

5.3. ALLOCATION OF RESOURCES

As regards the second point, concerning resource allocation, the importance of distance travelled clearly emerges: an analysis of air transport distribution according to distance flown, based on ICAO data for 2009, shows that propensity to travel is inversely proportional to the square of the distance. This type of variation can be seen to influence much social behaviour, particularly in the area of transport.

5.4. OPERATIONAL ANSWER PROVIDED BY THE AIR TRANSPORT SYSTEM

In terms of the operational answer provided by the air transport system, aircraft capacity has to be adapted to needs. Studies on the evolution of the air transport fleet indicate that capacity increases with range (adaptation to time zone differences and greater operational efficiency) and also to cope with the growing numbers of passengers transported (60% of the rise in passenger numbers is covered by the increased number of flights and 40% by greater aircraft capacity).

5.5. AIR TRAFFIC MODELS

Based on the above, the following models have been used to forecast global and domestic traffic:

- *air transport passenger revenue "AR" in $ is estimated as a percentage of GDP (Gross Domestic Product) according to the analysis in § 3.2:*

$$(AR/GDP)\ in\ \% = 1.1 - 0.15 \times e^{-0.03 \times (Year - 2010)}$$

- ***global air traffic in RPK** (Revenue passenger kilometre) is estimated from air transport revenue AR and average ticket price ($ per passenger and per kilometre):*

$$Traffic\ (RPK) = \frac{(Passenger\ Revenue\ AR\ in\ \%\ GDP) \times (GDP\ in\ \$)}{(ticket\ price\ in\ \$\ per\ passenger\ and\ per\ km)}$$

- ***domestic air traffic in RPK*** *is obtained by application of the "gravitational" model (c.f. § 5.3): the number of passenger-trips NA,B between region A (characterised by its GDP PA) and region B (characterised by its GDP PB) can be estimated proportionally to the product of the two regions' GDP (PA x PB) divided by the square of the distance « d » separating them (traffic volume TA,B is obtained by multiplying NA,B by d) :*

$$N_{AB} = proportional\left(\frac{P_A \times P_B}{d^2{}_{AB}}\right) \; and \;\; T_{AB} = N_{AB} \times \; d_{AB} = proportional\left(\frac{P_A \times P_B}{d_{AB}}\right)$$

- ***average payload P for each regional flow*** *is estimated according to the operational model taking into account regional characteristics (range d and global passengers volume N):*

$$P = 2.8 \times (1 + 0.6 \times d) \times (N^{0.4} + 6)$$

5.6. SET OF ASSUMPTIONS

GDP assumptions from the "Economy" working group were based on:

1. *For past statistics, data from the World Bank and CEPII, for future forecasts, a 2.8% global yearly growth shared between regions, with a diminishing share for Europe balanced out by growth in the Asia-Pacific region.*
2. *The* ***price of oil*** *will rise from $80 per barrel in 2010 to $250 in 2050.*
3. ***Airline turnover*** *is expressed as a percentage of GDP.*
4. ***Unit ticket price*** *in $ per passenger and per kilometre is based on estimates by the "Operating structure" working group and takes into account improvements in operational efficiency and the increasing price of petrol.*
5. *The matrix of flight distances (internal and between regions) was based on geographical and statistical data.*

5.7. RESULTS OF MODEL APPLICATION

The ***following figure shows global RPK traffic development*** *from 1970 to 2050:*

- *statistic data for the past is given by the line;*
- *the Boeing forecast (yearly Market Outlook) is shown by triangles;*
- *the Airbus forecast (Global Market Forecast) is shown by circles;*
- *the AAE model is marked by dashes.*

A comparison of forecasts in 2030 between the present model and that of the aircraft manufacturers (based on a growth of 5%) brings to light a difference of roughly 15 years to obtain the same level of traffic: thus the traffic forecast by Airbus and Boeing for 2030 will only be attained according to the present model by 2045.

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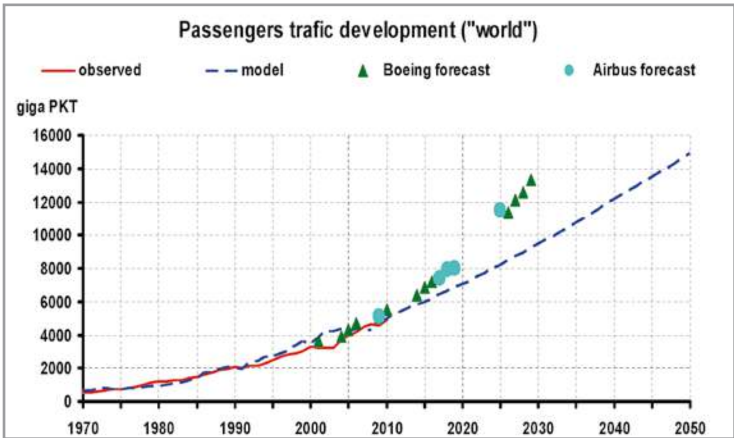

Figure 6 : *Evolution of passenger trafic*

The following table presents detailed information for regional traffic flows *for years 2010 (in comparison with real data), 2030 (comparison with Airbus and Boeing forecast) and 2050.*

	2010 AAE model (data)	2030 AAE model (Boeing)	2050 AAE model
Assumptions			
GDP World (Trillion $)	52	90	156
% Europe	32.3%	24.6%	17.6%
% North America	29.0%	24.7%	21.9%
% Asia-Pacific	26.6%	36.7%	42.4%
Airline turnover (%GDP)	0.95 (0.91)	1.02	1.055
Oil barrel ($)	80	210	250
Traffic RPK (Trillion)			
World	5.1 (4.9)	9.0 (13.3)	15.5
Europe	1.6 (1.4)	1.9 (3.3)	2.2
North America	1.6 (1.4)	2.2 (2.7)	3.3
Asia-Pacific	1.4 (1.4)	3.8 (5.0)	7.7
Passengers (Billion)			
World	2.7 (2.6)	4.8	7.9
Europe	0.7 (0.7)	0.7	0.8
North America	0.9 (0.8)	1.2	1.7
Asia-Pacific	0.9 (0.8)	2.2	4.0
Flights (Million)			
World	29 (28)	42.2	61.2
Europe	6.2	6.8	7.1
North America	8.8	10.8	13.8
Asia-Pacific	8.7	15.7	21.2

Table 1 : Regional traffic flows

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This table shows the following results:

- *consistency between the results from FC model and real 2010 data for regional flows;*
- *a tangible diminution of Europe's relative traffic share, compensated by equivalent growth in the Asia-Pacific region (the logical result of FC economic hypotheses): Europe's share of world traffic and GDP would thus fall from 30% in 2010 to 17% in 2050;*
- *the FC model, unlike the Airbus and Boeing forecasts, can forecast passenger and flight volume, which is important for management of the air transport system.*

5.8. CONCLUSION

This new approach to predicting traffic development provides:

- *consistency between the model's results and existing statistical data;*
- *consequently a more realistic extrapolation from the present situation;*
- *figures for all traffic parameters (RPK, passengers, flights, payload…) for regional and extra-regional flows.*

The model also facilitates ***sensitivity analysis****: the table below shows the effects on traffic evolution of changing the following three assumptions:*

- *less pessimistic forecast for GDP growth (+ 10 % in 2050);*
- *increase in resources devoted to air transport (1,2 % of GDP instead of 1.1);*
- *lower increase in oil price ($200 per barrel instead of $250 by 2050).*

Traffic in 2050	basic	GDP +10%	Turnover/ GDP = +0.1%	Barrel $200 (-20%)
RPK (Trillion)	15.5	17	17	17
Passengers (Billion)	7.9	9	9	9
Flights (Million)	61.2	65	65	65

Table 2: Traffic in 2050

6. SERVICE QUALITY

Although quality of service is not limited to the perception that passengers may have, it must primarily meet their main expectations which, in 2050, are considered to be:

- *reasonable cost;*
- *punctuality;*
- *ease in the entire process from booking to the end of the trip;*
- *seamless travel experience from place of departure to final destination (duration, reliability);*
- *information before and during the trip;*
- *communication during the trip;*
- *comfort;*
- *sense of safety and security.*

An in-depth study was carried out into three different functionalities concerning Quality of service:

1. *Making air transport more attractive.*
2. *Reinforcing air transport safety and ensuring security.*
3. *Implementing true co-modality.*

These three functionalities give rise to different messages and recommendations.

6.1. MAKING AIR TRANSPORT MORE ATTRACTIVE

The following three sets of recommendations were put forward to enhance air transport's appeal.

6.1.1. European and/or international governance

***An international authority should control the international market of "slot" allocation** so that passengers' needs take priority over the domination or protection of the market sector by specific airlines.*

***A ceiling on the number of daily frequencies should be established** for each airline in order to avoid needless occupation of slots and contribute to increasing the average passenger load on each flight, thus improving traffic fluidity and the economics of air transport while reducing the negative environmental impact of noise and emissions.*

States will have to ensure that a varied transport offer is maintained - thus guaranteeing healthy competition - and continue to support liberalisation of the air transport sector, bearing in mind that extreme concentrations and total liberalisation do not improve quality of service to passengers.

6.1.2. Passengers' rights

With regard to the airport

Clear, universal signage should be enforced so that airline passengers feel at ease in airports wherever their journey takes them.

Although automated procedures will probably become the rule, a staffed reception desk must exist for passengers unfamiliar with modern equipment.

Handicapped passengers must have access to all airport installations and facilities forming part of a standard trip.

In order to open up access to air travel for people residing far from an airport, all airports should be connected to a public transport system.

The creation of any airport or terminal should be accompanied by the creation or development of a direct public transport link between the facility and the nearest urban centre. This link should be capable of dealing with at least 50% of planned capacity.

With regard to carriers / tour operators

The development of information and communication technologies will have a very positive impact on passengers, who will receive more customised services.

Carriers and tour operators must be compelled, via regulations, to provide clear, comprehensive, non-ambiguous information on tariffs and services offered.

Information in the event of an incident must be significantly improved (in terms of clarity, speed, accuracy and comprehensiveness) and general information campaigns carried out on the inevitable unforeseen events and constraints of air transport, in order to improve public opinion, independently of any traffic incidents.

Before and during the flight, each passenger must be informed of any changes to their trip and should be able to make new provisions immediately.

6.1.3. Comfort on board

The volume available for each passenger must take account of the evolution in standard size of the population (increase in corpulence); in high-density cabin class, the seat spacing must allow enough mobility in order to reduce the risks of medical incidents.

An international standard applying to all new commercial transport aircraft should be established governing cabin pressure and noise level.

6.1.4. Baggage

Baggage handling at airport facilities must be completely overhauled (reconfiguration of departure halls, check-in, loading, itinerary, standardised containers, etc.).

A radically new system of baggage handling must make it possible for airlines to confirm to passengers that their baggage is really on board, and for airports to ensure delivery within minutes of the aircraft arriving at its gate.

6.2. SAFETY / SECURITY

6.2.1. Improving safety

A worldwide objective should be fixed, aimed at improving safety by a factor of 4 by 2050, as compared to the 2009 level, and no continent should have a safety level under half of the worldwide average level.

The monitoring of conformity with the provisions of the new ICAO Annex on safety – as for those of Annexes 6 (Operation of Aircraft) and 8 (Airworthiness of Aircraft) – should be transferred by 2025 to supranational, even intercontinental bodies (at present ICAO limits itself to conferring this responsibility on states).

ICAO's monitoring and supervisory powers (and thus its resources) must be reinforced in order to ensure minimum standards for initial and continuous training for aeronautical personnel throughout the world.

By 2025, technical accident investigations should be carried out by internationally recognised bodies, independent of monitoring organisations but covering the same territories, free of national interests, like ICAO.

The legal inquiry, if it is necessary, should base itself on the results of the technical investigation. The conclusions of accident investigations should be communicated publicly, clearly and completely.

By 2020, all public transport aircraft must be constantly tracked during flight (transmission and signal monitoring).

6.2.2. Ensuring security

It is vital to:

- ***launch a wide-ranging debate from an ethical point of view on security and personal liberty;***
- ***intensify research** into developing equipment for streamlined security checks enabling rapid control without body and baggage search (except when there is a doubt);*
- *launch a reflection activity at international level on the training and monitoring of security personnel.*

6.3. IMPLEMENTING TRUE CO-MODALITY

It is necessary to:

- ***create a single European planning authority** for transport and energy by 2020.*
- ***create fast public ground transport networks** for main airports.*

6.4. JUSTIFICATIONS/EXPLANATIONS

The quality of service of air transport is measured today according to the same criteria as other means of transport, i.e. in terms of passenger safety, comfort in the various phases of the trip, accessibility of airport installations and ground and on-board security. In 2050 these criteria will be the same, but the corresponding levels of satisfaction will be very different as a result of significant changes in customer expectations under the effect of demographic expansion and globalisation.

6.4.1. Travel comfort

Passengers, more so than today, will be in a position to choose between several means of transport, so their comfort must be enhanced to make air transport a more attractive proposition.

The passenger has a contractual relationship with the airline alone, but the high number of stakeholders and authorities that interface with the passenger in the course of his journey (authority responsible for ground transport / airport / state bodies / service providers / airline) must work together in close cooperation in order to obtain the desired improvement in quality of service. Their combined efforts will be directed at supplying passengers with clear, comprehensive, customised information on departures and arrivals (particularly in the event of glitches) and on tariffs and services provided, thanks to the increasing use of information and communication technologies. In parallel, an information campaign will aim to raise the user's awareness of the fact that even in 2050 there will still be external and unavoidable (weather, volcanic ash, earthquake…) events capable *of temporarily disturbing an air transport service which therefore cannot, in spite of the concerted efforts of all concerned, be guaranteed free of unavoidable consequences.*

Air transport will clearly need to increase the use of new technology (terminals, locating systems, Smartphones, etc.) for communicating with passengers, but it is important to preserve a human interface at reception desks for passengers with special needs, or those unfamiliar with air transport or a particular airport, in order to reassure them. This should also take into account cultural differences.

Efforts will also have to be put into dealing with the significant increase in the number of passengers, their increased average height, corpulence and age, and to ensure full access by handicapped people to all installations. The current baggage processing system will have to be overhauled to eliminate losses, thefts, damage and delays, which all generate stress. All this will have consequences on the configuration of the aircraft, on the installations and the size of airports, on the baggage handling equipment and, in the final analysis, on the attractiveness of air transport.

For their part, while supporting a policy of liberalisation of the sector, states must maintain plurality in the offer of transport. ***An international authority will control the allocation of "slots"*** *on the basis of passenger needs and traffic fluidity, rather than carriers gaining or protecting market shares.*

A charter for how to look after passengers must be developed as soon as possible, and will relate not only to their rights, but also to the quality of service on the ground as well as onboard the aircraft. This charter should be enforced by appropriate authorities.

6.4.2. Passenger safety

The current global safety level is 0.5 fatal accidents per million flights. This makes aircraft one of the safest means of transport even if, unfortunately, there is a great difference between one continent and another. The forecast threefold increase in the number of passengers transported by 2050, corresponding to a doubling in the number of flights, will thus have to be accompanied by a cut in the risk level by a factor of 4, with no continent having a safety level under half the world mean level.

To achieve this goal, ICAO decided to devise a new Annex relating to safety, in complement to existing Annexes; ***it is recommended that the monitoring of conformity with the provisions of this new Annex, as for those of Annex 6 (operation of the aircraft) and Annex 8 (airworthiness of the aircraft) should be transferred between now and 2025 to supranational, bodies, covering continents, whereas ICAO leaves this responsibility to each state.***

This situation already exists with regard to aircraft design (e.g EASA in Europe…). To become more effective and sidestep the national characteristics which paralyse *any evolution, a central organisation should be set up on a continental level with the means to carry out operational monitoring of increasingly multinational airline and maintenance companies. Each actor would thus have to respect an equivalent process of certification.*

Accident investigations are a means of both increasing safety and providing victims' families with the information they have a right to concerning the causes of accidents. In the case of France, public confidence in the BEA's conclusions has been eroded; it is believed to report to the DGAC and as such to be in the service of the state and the manufacturers. A similar situation exists in other countries. The only way of removing this suspicion would be for technical investigations, by 2025, to be carried out by internationally recognised organisations, covering the same territoriality as the previously mentioned monitoring organisations, but independent of these, and recognised to be above national interests, like ICAO. A worldwide body must be considered by 2050. These investigative bodies must be able to exchange all their data on accidents and incidents. These organisations are charged to inform the families of the victims.

The general public finds it hard to understand why these investigations take such a long time, to grasp the difference between technical investigations and legal inquiries. That adds to the fuzziness, incomprehension and distrust. It is recommended that the legal enquiry, if it is necessary, should base itself on the results of the technical investigation. The conclusions of accident investigations should likewise be communicated publicly, clearly and completely.

Aircraft must be able to be localised constantly during their flight in order to ensure SAR help as soon as possible and to find the flight recorders rapidly in the event of accident. From now until 2020, all public transport aircraft must be provided with the means to ensure they can be constantly located during flight.

6.4.3. Security

The need for intensifying security checks can only continue. These controls must be less difficult to set in place and less invasive and should not increase boarding or transit times. In particular, passengers should be subjected to a security check only at the first airport of their trip, even if they have a complex journey with connections. However the conceivable means to date to achieve this goal could have unacceptable consequences in terms of the passenger's privacy, intimacy and dignity. It is thus vital that a vast debate be launched as soon as possible from an ethical point of view on security and personal freedoms. On an international level, the training and monitoring of security personnel should be reviewed.

6.4.4. Co-modality

Alternative methods of public transport (rail, road, marine) will inevitably be used for shorter and medium distances (with a potential for redundancy) and must be *considered as complementary rather than competitive; this is the basis of the "co-modality" concept, which must be embraced. Expansions in, and the limits of, airport capacity will increase the need to develop co-modality and such developments will influence the airlines' strategy in terms of hubs. Current ground access to airports from town centres must be improved urgently, by promoting all types of public transport. New airports will necessarily include a public transport access network in their design. Connections between means of transport must be adapted to travellers' expectations, requiring collaboration of all participants, leading to coherent information and simple ticketing. Moreover, the European air and ground network will have to be optimised in order to make it possible to swap, in certain cases (weather, social or other), from one means of transport to another, thus increasing the resilience of the system. Choices to be made will clearly depend on regional planning, the cost of redundancy and the energy costs of the various modes. It is thus important to create a common authority at European level to deal with all transport, regional planning and energy, if possible by 2020 (for results in 2050).*

6.5. EMERGENT ISSUES AND CONTINGENCIES

Breaking with estimated or projected trends, a number of elements could emerge in the period, significantly changing the landscape in terms of quality of service. In particular, the consequences of the following should be studied carefully:

- *in the field of attractiveness:*
  - *unacceptable drop in punctuality,*
  - *excessive concentration of airlines,*
  - *changing aspirations for some categories of passengers,*
  - *change in carrying standards (disabled passengers, luggage ...);*
- *in the field of safety:*
  - *unrealistic safety requirements, due to judicial overkill,*
  - *huge increase in the number of individual aircraft;*
- *in the field of co-modality:*
  - *changes in the institutional environment between air and rail (e.g. creation of global international multimodal companies, or on the contrary, excessive competition between modes of transport).*

7. AIRCRAFT MANUFACTURING

7.1. INTRODUCTION

Aircraft, for obvious reasons, are at the heart of the passenger air transport system. For this reason, the FC's aircraft manufacturing working group conducted its foresight analysis for 2050 along two complementary axes:

- *composition of the fleet of aircraft in service in 2050 and specifications of aircraft delivered at that time;*
- *characteristics of the overall aircraft manufacturing industry and preservation of European leadership in the worldwide aeronautical industry.*

7.2. COMMERCIAL AIRCRAFT FLEET IN 2050

The most vital, challenging aspect of the study carried out by the aircraft manufacturing working group was its analysis of future enhancements to the worldwide fleet of passenger transport aircraft. First a description was given of the fleet in service in 2010 - its characteristics and performance - then an assessment was made of the technological gains that can realistically be introduced into the fleet by 2050.

Evolution of the fleet is heavily dependent on evolution in demand for passenger air transport. Detailed figures for the latter are given in Chapter 5 on Market volume, which forecasts market needs in terms of global traffic as well as operational parameters, based on an analysis of historical trends.

The question is: in order to satisfy future demand, will it be necessary to resort to futuristic configurations or will it be enough to push conventional technologies to their asymptotic imits?

To answer this question the following issues have to be examined:

1. ***Economic constraints for both aircraft manufacturers and airlines as well as for the end user, the passenger**. The whole chain of operating costs must be optimised, from initial purchase (including financial charges) to fuel and maintenance costs, wages and the various taxes.*

2. ***Growing scarcity in fossil fuel and consequent increase in price**, doubts concerning the availability of alternative fuels (cf. Ch.9 Energy).*
3. ***Environmental constraints** (cf. Ch.11 Environment).*
4. ***Increased competition with the main emerging countries and upward development of the regional aircraft manufacturers**. This will impact the Airbus and Boeing duopoly. In each country, adapting means (skills and workforce) to requirements in the areas of research activities, development of new products and in-service maintenance of the rapidly growing fleet will constitute a major difficulty for both aircraft manufacturers and airlines (crew and maintenance). This difficulty will be compounded by a drop in interest on the part of young engineers in the aeronautics sector, especially concerning technical matters. Moreover, preserving manufacturing know-how casts serious doubts on the current policy of relocation, which will inevitably have catastrophic results in the long term.*

7.2.1. Identification of the 2010 fleet

Variety of demand for air transport and its available technologies has justified the production of a host of different aircraft models, ranging from short-haul, single-aisle aircraft with small capacity to large capacity wide-bodies operating on long or very long ranges. To trace the specific evolution of the different aircraft, they have been classified into 5 types closely matching market segmentation: short-haul turboprop (SH TP), short-haul turbofan (SH TF), medium-range (MR), long-range (LR) and very large aircraft (VLA).

The table below summarises the main characteristics and performance of the 5 aircraft types, each of which represent a variety of aircraft. Only active aircraft are counted, containing more than 19 seats and regularly notching up RPKs. Their EIS date serves as a reference for their technology standards. Their characteristics and performance are derived from their identified reference aircraft using appropriate simple methods based upon the Breguet range equation.

*This well-known formula evaluates the range (**R** km) that can be flown by an aircraft taking into account cruise speed (**V** km/h), lift to drag ratio (**f**), specific fuel consumption (**Cs** kg/N/h), take-off weight (**Mtow** kg) and landing weight (**Mldg** kg)*

$$R = V \times f / (g \times Cs) \times LN(Mtow / Mldg)$$

*The number of aircraft attributed to each segment is based mainly on ICAO data; a slight difference emerges with the FC assessment of the fleet. For each representative aircraft, the parameters taken into consideration are the number of passengers (**NPax**) in a typical cabin layout, maximum range (**RMax**) and average mission length (**RAver**) expressed in km. Rmax can be used to assess the main characteristics (wing area and thrust or power) for each representative aircraft, RAver serves to identify the number of flights per year and the corresponding fuel*

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burn. To match the inputs of the ICAO fleet main parameters, the capacity, average range and utilisation of each average aircraft type are optimised to minimise the difference between the FC fleet and the ICAO data.

In order to adjust the FC assessment to actual global fuel consumption, a dilution factor (1.16) was introduced to cover uncertainties resulting from the simplified method, the differing performance of the various aircraft of each segment, the drop in efficiency of aging fleets, the ATM impact on the actual route, the utilisation of non-optimal cruise conditions….

FLEET 2010 AIRCRAFT	SH TP	SH TF	MR	LR	VLA	AAE fleet (#ICAO)
Number of aircraft	3111	3819	10036	2837	528	20331
Reference aircraft	ATR 42	CRJ 700	A320	A330 340	B747 400	
EIS Technology	1985	2001	1988	1994	1989	
Average aircraft						
Npax C1	43	66	154	271	375	143
RMax km	2000	4000	6000	10001	12964	
RAver km R1	567	939	1251	4431	6741	1841
Vcr kt TAS	300	446	454	473	482	
Block time hrs (BT)	1.37	1.61	1.96	5.53	8.02	
Utilisation BT/yr	2462	2812	2631	3810	4602	
Flights/year	1794	1750	1343	689	573	1377
Fuel kg/flight	718	1940	4265	27580	73429	
Fuel g/pax/km	29.7	31.5	22.1	23	29.1	24.1
Load Factor	0.78	0.78	0.78	0.78	0.78	0.78
Dilution	1.16	1.16	1.16	1.16	1.16	1.16
Average capacity C2	43	66	154	271	375	121
PAX millions	185	342	1622	413	89	2651
RPK	105	321	2029	1829	597	4881
Overall distance 10^6 km	3165	6275	16865	8657	2041	37004
Flights millions	5.6	6.7	13.5	2	0.3	28
Ticket $/flight	100	123	143	331	505	179
Income $billions	19	42	231	137	45	473
$/Pax/Km	0.177	0.131	0.114	0.075	0.075	0.097
Fuel kg/RPK thousands Dil	44	46.6	32.7	34	43.1	35.6
Fuel kg billions Dil	4.63	14.98	66.43	62.26	25.69	174

Table 3: Characteristics and performance of aircraft in 2010

Explanation for this table:

- *R1: average distance flown by a passenger* ***R1 = RPK / Pax***
- *C1: average capacity (number of seats) of the aircraft in the fleet*

- *C2: average capacity (number of seats) per flight* ***C2 = Pax / flights/LF*** *(LF : load factor)*

7.2.2. Asymptotic tendencies

It is assumed that aircraft will utilise a type of fuel with similar characteristics to kerosene, which will be scarce and therefore more expensive, whatever its origin. Other energy sources are neither considered to be appropriate for use in passenger air transport, nor indeed indispensable within the 2050 timescale.

Improvements in fuel consumption will come about by progressively incorporating results from on-going research activities in all fields and implementing new designs that take into account the impact of the rising price of fuel on operating costs. Operating cost, which includes fuel price, financial costs, maintenance and operational costs, will still be the parameter with most need of optimisation. Taking into account gains in fuel consumption in the last 40 years, further improvements in the next 40 years will be smaller in percentage terms, and even more so in absolute terms, clearly reflecting the asymptotic tendency of the improvements.

Any attempt to put a figure on these asymptotic limits is tricky, so a realistic, reasonably ambitious approach was selected.

Gains in high speed aerodynamics will result mainly from the selection of higher aspect ratios for the wing in combination with a modest improvement due to laminarity. The cruise L/D will be improved by 12% to 15% on average.

Gains in terms of isolated engine fuel consumption have been put at 25% for all engine types but these values must be reduced to take account of the effect of

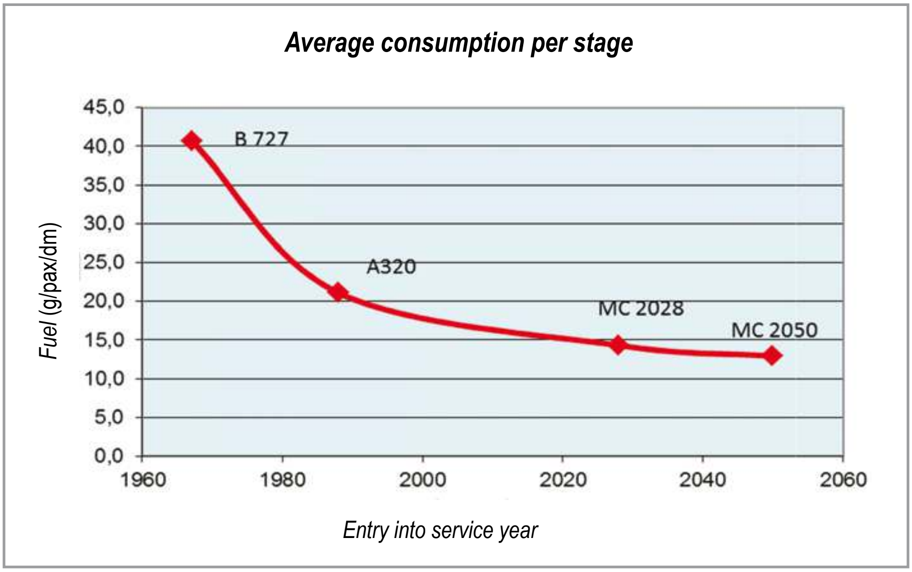

Figure 7: ***Asymptotic trend in aircraft improvements***

unfavourable installation configurations (weight of the propulsion system and nacelle drag) which varies from one aircraft type to another.

In terms of airframe weight, a 10% reduction in empty weight was assumed.

The average cumulative effect of these improvements, combined with the impact of changes to capacity and range according to the Breguet coefficient, is of the order of 32%; the resulting fuel burn improvement on an average mission for medium-range aircraft (MR) - the segment which had the largest contribution to fuel burn - is presented on the following figure which represents the asymptotic tendency of such improvements; a similar tendency is found for the other aircraft types.

Furthermore, improvements will not be incorporated identically and simultaneously into each segment, indeed only newly launched programmes will benefit from all cumulated improvements in aerodynamics, propulsion and weight; re-engined or otherwise modified versions of existing models will reap only partial benefits. As a result, average fuel consumption of aircraft in 2050 will not be representative of contemporary technological standards, since the latter will be only partially incorporated.

7.2.3. Unconventional solutions

A large number of exploratory studies and research activities have been or will be conducted by manufacturers, research organisations and universities. They cover various unconventional solutions, using both innovative configurations and new sources of energy with the objective of significantly reducing fuel (energy) consumption and/or acoustic levels.

They can only be introduced of course if safety criteria, technical performance, operational costs, environmental compatibility and supply volume are compatible with market demand. A degree of flexibility as regards criteria such as operational costs or supply volume could enable the emergence of new niche market technologies with limited impact on the performance of the main transport fleet.

The best-known new, unconventional configuration is the blended wing concept or its derivative, which has inspired numerous research projects in Europe and the US with the promise of substantial aerodynamic improvements (more than 15% in the aerodynamic efficiency factor MxL/D, a product of Mach number by lift to drag ratio, mainly due to reduction of the wetted area) and a significant reduction in acoustic levels (mainly due to forward noise shielding). However, the limitations (longitudinal control, structural aspects and weight breakdown…) and identified risks (passenger acceptance, certification…) significantly counterbalance these potential gains, ruling out use of such a configuration for passenger transport at the current level of knowledge, whatever the range and capacity considered. A possible long-term civil application could be freight transport, provided that successful large-scale development tests are performed and a full-scale military application enters into service first.

Other unconventional configurations are being studied by research organisations (Bauhaus Luftfahrt, EREA…) but the maturity and level of validation (technical readiness) of these concepts have not yet reached the level required for the kind of widespread usage that would impact air transport by 2050. New "innovative" configurations must be researched, particularly more efficient, integrated propulsion systems.

In terms of new energies, hydrogen has long been considered to be an attractive potential candidate since, to produce the same amount of energy, it requires only a third of the weight. Unfortunately, H_2 requires 4.2 times more volume than kerosene and it must be kept in a cryogenic environment. Its overall energy consumption, including the production phase, is less than favourable even according to the most optimistic estimates. Concerning local effects on air quality and global effects on atmospheric warming, H_2 produces neither hydrocarbons, carbon monoxide, carbon dioxide nor soot, but does give off a small amount of nitrogen oxide and a large amount of water vapour, with a potentially significant impact on the induced greenhouse effect. As a consequence, it suffers from a questionable environmental assessment as compared to kerosene. With H_2, the current overall engine architecture could be maintained, with a smaller core size for a given thrust and considerable adaptation of "ancillary" equipment to make it compatible with the cryogenic environment. The major unresolved issue is the frequent handling of large quantities of highly reactive molecules during the chain of production, ground transport, storage in the airport, loading and storage in the aircraft and finally injection into the combustion chamber, whilst respecting the safety level required for regular passenger air transport.

Under these conditions, the use of H_2 appears incompatible with the safety objectives and, taking into account that the price of the loaded energy will probably be much higher, one cannot consider H_2 as a kerosene replacement in the 2050 timeframe.

The use of electricity for propulsion, by means of either photovoltaic cells or batteries, is often considered. Unfortunately, the extremely low efficiency of photovoltaic cells requires large exposed surfaces incompatible with current commercial aircraft, not to mention the increased weight. Potential improvements to these cells will not suffice to render them compatible within the 2050 timeframe.

Similarly, if we consider the Short-Haul TurboProp to be the most appropriate candidate for use of batteries due to its modest energy requirement, with current battery technology offering 150 Wh/kg, the weight of batteries would represent more than 3 times the maximum take-off weight of the reference aircraft. In order to maintain the payload on such a mission, it would take a battery technology improvement of a factor of 50 in terms of Wh/kg; furthermore, the onboard electrical engines should themselves be capable of producing 3 KW per kg. It is *considered that these objectives, in a context of severe economic constraints, will not be met within the 2050 timeframe.*

The market could also evolve, opening up new fields of research with new requirements, as envisaged below.

Passenger transport within megalopolises should make use of appropriate aircraft which, provided their urban integration is acceptable, could become a significant market, although this is of course the domain par excellence of high speed rail transport.

High-speed and even very high-speed transport, meeting a need for improved productivity and timesaving, continues to constitute a research domain in spite of economic and environmental constraints. Supersonic air transport is still under study although problems linked to the need for sub- and supersonic flight, noise, sonic "boom", traffic integration and traffic rights need to be resolved. It is possible that supersonic commercial transport might reappear towards the end of the period in question, if research converges, although with a small market, and probably after a trial phase using supersonic business jets.

Hypersonic flights are attractive for very long distances (transpacific) or to enable return the same day. They would require multiple propulsion systems and technologies that are barely applicable for civil air transport today.

Summary:

- ***Unconventional solutions should continue to be subjected to in-depth critical assessment but would not appear to be capable of making a significant contribution to air transport by 2050.***
- ***Aircraft flying in 2050 will be equipped with engines using kerosene-based fuel along with alternative fuels with identical characteristics; their classic architecture will nonetheless offer improved performance.***

7.2.4. Extrapolation to 2050 fleet

The table on the following page presents AAE's extrapolation to 2050 of the characteristics and performance of the 2010 fleet, using the FC's assumptions for improvements to be expected for each average aircraft in the next 40 years.

The results of this projection can be summarised as follows: to satisfy RPK demand, the number of aircraft must be doubled, these aircraft must be larger and their average stage length slightly increased. Maximum ranges were increased to correspond to the trend in airline requirements, although the percentages decreased with length of mission. It is considered that producing aircraft capable of flying the very uncommon over-16.000 km stages penalises the overall family of aircraft, in terms of fuel consumption and operational costs.

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2050 Fleet

Aircraft		SH TP	SH TF	MR	LR	VLA	AAE fleet (#ICAO)	K 2050/2010
EIS Technology		2025	2041	2028	2034	2029	2050	
Number A/C		6505	7766	19077	7379	1401	42128	2.07
Npax	C1	54	74	193	358	482	188	1.32
Rmax km		2420	4840	6667	12964	15186		
RAver km	R1	567	937	1250	4426	6719	1961	1.06
Vcr kt TAS		300	446	454	473	482		
Block time (BT) hours		1.37	1.6	1.96	5.53	8		
Utilisation BT/year		2684	2975	2809	3442	4363		
Flights / year		1956	1854	1435	623	545		
Block fuel kg/flight		567	1377	3554	24006	58739	4658	
Fuel g/Pax/km		18.6	19.8	14.7	15.2	18.2	15.7	0.65
LF		0.85	0.85	0.85	0.85	0.85	0.85	1.09
Pax millions		580	907	4496	1398	313	7694	2.91
Average capacity	C2	54	74	193	358	482	151	1.25
RPK (billions)		329	850	5618	6187	2102	15086	3.09
Overall distance (million km)		7216	13491	34216	20344	5135	80401	2.17
Flights millions		12.7	14.4	27.4	4.6	0.8	59.9	2.14
Ticket $/flight		120	144	164	367	510	209	1.17
Income $ billions		70	130	737	513	160	1610	3.4
Dilution		1.16	1.16	1.16	1.16	1.16	1.16	1
$/PAX/KM		0.212	0.154	0.131	0.083	0.076	0.107	1.1
Fuel/RPK g/km/pax		25.3	27	20	20.6	24.7	21.4	0.6
Fuel kg billions	Dil	8.34	22.91	112.44	127.49	51.87	322	1.85

Table 4: Characteristics and performance of aircraft in the 2050 fleet

The LR segment provides the largest contribution to RPK and fuel consumption but the MR segment still contains the most efficient aircraft. It must be pointed out that aircraft of the 2050 fleet will have design characteristics (NPax and RMax) that strictly match market requirements, without limitations due to technological constraints.

Fuel consumption for 2050 aircraft takes into account the 2010 "aircraft age pyramid" for all five segments, with each average aircraft drawing benefit from a 40 year leap in technological improvement.

As a combined result of technological improvements, greater capacity and average stage length and fleet restructuring, overall fuel consumption will be improved by 35% in terms of consumption per seat and per kilometre, not including the benefits of improved load factor and any new ATM organisation.

Fuel consumption of the fleet will thus increase by a factor of 1.85, while RPK will more than triple (x3.1).

A sensitivity study of results for fuel consumption, keeping total RPK constant and varying the operational parameters (R1 and C2), indicates that the results are robust, with fuel consumption being almost proportional to RPK demand.

The cumulative noise level at the 3 certification points will improve by between 15 and 25 EPNdB for turbofan aircraft. This improvement will be obtained at the expense of a smaller reduction in fuel burn. Installation of engines with contra-rotating propellers would result in noise levels higher by some 10 EPNdB compared to turbofans of the same generation.

The main conclusion is therefore: market requirements - as specified by the "Market volume" working group, i.e. RPK multiplied by a factor of 3.1 - can be met with a fleet of 42,000 aircraft, burning 1.85 times the fuel of the 2010 fleet (20,331 aircraft). The length of the average stage will increase slightly and capacity and load factors will increase respectively by 25% and 9%.

The operating savings resulting from these new characteristics and performance will succeed in limiting ticket prices rises (+10%), without pressure on selling prices, in spite of a likely doubling or tripling in fuel price.

7.3. AIRCRAFT MANUFACTURING CHARACTERISTICS AND PRESERVING EUROPEAN LEADERSHIP

7.3.1. Main characteristics of the aircraft manufacturing industry

The aircraft manufacturing industry plays a multi-faceted role in air transport:

- *conducting the necessary research activities, developing new models and new versions, supporting serial production of aircraft to be delivered and covering their type certification process;*
- *delivering aircraft with the associated documentation (individual certification, operation and maintenance...);*
- *supporting the in-service fleet, providing solutions to meet evolving airworthiness requirements, in-services issues, new requirements from airlines.*

These activities are carried out by a broad, international network made up of aircraft manufacturers and their suppliers and, increasingly, systems and equipment manufacturers with direct product support responsibilities.

In this context, it is important to consider the following factors, which affect the evolution of the aircraft manufacturing industry:

- *the political will on the part of certain countries to enter the sector;*

- *the anticipated growth of the fleet;*
- *rapid technological progress, in particular thanks to the growing contribution of electronics (a systemic approach for aviation is more and more necessary, given the importance of the interactions between functions);*
- *the evolution of airworthiness requirements, especially when applied to in-service aircraft;*
- *adaptation of skills to these evolutions. This results, on a worldwide basis and in accordance with WTO rules, in:*
  - *a more global organisation of the aircraft manufacturing industry in 2050 with two segments :*
    - *below 150 seats, with several competing aircraft manufacturers and an extended enterprise based upon partnerships or competition,*
    - *over 150 seats, with a limited number of aircraft manufacturers (maximum of three), cooperation agreements and an extended enterprise based on selection of suppliers after competition with due respect of the cooperation agreements,*
  - *an increase in product support activities for in-service aircraft:*
    - *maintenance activities with dedicated bodies,*
    - *activities associated with in-service aircraft follow up and retrofit will be shared between specialised companies and aircraft manufacturers/extended enterprises, with the latter maintaining the necessary competences,*
  - *a recognition of the need to increase competitiveness, in a global context with major technological opportunities and high customer expectations (airlines, passengers), which justifies R&D efforts into new, innovative products.*

7.3.2. Preserving the European industry

The European aircraft manufacturing industry holds a leading position worldwide thanks to its aircraft manufacturers and its contribution to the different fields of the extended enterprise. It plays a major role in the economic and social life of Europe. The vision for 2050 is to preserve this position by implementing the following recommendations:

To preserve a prominent worldwide position and an industrial base it is vital to maintain the design and production skills required for European aircraft manufacturing.

In an open, worldwide market it is important to act globally through WTO and ICAO and set the following stringent rules:

- ***no unfair competition**, which means respecting the same rules in terms of state support;*
- ***shared standards** and high quality, ensuring passengers' safety and comfort…*

Europe must thus:

- ***design and produce the best products****, at acceptable costs, aiming to satisfy market demands better than the competition;*
- ***maintain knowledge, know-how and experience transfer*** *thereby offering attractive jobs to students with high qualifications and training; on the industrial side, maintain a reasonable level of strategic manufacturing capacities;*
- ***improve current technologies*** *leading potentially to a significant improvement in fuel consumption (approximately 40% as will be seen later, thanks to gains in all fields: aerodynamics, structure, propulsion...);*
- ***carry on investigating new "innovative" configurations****, in particular a more efficient integrated propulsion system;*
- ***increase the level of automation*** *in order to improve the safety rate, keeping the human contribution to a managerial role to cover unexpected conditions (for example a new flight system involving an onboard engineer-pilot combined with a ground capacity to monitor, provide assistance and, if necessary, take over control);*
- *at a European level, it is important to make the best possible use of available resources while prioritising the most promising innovations.*

Important note: *The Chinese market is without doubt a crucial one and cooperation with China cannot be avoided. But this cooperation must be carried out on a fair basis, by which European knowledge and know-how is preserved and off-shoring limited to the essential.*

8. NOTE ON HELICOPTERS

It was decided not to include helicopters in this study, on the one hand due to lack of data and, on the other, because rotorcraft developments are not expected to have a significant impact on main air transport orientations as outlined above because of the predominance of aeroplanes.

However, it is worth noting that since helicopters do not require long runways, they are an ideal complement to planes for specific sectors and missions. Moreover, the use of rotary wing aircraft, with their distinct approach procedures and dedicated landing areas, could improve airport accessibility, although much remains to be done to facilitate the coexistence of planes and helicopters on major airports.

As is the case with short take-off and landing concepts, rotorcraft will not represent a significant air transport offer due to their excessive energy consumption and limited capacity. The noise levels produced in certain phases of flight close to the ground will also have to be considerably improved if urban links are to be developed. However, increasing affluence in some emerging countries, together with the advent of automatic systems easing the pilots' task, would seem to suggest that the market will grow faster than that of commercial airline transport.

New (mixed) concepts are currently under development but additional studies will be required to assess their properties and chances of success, and to judge whether they are capable of winning a sizeable market in the future.

9. ENERGY

The energy topic owners have focused on verifying jet fuel availability in the quantity required by 2050. This evaluation uses the results of other themes like the "Market Volume" topic, which predicts an annual worldwide GDP growth of 2.8% associated with a jet fuel price of up to $250/barrel, including all eventual taxes, and the "Aeronautical Manufacturing" topic that, with technological improvement, predicts for 2050 a worldwide fleet size and aircraft model distribution close to those foreseen by Airbus and Boeing for 2030.

A strong link exists between the "Energy" and the "Environment" topics, as CO_2 emissions are strictly proportional to fuel consumption. So, the fuels substituted for conventional jet fuels will have to significantly reduce the environmental impacts of aviation. Two main results of this study can be highlighted:

- *the aviation development forecast will lead to double 2010 jet fuel consumption by 2050 even with industry improvements during this period, requiring 450 to 500 Mt (millions of metric tons) of jet fuel per year;*
- *conventional jet fuels derived from fossil resources will be very likely scarce and expensive, justifying giving particular attention to alternative fuels.*

As a result, the following recommendations are made:

- ***the uncertainties of crude oil production and of aviation consumption are such as to justify the supply of jet fuel being carefully studied and safeguarded;***
- ***up to 2030-2040, conventional jet fuel will satisfy the air transport requirement, subject to raising the jet fuel distillation fraction from 6 to 10%, which is technically possible. This change will lead to lowering the gasoline and gasoil fractions or using more cracking, to the detriment of other business sectors. Going to 10% is not enough to meet the 2050 objective, encouraging starting now the study of alternative fuels, reaching about 100Mt per year production of these in 2050.***

Going to hydrogen or electrical motors appears today feasible in the second half of the century, at best. These solutions come up against either technological obstacles (hydrogen and electricity storage and associated systems are not expected to *achieve the energy and the power density needed for aeronautical usage), or economic (high hydrogen cost linked to massive means of production and the need to build specific aircraft).*

9.1. CONVENTIONAL JET FUEL AVAILABILITY

Jet fuel is one of several crude oil distillation fractions. The current proportion of jet fuel derived from crude oil varies from one author to another: these data are in fact consistent, as non-aeronautical kerosene is sometimes also counted in the same fraction, thus changing the numbers. Conventional jet fuel availability depends on crude oil availability, leading to the crude oil forecast and more generally the energy forecast being of interest. It is also dependent on the refining techniques used.

Commercial aviation is moreover being asked to strongly reduce its environmental impact on climate and air quality. This will be partly enabled by technical improvements in aerodynamics, structures, propulsion and air traffic management but this will be not enough.

This is the reason that bio jet fuel could help in achieving the expected reduction, as biomass growth absorbs atmospheric carbon dioxide. We will see later that the usefulness of the environmental benefit of bio-fuels has to be carefully evaluated.

Fuel production in the next few decades has been the subject of numerous predictions carried out for various reasons by national and international organisations, oil companies, and various "think tanks". The results have a wide scatter: for example, predicted 2030 oil production varies from 65Mbl/d (65 millions of barrels per day or 3 billion tons per year) to 140Mbl/d (about 6.5BnT per year), current production being 86Mbl/d (4 BnT per year). Some predict a decline in oil production, others continuing moderate growth. Behind these divergences lie different assumptions, some predictions taking into account solely conventional oil, others including non-conventional oils such as gas condensates and tar sands…

A middling hypothesis is to use a ceiling of 90-100Mbl/d sometime between 2030 and 2040. This will lead, on one hand, to difficulties in increasing jet fuel production up to the level required by market demand, and on other hand probable tensions on jet fuel price. Using this hypothesis 2050 production would be in the range of 80-95 Mbl/d (3.5-4.4BnT per year).

There are two approaches to make up the shortfall in jet fuel: either using more fossil resources, or, developing renewable resources.

9.2. INCREASED USE OF FOSSIL RESOURCES

Whatever the assumed strategy, the aeronautical community has chosen the "drop-in" concept, that is to say alternate fuel with properties close to the essential characteristics of conventional jet fuel, so as to minimize the changes to in-service *and in-development aircraft, because the life of an aircraft type, between the certification of the first aircraft and the retirement of the last aircraft is longer than 50 years. These essential properties address energy (slightly lower heating value and density), and physical properties (low waxing point & high flash point temperatures, similar viscosity). A specific point is the aromatics ratio of the fuel. This ratio has a positive impact on the fuel's lubrication properties and compatibility with seals, but, increases soot emissions, as the aromatics are precursors of soot. It has been established that the first generation agro bio-fuels (ethanol or ETBE and Bioester) are not suitable for aeronautical use.*

An aviation-oriented possibility has been developed by (2)[7]*, consisting of enlarging the proportion of the jet-fuel fraction up to 10% of crude oil. This does not involve significant technical problems with existing refineries. This increase would allow the 2050 jet fuel shortfall to be reduced to about 100 million tons. Nevertheless, as the kerosene fraction lies between those of gasoline and gasoil, this will require arbitration favourable to jet fuel, to the detriment of gasoline and gasoil, which are mainly used for road traffic. There are only three ways to perform this arbitration: drastically improved road vehicle efficiency, fuel price or government regulations.*

The following figure compares kerosene production with the 10% ratio and the AAE FC's prediction of jet fuel consumption, which is lower than that predicted by the industry.

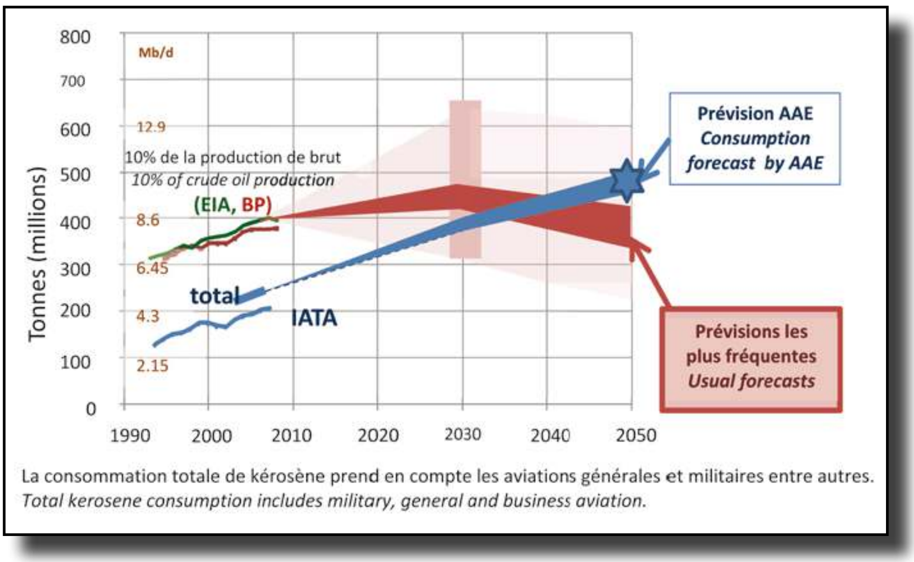

Figure 8: ***Jet fuel consumption forecast***

7 *The presentations of the different speakers are identified as follows in this chapter:*
(1) Xavier Montagne, Sources of Energy Sources for air transport, Introduction
(2) Gérard Théron, Sources of Energy for Air Transport, view of the FC
(3) Jim Hileman, Fueling Aviation in 2050, view of the (US) FAA
(4) Jean-François Garnier, Biojet Fuels, Renewable Sustainable Aviation Fuels, Total Aviation Fuel Department

More extensive hydro cracking of other crude oil fractions would allow 15% kerosene, with enough gaseous hydrogen input and an associated cost increase. This approach will not allow the air transport CO_2 emission reduction environmental objective to be achieved. "When all is said and done, the 10% option will not meet the 2050 demand, the 15% one could do it but push back problems to the refining technologies and the competing demands."

A second possibility is to use other fossil resources like coal and natural gas. The advantage of coal is its comparative worldwide abundance (less so in Europe), as the reserve to production ratio is close to 400 years. Coal to synthetic fuel transformation is a well-known technology since the 1930's. (Bergius and Fisher-Tropsch processes); SASOL (South Africa) presently produces internationally certified CTL (Coal to Liquid) synthetic kerosene.

Unfortunately, CO_2 emissions within the life cycle, (Well to Wake) are about 2.5 times higher than conventional jet fuel's. A way to reduce the CTL CO_2 emissions down to conventional jet fuel levels requires carbon capture and sequestration (CCS) for the transformation; however this technology is not yet mature and will require huge investments. To put things into perspective, 100 Mt CTL yearly kerosene production would need about 8% of current coal production.

Natural gas would be more advantageous as a fossil resource as it is already a hydrocarbon blend, with a large proportion of methane. Its transformation into synthetic SPK (Synthetic Paraffinic Kerosene) jet fuel is a well-known process (Shell, Qatar, ENI-IFP) and is much more efficient than for coal: five tons of coal are needed to produce a ton of CTL kerosene, whereas only two tons of gas are needed for a ton of GTL (Gas to Liquid) kerosene. The Well To Wake (WTW) life cycle analysis of its production shows that without CCS, GTL's CO_2 emissions are 15% higher than those of conventional jet fuel and with CCS, at the same level as conventional jet fuel. GTL could be a good transitional fuel to take over from conventional jet fuel, but will not bring any environmental progress and probably will have to face strong competition from other users, in particular electricity production and domestic heating, despite the recent production of shale gas. The natural gas prospective analysis has not yet been carried out and will have to be done later; for information, 100 Mt GTL yearly kerosene production would need about 8% of current natural gas production.

It is seen without surprise that only the biofuel option can potentially meet the different environmental challenges facing civil aviation in 2050 and beyond. Biofuels, are by nature renewable, and also could be sustainable: In fact, they could simultaneously compensate fossil resource depletion and produce a substantial environmental benefit.

9.3. BIOFUELS

All four presentations address biofuel developments, (4) being totally devoted to this topic. Biofuels are frequently claimed to be the sole solution for the future, but as reference (4) says, too often this is optimistic communication or a marketing approach. It is appropriate to tackle the biofuel subject with a critical eye, without leaving the open questions hidden.

First generation ground transportation biofuels are agro biofuels, that is to say biofuels based on farm crops such as rape and sunflower seed in France, soya bean and corn elsewhere; for example 40% of the corn produced in the United States is converted to ethanol. The life cycle analyses of these agrobiofuels show a poor to negative environmental benefit and clearly lead to competition between human or animal food and renewable biofuel production.

The aeronautical community, educated by the first generation ground transportation biofuel experience, bases its "drop-in" approach on new generation, naturally renewable and sustainable biofuels.

Various production possibilities have been studied and used for successful demonstration flights, in particular by Lufthansa for six months: nevertheless, biofuel compatibility with engines and aircraft during close to 100 000 flight hours in extreme temperature and pressure conditions has not yet been verified.

Ref (4) shows the main processes currently being developed:

- *synthetic gas production from biomass, then synthetic gas transformation into liquid hydrocarbons using the Fischer-Tropsch process, then refining them to produce bio Jet-fuel: these are the FT-SPK (Fischer-Tropsch Synthetic Paraffinic Kerosene) or HEFA-SPK Hydrogenated Ester and Fatty Acids-SPK) processes producing a BTL (Biomass To Liquid) or a WTL (Waste To Liquid) kerosene;*
- *oil hydrogenation: this is the HEFA-SPK or HRJ ("Hydrotreated Renewable Jet") method. Oil can be also produced by biomass pyrolysis;*
- *sugar and biomass fermentation: this is the FRJ ("Fermentation Rewewable Jet") process. The fermentation produces alcohol which is then transformed into hydrocarbons (ATJ for Alcohol To Jet).*

Numerous issues still remain to be addressed before mass production. The most significant ones are:

- ***The sustainable nature and environmental benefit of biofuels**. Ambitious objectives have been set in Europe (60% reduction of greenhouse gas compared to fossil fuels) as well in the United States (50 to 60% reduction of CO_2 emission). Environmental benefit evidence has to be carried out using a detailed life cycle analysis. Some claims are very optimistic; for example ref (4)*

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shows benefits of 65% for bio-SPK using jatropha curcas and 82% for bio-SPK using camelina, when ref (1) mentions that only switchgrass. miscanthus and SRC (short rotation coppice) can achieve 60%, and ref (3) points to palm tree, camelina, switchgrass and micro algae feedstocks. There are two explanations: the life cycle analyses do not include the same emissions topics, in particular direct and indirect Land Change Use (LCU), and the yield, for example in litres/ha/year for oil is heavily dependent on the cultivation methods; it is possible to increase yields using fertilizers and irrigation, but at the cost of increasing emissions and reducing the life cycle analysis benefits.

- ***Biomass availability**. This assumes land is available. The yield of the land is very dependent on the geographic and climatic conditions, as well on whether it is farmed intensively or by artisan farmers. A study was carried out on this topic distinguishing between the dedicated ground plants (jatropha curcas, camelina, salicornia), the use of rough biomass and biomass wastes and micro-algae cultivation. 100 Mt of biofuel production in the 2050's may be possible using the world's unused lands if intensive farming is used. Nevertheless, two arguments show that this is unrealistic: the priority will likely go to food production and the available biomass will be subject to competition from other users. On top of this, the bio refinery concept is based on the production of optimal value, and it is to be feared that the priority will not be road and aviation fuels. This is why the energy mix concept seems the realistic solution: all the various resources must be used together.*
- ***Synthetic paraffinic kerosene price**. Beyond political issues like embargos and energy independence, the price of crude oil and will be deciding factors for biofuel viability. Ref (3) cites USD110 to 120 per barrel in 2030. Biofuels, especially those manufactured with micro-algae, are still more expensive than conventional fuel. Their costs will be a heavily dependent on the available biomass and on competition between the potential users. The investments needed for the production facilities to be able to produce about 100 Mt a year of biojetfuel would amount to hundreds of billions of dollars. To reduce the necessary investments, (4) proposes to look for synergies with existing oil installations for refining, logistics and marketing.*

9.4. CONCLUSIONS AND RECOMMENDATIONS

To allow commercial aviation to develop to 2050, it will be necessary to increase the proportion of the jet fuel fraction extracted from crude oil, and/or to manufacture alternate fuel from other fossil resources with CO_2 sequestration, and/or use biomass while satisfying the environmental requirements. The jet fuel produced must be “Drop in” compliant.

Alternate jet fuel prices have to be competitive compared to conventional Jet Fuel, which will be possible only with optimised production processes, adequate primary *energy (coal, gas and biomass) and extensive investments in due time. It has been estimated that the fossil or sustainable resulting jet fuel balanced price would be between $200 and 250 per barrel as indicated in the introduction. This last value has been used by the other themes and the "market volume topic" in particular. A lower price may lead to a demand increase with more difficulties to produce the necessary fuel volume.*

Considerable competition between users will occur, for both primary energy and final products. This could lead to a price war and/or high level worldwide arbitration.

The analysis and the decisions to be taken to secure fuel for air transport could be done only through an organisation including all concerned bodies, energy providers, and aviation and administration actors to achieve the needed arbitrations between the users of the available energies. This will have to be done taking into account the global impacts, in particular the impact of aviation on the economy and society. The air transport representatives must be watchful that its social and economic role has been judged at its true value.

NB: in terms of energy, the growing exploitation of shale gas recently might impact the availability of oil for transformation into kerosene for aviation. This effect should be assessed at a later date, given possible future restrictions on this exploitation (what will the ceiling be?).

10. OPERATING STRUCTURES AND FARES

10.1. SUMMARY OF ASSUMPTIONS

Demand in terms of passenger/kilometres will triple between 2010 and 2050, while the number of commercial flights will double (x1.2 in Europe, x1.6 in North America and x2.9 in the rest of the world), with an average payload increasing from 96 people per plane in 2010 to 128 in 2050 and a slightly longer average trip.

The number of aircraft will therefore double between 2010 and 2050. The maximum size of aircraft in 2050 will still be 80m long x 80m wide.

The share of vertical and short take-off and landing aircraft will remain marginal. Airport runways will be as long in 2050 as they are currently and will remain located outside urban areas[8]. Trips for personal reasons (tourism, family), already the majority, will increase more than business travel.[9]

We assume that in 2050, air travellers will continue to pay for all services provided and for most of the infrastructures used.

10.2. RETAIL TICKET PRICE

An airline's "average" ticket retail price is given by dividing air transport passenger turnover by the number of passengers carried.

***In 2010, the average global retail price per trip was $178 US** (passenger turnover of all airlines in the world not including supplements - $463 billion - divided by 2.6 billion passengers), i.e. **$0.097 per km** with an average distance of 1,833 km according to ICAO sources (annual Council reports for 2011 and previous years[10]).*

8 AAE Dossier 33: "Airports and their Challenges", November 2010.

9 Oxford Economics, Amadeus, "Gold rush 2020, Profitability trend in the travel sector", October 2010.

10 Websites of airlines, airports, ICAO, IATA, AEA, ACI, ADPI, etc.

The table below, drawn from the accounts of 16 major legacy airlines gives a breakdown of average ticket price in 2010 and its projected evolution in 2050 with the following assumptions:

- ***productivity gain of 1% per year** between 2010 and 2050, i.e. a rounded coefficient of 0.7 applied to all items, with the exception of fuel and airports (for the latter, productivity gains will be offset by increased costs of security),*
- ***fuel price set at $250 US per barrel** (inclusive of VAT) in 2050 (3.125 times the average price of $80 US in 2010), environmental charges included: given an estimated increase in energy efficiency of 35%, the fuel item would be multiplied by 3.125 x 0.65 = 2.03 between 2010 and 2050. This cost is chosen because at this price, it will be possible to manufacture kerosene from various sources other than fossil fuel.*

The items "maintenance", "stopover services" and "selling, general and administration" do not include operators' personnel wages, which are grouped under the section related to "staff".

Going by these assumptions, the average fare in constant currency value could rise by only a little over 6% between 2010 and 2050 for the same distance.

*Composition of **retail ticket price** according to various airlines' accounts*	***2010 % range***	***Average ticket 2010 sold** for 100 units (u)*	***2050 ticket** for the same distance as in 2010*
Aircraft + maintenance	*14 to 20%*	*17 u*	*11.2% 11.9 u*
Fuel	*22 to 28%*	***25 u***	***47.8% 50.75 u***
Staff	***12 to 32%***	*22 u*	*14.5% 15.4 u*
Air traffic control charges	*3% to 4%*	*3.5 u*	*2.3% 2.45 u*
Ground handling services and catering	*6 to 12%*	*9 u*	*5.9% 6.3 u*
Airports (real estate, environment and security)	*8 to 11%*	*9.5 u*	*9.0% 9.5 u*
Selling, general and administration + margin	*10 to 18%*	*14 u*	*9.3% 9.8 u*
Total	*100%*	***100 u***	***106.1 u***

Table 5: Composition of retail ticket price

***The range of staff costs is particularly wide** due to wages and particularly to the very different social security charges and working hours depending on the airline and the country.*

- *The hypothesis of a productivity gain of 1% per year for 40 years is in line with industry practices as a whole for the past 40 years. This may seem optimistic because of the additional expenditure involved for environment and security. A gain of 0.75% instead of 1% per year would increase the ticket price by about 10%, instead of 6.1%.*
- *The same figure emerges (ticket prices up by 10%) if the gain in energy efficiency was of only 30% instead of 35%, all other things being equal.*

*A trend can be noted on the part of **short/medium haul legacy airlines to align fares on low-cost carriers' prices**, especially if ancillary revenue is added to the price of an average ticket (hold luggage, on-board services, rebooking ..., sometimes even grants accorded by local councils to attract airlines to their airports). This income, still marginal for legacy airlines, represents up to 25% of revenue for low-cost carriers.*[11]

*Conclusion: **even if the price of fuel tripled, with crude oil at $250/barrel in 2050, the average ticket price per km in constant currency would increase by only 10% between 2010 and 2050.***

However, this forecast breaks with the drop in average retail ticket price per kilometre observed up until 2000.[12] *The broken line between 2010 and 2050 means that the evolution will be irregular, mainly depending on fluctuations in oil prices, while the green line representing prices excluding fuel is more regular.*

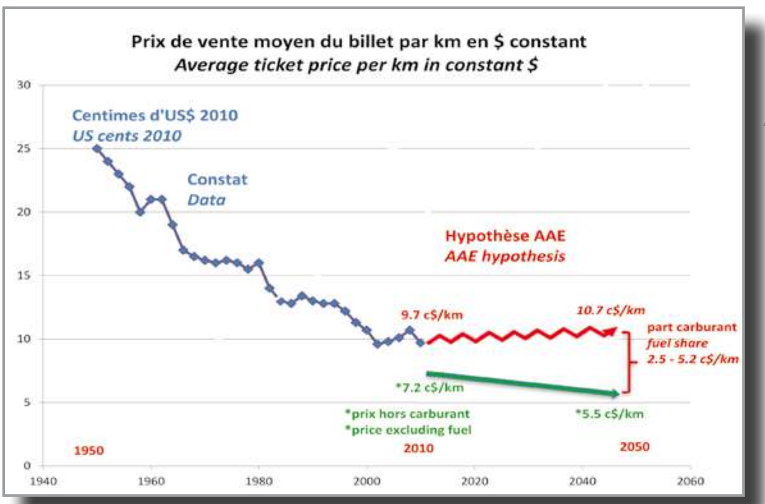

Figure 9: *Average ticket price*

11 Oxford Economics, Amadeus, "Gold rush 2020, Profitability trend in the travel sector", October 2010.
12 Stanford University, "Evolution of average fare by air transportation", 2006.

10.3. TRAFFIC RIGHTS AND AIR TRANSPORT DEVELOPMENT

According to the Chicago Convention (1944), air traffic rights belong to states that designate operators of air routes departing their territories. For domestic flights, the choice is made in principle between national operators, that is to say operating fleets registered in the state with crews that have national licences. For international flights, bilateral agreements between states designate, in principle on the basis of equal capacity offers, carriers from both states to operate them.

In 1978, US deregulation did away with the designation for US domestic flights whilst still reserving them for American operators. Then Europe did likewise in 1986-92 for domestic flights within the European Union and for European operators. Finally, the US and Europe agreed (2007 Open Skies Agreement) to deregulate transatlantic flights between European countries and the US. Europe also entered into comprehensive agreements with Morocco in 2006, Canada in 2009 and a few other countries. The effect of these changes has been an increase in transport supply and a clear drop in costs, as well as a shake-up of airlines, with a growing share of the market going to "low-costs", to the detriment of legacy carriers.

***But the majority of intercontinental flights are still governed by bilateral agreements between states** and changes to these regulations are down to each pair of states. The general trend is to deregulate within free trade zones. In the past 10 years, the number of "deregulation" agreements has tripled, involving 32% of global routes in 2011, corresponding to 57% of flights, according to ICAO[13]. "International" deregulatory decisions that could still be taken by states would have a strong impact on the future of their operators, especially when major differences exist in charges between flags. It is therefore necessary to **ensure that any such deregulation is carried out properly** (cf.10.6).*

10.4. AIRLINES

*There are over **1,000 "scheduled" airlines in the world**, the largest of which (230) belong to IATA, excluding low-cost carriers. These legacy airlines frequently form alliances to streamline their services and offer passengers the choice of a global network. The **three global alliances** - Oneworld, SkyTeam and Star Alliance – account for 2/3 of global air transport.*

Some major airlines such as TWA, Sabena and many others have disappeared. In 2010 the main airlines were the Lufthansa Group (turnover of US $34.5 billion) with 744 aircraft, United + Continental group ($34 billion, 700 aircraft), Delta Air Lines $31.8 billion, Air France-KLM $30.3 billion, American $22.2 billion, IAG (British

13 Websites of airlines, airports, ICAO, IATA, AEA, ACI, ADPI, etc.

Airways + Iberia), Emirates $16 billion, Southwest $12.1 billion, the first low-costs, etc. Chinese airlines are rising fast in the world rankings.

In terms of results, however, the ranking is very different, with Emirates at the top ($1.6 billion profits in 2010) and several "low costs" very well placed. For a long time, airlines have shown a chronic lack of profitability. The CEPS[14] notes that return on invested capital has never exceeded 7% despite a growing market. For 10 years, airlines have experienced heavy losses and few profitable years and much concern has been expressed about their future[15], which has not prevented certain states or authorities introducing additional taxes (in Europe and India for example!).

Airlines are ***service companies and are highly sensitive to worldwide events with few "entry barriers"*** *and little "captive audience". Leasing an aircraft is a relatively simple affair, there are plenty of pilots and other professionals available, the number of routes has increased significantly and travellers can easily compare offers online.* ***Competition is thus particularly fierce****.[16]*

The system of bilateral traffic rights maintains the quantitative balance of supply between two states, but obviously does not guarantee balanced revenue. Combined with the rule limiting the proportion of "foreign capital" and with requirements in terms of crew licenses and aircraft registration, it plays a protective role vis-à-vis uncompetitive operators. However it also contributes to low levels of profitability by making mergers between two 'foreign' airlines very difficult, thus breaking up the market. A way must be found (see §10.6) to rationalise the market and allow a reasonable number of airlines (much lower than today) to provide services under acceptable economic conditions.

The ***short/medium haul*** *will be operated by all carriers on today's "low-cost" model, with the goal of faster turnarounds and lower overheads. Indeed, many legacy carriers are creating low-cost subsidiaries, sometimes conferring all their "point to point" connections to them, as Lufthansa did with Germanwings in early 2012 (with the exception of its Frankfurt and Munich hubs, but for how long?).*

The ***long-haul sector*** *will of course be monitoring costs and will make certain options payable (e.g. rebooking) even if long-haul low-cost initiatives rarely last (Air-AsiaX, for instance, recently closed its Paris-Kuala Lumpur link, opened less than 3 years ago).*

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14 CEPS Centre for Study and Strategic Prospective, Arthur D. Little, "Is air transport activity a profitable business model?", 8/02/2012

15 AAE conference, Toulouse, May 2012, "Flying in 2050", with presentations notably from the following speakers:
- *Gilles Bordes-Pages "What visions do airlines have of their future?"*
- *André Deistler "Airports in 2050",*
- *Marc Noyelle "Airports, airlines and ticket price."*

16 Henri Gueusquin "la concurrence économique dans le transport aérien", 2005.

10.4.1. Commercial fleets

In 2010, there were about 21,000 commercial aircraft (excluding 2,000 freighters) in regular operation: 15% long-haul (LH), 50% medium-haul and 35% short-haul.

Certification of an aircraft allows for a ***lifetime of several decades so legacy companies' fleets are (and will continue to be) composed of aircraft*** *of very different ages. Low-cost airlines generally have standardised fleets, often with newer aircraft, which simplifies maintenance and helps to optimise aircraft operations.*

Average annual aircraft flight time *in 2010 was 2,500 hours for short and medium-haul (more for low-costs), and over 4,000 hours for LH. It will be higher in 2050 for short and medium-haul with a faster aircraft turnaround, thanks to more efficient ground processing and less time-out for maintenance.*

To meet demand, the ***number of commercial aircraft will double by 2050*** *(42,000 in all, not including freighters).*

10.4.2. Hubs

The search for productivity and new traffic led to setting up ***hubs****, in which successive waves of short and medium-haul arrivals are followed by long-haul flights departures in an effort to better fill the latter. There are about 40 major hubs and 100 secondary hubs[18]. Connection time between the last short/medium haul arrivals and the first long-haul departures must be kept to a minimum. But this drastic reduction of MCT (minimum connecting time) is expensive both for the airport, which must be equipped with high performance luggage transfer for instance, and for the airline which guarantees the journey end to end and has to deal with all unforeseen circumstances.*

At Dubai (LH/LH), on the contrary, there is often more than 3 hours transfer time so as to encourage travellers in transit to make purchases in the 24 hour shops, or to use hotel rooms built inside the vast, magnificent boarding halls.

The optimising of airline networks around hubs is a lasting feature because it alone enables the productivity gains and environmental efficiency brought by large aircraft. ***The growth of large hubs will thus be significantly higher than the average****[17]. They are even beginning to attract some low-costs, which can also feed into long-haul flights. It is possible that a very small number (well under 10) of new major hubs will be created to optimise networks by 2050 (see §10.5.1).*

17 BCG, Boston Consulting Group, "Airports – Dawn of a new era", 2004.

10.5. AIRPORTS

10.5.1. How many commercial airports by 2050?

Airport capacity

The capacity of an airport depends on ***four aspects****:*[18] *two "air" factors (runways and aircraft capacity), and two "ground" factors (terminal capacity and environment):*

- *The theoretical capacity*[19] *of a* ***runway*** *is currently close to 250,000 movements (mvt) annually. The real capacity depends on opening hours, local geography, climate (separations between planes must be increased in bad weather), type of demand (peaks of traffic) and size of aircraft (the wake vortex created by a wide-body requires greater separation with the next plane).*
  For example, Paris-CDG today with its 4 runways has a programming capacity (timetable) of 120 aircraft movements per hour which in good weather conditions allows significantly more movements. With 500,000 movements per year, CDG is far from being saturated, although the pressure of demand at certain peak times is very high. London/Heathrow handles 475,000 movements per year on only two runways with poorer weather and larger aircraft on average.
- ***Average payload*** *was only 96 passengers per flight in 2010, lower in the US*[20] *than in the rest of the world because of the large number of regional flights with small payloads*[21]*: 75 passengers per plane at Chicago/O'Hare, 115 at CDG, 150 at Heathrow and close to 200 at Jakarta, Dubai and Tokyo/Haneda whose runways are often saturated.*
  Average payload is increasing quite rapidly and could be ***128 passengers per flight*** *by 2050.*
- *On the "ground" side, the number of passengers an airport can accommodate depends on the number and size of* ***terminals****, the number of gates and whether they are equipped with boarding bridges and the* ***elimination of bottlenecks*** *which can vary according to size of aircraft and security and border control rules.* ***Investment is needed*** *so as to constantly adapt the airport to passengers' needs: sorting system and baggage delivery belt, police booths, customs and security check posts,* ***with sufficient staff available at the right time****.*
  The organisation of all ground and air services (aircraft maintenance, cleaning, refuelling, loading) naturally impacts airport capacity.[22]

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18 Marc Noyelle "Les aéroports du futur", Aéroports de Paris 2007 and CEAS October 2011.

19 Richard de Neufville and Amedeo Odoni, "Airports systems", McGraw-Hill 2005.

20 R. John Hansman, MIT, ICAT International Center for Air Transportation, "Airline Industry Trend Update", 2012.

21 NASA, Purdue University, "Metropolex Operations" 2008.

22 FAA, Fact 2, "Future Airport Capacity Task", 2007.

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- *Finally, airport capacity depends on the* ***environment with its two aspects: effective land access and urban planning*** *(to limit the impact of noise). §10.6 gives recommendations on these topics.*

Number of platforms

There were around 4,000 airports in the world open to scheduled commercial traffic in 2010 and 10 times more civil or military airfields, but only just over ***1,600 airports with more than 10,000 passengers/year****, of which 600 in North America, 400 in Europe, some 200 in Asia + Pacific, 200 in Latin America and 200 in Africa + Middle East.*

In 2010, ***500 airports handled over 1 million passengers****, 175 of which were in Europe, 120 in North America, 95 in Asia/Pacific, 65 in Latin America and 45 in Africa/Middle East.*

Nearly 30% of world traffic is concentrated on the 30 largest airports. The ranking of these airports is changing rapidly: Atlanta remains in the lead with just under 100 million passengers (MPax), Beijing-Capital moved from eighth place in 2008 to second place in 2010 with nearly 20 million more passengers in two years. Dubai is now in 12th place with 50 MPax, 4 times more than 10 years ago. Among the major airports, Jakarta, Hong Kong, Singapore, Guangzhou, Shanghai, Kuala Lumpur and Istanbul are also growing very rapidly.

By analysing each of the world's ***150 airports with over 10 Mpax****, it emerges that most could deal with 2, 3 or even 4 times more flights by 2050, or else rely on nearby airports, existing or new.*

Some regions will pose particularly tricky problems such as Tokyo Haneda Airport (but Narita could perhaps be extended). Hong Kong will quickly have to build a 3rd runway, Jakarta and Mumbai will need to search for additional sites as Istanbul airport has just done. The five London airports are all too small and a solution must be found (in the Thames Estuary, for example) to ensure decent access to London by 2050.

In practice, the number of commercial airports will increase in some parts of the world such as China, which is currently building dozens of new airports (along with an outstanding railway programme with more than 20 high-speed train lines!).

In Europe and the US, the number of airports, with a few exceptions, is sufficient to meet expected demand in 2050, but ***major investment will have to be made in and around many existing airports*** *(access, extensions and sometimes new runways) and effective means of land transport developed to enable some airports to operate as networks. Elsewhere in the world, nearly 200 new airport platforms will have to be built[23], in addition to adapting existing airports, in order to meet demand in 2050.*

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23 *Marc Noyelle «Airports of the future», Aéroports de Paris 2007 and CEAS October 2011.*

The number of commercial airports with more than one million passengers per year will rise from 500 in 2010 to 700 in 2050.

10.5.2. Improvements to services provided by airports

An airport must provide the services expected by its three categories of customer: airlines, their customers (passengers) and the many other users renting its spaces.

***Passenger services are constantly evolving**. The quality of service rendered to passengers is increasingly measured and "rated", and features in airport operators' performance contracts*[24]*.*

Security

*Security has become essential, but it takes time, causes inconvenience to passengers and can even be an assault on their dignity. Arrangements set up in airports between 2000 and 2010 - flow separation, efficient security checkpoints, etc. – take up **15% additional space per passenger**, a significant increase and one which is likely to continue.*

*Security is an **expensive "sovereign" activity**. In Europe, however, its cost is entirely footed by passengers, although this is not the case in some countries (e.g. US) or for other means of transport. It already accounts for over one third of airports' operating expenses.*

More efforts must be put into making malicious acts more difficult to commit in airports and into elaborating highly reliable checks that are acceptable to passengers.

New technologies will be available, large-scale scanners for instance for carrying out checks on passengers and their luggage in a corridor equipped with highly reliable sensors, where passengers will not be required to stop (except when justified of course).

Baggage handling

Baggage handling comprises check-in, security checks, sorting, loading, unloading and delivering tens of thousands of cases per day in the major hubs, with 2/3 of the passengers in transit. It is highly work intensive and very expensive. Many existing airports lack space to improve the situation whilst meeting new security standards.

The objective is to increase system throughput and performance with a luggage delivery time after arrival of the aircraft at its parking stand (block) of less than 20 minutes for passengers arriving at their destination, and a transfer time between aircraft holds of less than an hour for connecting baggage. Reliability must also be

24 *Dossier AAE 33: "Airports and their Challenges", November 2010.*

improved, and the number of wrongly routed cases divided by three, to achieve less than 1% error. IATA estimates that baggage routing errors cost its members alone \$3.3 billion annually[25] *and is encouraging "BIP" (Baggage Improvement Programmes). One example would be to integrate an RFID chip (Radio Frequency Identification) from manufacturing stage into all suitcases and travel bags designed for air travel.*

More mechanical aids should be installed to improve baggage handling working conditions*, as already tested at Nice airport and in Sweden, or even a fully automated system as in Amsterdam/Schiphol's new SBH (South Baggage Hall) which went into service in late 2012. This will take up even more space within the airport …*

Other services

Particular attention will be paid to passenger information *by all stakeholders thanks to systematic use of the geolocation facility of mobile phones and other devices. For check-in, e-services are developing very quickly. For border controls, the use of biometrics to simplify identification will probably become standard.*

Many services will become optional and therefore fee-paying*. In addition to traditional services such as parking (with several offers according to duration, possibility of reserving a space, etc.), a variety of shops (income from shops can represent almost a third of overall airport income, and even more in terms of profits), restaurants for all tastes (including local specialities), lounges, customised reception of individuals or groups, etc., the following "premium" services are or may be proposed*[26] *:*

- *"Fast track" or "fast travel" queue-cutting subscription service;*
- *personal assistance to persons of reduced mobility;*
- *relaxation areas and, in transit zones, hotel rooms bookable by the hour as already exists; in Dubai, Singapore and Paris-CDG;*
- *internet facilities, secretarial services;*
- *play or sports areas, spas, massage and beauty treatments, libraries, etc.;*
- *valet parking, porter services, etc.*

Retail concessions generate a significant, growing share of airport revenue*. The "dual till" principle can isolate this revenue so that it benefits airports alone: a certain redistribution of this profit and convergence of missions should be ensured in the future between airports - which provide the investment (but benefit from a territorial monopoly) - and airlines that "bring in" their customers.*

25 *Websites of airlines, airports, ICAO, IATA, AEA, ACI, ADPI, etc.*

26 *Marc Noyelle «Airports of the Future», Aéroports de Paris 2007 and CEAS October 2011.*

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Airport city or "Aerotropolis"[27]

Like all major transport intersections, airports generate commercial activities that go way beyond the simple transfer of passengers and goods.

They not only accommodate airlines, passengers and accompanying parties, taxis, rental cars and other means of transport, but also a host of service providers for passengers, aircraft, freight and mail, and numerous offices, hotels, import-export companies, convention centres, businesses, etc., attracted by this "border" location.

Airports are no longer regarded as simply places of transit and as a nuisance to the locals for the benefit of "foreigners", but as veritable cities, dynamic sources of wealth and jobs, which helps them to be accepted locally.

Roissy/Charles de Gaulle for instance generates about 100,000 jobs locally with more than 1,000 companies and twice as many indirect jobs[28], in a site that was almost deserted 40 years ago. ***These "airport cities" will continue to grow, creating local wealth.***

New airport concepts

To ensure the interface between aircraft (sky) and passengers (earth), the airport concept has evolved over 100 years[29] to better meet the ***demand for easy, "seamless" connections and pleasant surroundings***[30]*. These different concepts can be divided into three categories:*

1. *"No airport": an expensive dream, limited to helicopter or small aircraft users outside the scope of this study;*
2. *"Decentralised" with two variants:*
    - *"terminal in the city centre": by which baggage can be dropped off in this city centre terminal or at home, and essential services (baggage check-in, checks, etc.) are provided on dedicated, rapid public transport to the airport itself. But this attractive concept is fraught with* ***as yet unresolved security problems****;*
    - *"automatic vehicle" PAS = Passenger Airport Shuttles to get from point of arrival at the airport to one of the boarding lounges spread over the airport, completing formalities on the shuttle. However, this concept requires a lot of space and has not yet proven its feasibility;*
3. *"Compact": the basic idea is to assemble in one multi-storey building, with the shortest walking distances possible, all of the airport functions, from car parks*

27 *Kasanda John D., "Global Airport Cities" [Aerotropolis] 2010.*

28 *Websites of airlines, airports, ICAO, IATA, AEA, ACI, ADPI, etc.*

29 *Hugh Pearman "Aéroports, a century of architecture", Seuil 2005.*

30 *EU, "Flight Path 2050" 2011 and EU "External Aviation Policy Package", October 2012.*

and public transport terminal to boarding. But terminals seem to be unmanageable beyond a certain size (40 million passengers per year?), which means that very large airports must be equipped with several well-interconnected (people mover) terminals, possibly with satellites. An interesting variant was created in Dubai, where the main buildings are buried: only the huge boarding lounges (concourses) are above runway level.

More than one airport serving the same region is often not practical and can only function optimally if they are highly interconnected*, which is rarely possible.*

10.6. RECOMMENDATIONS

The "Airports and their Challenges" dossier published by AAE in late 2010 submitted 10 recommendations which the Foresight Commission incorporated, focusing on four of them and reformulating them as follows:

1. *Ensure that urban planning enables airport development and that airports do all in their power to harmoniously integrate into the local fabric. Value added by the employment created in the vicinity of the airport (Aerotropolis) and the local taxes it generates should contribute to this.*

2. *Ensure that land access (railways, roads, parking, taxis and other public transport) is comprehensive enough, practical and at a reasonable cost. In particular, a fast, comfortable, public transport link-up (rail if possible) to the city centre, as well as good connections with high-speed rail networks, are essential for major airports.*

3. *Review the entire baggage process: room in the aircraft, more effective handling systems, etc. Set up an international baggage tracking system which is reliable, economic and interoperable (eg RFID as recommended by IATA). These RFID chips could even be included in air luggage during manufacture.*

4. *New terminals must be large (surface per passenger) and flexible enough to meet growing security demands; they should offer the new services expected of them and noticeably improve quality of service as perceived by passengers and other users at all times.*

The FC adds four other recommendations to enable fair competition and competitiveness of air transport:

5. *Do not consider environmental constraints that are not global: no "regional" additional charges such as were proposed in Europe for the trading of CO_2 emission permits ...*

6. *Adopt on a global (or at least European) level the equivalent of the American "Chapter 11" for airlines because of their particular sensitivity to global and local economic conditions.*

7. *Ensure that social security contributions and legislation (on working time in particular), as well as taxes and other charges applying to deregulated routes and their supply networks, promote fair competition, before considering any new international deregulation.*

8. *Allow cautious but healthy consolidation of the sector by revising current legislation which restricts mergers between airlines of different nationalities (due to the states' requirements in terms of nationality of registration and professional licenses in order to use their traffic rights, and because of restrictive terms on the proportion of stakes hold by foreign investors).*

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11. ENVIRONMENT

11.1. THE ENVIRONMENTAL CONTEXT

Environmental issues (noise, local emissions and air quality, greenhouse gas and global warming) are closely linked to scientific, energy, geopolitical, economic and social issues. They involve multiple interactions between innumerable factors and actors and are therefore rapidly evolving. As a result, the 2050 horizon is ***clouded by uncertainties****. The underlying stakes are growing fast and matching efforts are needed in order to address them, reduce the level of uncertainty, take adequate measures and implement efficient solutions.*

In the technological and operational fields, efforts need to be reinforced and the correct balance found between the different disciplines and between upstream and downstream research.

Cross-disciplinary expertise should be developed, in order to better apprehend the ***multidisciplinary nature of environmental issues****.*

Implementation of proposed solutions, including those aimed at curbing the growth of air transport-related CO_2 emissions or keeping them within certain limits, must be properly refined and regulated, with a view to ensuring global optimisation, promoting equal treatment and protecting the viability of the sector.

A ***global assessment*** *of needs, assets and interactions should make it easier to manage interlinked problems.*

Finally, ***communication*** *on the environmental aspects of air transport should be enhanced, in an unbiased, professional way, so as to keep it robust, coherent and credible.*

11.2. NOISE

Noise limits are set by a strong, proven framework at national and international levels (ICAO standard[31]) which has stimulated technical progress and significantly reduced noise pollution (perceived noise reduced by 75%, cumulative noise, noise contours and exposure areas reduced). Stiffer limits have been periodically introduced, and certification procedures regularly reviewed and refined.

This overall trend should continue, despite the growth in air traffic, thanks to fleet renewal with enhanced aircraft. Thus, ***total acoustic energy could decrease by 15 to 20% between 2010 and 2050****, taking into account the evolution in air traffic and the technological benefits as analysed by the Foresight Commission.*

The decoupling of noise and traffic therefore appears plausible, even for the type of aircraft equipped with noisier counter-rotating open rotors (see figure 10). A similar improvement can be expected for rotary wing aircraft.

Those results would seem to indicate some room for manoeuvre on the noise side in the trade-off between noise and CO_2 (see thereafter). They do not however take account of local situations and should therefore be placed in context. In fact, on some potentially critical platforms with high traffic, noise will remain a major issue and will have to be closely monitored, factoring into the analyses and the regulatory framework all elements contributing to acoustic nuisance, especially:

- *acoustic spectrum characteristics that could impact perceived noise in the airport vicinity and possibly en route;*
- *the risk of noise disturbance generated by an isolated event[32];*
- *the exacerbating effect produced by cumulative/repetitive events.*

Asia presents a different situation to Europe and to the US; on the one hand, it has a faster growth rate in traffic but, on the other, a growing number of airports in which preventive measures can still be put in place.

The ICAO ***Balanced Approach*** *principle[33] should be applied everywhere, so as to efficiently manage noise issues around airports, both from an environmental standpoint and an economic perspective. The four main pillars to consider are: noise reduction at source, land use planning and management, noise abatement procedures and operational restrictions.*

31 ICAO - Convention on International Civil Aviation - Environmental Protection - Annex 16 - Volume I - Aircraft Noise. ICAO - Environmental Technical Manual - Volume I (Doc 9501 - vol.I)

32 The limit of the zone authorised for building construction - noise insulation included - must be adjusted to ensure that the noisiest recurring aircraft in the traffic does not exceed the acceptable noise intensity threshold.

33 ICAO - Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829 AN/451- 2nd Edition - 2008).

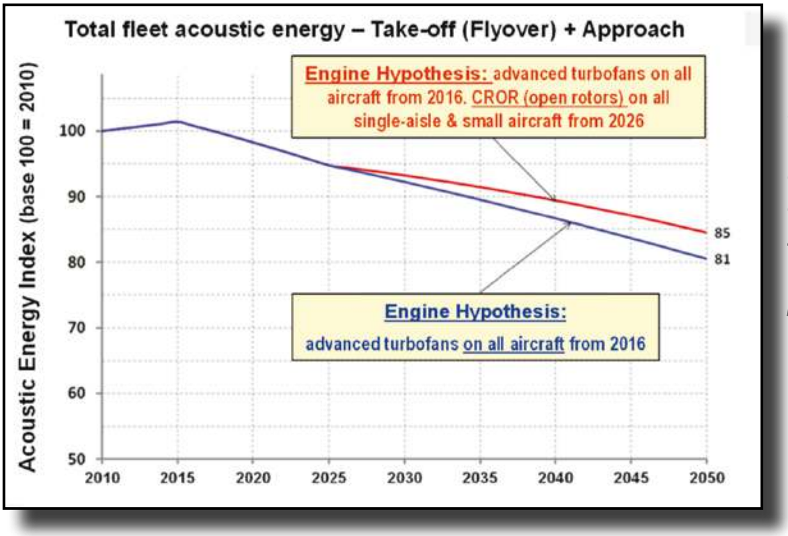

Figure 10: *Evolution of total acoustic energy 2010-2050 (FC projection)*

Noise reduction at source, a fundamental step in this approach, requires continued intensive research and development, with proper funding[34].

In order to derive full advantage from technologies and operational procedures, an authority should be set up, and reinforced whenever necessary, responsible for managing and controlling urban development plans as well as implementing the full set of applicable regulations*[35]*, while preventing any undue building construction.

11.3. LOCAL EMISSIONS AND AIR QUALITY

11.3.1. NOx

The overall situation of nitrogen oxides (NOx) is similar to that of noise, in the sense that total emissions will be relatively stable between 2010 and 2050 - according to FC forecasts for traffic growth, reductions in fuel consumption and NOx emissions - thanks to dedicated technological advances. The corresponding standard is thus periodically reinforced with an updating of the relevant engine certification procedures (ICAO[36]*).*

As is the case for noise, local situations concerning low altitude NOx emissions need to be carefully monitored, especially in places where air quality limits can be

34 Should the worldwide fleet significantly exceed the FC forecast, noise limitation constraints might stimulate a reshaping of the fleet (e.g. bigger aircraft, limited flight frequencies, more radical application of noise reduction technologies and operational procedures).

35 Appropriate grants to aid noise insulation, or even air conditioning, could fall within the responsibilities of such authority.

36 ICAO - Convention on International Civil Aviation - Environmental Protection - Annex 16 - Volume II – Aircraft Engine Emissions. ICAO - Environmental Technical Manual - Volume II (Doc 9501 - vol.II).

exceeded under the combined effect of various contributors. Although aviation is a minor offender when compared with surface access transport, the issue can put a curb on airport development (e.g. London Heathrow). It is also important to ensure that the results of research and development efforts into NOx emissions meet expectations.

Operationally-driven reductions in NOx emissions at low altitude through operational procedures can only remain minimal, inasmuch as procedures currently in use already restrict engine power, and therefore NOx emissions[37].

11.3.2. Particulate Matter

*Particles emitted by aircraft/engines are the object of **growing concern**, due to their impact on air quality and human health.*

*In aeronautics, scientific knowledge on particulate matter and the means to measure, quantify and assess its impact remain limited. **Research should be intensified**, possibly leading to a new specific ICAO standard in coming years.*

The involvement of particulates in cirrus cloud formation at altitude (therefore also impacting the greenhouse effect) is still very poorly understood. Further scientific progress is needed in order to improve our knowledge on this effect.

*The quantities of particulates emitted will benefit from reductions in fuel consumption and from an improved understanding of associated phenomena. Nevertheless, the combination of their impact and of the growth in total emissions will make particulates a **major issue in the future**.*

11.4. GREENHOUSE EFFECT AND GLOBAL WARMING

11.4.1. Global CO_2 emissions

Aircraft fuel consumption and CO_2 emissions have benefited from spectacular improvements in the past (more than 75%), thanks to concerted efforts to improve engines and aircraft performance, in response to growing mobility needs and a competitive, exacting market.

The aeronautics industry and ICAO have set ambitious goals for the coming years[38]: a 1.5% increase in fuel efficiency per year until 2020 (2% for ICAO), carbon neutral growth from 2020, and a halving of total CO_2 emissions by 2050 relative to 2005 (industry only). These objectives rely on strong governmental

37 *The correlation between NOx emissions at low altitude and during climb and cruising is such that the benefits of low altitude regulations and emissions reductions also reflect on total NOx emissions.*

38 *Air Transport Action Group (ATAG) - www.atag.org*

support, technological progress, optimised operations, air traffic and infrastructures, use of sustainable biofuels, and finally economic instruments.

The FC has analysed the various factors that will drive fuel consumption and CO_2 emissions between 2010 and 2050, and has forecast the following cumulative gains in fuel consumption per passenger.km: 25% from technology and new aircraft introduced, 31% when air traffic and operational improvements are factored in and 37% due to increased load factor. To this can be added a decrease in CO_2 production of 40% (cumulative) due to biofuels, and 47% thanks to various types of carbon compensation effects.

Since air traffic is growing at a faster pace than improvements (multiplier 3.1), total fuel consumption will double during the period, with total CO_2 emissions growing by a factor of 1.6 (see figure 11).

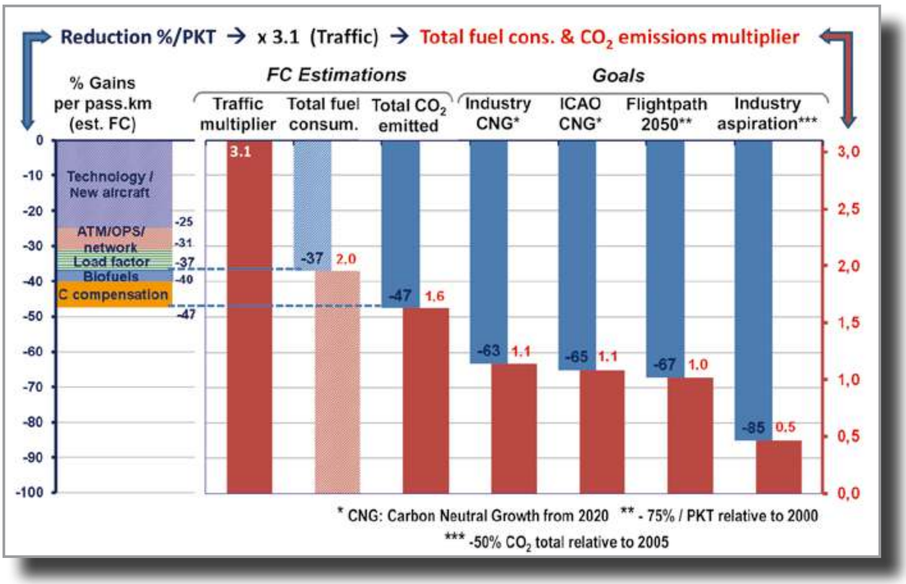

Figure 11: ***Fuel consumption and CO_2 emissions 2050 / 2010 (comparison: FC projection vs industry / ICAO / EU)***

These results, as shown in figure 11 above, are well below industry and ICAO goals, notably as far as "carbon neutral growth from 2020" is concerned (including biofuels). The FC's 47% compares with 63%/65% industry/ICAO goals, with a multiplier on total emissions of 1.6 (FC) as against 1.1 (industry/ICAO). The objective of halving total CO_2 emissions by 2050 relative to 2005 implies an even more drastic reduction: - 85% per passenger.km, taking into account growth in air traffic. The European objective of Flightpath 2050 (-75% in CO_2 emissions per *passenger.km relative to 2000[39] – is close to industry/ICAO objectives in terms of carbon neutral growth[40].*

So, in spite of an air traffic growth hypothesis well below the one considered by industry, it seems that there is a ***low likelihood that technical progress will fill the gap*** *in order to reach the required objectives. It remains a key factor however in reducing the sector's CO_2 emissions;* ***intensive research efforts*** *will be needed in particular to develop new biofuels and innovative technologies.*

Carbon compensation[41] may contribute to closing in on objectives. However, in order to avoid damaging effects on air transport, ***it is vital that "compensation" measures, such as emissions trading systems, be managed on a worldwide basis, in order to ensure equal access, non-discriminatory treatment and unbiased competition, and control of costs so they are compatible with the sector's viability, taking into account the socio-economic role of air transport***[42]. *The authorities are considering other forms of carbon compensation. In any case, all possible means will have to be combined, and ICAO should play a major role.*

11.4.2. Effect of contrails – Possible actions for aviation?

The direct effect of contrails is negligible. The only significant indirect effect might be their contribution to cirrus cloud formation, a phenomenon that is still poorly understood to-day.

The feasibility and efficacy of operational measures must be confirmed, in terms of the overall greenhouse effect.

11.5. INTERDEPENDENCIES AND ENVIRONMENTAL REQUIREMENTS

Environmental interdependencies and trade-offs between noise, local and global emissions are inherent to the cross-disciplinary nature of the subject and intrinsic to all phases of design, from initial selection of overall goals to choices as to

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39 *European Commission Europe's Vision for Aviation - Report of the High Level Group on Aviation Research.*

40 *-75 % relative to 2000 is equivalent to -67 % relative to 2010*

41 *It consists of subtracting from the CO_2 emissions attributable to air transport, the quotas purchased from outside the sector within the framework of emissions cap-and-trade emissions trading schemes.*

42 *This is a point of contention between the European Union and almost the rest of the world, due to the integration of aviation into the European CO_2 emissions trading scheme (European Directive 2003/87/EC of 13/10/2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC European Directive 2008/101/EC of 19/11/2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community). It has led the European Commission to postpone implementation of the corresponding European Directive regarding flights outside Europe for one year (November 2012).*

configurations and technologies. They impact propulsion system design, integration and operation and also influence regulatory processes.

There are many environmental trade-offs, linked to physical principles and factors such as engine internal temperatures, bypass ratio, specific fuel consumption, aerodynamic drag and nacelle acoustic treatment area, with varying impacts on noise, fuel consumption and NOx/CO_2 emissions.

Such trade-offs concern all new aircraft and are based on the overarching requirements adopted, in close connection with economic performance drivers. Interdependencies and trade-offs are difficult to analyse due to the complexity, uncertainties and evolving characteristics of the phenomena involved, and their different effects, both time- and space-related. These trade-offs are particularly challenging to resolve since there are no single criteria or universal scales of comparison. Nevertheless, it is essential to quantify the rates of different exchanges.

Levels of technical refinement and component efficiency have been increasing over time and are currently approaching ultimate physical limits. Beyond the primary gains being sought, each evolution brings with it a number of undesirable side effects. Arbitration thus becomes more and more tricky, for instance between engine specific fuel consumption (hence CO_2) and NOx emissions, or between noise and fuel consumption (hence CO_2). Choices of types of engines and their configuration will be even more crucial in the future (between open rotors and advanced turbofans for instance) and will need to take into account the overall impact on fuel consumption (CO_2), noise and other key factors.

11.6. DEVELOPMENTS IN THE ENVIRONMENTAL CONTEXT

Should innovative products emerge from studies for new aircraft concepts, they could bring additional environmental benefits.

This could also be the case for the possible discovery of new n^{th} generation biofuels, although the likelihood of decisive progress in this area remains slim.

Developments in the area of operations and air traffic management could involve the widespread adoption of "green" practices in terms of energy and fuel consumption by operators and airports (e.g. electric taxiing, already under development). Potential reductions in CO_2 emissions in this domain are however limited by the low impact of ground and low altitude operations.

Additional gains might come from more sophisticated modelling of environmental interdependencies, optimal combinations of standards or a broader carbon compensation scheme.

A slackening of environmental constraints cannot be ruled out in the event of growing economic or energy pressures. Neither can the granting of special *emission permits or exemptions if CO_2 reduction objectives are recognised as over-ambitious for aviation, in view of the major socio-economic role played by air transport and the irreplaceable services it provides (should an accompanying communication campaign emphasise its low past and present contribution).*

The situation could also develop in the opposite direction, through a CO_2 standard and/or more stringent measures/penalties for instance, or should a significant worsening effect come to light linked to contrail-induced clouds. Very ambitious research goals might also impact the regulatory framework[43].

43 *Certain developments could go one way or the other, depending on circumstances, politico-economic factors and issues at stake.*

12. AIR NAVIGATION SERVICES

According to the Single European Sky Regulation No. 549/2004 of the European Parliament and Council:

- *"'Air navigation services' means air traffic services; communication, navigation and surveillance services; meteorological services for air navigation; and aeronautical information services;*
- *'Air traffic services' means the various flight information services, alerting services, air traffic advisory services and ATC services (area, approach and aerodrome control services)."*

They shall comply with standards issued by the International Civil Aviation Organisation (ICAO).

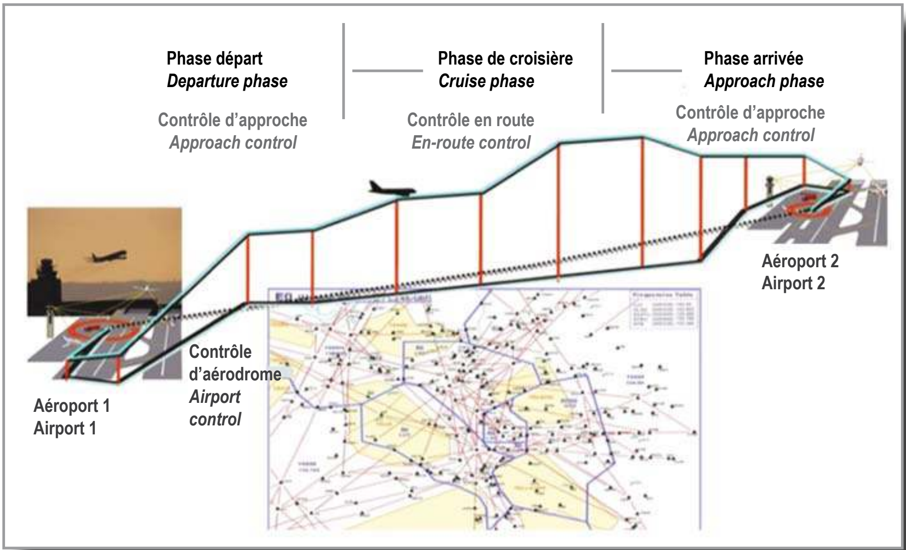


Figure 12: *Control zones according to flight phase*

12.1. SAFETY: THE "RAISON D'ÊTRE" OF AIR NAVIGATION SERVICES

Air navigation services contribute to enhancing safety. The share of aviation accidents attributable to them, due in main to collisions with the ground, is only a few percent.

Safety is based on the principle of layered defences and a very low probability of common failure. This experience-based safety approach can make it difficult to integrate new technologies and procedures. It has not been put into question by some very serious accidents, such as the collisions at Tenerife, Überlingen and Milan.

A more systematic approach to safety, such as that used for other complex systems, could lead to a fundamental change in the current organisation of air traffic control, but it is still in the stage of initial ideas. It requires research and remodelling, including an analysis of the impact and criticality of failure modes. By 2050, the current principle will probably persist.

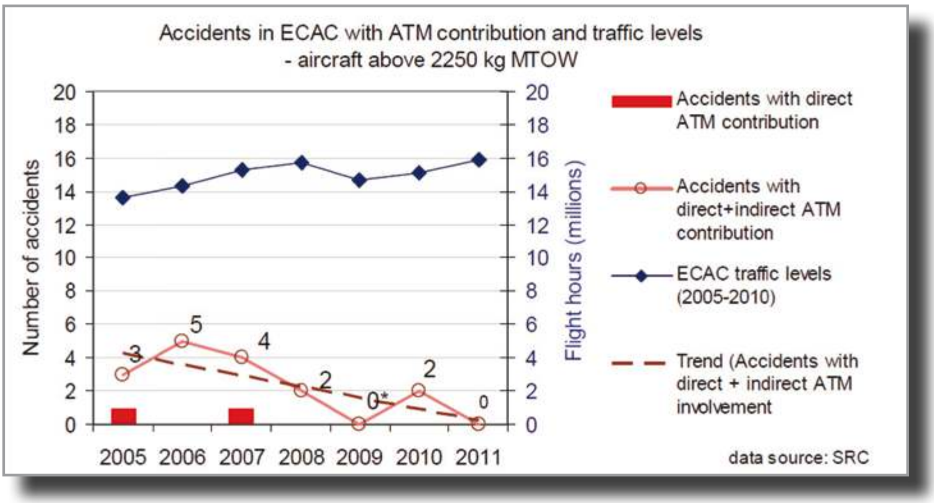


Figure 13 : ***Accidents in ECAC with ATM contribution and traffic levels***

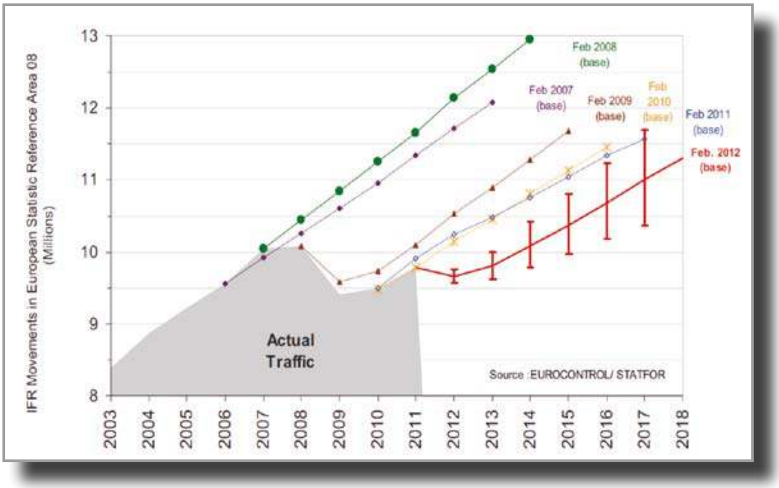
12.2. TRADE-OFF BETWEEN DIRECT COSTS AND SYSTEM PERFORMANCE

Aircraft separation provisions to ensure safety have a negative impact on airspace capacity, cost-efficiency and environment due to non-optimal trajectories.

Moreover, although the direct cost of air navigation services only represents a small part of the operating cost of airlines (5 to 7%), the latter are unwilling to pay for new ground infrastructures and update on-board equipment if they cannot be assured of tangible benefits in the short-term.

Any evolution in the air traffic control system should therefore be a trade-off between development cost and expected improvement, but cost-benefit analyses are difficult to perform and often unconvincing, due, in particular, to the difficulty of assessing the indirect costs and socio-economic impact of poor performance. As a result, choices are strongly influenced by political and media aspects.

Figure 14 : ***IFR movements in European Statisticc reference zone 08***



For 50 years, in the US and Europe, air traffic volume steadily increased with temporary blips due to political and economic crises. Slowdowns and recoveries, over time, shifted the balance of the trade-off between the direct cost of providing capacity and the indirect cost of inefficiency. But traffic growth has now slowed down enduringly in these areas, so where in the past, priority was given to system capacity, the focus is now on decreasing fuel consumption and environmental impact as well as reducing the cost of air navigation services.

However, capacity will continue to be a problem at major airport hubs in Europe and the US (and very likely soon in China) and innovative solutions (described in § 12.7) will need to be implemented to overcome this lack of capacity. Arbitration in these cases is often easier, since there are fewer actors involved in an airport and the cost advantages are more easily estimated.

In the rest of the world, traffic is expected to grow strongly for a long time. Therefore lack of capacity will be a handicap. However this problem will not require significant technological innovations, since this growth is really due to a catch up effect with the US and Europe. It will be easy to increase capacity, as needed, making use of the most effective available technologies.

12.3. THE INSTITUTIONAL ASPECT IS CRUCIAL TO WORLDWIDE AND REGIONWIDE EVOLUTION

The analysis here is focused on the US and Europe, but some aspects apply to other parts of the world.

A comparison between the US and Europe for 2010 is instructive: with 35,000 staff, the US manages 70% more traffic than Europe (which employs 57,000 staff), for a total cost per flight of half what is spent in Europe.

The main reasons for this difference are:

- *a single air traffic control provider in the US, while in Europe there are many;*
- *the budget of the Federal Aviation Administration (FAA) is separate from its revenues – which are made up of taxes on passenger tickets or kerosene (70%) and federal funding (30%) - and is under the control of Congress; in Europe this funding is based on fees, the rates of which are set to cover expenses (without any control on expenses);*
- *the American Air Traffic Control System Command Centre (ATCSCC) has the authority to optimise traffic services and flow. It regulates air traffic in the event of adverse meteorological conditions, equipment shutdowns, closures of runways or other disruptions and can thus take measures, in cooperation with airlines, to change aircraft routings and alter the capacity of ATC centres, over which it exerts a true authority. This is not the case for the European Central Flow Management Unit, despite its new name of Network Manager Operations Centre.*

It is for this reason that the European Commission set up, in the 2000s, the two legislative packages of the Single European Sky. But it is clear that, 10 years on, these incentives have failed to achieve the objectives of improved performance and reduced costs. The main reason is the resistance on the part of EU member states to the defragmentation of airspace as stipulated in the regulations (reasons of national defence have been invoked), as well as the loss of revenue generated by fees.

12.4. COST REDUCTION

In Europe, expenditure of revenue from user fees breaks down as follows: 30% for air traffic controllers, 20% for depreciation and financial expenses, 35 % for other personnel and operations and 15% for logistics and support services.

While some productivity gains can be achieved through technological developments, the objective of bringing European costs down to the level of US costs can only be achieved by rationalising air traffic control services in Europe.

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12.5. CAPACITY

In Europe, en-route capacity will be significantly increased by giving the Network Manager real authority in defining the structure of airspace and the route network and mobilising the available resources.

This change will by itself ensure sufficient capacity, except in and around some major airports where limitations will remain.

Figure 15 :

Central Flow Mangement Unit (Eurocontrol)

12.6. MANAGING PRIORITIES IN THE FACE OF SCARCE RESOURCES

Managing capacity limitations, especially temporarily during crises, calls for the establishment of priorities and regulatory mechanisms different from the present "first come, first served" principle (whose interpretation is already variable).

Research must therefore be carried out, from both a theoretical and operational point of view, into:

1. *socio-economic aspects;*
2. *airspace and traffic flow management;*
3. *aeronautical meteorology;*
4. *changes in modes of operation according to circumstances (traffic, weather, crisis, failure and emergency plan / contingency) and system flexibility.*

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12.7. AVAILABLE TECHNOLOGIES ARE ADEQUATE BUT IMPROVEMENTS ARE POSSIBLE

12.7.1. Automation

Although fully automated flights are seen by some to be a possibility (without specifying what this concept actually involves, for example with operators on the ground but no controller on the ground and without a pilot), it seems likely, for sociological and psychological reasons, that there will always be a pilot on board for passenger transport. This does not preclude an evolution in the roles of operators and automated systems on the ground and on board.

Remotely piloted freight aircraft would seem to be technically possible, as shown by the current use of drones by the military. ***Social acceptability will depend on safety demonstration, in particular with respect to communities living under flight paths, and liability issues and insurance will need to be resolved****.*

12.7.2. Communication, Navigation, Surveillance systems and information processing

Since the 1980s the question has been raised as to the use of satellite systems for ***communication, navigation and surveillance systems*** *in addition to, or instead of, terrestrial systems. Where a ground infrastructure for navigation (radio beacons) and surveillance (radar) exists, the justification of a new infrastructure using space systems and corresponding aircraft equipment is difficult. However, in places where the ground infrastructure does not exist or is not possible (ocean, desert and polar regions, emerging countries), a satellite-based infrastructure has many advantages.*

Radio frequencies are a limited, highly coveted resource. They therefore have a price, and could limit the development of drones and new services. They should be managed carefully.

In terms of ***information processing****, rather than continue to buy or develop complete systems for each control centre, a set of centralised servers and secure data should be set up, leaving only controllers' workstations in control centres.*

Research will be necessary to protect these CNS and information processing systems against deliberate (cyber security) and involuntary attacks and work must go into defining needs in terms of aeronautical frequencies and means of protecting them.

12.7.3. Operational procedures

As far as ***airspace organisation*** *is concerned, in dense areas and during busy periods, there will be no free routes, but rather highly capacitive highways, with* *built-in deconfliction (highways separated as much as possible, minimising crossing points at the same altitude) on which traffic will be organised by air traffic control (with the power to impose speed) and where separations between aircraft will be provided by the pilots, assisted by on-board systems.*

All flight operations will use complete trajectory management *(off -block to in-block), by which information is shared between all stakeholders.*

Separation will be maintained *and collisions with other aircraft, natural or artificial obstacles, hazardous weather and wake turbulence from other aircraft will be avoided in a complementary way either by the ground or on board, depending on place, time, traffic density and ground services available.*

For airports*, the arrival sequence will be scheduled from a point in time as far back as off-block time, and time of arrival at the point of entry to the terminal area should be foreknown to within 5 minutes.*

Arrival paths will be continuous descents, precisely defined in three dimensions. They will be enabled by precise meteorological models and by horizontal and vertical navigation systems in order to bring the aircraft down to the runway taking account of local constraints, in particular nuisance to local residents.

The aircraft will be put into sequence according to these trajectories. The plane will follow its path to the runway and the pilot will separate it from the preceding aircraft by means of on board equipment without controller intervention. This separation will take into account the dynamic wake vortex turbulence affecting the pair of aircraft (according to types, weights and configurations adopted) whose effects will be better known through fine-grid meteorological models.

Precision navigation and surveillance and a better understanding of wake turbulence will make it possible to build closer independent parallel runways.

Operational procedures will take into account new aircraft, all various airline operations (flight training, air refuelling, space flight) and new needs (avoidance of condensation trails).

Research is needed on:

- *on-board separation in airspace that otherwise has no separation service (due to high cost for low traffic) and as a means to reduce the cost of ground services;*
- *collision avoidance systems based on a systemic approach to safety.*

12.8. FROM A SYSTEMS-DEVELOPMENT INDUSTRY TO A SERVICE PROVIDER

Air navigation services providers will have a field of activity limited to operational services (they will no longer be providers of communication, navigation, surveillance, aeronautical and weather information and flight information systems) and their

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activity will be distributed over a suitable, flexible but reduced number of en route and major approach centres and towers.

The success of projects in Europe and the United States should enable manufacturers of these countries to be more competitive on this market in other regions. The costs of R & D will be amortised by the first deployments.

Some manufacturers will be able to both develop and operate the systems and provide associated services to air traffic control, but also to other clients such as airports and airlines.

European manufacturers must position themselves to offer these services.

***New services**, using available information, could be offered to aerospace professionals to manage their fleets, optimise operations, manage crises and better serve their customers (passengers ...).*

12.9. FOR OTHER TYPES OF AVIATION, THE CHOICES ARE POLITICAL

This refers to state aviation (mainly military), business aviation, general aviation, and new types of aircraft such as remotely piloted aircraft. There will still be a great disparity worldwide in terms of importance, budget and economic role of these different types of aviation.

The US, long-time leader in these niche markets, benefits from a significant level of financial support and is at the origin of most technical developments; as for remotely piloted aircraft, they will influence the rest of the world. Initially, only the US Department of Defense was able to finance the development, deployment and maintenance of a specific navigation system, the GPS. It was also the only one capable of supporting a digital satellite communications system such as Iridium. But other actors are emerging, since satellites are seen as instruments of sovereignty.

***Military aviation** will always raise specific issues: the cost of equipment for new aircraft and especially for the upgrading of old equipment, even if it may seem minimal compared to the cost of the planes themselves, nonetheless impacts shrinking national budgets. In addition, for reasons of state, government aircraft missions will always get first priority, even if the aircraft are not properly equipped. In addition, military aircraft equipment will always be more expensive to develop compared to equipment for civil aircraft due to additional requirements for military missions. On the other hand, some of these aircraft do not have to land on all airports, which can alleviate this equipment issue.*

***To enhance safety in general aviation**, cheaper, appropriate on-board equipment will have to be developed that will enable easier access to certain airspace and airfields. Broadcasts from the ground to the aircraft on the traffic situation, weather* *and aeronautical information will make the circulation of these aircraft more fluid and safer.*

***Business aviation**, well equipped, will operate low visibility landings on most airports using satellite means and enhanced vision means; business jets will be able to use trajectories optimised for their needs, or even set separation on their own in low traffic areas or areas without ground service.*

*In order for transport **remotely piloted aircraft** to develop, the problem of their integration into airspace must be resolved. A first step will be taken in 2015 in the US and in 2016 in Europe. There will be 3 stages: accommodation in designated areas, integration of remotely piloted aircraft into shared airspace and, much later, the management of autonomous drones (UAVs). The "detect and avoid" function, an extension of the current anti-collision system, will be developed for deployment expected in 2025.*

***Helicopters** and rotary wing aircraft will benefit from developments within general and business aviation in terms of specific procedures around airports and landing areas.*

12.10. RECOMMENDATIONS FOR EUROPE

1. *To reduce costs it is necessary to:*
   - *look into a new system of user charges for financing air navigation services that would provide real economic regulation;*
   - *establish a true authority for managing capacity, defining the route network and mobilising the available resources (controllers), given that overall capacity is sufficient.*
2. *In order to rationalise the provision of air navigation services, it is necessary to:*
   - *group together air navigation service providers in geographical areas to optimise air traffic management;*
   - *separate operational service providers from technical service suppliers;*
   - *design and develop a virtual information data system for all air navigation service providers.*
3. *To ensure the survival of European companies involved in developing these systems and services, it is important to involve them in R & D programmes and in the elaboration of international standards for safety and interoperability.*
4. *A research programme should therefore be promoted into these areas.*

13. CONTRIBUTION OF SPACE TO AIR TRANSPORTATION

In the early 21st century the contribution of space to aeronautics has become essential in the fields of navigation, telecommunications and meteorology. Well before 2050 other space-based services will also benefit aeronautics in areas such as surveillance, search and rescue, ground-based crew support functions and digital terrain data updating.

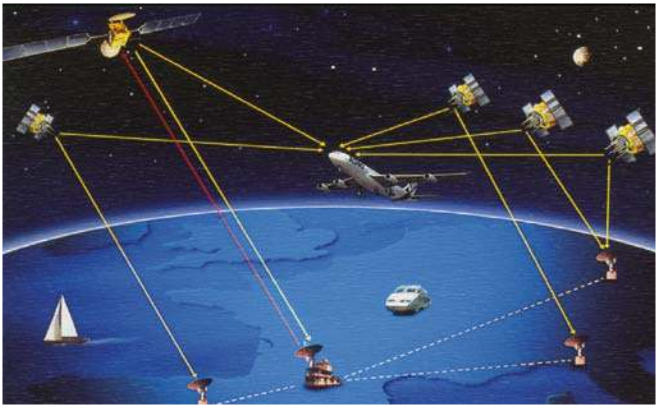

Figure 16 :
Space contribution to navigation. © ESA

Ongoing developments in the field of satellite navigation illustrate the role of institutions in identifying new worldwide service opportunities aimed at satisfying needs or societal aspirations, in negotiating international agreements, and in developing and managing large infrastructures and facilities.

Europe must use its capacity for innovation and its technological potential to remain one of the major global actors in the development of space infrastructures, facilities and services for the benefit of aeronautics in the next few decades, so as to obtain a share of the benefits from the resulting economic development.

To this end, Europe should promote new system and service concepts by reinforcing the dialogue between aeronautics and space experts. It should pursue feasibility studies for new services up to and including full scale demonstrations by means of test beds involving ground and space elements.

A short analysis is given of the current and potential contribution of space to aeronautics for each type of service, followed by recommendations for future European actions in each related field.

13.1. TELECOMMUNICATIONS

***Mobile telephone and internet communications for the benefit of air passengers**, although still limited to a small percentage of aircraft and to specific geographical zones, have been developing very rapidly for some years. Most systems already in place make use of commercial satellite services. Legal and commercial agreements are being implemented in most countries around the world.*

However airlines are making little progress in terms of onboard services because of the difficulty of anticipating passengers' rapidly evolving expectations when constructing the aircraft equipment and also of setting prices for such services.

***Communications for the needs of airline management** will benefit from the development of passengers' onboard communications as soon as a sufficient number of aircraft are equipped with telecommunication terminals.*

***Communications meeting critical air transportation needs** make some use of satellites above oceanic zones, but overall the utilisation of satellite communication links remains fairly limited today. Current telecommunication satellites based on existing commercial systems are apparently not yet considered as fully meeting requirements of reliability, integrity and availability. Doubts are also raised as to their long-term availability and cost-benefit ratio.*

Current studies in Europe, notably within the framework of the SESAR programme, are aimed at defining dedicated space systems which could be deployed by 2020 or alternatively adaptations which could be made to commercial satellite communications systems for operational use by aeronautics after 2020.

At the same time, some commercial initiatives supported by non-European institutions aim to provide such a service worldwide.

Europe must prioritise guaranteed access to services and play a leading role in future systems infrastructure, services and equipment for critical and non-critical aircraft communications. With a long-term vision going well beyond 2020, it must reinforce levels of security, integrity and availability of communications, as well as the cost efficiency of existing and planned systems. Decisions related to institutional initiatives and/or international and commercial agreements must be taken urgently.

Particular attention should be paid to preserving frequencies allocated to aeronautics at worldwide level according to future needs.

13.2. NAVIGATION

Satellite-based navigation is progressing in aeronautics, thanks to the availability of GPS signals and to on-going implementation of regional and local augmentation systems. In Europe, the "safety of life" service of the regional augmentation system EGNOS has been in use by civil aviation since March 2011. Partial operational implementation of the Galileo satellite navigation system is planned for 2015.

However the European navigation system will struggle to gain acceptance as one of the future worldwide reference systems alongside GPS for civilian applications, in particular aeronautics, because no fewer than 4 satellite navigation systems (GPS, Glonass, Galileo, Beidou) will offer worldwide coverage by 2020. As the only system under non-military authority, Galileo has some positive assets to gain the confidence of civilian users, but also a potential weakness in terms of funding the next generation of satellites.

Europe must therefore: ***actively prepare concrete implementation of Galileo as early as possible, including at aeronautics user segment level, plan subsequent evolutions of Galileo with the aim of reinforcing precision and robustness (notably with respect to jamming and spoofing) and finally think about the next step in international cooperation****.*

13.3. SURVEILLANCE

*"****Cooperative dependent surveillance****" of aircraft above desert, oceanic or other hostile zones is already in operational service under the name of ADS-C[44], making use of satellite links. For the moment, it is limited to low frequency periodic reports probably due to cost issues but this may change shortly as a result of improvements to communication services and a better understanding of the potential benefit.*

The idea of broadcasting short messages towards micro satellites in low Earth orbits, taking advantage of the accuracy of the time reference provided by GPS (and later Galileo) could also be explored.

*"****Cooperative independent surveillance****" would be useful as a complement to dependent surveillance in order to speed up Search and Rescue alerts even for aircraft not equipped with ADS-C. A system re-using the technical principles implemented for the future Sarsat-Cospas (with dedicated frequencies), with hosting satellites in Medium Earth Orbit like Galileo, could enable localisation of aircraft, even when in the air.*

*"****Non-cooperative independent surveillance****" is used under police, defence and security supervision over the "whole controlled airspace" in order to detect non-cooperative aircraft. At present it is performed only by means of primary radars*

44 ADS-C Automatic Dependent Surveillance - Contract *on the ground. The extension of such surveillance to certain oceanic zones could prove useful, or even necessary, in the future due particularly to increasing numbers in unmanned aircraft. Such an extension could be achieved by mono-static or multi-static radar systems making use of at least one space component.*

Given the potential benefits in terms of enhancing monitoring capabilities in the short and long term, ***Europe should assess the feasibility, costs and potential advantages of different types of "surveillance" missions using space technologies****.*

13.4. SEARCH AND RESCUE

Search and rescue (SAR) services making use of space systems have been fully operational for decades. Significant developments to the space segment are expected in the coming years, notably the use of payloads on board satellites in medium Earth orbits such as Galileo. Improvements expected in the quality of services will include the possibility of localising aircraft in distress either through triangulation or through transmission of coordinates determined on board with GPS or Galileo. Some possibilities of the future systems still remain to be explored.

In addition to preparing the transition of operational localisation services when the future system making use of Galileo becomes available, Europe should, as a matter of urgency: ***define the potential uses of the return link offered by the new Galileo SAR system and make the necessary adaptation of user equipment****.*

13.5. DATA GATHERING FOR AERONAUTICAL SERVICES

13.5.1. Digital terrain data

The determination of "safe trajectories" for approach – and to some extent for take-off – requires regular updates of digital ground data and continuous monitoring of compliance with civil aeronautical restrictions around airports. Such monitoring is generally done through observation from the ground. Periodic observation from air or space could reduce risks at least for some airports in the world.

In future, aids to pilots encountering adverse weather conditions, making use of "reinforced vision" techniques, will also need frequent (weekly) updates of ground data around airports.

The acquisition of digital ground data from space is a fully operational service today but cannot yet meet all the above type of needs due to delays "revisiting" a particular site and to system utilisation costs. However, by a 2050 timeline, Earth observation systems from space will have evolved considerably.

As part of research and development activities related to future Earth observation space systems and services, Europe should therefore: ***analyse the potential applications to aeronautics, identify shared needs with other sectors and assess the feasibility of observation systems corresponding to these types of applications****.*

13.5.2. Meteorological and environmental data

Space systems offer more and more opportunities to collect a large amount of varied meteorological data. A significant effort should be made for evaluating these opportunities and for defining the best use of space systems in the future.

On the operational side, meteorological and forecasting data are provided to crew essentially before take-off, except in the case of an alert. Current broadband communications are still not seen as being capable of efficiently transferring meteorological data during flights.

Through wider use of telecommunication services, the time needed to access meteorological information could be significantly reduced.

Europe must: ***actively pursue studies related to the use of space-based weather information and define, set up and validate methodologies for its acquisition and use. It must also: assess the benefits to be gained from reducing, on the one hand, weather centres' access time to observation data and, on the other, the time required to transmit the information to pilots, and define the most effective means to be implemented.***

Similarly, studies should also be pursued into the use of ***new space-based environmental data*** *and Europe should define, set up and validate methodologies and uses of data acquisition.*

13.6. SUPPORT FUNCTIONS TO CREW, PASSENGERS AND AIRLINE OPERATIONS

13.6.1. Security, remote surveillance and flight management support

With the implementation of broadband communication links protected against intrusions with quasi nil response delay and a high level of reliability and availability, it will become possible to collect critical aircraft parameters in real time on the ground and to assist crews in controlling the aircraft. Potential applications range from transfer of "black box" type data, remote surveillance, assistance to the crew, and control of unmanned air vehicles from the ground (linked to more advanced automation on board).

For each of the above potential applications actions should be taken to: ***(1) analyse the levels of requirements applicable to communication systems and services, including aircraft equipment, (2) study current and future ways of addressing the different levels of requirements and the associated economic impact and (3) anticipate future needs for the development of European infrastructures and facilities.***

13.6.2. Remote onboard medical care

Several experiments, supported by ESA and national space agencies in Europe such as CNES, have already demonstrated the feasibility of onboard remote consultation/telemedicine. Such opportunities have not yet been converted into operational services.

Potential interests of such services are related to the quality of diagnosis and first aid, and also to the appropriateness of the decision taken by the pilot to continue or to divert the flight.

Taking into account the emergence of very large long-haul aircraft and the increasing number of senior citizens on board, it would be advisable to: ***reassess the interest of setting up a service of telemedicine by satellite on board long-haul aircraft and define the conditions of implementation, including issues linked to crew training and legal responsibility.***

ANNEX 1: SUMMARY OF NUMERICAL VALUES

Category	2010 (best data)	2050 (forecasts)	Observations
World population and variation rate/year (billions)	6.9 (+0.1/year)	~ 9.3 (~ +0.04/year) (~ +35 %)	Median value of UN forecasts 2010
Of which : **China** **India**	1.34 (+7 million/year) 1.22 (+17 million/year)	~1.3 (-7 million/year) ~1.7 (+6 million/year)	
Annual world GDP in constant monetary units 2010	Basis	Multiplying factor ~ 3.0 average ~ 2.8 % year	
Ratio of global airline turnover to global GDP (%)	0.91	1.055	Average of data from various sources
Air traffic in giga rpk (passenger-kilometres)/year	4,960	15,500 (Multiplying factor MF ~ 3)	Forecast 2050 deduced from turnover and ticket price
Spread of traffic rpk (%)			
Europe	31	15	Indicative percentages, derived from various sources (ICAO, ACI, IATA) and GDP modelling for 2050
North America	31	21	
Asia-Pacific	28	48	
Latin America	5	8	
Africa	2	3	
Middle East	3	5	
Price of jet fuel $US/USG *Price of oil $US/Bl*	2.03 average price noted in 2010 *80*	5.5 to 6.6 MF 2.5 to 3 *200 to 250*	FC estimate taking account of jet fuel availability
Accident rate per million flights	0.5	0.12	3.5 in 1970
Air ticket price $US/km (constant economic conditions)	0.097	0.107(+ 10 %)	Effects of more expensive fuel and other improved posts
Load factor (passengers)	0.78	0.85 (+ 9 %)	Global average (sources 2010: IATA, ICAO)
Number of passengers carried per year (billions)	2.7	7.9 MF. ~ 2.9	
Average trip (km)	1,830	~ 1,950	Deduced by calculation RPK/Pax
Number of commercial flights per year (millions)	29	61	MF : 2.1 for the whole world, of which 1.2 for Europe, 1.6 for North America and 2.9 for the rest of the world.
Number of aircraft in service (thousands)	20.3 (*23 with freight*)	~ 42 (*48 with freight*) MF ~ 2	Commercial aircraft > 19 pax (*or with freight*)
Number commercial airports with over a million passengers per year	500	~ 700	Increase expected essentially outside Europe and US
Average jet fuel consumption per RPK	Basis	Reduction ~ 35 %	Average aircraft, average mission
Total consumption of jet fuel	Basis	MF ~1.85	Modelled on the basis of average consumption and fleet renewal
Total production of kerosene	240 to 250Mt ~ 7 to 8% of petrol produced ~ 6.2% for civil aviation	450 to 500 Mt ~ 10% of petrol produced + alternative fuel	Risk of competition with other users over use
Total aircraft CO_2 emissions (world fleet)	Basis	MF ~ 1.6	Estimation taking into account the contribution of biofuels and carbon offset initiatives
Total aircraft NOx emissions	Basis	~ +7 %	Combined effects of traffic, fuel consumption and reductions in NOx
Total acoustic energy of world aircraft fleet, on the basis of certification points take-off (overflight) and approach	Basis	Reduction 15 to 20 %	Modelled according to number of flights and noise levels (reduced in 2050)

ANNEX 2: PARTICIPANTS IN WORKING GROUPS

Chairman: Alain Garcia

Working group leaders:

- *Society, demographics and the economy: Jean-Claude Ripoll*
- *Market volume: Georges Ville*
- *Quality of service: Michel Vedrenne then Gérard Rozenknop*
- *Aircraft manufacturing: André-Denis Bord*
- *Energy: Marc Pélegrin then Gérard Théron*
- *Operating structures and fares: Marc Noyelle*
- *Environment: Alain Joselzon*
- *Air traffic management: Jean-Marc Garot*
- *Contribution of space: Jean Broquet*

With the constant participation of:

- *Pierre Calvet*
- *Xavier Champion*
- *Dominique Colin de Verdière*
- *Gérard Delalande*
- *Philippe Jarry*
- *Paul Kuentzmann*
- *Michel Lemoine*
- *Anne-Marie Mainguy*
- *Christiane Michaut*
- *Peter Potocki*
- *Jean-Baptiste Rigaudias*
- *Manola Romero*
- *Gérard Rozenknop*
- *Jacques Renvier*
- *Michel Vedrenne*
- *Jean-François Vivier*
- *Nicolas Zveguintzoff*

And the contribution of:

- *Pierre Andribet*
- *Lionel Baize*
- *Alain Baudoin*
- *Pierre Bauer*
- *Olivier Colaitis*
- *Daniel Deviller*
- *Patrick Dujardin*
- *Daniel Hernandez*
- *Raymond Rosso*
- *Yves Trempat*

ANNEX 3: GLOSSARY

AAE	Académie de l'air et de l'espace / Air and space academy
ADS-C	Automatic dependent surveillance - contract
BEA	Bureau d'enquêtes et d'analyses / French accident investigation agency
CCS	Carbon capture and sequestration
CEPII	Research centre in international economics
CTL	Coal to liquid
DGAC	Direction générale de l'aviation civile / French civil aviation authority
EASA	European aviation safety agency
EC	European commission
FAA	Federal aviation administration
FC	Foresight commission of AAE
GDP	Gross domestic product
GTL	Gas to liquid
IATA	International air transport association
ICAO	International civil aviation organisation
IMF	International monetary fund
LET	Laboratoire d'économie des transports
LR	Long-range
MR	Medium-range
NGO	Non-governmental organisation
NOx	Nitrogen oxide
RPK	Revenue passenger kilometres
SAR	Search & rescue
SH TF	Short-haul turbofan
SH TP	Short-haul turboprop
SPK	Synthetic paraffinic kerosene
UNFCCC	United Nations framework convention on climate change
VLA	Very large aircraft
WTO	World trade organisation
WTW	Well to wake