PERSPECTIVES FOR AERONAUTICAL RESEARCH IN EUROPE

PARE

CHAPTER 7

Long-range Air Transport

Final Report

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The long-range airliner market is dominated by the Airbus-Boeing duopoly (section 7.2) that arose at the end of a long competitive period in which Airbus steadily gained ground (section 7.1) starting from a newcomer status. The possibility of other competitors emerging in the long-range air transport market (Russia, China, or cooperation) is also considered (section 7.3). The long-range airliner routes are fed by regional airliners that have a significant market of their own (section 7.4). Europe is strongly competitive not only on long-range and regional airliners but also in other categories like business aircraft (section 7.5) and helicopters (section 7.6).

7.1 The Growing Airbus Challenge to Boeing

Airbus as a newcomer to the airline market (subsection 7.1.1) started with the A300 by filling an empty niche: the short-haul wide body aircraft (subsection 7.1.2). A further advance in competitiveness was achieved with the increased use to electronics in the forward-facing crew cockpit (FFCC) of the A310 that reduced flight crew from three to two (subsection 7.1.3). An even more significant innovation in the A320 as the first fly-by-wire airliner in the world that was countered by Boeing with an improvised second-generation B737 that managed to compete only through the trick of “grand-father rights” (subsection 7.1.4). The fourth stage of the Airbus challenge with the twin-engine A330 and four-engine A340 pair was met head-on by the Boeing 777 (subsection 7.1.5). Airbus decided it had to challenge the remaining Boeing monopoly, the jumbo market of the B747, but the A380 as the world’s largest airliner has had a troubled development and poor market history (subsection 7.1.6). Boeing took advantage of Airbus troubles with the A380 to launch a new challenge in another sector with the 787 to which Airbus responded late but successfully with the A350 and A330neo (subsection 7.1.7). Since the A350 was designed to outperform both the Boeing 787 and 777, Boeing reacted with the stretched 777X out of reach of further A350 developments, threatening both the Boeing 747 and Airbus A380. The Bombardier temporary challenge with the C-series to companies 10 times larger, together with development delays, lead to the massive success of the second-generation Airbus A320neo and the late response of the third-generation Boeing 737max (subsection 7.1.8). Also the greater stretch potential of the A320 allowed Airbus to develop the A321/LR/XLR (subsection 7.1.9) for which B737 stretches offer weak competition.

7.1.1 The European Pioneers and American Successors

The first generation of jetliners (Table 7.1) came mostly from Europe as pioneers, but their American competitors, in spite of coming later, achieved greater commercial success:

- The Sud-Aviation Caravelle and British Aircraft Corporation One-Eleven were the pioneer twin jets, although the market came to be dominated by the later entries from the Douglas DC-9 and Boeing 737;
- The Hawker Siddeley Trident was the first tri-jet but the market was subsequently dominated by the later entry into the market of the Boeing 727;
- The Vickers VC10 was a pioneer four-engine aircraft with pioneer Rolls-Royce Conway turbofans, but like the Convair CV-880/990, it lost market position to the Douglas DC-8 and Boeing 707/720.

Type	Short range twin engine	Medium range tri-jets	Long range four-jet
British	DH Comet BAC One-Eleven	HS Trident	Vickers VC 10
French	SA Caravelle	-	-
Boeing	B737	B727	B707
Douglas	DC-9	-	DC-8
Convair	-	-	CV-880/990
Tupolev	Tu - 104	Tu - 154	Tu - 114
Ilyushin	-	-	Il - 62

Table 7.1 – First generation jet airliners (all single aisle)

As for 'government' versus ´commercial' airliners:

- The private venture De Havilland Comet was the first jet airliner and a commercial failure due to structural fatigue problems unknown at the time;
- Before Boeing sold the first commercial Boeing 707 it had several years of development funded by the U.S. Air Force that had ordered hundreds of similar KC-135 in-flight refuelling tankers.

The case of Britain illustrates why the Europeans were the pioneers in commercial jets but later American designs came to dominate the market.

Even not taking into account the ill fate of the pioneering jet liner, the De Havilland Comet, there were British jet liners in each category of the first generation: (i) the short-range twin engine BAC One-Elven;(ii) the medium-range three-engine HS Trident, and; (iii) the long-range four engine Vickers VC10.

However these aircraft were optimised for very specific requirements, for example:

- The HS Trident for the London-Athens route of British European Airways (BEA);
- The Vickers VC10 for the London-Nairobi route of British Overseas Aircraft Corporation (BOAC).

These narrow focus requirements made the aircraft less adaptable to other routes compared with the American designs catering for broader airline requirements.

For example of two South African airlines one chose the Vickers VC10 and the other Boeing 707. Being designed for the London-Nairobi route, the VC10 had a large wing to land at hot and high Nairobi and did not need too long range to fly from London.

When because of apartheid nearly all African States banned South African aircraft, the Vickers VC10 could not fly non-stop between Europe and South Africa, and the airline that bought it because became bankrupt. The Europeans were pioneers in other areas of the market ultimately dominated by the Americans. The Rolls-Royce Conway of the Vickers VC10 was the first turbofan in service with better fuel economy than the Pratt & Whitney JT3 turbojet on the rival Boeing 707.

Although the RR Conway could be fitted to the Boeing 707, most were sold with the Pratt & Whitney JT3D, a turbofan development of the JT3C. Next Pratt & Whitney developed the smaller JT8D turbofan, to power the Boeing tri-jet 727 and the bi-jet 737. The Boeing 737 was the last of the first-generation twin jets, but ultimately displaced the first twin-jet the SA Caravelle, and also the BAC One-Eleven. They sold well in the United States before the Douglas DC-9 and Boeing 737 became available, and were practically ousted from the U.S. market by their American competitors.

7.1.2 Airbus A300 (Figure 7.1) and the high-capacity short-range niche

Just before the Airbus entered the airliner market there were two disjointed sectors:

- Small single-aisle short-range narrow bodies up to 190 seats and 6 000 km range;
- Large double-aisle long-range wide bodies up to 450 seats and 14 000 km range.

Airbus identified a niche for short high-density routes: the A300 twin-aisle wide body carrying up to 300 passengers up to 8 000 km. Boeing arrogantly both dismissed (i) this Airbus niche market as non-existent and (ii) the A300 as another government aeroplane doomed to failure. Although ultimately proved utterly wrong, both these charges could not be easily dismissed at the time and were actually the statement of two major challenges.

Figure 7.1 – Airbus A300

The Franco-German initiative to develop the Airbus A300 was met by the British government with the demand to use a new Rolls-Royce high by-pass ratio (HBPR) turbofan, the RB207. This was similar in configuration but distinct from the RB 211 under development at the time, whose composite fan failures ultimately lead to the bankruptcy of both Rolls-Royce and Lockheed, followed by their rescue respectively by the British and United States governments. Airbus refused to develop at the same time a new aircraft (A300) and a political engine (RB 207) and opted for an American well-proven engine, the General Electric CF6. The British still participated in the A300 with Hawker building the wing as a 'private' partner 'supported' by the government. The Airbus decision to choose the existing General Electric CF 6 over the new Rolls-Royce RB. 207 was proof that the A300 was not a 'government aeroplane' and that Airbus had the courage to resist political pressures and aim squarely at the market ensuring its success. The AIRBUS A300 was one of the first of the second generation jet airliners (Table 7.2)

Type	Short range single aisle	Medium range		Long range twin-aisle
		Single aisle	Twin aisle	
Boeing	737NG	757	767	747/777
Airbus	A320	-	A300/A310	A330/A340
McDonnell Douglas	MD-80	-	-	MD-90
Lockheed	-	-	-	L-1011
Russian	Tupolev TU-134	-	-	Ilyushin Il-76

Table 7.2 – Second generation jet airliners

7.1.3 The Airbus A310 (Figure 7.2) and the Forward-Facing Crew Cockpit (FFCC)

Although the A300 achieved a 10% market share Boeing refused to consider it in its market projections, allowing Airbus to strike the next coup unchallenged. At the time the airliner cockpits consisted of large arrays of mostly duplicate analogue flight instruments facing the pilot and co-pilot plus large side panel(s) with system instruments facing the flight engineer; since the flight navigator had been dispersed earlier, at this time the minimum flight crew was 3. Airbus proposed the introduction of multi-function electronic flight displays capable of showing different information at different stages of flight or in different circumstances, such as system diagrams in the case of a failure or emergency; together with a much-increased level of automation this would allow the flight engineer and his side panels to be dispensed with, hence the publicity kind designation forward-facing crew cockpit (FFCC). The elimination of the flight engineer was rather controversial, and it did not escape anyone that the ultimate motivation was to reduce flight crew costs from 3 to 2. Nevertheless, the electronic flight instrument displays were an innovation to stay providing a much more flexible way of selecting among a wide array of information and the increased efficiency of the A310 added to the market penetration of the A300 reaching 20%. Still, Boeing continued to refuse the inclusion of Airbus in its market projections, making the third stage of the Airbus challenge, the A320, the rude awakening.

Figure 7.2 – Airbus A310

7.1.4 The Airbus A320 (Figure 7.3): The First Fly-by-Wire Airliner

The introduction of fly-by-wire technology from fighters in the first airliner allowed the A320 to be designed with a smaller tail plane area, less cruise trim drag and higher efficiency. Boeing initially dismissed the A320 diffidently as the 'wonder plane' until realizing that it made the existing B737 uncompetitive. Boeing rushed to upgrade the 737 into a 737 NG ("New Generation") with some limitations. For example, the lack of ground clearance below the wing limited the diameter of the turbofan engine used and required a non-circular flat-bottomed nacelle; the short nacelle pylon also caused transonic flow problems. After all the possible modifications Boeing realized the second-generation 737 could still not compete with the A320 and resorted to a certification trick: "grandfather rights". It claimed that the second-generation Boeing 737 only had to meet certification rules holding at the time of the first generation and need not comply with current certification rules that applied to new aircraft like the A320. As a consequence, the Boeing 737 could seat more passengers in a cabin smaller than that of the A320 by not meeting current emergency evacuation standards. The granting of grandfather rights to the second-generation Boeing 737 by the Federal Aviation Administration (FAA) drew considerable criticism from outside the United States as a poorly disguised protectionist measure, and it was eventually agreed internationally that this would not be repeated in the future. With the extensive redesign and the unfair economic advantage of carrying more passengers in a smaller cabin, the second-generation Boeing 737 managed to compete the all-new A320, and Airbus reached a 30 % market share. The fourth stage of the Airbus challenge, the A330/A340, no longer benefited from the disdain or complacency of Boeing that by now realized it had a serious rival and had to compete on merit rather than by tricks like «grandfather rights».

Figure 7.3 – Airbus A320

7.1.5 The Airbus A330/A340 (Figure 7.4/7.5) and the Family Commonality Concept

The Boeing family of airliners consisting of the short-haul 737 and medium-haul 757 single-aisle and wide body medium-range 767 and long-range 747 was a mixed bunch of designs with different ages and standards preventing economies of scale in crew training and maintenance tasks across different types. The more recent and up-to-date Airbus range besides consisting of models competitive individually against their Boeing counterparts had the additional advantage of commonalities requiring less maintenance infrastructure and shorter crew retraining across a mixed fleet. Airbus followed conventional belief (A) that long overwater flights required four engines, an assumption that may have been its only questionable choice and would haunt it for two decades. The fourth Airbus challenge (B) shared the fuselage cross-section of the A300/A310 in the twin-engine medium-range A330 and four-engine long range A340, using different wings with the same gross weight capability that would later enable the A330neo. The A330/A340 completed the Airbus family started with the A300/A310 and continued with the A320 and enabled a 40

% market share. Contrary to the past Boeing had shaken off its former complacency and was back in its best competitive talent.

Figure 7.4 – Airbus A330

Figure 7.5 – Airbus A340

The earlier Boeing complacency was supported by the demise or decline in the market of its main American competitors:

- The Convair CV-880/990 transcontinental four jets lacked the transoceanic range potential of the Boeing 707, and were the last Convair airliners:
- The failure of the carbon fibre fan in the Rolls-Royce RB.211 engine without a titanium fan alternative led to the end of the (Lockheed L-1011) Tristar as the last Lockheed airliner.
- McDonnell Douglas was limping along in a survival mode with low production rates of the DC-9/DC-10 and derivatives, surviving on spares revenue from existing fleets, which was doomed to decline.

The success of Boeing over Douglas was a testimony to boldness and innovation.

- The Boeing 707 held the lead over the Douglas DC-8 up to the series 50 until the DC-8-60 series stretch from 190 to 260 passengers gave a 25 % seat-mile advantage that could not be matched;
- Boeing countered with the first jumbo, the 747 that needed a new factory and did not fit existing airports, and made a success out of gambling on its existence;
- Douglas countered with the DC-10 as a wide body tri-jet, and cancelled the DC-8-60 series because it was too much of internal competition;
- The decline of the DC-10/MD-10 versus B747/B767 and DC-9/MD-80 versus the B737/B757 allowed Boeing to take-over its last American competitor;
- The Boeing attempt to salvage the McDonnell Douglas MD-80/90 as a Boeing 717 was an abysmal failure since no airline wanted an aircraft having nothing in common with the Boeing family except the name;
- Airbus had vowed not to make an aircraft smaller than the A319, but did an A318 to counter the B717, and managed relatively modest but still better sales than its rival.

By now the only significant remaining Boeing rival in the world airliner market was coming from an unexpected quarter: the Europe of government aeroplanes had spun a truly market-oriented competitor: Airbus. NASA complained that a complacent Boeing was no longer interested in new technologies, which were not needed for the sole market leader. All changed as Boeing decided to counter head-on the Airbus A330/A340, focusing on its two weak points (A) and (B) above.

Boeing made the bold assumption that twin-engine aircraft could fly over water over the whole world, including both the Atlantic and Pacific Oceans. The realization that modern turbofan engines seldom failed in cruise lead to the prospect of extended overwater flights more than 90 minutes away from the nearest airport. ETOPS allowance increased steadily from 90 minutes to over 3 hours allowing unrestricted transatlantic and transpacific flights. With ETOPS Boeing needed only one twin-engined B777 to counter the A330/A340 pair.

With the benefit of the hindsight of coming later, Boeing adds to (A) the further gauntlet (B) choosing a wider fuselage cross-section than that the A330/A340 'inherited' from the A300/A310. The larger capacity of the B777 versus the A340 had this time Airbus scrambling back to the drawing board with the A340-600. Bound to the same cross-section as the A300/A310/A330 all that Airbus could do was to increase the length of the fuselage to the airport limit; the A340-600 had the longest fuselage of any airliner and was the first whose flying qualities were affected by the elastic modes of the fuselage. The A340-600 was almost a totally new aircraft relative to earlier A340 variants, and the large effort and expenditure in its development served only to prolong its life for some years. The end of production of the A340 left the airliner market only with twins except for the old B747 and new A380 still based on the belief that 4 engines were needed for long overwater flights.

7.1.6 The Airbus A380 (Figure 7.6), the World`s Largest Airliner

Airbus launched the project of A380 in 2000. The initial rationale for it was quite compelling:

- Airbus had reached a 40 % market share and was competing with Boeing on every sector except the jumbo aircraft;
- Boeing was using its 'jumbo monopoly' selling a B747 for twice the price of a B767, collecting profits to finance the rest of the range;
- To reach 50 % or parity, Airbus had to challenge Boeing in every sector, breaking its last monopoly with the jumbo aircraft.

Figure 7.6 – Airbus A380

As the world's largest airliner the A380 was not short of challenges:

- Its size and weight were well beyond the minimum weight per passenger of an airliner at about 350 seats;
- As a consequence, the A380 had 30 novel weight- saving features, like 4,000 psi hydraulics instead of the 3,000 psi standard up to then;
- Given the larger number of in-flight entertainment systems for passenger seats with different arrangements for each airline, the replacement of copper wires by aluminium wires was one of the 30 significant weight savings.

This apparently innocuous change was the start of a far-reaching chain of events:

- The aluminium wires could not be bent to the same small radius as copper wires, leading to installation problems that were reported late;
- The Airbus method of sending fully equipped sections for final assembly maximizes added value to partners (the opposite of Boeing);
- The arrival of unfinished sections at final assembly caused a production bottleneck with a large number of workers brought in Toulouse from factories in other countries;
- The rate of expenditure would have bankrupted Airbus in two years unless a new strategy was adopted.

The detailed redesign of elements of the A380 was not helped by another contrast:

- All Airbus partners used the CATIA design software developed by Dassault;
- Except for its former Aerospatiale rival that used software from a firm in Seattle, the home of Boeing.

The Airbus A380 is certainly the most spacious and probably the most comfortable airliner flying. It did upstage the Boeing 747, which was in any case undermined by the Boeing 777 as an in-house rival. It is not only the largest airliner ever but also one of the most sophisticated. However, some important weak points made for its failure as a sound business case and finally determined the decision in February 2019 to terminate the production at the end of 2021.

7.1.7 The Sonic Cruiser, B787 and A350 (Figure 7.7)

Boeing recognized that the market could not support two jumbos, and thus decided not to develop a direct rival to the A380. The Airbus troubles with the A380 were an opportunity not to be missed to strike back in another sector. The Boeing counter, the 'sonic cruiser' was a daring and brilliant design: it managed to have a fuselage of constant cross-section while obeying the area rule for low shock wave drag by clever blending with the canard foreplane and main wing. It was capable of cruising efficiently at Mach 0.95 versus Mach 0.85 for a conventional airliner, but sales may depend more on attractive economics than brilliant engineering. Boeing argued in vain that a 10-12% decrease in flight time in long-haul routes would allow more daily flights with the help of shorter turn around at airports. Airlines were not convinced, and Boeing brought along as a fall back the 7E7: a conventional design using the advanced technologies of the sonic cruiser, like a composite fuselage, to reduce cost. The 7E7 was the preferred choice for every airline and became the Boeing 787. The B787 gained the largest order book of an airliner in history before its first flight. Boeing predicted that the 787 would be its quickest development and certification programme in recent times with entry into service 3 years from start-up. This optimism was not supported by a development period more than twice as long, with perhaps not surprising problems in the production of the single barrel all-composite fuselage. After entry into service, the Boeing choice of a type of lithium-ion battery with high energy density for low weight, turned out to cause battery fires that were cured by a redesign adding weight. Notwithstanding the usual development hurdles the Boeing 787 is a considerable success, this time helped by the reluctance of Airbus to offer a matching competitor. The Boeing 787 may be considered the first third generation jet airliner (Table 7.3).

Figure 7.7 – Airbus A350

Type	Single-aisle			Long range	
	regional	short-range	medium range	long range	jumbo
Airbus	A220	A320neo	A321LR/XLR	A350/A330neo	A380(i)
Boeing	-	B737-Max-7	B737-Max-9/10(iii)	B787/777X(iii)	B747-8
Russia	Sukhoi Su-100	-	-	Ilyushin Il-86	-
China	ARJ21(ii)	Comac C919(iii)	-	CR929(iv)	-
Brazil	Embraer E-series		-	-	-
Japan	Mitsubishi MRJ(iii)	-	-	-	-

(i)Production stopped; (ii)Chinese certification only; (iii)Not yet certified; (iv)Project with Russia

Table 7.3 – Third generation jet airliners

Saddled with the A380 issues Airbus could hardly cherish another totally new aircraft development. In contrast with the past, when Boeing was slow or inadequate in its responses, this time it was Airbus that delayed a competitive answer. The initial Airbus argument that the A330 was an already available B787 competitor did not convince airlines. The reluctant further developments of the A330 were not too well received either, although the second-generation A330neo later proved to be a moderate market success. When Airbus finally accepted the reality that nothing short of a new clean-sheet design would convince airlines, the A350 was the resulting clever design 'splitting' the B787 and B777:

- Larger than the B787 with a comparable cost;
- Comparable in size to the B777 with lower cost.

This clever killing of two rabbits with a single stroke drew the predictable matching reaction from Boeing;

- a – Trying to improve the competitiveness of the 787;
- b – Stretching the 777 to a second-generation 777X beyond the growth potential of the A350.

The move (b) meant that the B777X effectively superseded the B747 and also brought stronger competition with the A380 as the world's largest airliner and nearly sole remaining four-engine type. Concerning move (a) the reengining of the Airbus A330 as the second generation, A330neo proved after all that a cheaper to buy and cost-effective to operate aircraft could be rapidly developed as an alternative to the B787. The A330neo was inspired by the success story of the A320neo.

7.1.8 Bombardier C-series A220, Airbus A320neo and Boeing B737max (Figures 7.8 and 7.9)

The third and fourth largest airliner manufactures in the world, Embraer of Brazil and Bombardier of Canada, are about one-tenth of the size of the two world leaders, Boeing of America and Airbus of Europe. Only the brave or the foolish would try to bridge a gap of one order of magnitude. Embraer has wisely stayed below the Airbus-Boeing market, perhaps scraping it at the lower end, without ever venturing into a direct challenge. Bombardier claimed it was not trying to compete with Airbus or Boeing but in fact, tried to do just that with the C-series. The main advantage of the Bombardier C-series was a new generation of geared turbofans from Pratt & Whitney; this advantage would easily disappear if the same engine was adopted by the A320 or B737. The PW1200 geared fan had the development problems and delays of its own and comparable performance was achieved by the Snecma/General Electric LEAP engine, which used advanced technology in a more conventional design to come to market earlier. Not only the Bombardier C-series lead in engines was lost, but also the lead in time was compromised by development problems delaying entry into service. The Bombardier C-series was completely upstaged by the rival developments of the Airbus A320neo and Boeing B737max. Following commercial attacks by the US Government meant to cut the access of the plane on the US market, the acquisition of a majority in the C-Series by Airbus marked the end of the adventurous challenge. The C-Series was rebranded A220. In fact, the reactions of Airbus and Boeing to the Bombardier C-series were somewhat different.

Figure 7.8 – Airbus A220

Figure 7.9 – Airbus A320neo

Airbus would not let the Bombardier C-series erode the A320 market; bearing in mind the first-generation A320 was relatively modern and efficient, a second-generation reengining in the A320neo would completely upstage the challenger and consolidate its market. The A320neo was a runaway success, collecting orders at a rate never seen before, and forcing Boeing to enter the fray with the third generation B737max. Boeing was understandably reluctant to go into a third generation of the B737:

- The first-generation was by now over 50 years old;
- The second generation had struggled but managed against the first generation A320 with the help of grandfather rights;
- Without the help of grandfather rights, a third redesign of the B737 would be an even greater struggle against a second generation of the newer Airbus A320.

The Boeing decision to counter the new A320 with a second-generation B737 rather than a new design came back to haunt it again with the third generation B737 versus the second-generation A320. For example, the low ground clearance of the flat-bottomed nacelle of the second-generation B737 could only become a more difficult problem with the increased diameter of more recent higher by-pass ratio engines. Boeing was well aware that the engine under the wing of the third generation B737 would have a smaller diameter and lower by-pass ratio than for the second generation A320. This shortfall in engine efficiency would have to be compensated in other areas like aerodynamics, yet Airbus would hardly be left behind in any area and allow Boeing to recover its weaker starting position. The preference of Boeing was to let some years pass to design an all-new single-aisle replacement for the B737. For this reason, Boeing did not feel it necessary to counter immediately the Bombardier C-series, but after the runaway success of the Airbus A320neo, it had no choice but to join the fray. Just as Airbus had been reluctant to launch the A350 to counter the B787, Boeing was reluctant to launch the third generation B737max against the second generation A320neo. In both cases there was no choice, with the A350 recovering only partially the order book lost to the B787, and similarly the B737max trying to narrow the initial gap to the A320neo.

7.1.9 Success of the A321/LX/XLR (Figure 7.10)

In addition, the gap between the third generation of the old B737 and the second generation of the not so old A320neo created another market impact:

- The A320neo has enough stretch potential into the A321neo, which is an effective replacement for the Boeing 757, still used on long thin routes;
- The stretched A321/LR was an immediate success, amplified by the further stretch to the A321XLR;
- The lack of stretch potential of the B737 leaves Boeing with a weak alternative the B737Max-9/10 or no alternative other than to develop an all new MMA (Middle-of-the-Market Aircraft) of a FSA (Future Single Aisle).

Figure 7.10 – Airbus A321XLR

The Airbus A321/LR/XLR is in production whereas an eventual Boeing MMA could be offered much later when the need for 757/767 replacements would have been satisfied by Airbus products. Although Boeing has toyed with the idea of an MMA/FSA, which is what it would have liked to do instead of the 737max, the prospects are challenging. A new aircraft can be amortized only if it provides at least a 10-20 % improvement in fuel consumption to lower direct operating costs. This is unlikely to be achieved bearing in mind that the A320neo and B737max use state-of-the-art engines and a new engine generation might be needed. The development of an MMA would be costly and time-consuming, and it is questionable if the market left unfulfilled would allow a break even. Boeing is, at last, having to live with the consequences of soldiering for too long with the B737 and may after all not have gained much from the trick of grandfather rights in the long term; it would be doing better now with a less old design. Airbus is benefiting from a more recent A320 design that was an inevitable consequence of being a newcomer to the market. However, with a production lifetime of 10 years longer than the 8 years of the A320, the B737 still has a larger number of units sold, although the gap is closing. This sets the background for the current status of the Airbus versus Boeing competition in the airliner market (section 7.2).

7.2 The Current Status of the Airbus-Boeing Competition

The situation is different in the single-aisle narrow body (subsection 7.2.1) and twin-aisle wide body (subsection 7.2.2) market leading to an approximate balance with Airbus leading the former and Boeing the latter. Both Airbus and Boeing are in the healthy situation of having the largest order books in history and face challenges in achieving higher production rates (subsection 7.2.3). The profits may be invested in evolutionary developments of existing aircraft (section 7.2.4) or in totally new designs that will require years of maturation to incorporate new technologies (subsection 7.2.8). In the meantime, the production of the A380 will cease, both as the world's largest airliners and few surviving with 4 engines (subsection 7.2.5). The prospects for a middle-of-the-market aircraft look slim (subsection 7.2.6) the absorption of the Bombardier C-series into Airbus (subsection 7.2.7) left both at advantage relative to their rivals Boeing and Embraer that failed to reach a similar deal.

7.2.1 Single-Aisle or Narrow-Body Market

The prompt and decisive response of Airbus to the Bombardier C-series challenge lead to a large order book for the A320neo as the second generation A320. The delays and hesitations of Boeing to commit to the third generation of B737 (i.e. the Max) lead to response only when there was a large gap to recover. Boeing proposed the third generation B737max to avoid the risk of losing traditional and faithful airline customers. This customer base amounted to a substantial backlog reducing but not closing the gap to the A320neo. The stretched A321neo dominates the long, thin route market, without a clear match in the B737 family, so this part of the gap is not readily closed.

Boeing would need an all-new Middle of the Market Aircraft that might come too late to an already partially filled marked, with questionable profitability. A bold and risky decision to develop the MMA aircraft by Boeing may be necessary to remain a strong supplier of narrow bodies in competition with Airbus. The Airbus lead in the orders of narrow bodies may be balanced by a Boeing lead in wide bodies, with higher unit values compensating the smaller number to lead to comparable profitability.

7.2.2 Twin-Aisle or Wide Body Market

The situation here is the reverse of the A320neo lead over the B737max, with Boeing amassing a large backlog of B787 orders before Airbus replaced its evolved A330 plans by an all-new A350. The A350 effectively targeted the B787 offering higher capacity for a comparable cost. And the second generation reengined A330neo proved after all that it also had a market as a lower cost B787 competitor. The double-pronged counterattack with the A350 and A330neo allowed Airbus to narrow the gap to the B787, helped by the development delays of the latter to reduce the effects of a late response. The A350 had the second task of matching the B777 capacity at a lower cost, which it did at the then status. But Boeing could hardly be expected to sit still and let two of its products be challenged by a single Airbus product. The second-generation stretched 777X moved beyond the stretch potential of the A350, and at the risk of killing the already moribund B747. However, as in many other large projects, 777X met some obstacles in the development which introduced some costly delays. Due to what Boeing euphemistically calls "GE9X Anomaly", the maiden flight of the aircraft, initially expected at the beginning of 2019, was first postponed to end of June and subsequently for the end of 2019. GE9X, the larger engine built ever, based on revolutionary technologies, revealed during the endurance tests and fan blade out test the need for some configuration modifications to satisfy the certification requirements. Boeing then hoped to customers, which some analysts consider to be "highly unlikely".

The sector seems to be under pressure. The trend in the recent widebodies backlogs evolution is rather similar at Airbus and Boeing: plenty of order cancellations, around 17% of the total for Airbus, 14% of the total for Boeing between 2014 and 2018. The manufacturers are expected to trim their production rates accordingly.

7.2.3 Production Ramp-Up to Meet Large Order Books

One point that Airbus and Boeing share, is their biggest order books in history, to the extent, some sceptics point to a historic risk of a collapse of the order bubble. This time around with a backlog of several years and a steady growth of air transport, it was hard to see how a calamity of such scale could occur. An unlikely big decline in the airliner market would have several years of production as a cushion and large-scale cancellations do not seem to fit airline plans. Rather the reverse, the industry is still trying to recover from an unexpected order boom. Tom Enders, the ex CEO of Airbus said that if some years ago someone suggested a production rate of 30 A320 per month he would have thought this was outright foolishness; but later Airbus was aiming at 60 A320 per month and even at this rate will take several years to fulfil its current backlog. Although many orders are the 'nice to have a problem' it does pose many challenges, not only at expanding the final production line but also with suppliers: some may be wary of growing oversize, especially when Boeing and Airbus try to squeeze lower prices. Others may see expansion plans limited by access to credit. In some cases, Airbus has bought suppliers mainly to ensure that they have the resources to deliver the required quantities. Several months after the Max grounding crisis, Boeing reduced 737 production rate from 52 to 42 per month which they plan to maintain before the lifting of the ban.

The A321neo/XLR and future developments are the current success story. In the past single-aisle aircraft had smaller capacity (up to 200 seats) and transcontinental range but were unable to cross-oceans. Twin-aisle aircraft (300-seats or more) were needed for transoceanic routes. Retrofitting the more efficient engines developed for the Bombardier C-series to the A320 family lead to the A320neo version A321LR able to cross the Atlantic. With further stretches the A321XLR has really become a middle-of-the-market aircraft able to replace widebodies in medium range routes with lower costs and higher frequencies. Thus the A321neo/XLR is not only extending sales of the A320neo family to longer routes but also taking away sales from widebodies, leaving for them only long-range routes. The A321neo/XLR are currently receiving most of the airliner orders with Boeing 737/9-10 showing little ability to compete.

7.2.4 Continued Competition through Evolutionary Developments

A heavy workload in increasing final production rates and shoring up the supply chain to much higher outputs leaves Airbus and Boeing with little spare capacity for major all-new designs. The current aircraft are selling at unprecedented rates so there is no need or incentive to come up with radical improvements. A radical improvement might require much more efficient engines, but the reengined second and third-generation aircraft already rely on the latest and most advanced technology, so there is little scope for a major improvement in a few years. Besides the engine manufactures are enjoying an order boom in proportion to that of airframe manufactures: Snecma and General Electric have challenges similar to Airbus and Boeing in increasing the final production rates and shoring up the supplier base; in spite of problems with the geared fan at Pratt & Whitney and the 'self-limitation' of Rolls Royce to wide body engines, neither seems to be in a less than healthy state. With both airframe and engine manufacturers busy to fill order books, incremental improvements are the feasible option, waiting for major progress that could take 5 to 10 years to mature to enable mew designs.

7.2.5 The Fall of the Airbus A380

Apart from the B747 as a freighter, the A380 is the last four-engined airliner still in production. Soon there will be none. The management at Airbus announced the termination of the production in 2021.

Since the launch of the project in 2000, the demand for the very large airplanes faded slowly. No US airline purchased the type. Lufthansa bought only 14. Air France-KLM, Qantas, Virgin Atlantic cancelled orders. Emirates, the larger operator lost enthusiasm more recently. The economic disadvantage relative to long-range wide-body twins is exacerbated by retaining an older generation of less efficient engines. Two flights of the B787/A350 carry as many passengers as a single A380 flight at a comparable or lower cost, with greater flexibility of schedule but using twice as many airport slots. The A380 would require the thrust of 3 existing engines sizes for the B777/A350 but this is not a feasible configuration. The development of a new twin-engine configuration would have required much larger engines than those currently available. Reengining with four engines of the newer generation, suggested by largest

Middle-East operators, would have implied development costs that engine suppliers were not prepared to shoulder due to limited market prospects.

After an investment of over $17bn in the development of the airliner, much above the programme break-even point initial calculation basis of $9.8bn, the expected total number to be delivered before the termination date would be only 251, one unit more than the break-even targeted in 2000. When A380 cancellation was announced on 14 February 2019, the then Airbus CEO Tom Enders said: "We were probably at least 10 years too late." Four years before, another high executive of Airbus, Fabrice Brégier, then Airbus Commercial Plane president, had said the A380 was "simply ahead of its time".

7.2.6 The Boeing New Mid-Market Airplane (MMA)

Generally, Middle of the Market segment is defined as a mid-size segment, located between the narrow-body and the wide-body market, and which encompasses aircraft carrying 200 to 270 passengers and a range that can vary from 3,000 nm to 5,000 nm, as defined by Boeing executives. Due to the poor definition of this market, some aircraft that are found in the limit can be considered or not part of this market such as the A321neo or some variants of the 737 family. However, the main aircraft that have represented the competition within this market until the date is the B757/B767 from Boeing and the A330 from Airbus, taking into account their different variants.

Due to its performance improvements and flexibility, the A330neo is being considered as a strong candidate for replacing the ageing fleet of Boeing 757/767's. However, as per July 2019, the backlog for A330neo was of only 207 units, all of them for -900 neo, none for the proposed longer-range -800neo. In the meanwhile, Boeing does not have a clear candidate to replace the 757/767 fleet, which may lead in the coming years to a drop in orders in favour of Airbus. It is possible that the new Boeing MMA aircraft change this scenario if its introduction to the market is not delayed and it offers performance advantages versus its competitors A good promise is the capability of A321neoXLR to cover the MMA segment. It still enjoys a good growth potential (the composite wing in A321neo-plus exercise). Its demonstrated current range is over 4000nm and its maximum capacity has still reserves to be increased from the existing 206 seats to perhaps 250. B737Max lacks this stretch potential. A321XLR project, launched in June 2019 declares a maximum range of 4700nm, covering a majority of the routes MMA is expected to target.

A clean-sheet design of the MMA would be a premiere at Boeing for the last 2 decades. Their commercial aircraft subsidiary seems to have preferred upgrading older models, a conservative strategy. A state-of-the-art solution for MMA is supposed to contain composite wing and fuselage, a hybrid cross-section and next generation engines, everything promising a low $/seat/nm index. If all this can be achieved at a reasonable list price it can be a winner in its market. However, a development cost somewhere around $15bn might need a higher value for the programme break-even volume, much more than the $1-2bn cost of A321 upgrade did imply.

The prospects for the Boeing MMA are analysed in detail in the Chapter 13. The lower end of the market is well covered by A321/XLR. The upper end is covered by the A330neo and would reduce the sales of widebodies operating in the sector. Boeing has cancelled the MMA to focus on the FSA (Future Single Aisle) replacement for the B737. The B737Max is challenged at the middle of the short-hall market by the A320neo, at the top by the A321, and at the bottom by the A220/Embraer C-Series.

7.2.7 The Bombardier C-Series as Airbus A220

The challenges that Boeing faces at the small capacity end of the market with the B737 Max are, rather serious. For a start the A321neo stretch beyond the capacity of the B737 to which Boeing must respond in order to continue to compete in the long thin routes. Boeing may have brought another challenge to itself by opposing the "subsidized" sales of the Bombardier C-Series in the United States. The cost-free acquisition of majority rights in the C-Series leaves Airbus with a formidable and comprehensive line-up of the state-of-the-art airliners in the 100-300 seat range:

- The A220, ex Bombardier C-Series is optimised for 100-150 seats and is a good alternative to the slow selling A319 shrink of the A320;
- The A320neo remains a strong and efficient contender for the 150-200 seats;
- The A321neo dominates the long thin routes with 200-250 seats with its stretch potential confirmed in 2019 by the launching of 321XLR;
- Beyond 250 seats the A330neo has a competitive price and good economy.

The link with Airbus benefits Bombardier C-series in several ways:

- Not only in circumventing possible United States protectionism by having a final assembly at the Airbus facility in Mobile Alabama in America;
- Also, because the Airbus clout can bring suppliers prices to levels that Bombardier would not be able to obtain, making the C-Series more competitive in capital cost;
- The Airbus sales and support network and the integration in a product line ranging all the way up from 100 seats gives a dimension to the C-Series that Bombardier could not hope to achieve on its own.

Against the formidable line-up of the A220/A319/A320neo/A321LR/A321XLR/A330neo, Boeing has only the third generation of B737 that manages to compete in the 130-200 seat range, leaving an important slice of the market for the replacement of the B757/B767, currently used on long thin routes, almost unchallenged to Airbus. The reaction to the Airbus-Bombardier link with a Boeing-Embraer link was predictable but not equally effective:

- The Embraer E2 Series does not go beyond 120 seats compared with 150 seats of the Bombardier C-Series;
- This leaves Boeing with the challenge to cover the 100-300 seat range with the existing B737max below 200 seats and the new MMA above.

The collapse of the Boeing-Embraer deal in a blow to both:

- Boeing is left without a competitor to the A220 in the small end of the short-hall sector;
- Embraer is left alone to compete against the former competitor Bombardier C-series now as an A220 with the full backing of Airbus.

While is widely believed that Boeing must launch an MMA, the challenges it faces are considerable:

- In order to differentiate from Airbus offerings and compensate late arrival to market, it could be a twin-aisle, but this adds cost;
- To recover the investment in an MMA, airlines need a 10% increase in efficiency that will require a new engine for which all major suppliers (General Electric/Snecma and Pratt & Whitney, while Rolls-Royce declared forfeit due to the short-termism of the project) will be competing;
- The development time and time to market of a totally new clean sheet Boeing MMA will give Airbus plenty of opportunities to upgrade its current range at a lower cost to try to reduce the market impact of its rival;
- If Boeing succeeds in putting the MMA beyond the nearly exhausted potential of the A321XLR, Airbus can still, with the benefit of hindsight, decide to develop an all-new aircraft possibly superior in at least some aspects.

Overall, Airbus should be able to keep an upper hand in the 100-300 seat airliner market until significant new technologies are implemented. In any case, the healthy and still growing order books of both Airbus and Boeing, if they can rise to the challenge of increased production, bring revenues to do more than evolutionary developments. Both Airbus and Boeing have the financial resources and engineering talent to keep up their healthy competition to the benefit of airlines and their passengers.

7.2.8 The Promise of Radical New Configurations

Recent years have seen a growing interest in configurations distinct from the classical tube-and-wing of current airliners dating back to the vision of Sir George Cayley in the mid XIX-th century. The sometimes called radically new configurations like flying wings or joined wings were envisioned about 80 years ago in the period between the two world wars, though use has been sporadic until recently. The Northrop Grumann B-2 Spirit stealth flying wing bomber and a variety of drone designs have proved the viability of these concepts in several contexts. However, airliner design is subject to a long list of technical, certification, economic and operational requirements that extend beyond military and drone requirements. The case of the flying wing serves as an illustration of this point. There are clear advantages:

- The higher lift-to-drag ratio can lead to a reduction of 20 % in fuel consumption and emissions;
- The large internal volume of the thick wing provides plenty of passenger and cargo space;
- The choice of overwing engine nacelles, or flush or buried engines, or distributed propulsion would reduce noise at airports.

All these benefits do not come without challenges, some of which can erode the final result:

- The engine nacelles in the accelerated airflow above the wing are affected by compressibility effects at lower speeds than underwing nacelles, and could reduce cruise speed for the same drag;
- The engines at the rear top of the wing would lie in a thick boundary, whose ingestion could cause a stall or operating problems, that could become more serious for flush or buried engines;
- Distributed propulsion raises issues of transmission of power, like high-pressure losses in ducted flows or resistive dissipation of high-electric currents;
- The top-mounted rear engines create a large pitch down moment opposing rotation at take-off, requiring a large lift and angle-of-attack and a long undercarriage to avoid tail scrapes;
- the trimming of the large pitch down moment in cruise with upward deflection of trailing-edge control surfaces would reduce lift and lower lift-to-drag ratio benefits;
- The wide fuselage would place most inboard passengers far from the windows whereas outboard passengers would have large displacements in roll manoeuvres;
- The certification requirement of emergency evacuation in darkness from one random side of the fuselage in 90 seconds is more difficult to meet in a wide and short cabin than in a long and thin one;
- The easy isotropic pressurization of a cylindrical fuselage does not apply to a flying wing that must be either divided into tubes or need extra bracing or both.

This sample of issues shows that it is not a straightforward conclusion to decide on the overall benefits of new aircraft configurations, although they will inevitably come, sooner or later.

Given the current large order backlog of modernized aircraft and the time to mature further significant advances in technology, the next generation in technology may not come in less than 5-10 years' time, with market competition making the Boeing MMA the most likely all-new aircraft no sooner than 2025. It will be a tube-and-wing aircraft, a configuration whose potential is far from exhausted since it is possible to incorporate several improvements. On the other hand, the radical transition to a new configuration could be too risky an experiment in a market-oriented product. A half-scale demonstrator of a new configuration like a flying wing or joined wing might be useful to:

- Convince industry that all design trade-offs have been mastered and a reliable design database has been created;
- Allow certification authorities, service providers, airlines, airports and maintenance organizations to prepare for upcoming changes;
- Familiarize and educate the public about upcoming progress out of past precedent.

The prospect of an evolved tube-and-wing next generation and a flying wing generation to follow may depend on a major effort for in-flight validation of the latter in parallel with the development of the former. The precursor half-for full-scale Boeing flying wing aircraft could arise out of a NASA experimental aircraft programme or a tanker/transport aircraft for the US Air Force or a combination of both. In this case, Europe should not fall behind and must support a comparable flying wing demonstrator.

This picture is substantially changed first by the B737Max crisis (Chapter 14) and then by the COVID-19 pandemic (Chapter 16) as the biggest crisis in the history of aviation.

7.3 Potential Competitors in the Airline Market

The Soviet Union had alternatives to offer in every airline market sector (subsection 7.3.1), although the closed and sheltered nature of its clients made a difficult transition to the post-soviet partial collapse of the Russian aircraft industry. Japan`s experience in contributing substantially to the design and production of Boeing airliners, has led to the design of complete regional aircraft, with no signs of higher ambition (subsection 7.3.2). That ambition clearly exists in China but may need foreign collaboration more likely from Russia than from Ukraine (subsection 7.3.3).

7.3.1 The transition from Soviet to Russian Airliners

The closed monolithic posture of the Soviet Union required that there must be an airliner in every sector, to be also used by satellite countries and support mostly politically motivated exports of:

- The Tupolev Tu-114 long range four turboprop;
- The Tupolev Tu-104/124/134 twin jets;
- The Tupolev Tu-154 tri-jet;
- The Ilyushin IL-62 four jet;
- The Ilyushin Il-86 widebody;
- The Yakolev Yak-40/42 regional jet;
- The Ilyushin IL-38 regional turboprop.

The Tupolev Tu-114 was an airliner adaptation of the four turboprop Tu-20 bomber that could fly non-stop from Moscow to Havana during the cold war. The Tupolev Tu-144 Koncordski supersonic airliner never entered airline service. It needed afterburning for supersonic cruise limiting its range: it never carried passengers, flying mail from Moscow to Alma Ata instead. All others in the list above were produced in sometimes large numbers and operated over the years without having to face the competition of western airliners. The collapse of the Soviet Union led to an abrupt change, with Russian airlines buying western airliners that were more efficient and reliable, besides having much better after-sales support. The poor record of Soviet-era aircraft for reliability and inadequate spares support was only made worse by the near-collapse of the former Soviet civil aircraft industry.

The former military aircraft industry survived better the collapse of the Soviet Union and transition to the Russian Federation, mainly through the Sukhoi family Flanker fighter variants, that gathered enough export orders to overcome the decline of the home military market. Its former fighter house rivals Mikoyan-Gurevich fared worse with limited sales of the Mig-29 Fulcrum and Mig-25/31 Foxbat/Foxhound relying mainly on the home market. The outcome of the reorganization of the former Soviet into the 'new' Russian aircraft industry was that:

- Mainly civil design bureaus like Tupolev, Ilyushin and Yakovlev tried to soldier on the basis of updated Soviet-era designs that were not too competitive to start with;
- Of the predominantly military design bureaus only Sukhoi had the market and resources to lead the consolidation and rationalization;
- As a consequence, Sukhoi became the leader in new civil aircraft designs in the Russian Federation, an area in which it had never participated in Soviet times.

There is no hint of doubt of the ability of Sukhoi to design most types of competitive military or civil aircraft if the resources, engines and avionics are available. The Sukhoi Superjet 100 (SSJ100) regional aircraft had limited success with slightly more than 150 units delivered during a decade, but hardly better could be expected in the circumstances.

Another civil challenge, a targeted competitor for the Airbus A320/Boeing B737 was developed by Yakovlev design bureau and 3 prototypes were built at Irkutsk. The aircraft, currently known as Irkutsk MC-21 but expected to be renamed Yak-242 when deliveries to customers have started, is at least on paper, an impressive design, matching the western aircraft is most respects, and perhaps having some edge in some areas by virtue of a clean sheet design versus second/third generation redesigns. With a very high percentage of composites in its structures of the fuselage, wings and fins, sophisticate aerodynamics and an efficient P&W geared turbofan, MC-21 is promising a state-of-the-art level of performance. In 2019 the certification programme with the local regulator is reported to be quite advanced, while EASA certification is expected in 2020. However, a long series of factors dim commercial prospects for this impressive initial effort:

- There was no evidence of a production line let alone a complete chain;
- The maturity of Russian made systems was an open question;
- The Russian occupation of Crimea and interference in Ukraine cast doubts on the supply of western systems and materials;
- This included western engines and avionics for which Russia has no equivalents;
- The 'Russification' of engine and avionics technologies to western standards would be costly and slow;
- The western sanctions and low oil prices reduced the Russian budget for all sectors, including aviation;
- The militaristic and aggressive Russian policy gives priority to the military over civil aviation;
- Given the cuts in military aircraft development and production it would be surprising indeed if civil aviation would fare any better;
- Even if a fully Russianized aircraft could be produced the necessary spares support for exports might not be credible.

It appears that Russia will have to make great efforts to sell types with limited export potential or failing that rely on western airliners or slowly develop more modern types in collaboration with China.

7.3.2 Japan`s Market Captive to Boeing

The large trade surplus of Japan relative to the U.S. has led to a long-standing policy of the Japanese government to keep the airline industry aware of the patriotic duty to buy Boeing. Not content with having a sizeable captive Japanese market, Boeing has subcontracted to Japanese industry the design, development and production of major parts of its aircraft. It has been mentioned that up to 40 % of the B787 development was financed by Japan. It is clear that in these circumstances, Japan is most unlikely to launch a Boeing competitor, and will instead continue to blend in, share and finance Boeing designs, keeping Airbus out of the Japanese market. The Japanese ambitions for the design of complete civil aircraft are thus limited to regional airliners. The Nanc YS-10 twin turboprop was an example in a distant past stretching to the current Mitsubishi MRJ-110. The Japanese have maintained a significant research effort in supersonic airliner design in the hope of becoming a full partner if such a project ever sees the light of the day after the memory of Concorde.

7.3.3 China`s Turboprop and Turbojet Certification Hurdles

China is well aware of the value of the aircraft industry. When the EU considered taxes or sanctions against Chinese 'dumping' practices, there was a reminder that "a single jet airliner is worth 200 million t-shirts". There is an Airbus A320 final assembly line in China using entirely imported components. When Airbus proposed sourcing locally some components the Chinese airlines rejected the idea. Embraer planned business jet production in China; however, the Chinese government taxed components imported for the Phenom business aircraft, making the whole operation unprofitable; Embraer had to scrap the production plan at a loss. These two opposite events show the Chinese government emphasis on local production and airlines mistrust of the same.

The Chinese are currently in process of development and certification for a turboprop (Xian MA700), a regional jet airliner (ARJ21) plus a single-aisle competitor to the A320/B737, (designated C919). MA700 project started the prototype building in 2017 and plans to certify with the local authorities in 2021 and subsequently with FAA and EASA. Taking into account the experience with ARJ21, this ambitious planning seems rather unrealistic. ARJ21 programme started in 2002 and the certification process with local regulator and FAA was initiated in 2011. FAA certification is not yet completed at present. CAAC certification obtained in December 2014 allowed the operation of the type in China and 7 units were delivered to local airlines. When asked about these long-delayed development programmes Chinese officials reply that their efforts are much younger than the decades of Airbus and Boeing experience. The Chinese lag behind most in engine technology. The engineer that developed the first Chinese military engine for the J-10 fighter received the highest decoration of the country, although the power plant appears to be rather unreliable, not boding well for the next developments of civil engines.

The Chinese difficulties in certifying its three civil aircraft, if and when eventually overcome, could lead to a significant change in the local and global market:

- The Chinese domestic market is large enough to support airliner development on its own;
- The availability of Chinese aircraft, say a single-aisle airliner, could partially close the local market for the A320/B737;
- A Chinese aircraft in this class would use western engines and avionics, so the advantage of low labour rates on final cost could be small;
- It cannot be excluded that the Chinese would promote exports by the use of dumping or subsidies as they have been accused in the past on lower value products;
- The focus of Chinese trade in Asia, Africa and South America and its lack of concern with local ethics could increase penetration of those markets;
- Even if unable to compete on fair terms in Europe and North America, the Chinese could significantly erode the Airbus and Boeing markets.
- Current Chinese production capacity for airliners is much smaller than Airbus or Boeing, at about one-tenth, and could take time to ramp-up.

The hardest sector for the Chinese to crack is wide body airliners, requiring cooperation with Russia.

7.3.4 China's Path Towards Wide-Body Airliners

The Chinese are clearly very far from being able to produce a wide body airliner, both from the airframe and propulsion points-of-view. The signature of a Sino-Russian agreement at the highest head-of-state level to jointly develop a wide body airliner demonstrates the high priority in both countries not to depend on Airbus and Boeing and to compete with them. This agreement could be seen as a partnership of Russian aviation technology and Chinese finance and market. The available Russian wide body technology is the updated Ilyushin IL-86 converted to IL-96 with engines less efficient and reliable than western engines; it's not really competitive now and would be less in the future. Besides the former Soviet experience with large aircraft was with Antonov military transports powered by Ivchenko high by-pass ratio engines both located in Ukraine, outside Russia now. The logical step of a Chinese approach to Ukraine would be most welcome for all sorts of reasons ranging from political, to economic, financial and technical. The pair Antonov Aircraft/Ivchenko Progress engines have a long record of producing some of the largest aircraft and engines at the time:

- the Antonov An-12 Cub was the standard Soviet tactical transport, as the Lockheed C-130 Hercules in the U.S. and Transall C-160 in Europe, and is currently produced in China;
- The Antonov An-70 with its contra-rotating propfan pioneered 20 years ago the technology now used in the Airbus A400M Atlas;
- The Antonov An-22 Antei was a four-turboprop large transport that preceded the An-124 Ruslan as a rival to the Lockheed C-5 Galaxy and Boeing C-17 Globemaster in the US:

- By growing the An-124 from 4 to 6 underwing engines the payload was increased from 150 to 250 tons in the single prototype of the An-225 Mryia, that with a gross weight of 600 tons is the world`s heaviest aircraft.

The tale of Antonov and Ivchenko after the collapse of the Soviet Union was a complex one:

- The close links between the Russian and Ukrainian aircraft industries meant that Russia remained an important but reluctant client, trying to do without Ukrainian products whenever possible;
- The 20-year lead of the An-70 was lost in protracted development of a Ukrainian aircraft and engine that Russia did not want to fund or depend on;
- Antonov/Ivchenko explored their smaller regional aircraft but this was a limited source of revenue;
- The An-124 Ruslan operated by Dnieper airliners become a leader in worldwide air transport of outsize loads, for example in United Nations humanitarian missions;
- The annexation of Crimea and Russian military intervention in the Donbass area was the final strain in soured relations, and a loss to both sides;
- Russia lost a part of its aviation supply chain that it would be costly and long to replace;
- Ukraine had to replace facilities lost in the Donbass region and look for new markets.
- The Ukrainian recovery strategy has included a plan for the production of regional aircraft in Saudi Arabia;
- License production of the An-225 in China has been reported in the press in September 2016, with details concerning plans to start building two prototypes in Chengdu and Shaanxi.

The latter would be heaven`s send that could allow China to overcome all its current limitations:

- Its military transports are based on the Antonov An-12 equivalent to the C-130 Hercules and Ilyushin Il-76 equivalent to the C-141 Starlifter; it lacks a strategic transport like the Lockheed C-5 Galaxy and Boeing C-17 Globemaster and is behind the Airbus A400M Atlas.
- The An-225 would give China the world's largest military transport aircraft and a power projection capability worldwide to exceed Russia and Europe and rival the US;
- Some annalists believe that the eventual use of the aircraft to transport and launch space vehicles is not excluded.
- Ivchenko can provide not only the engines for the An-225, but also for Chinese fighters, helicopters and other aircraft;
- The availability of a full range of modern engines gives the Chinese time to develop their own with less dependence on Russia or the west.

The last heard news in December 2017, of licence production of the AN-225 in China have not been confirmed.

Instead, the focus has returned to cooperation with Russia on a CR-929R wide-body with 3 variants having ranges of 6 500 to 7 570 nm with 250 to 320 passengers. It is estimated to have similar capability and size with A330-900 and 787-9. The designation CR-929R indicates the Chinese intent:

- The Chinese 'C' to follow the Airbus 'A' and the Boeing 'B';
- The 929 wide body to follow the 919 narrow body family;
- The 'R' in CR-929R for collaboration with Russia.

The project is based on the split of work between partners: China will produce the fuselage a will perform the assembly at COMAC plant in Shanghai, while the composite wings, empennage and tail section are to be produced in Russia. The engine selection is in process, with GE and Rolls-Royce the main contenders. Subsequently, Chinese and / or Russian alternatives are expected to be developed. The CR-929 project schedule was agreed to target the completion of the certification in 2027.

China had tried to buy the troubled Bombardier C-Series program which could have paved the way for the long relayed C919 certification. This was prevented by the cost-free acquisition of a majority stake by Airbus in the C-Series that was a masterstroke in several aspects:

- It prevents Chinese access to western airliner design and certification expertise;
- It extends the Airbus range down to 100-150 seats with an alternative to the slow-selling A319;
- It compounds the challenge that Boeing faces with the B737max and future MMA.

Thus, China may have to rely on cooperation with Russia on the CR-929R wide body which may not help with the certification of the C-919 and ARJ21. The lack of some advanced technologies and wish to satisfy the home market with local production have put the Chinese at odds with the Russians in the CR-929:

- The Chinese want transfer technology on high-bypass ratio engines and wide-body composite structures, that Russia wants to retain;
- The Russians want an export market, and do not agree on Chinese local production for the home market.

The disagreements have delayed the project by over two years. Russia has a fall-back solution in the Ilyushin Il-96 wide-body replacing 4 turbofans by 2 larger ones; China has no national solution.

7.4 The Regional Jet and Turboprop Market

The regional jet (subsection 7.4.1) and turboprop (subsection 7.4.2) market cannot be separated from the long-distance air travel (sections 7.1-7.2) because it acts as its feeder at major hubs, besides serving also shorter routes. It is also an important market for Europe, much more accessible to other entrants (subsection 7.4.2) than the Airbus-Boeing duopoly of giants. The link Airbus-Bombardier on the C-Series and the possible counter Boeing-Embraer on the E-Series imply a tie-up between regional and long-range jet airliners.
The reduction of the number of competing suppliers, from 4 to 2, may not please airlines, since it could extend the Airbus-Boeing duopoly from long-range to regional jets.
The main market for regional aircraft is represented by REGIONAL CARRIERS, i.e. carriers with an average stage range around 500 km or fleet without narrow-body and wide-body aircraft (turboprops and / or regional jets only). Their operators act as a feeder for long-distance air travel at major hubs, besides serving also shorter routes. It is also an important market for Europe, much more accessible to other entrants than the Airbus-Boeing duopoly of giants. It appears that the large corporate structure of Airbus and Boeing is well suited to the design and production of long-range single and twin-aisle jetliners, but not cost-effective at the one-tenth smaller scale of regional aircraft best left to smaller industry groups.
The regional airliners market appears to develop steadily. According to the data provided by European Regions Airlines Association (ERAA) the total deployed capacity of the intra-European market operated by its members is continuously increasing and reached on July 17 around 7.5 mil seats and 94k movements. The average stage length is 504km and the average flight duration 1hr14min. ERAA carriers operated 911 unique routes, their focus being shorter, thinner routes. The vast majority, 82% of the routes throughout the year was placed between 300 and 650 km, compared with 500 to 1500 km for LCCs (Low-Cost Carriers). ERAA carriers have a market share in Europe of approximately 16 % of flights and 9% of seats. The industry transports 45m passengers each year on 960,000 flights. In the US an average 22% of the total seating capacity is aboard regional aircraft and it continues to climb.

To keep the load factor at higher levels (i.e. to increase efficiency) smaller aircraft are preferred. As reported by the US' RAA (Regional Airlines Associations) in 2016, the average seating capacity of a U.S. regional aircraft was 62 seats. However a growth tendency is observed for this figure, it used to be 51 just 10 years ago (a 22% increase). In Europe, the current value is around 73, raised from 58 in 2007. The explanation for this tendency is in the increase of the share in the total of larger machines, as the old small capacity types are retired. However, the average value of the number of seats in the fleet is still much lower than those corresponding to LCCs.

7.4.1 Families of Regional Jets

Small turbofan aircraft with 50-120 seats are competing on this market now and in the near future. One can call such a rather crowded market as more competitive, at least compared to the one for larger planes. Embraer is a market leader with its E170 / E190 family, its position being at this moment threatened seriously only by A-220 (ex-Bombardier C-Series) family. The other regional jets from Bombardier, the mature CRJ family was rather neglected for some times and there are some indications that Bombardier current strategy is to exit the sector of commercial aviation.

However, other potential competitors on the regional jet market, like Comac ARJ21 (currently in the certification process for a too long time), Sukhoi Superjet 100 (already holding a Western Type Certificate) and, probably, Mitsubishi MRJ 90 will certainly create a regional turbofan market competition for Embraer and Airbus. Other (more remote) risk might come from the Turkish Do 328Jet, a product labelled TR Jet, or (less probable, due to the potential lack of financing) from upgraded variants of Antonov An-148.

Mitsubishi MRJ programme, still struggling in the certification process, entered in a final phase after more than a decade and is expecting the first deliveries in 2020 or 2021. That moment will not be lacking difficulties: as any new entrant on a market can testify, the need for an experienced sales organisation and of after-sale support will create some handicap. These weak points might be brilliantly solved if the CRJ programme is acquired by Mitsubishi, not especially for the product (which still keeps some development potential) but for the use of its existing global infrastructure efficient in the two fields mentioned above. In this situation, with a strong international maintenance organisation and a production facility in North America, MRJ might, after finalising the certification, become the only clean-sheet modern and efficient regional jet available on the market worldwide. The result of the current negotiations between Bombardier and Mitsubishi Heavy Industries are very important for the future of the sector.

Embraer has recognized the limits of an order of magnitude difference to Airbus and Boeing by staying below their markets and at most scraping the bottom end. It has avoided the risky challenge of the Bombardier C-series and used new geared fan engines later in the development cycle with reduced risk. As a consequence, Embraer has built a steady and stable market share, evolving from regional turboprops to regional jets, in a relatively smooth and orderly transition. The misfortunes of the Bombardier C-series lead to some neglect or underfunding of other activities, and thus Bombardier could not disturb significantly Embraer inroads in the regional jet market, although it has a larger order book. The Airbus take-over of the C-Series strengthens very much the Bombardier position; it remains to be seen what effect the Boeing-Embraer talks will have when a conclusion is reached.

7.4.2 The ATR42/72 Family of Regional Turboprops

The ATR42/72 family is the survivor of the European offer of regional airliners, following the demise of Dornier, rundown of British Aerospace models, end of SAAB 340 production and concentration of CASA on military transports. The revival of the ATR42/72 is due to the superior economics of turboprops over jets, with modest compromise on flight time due to lower speed on short routes. The Italian side of ATR has in the past advocated an extension to the 100-seats, a view apparently not shared by the French side. A basic question is whether the size of the market would justify the development cost and lead to break-even in an acceptable time scale. Some speculate Airbus could fear that a hypothetical ATR100 would compete with the modest selling A319, with 220-100 or erode the bottom of the vast A320 market. The Airbus-Bombardier deal on the C-Series, and a more cautious approach on the Leonardo side, may lead to a focus on updates to the ATR42/72 rather than stretched or new aircraft. Another explanation is that Airbus may not wish to follow the unsuccessful example of the Boeing acquisition of Canadair regional aircraft ending in a sale to Bombardier after years of losses. It appears that the large corporate structure of Airbus and Boeing is well suited to the design and production of long-range single and twin-aisle jetliners, but not cost-effective at the one-tenth smaller scale of regional aircraft best left to smaller industry groups.

Instead of stretched variant, ATR launched in 2019 and already successfully sold a STOL variant of ATR 42, which is able, with a minimum of modifications, to operate on runaways 20% shorter than the standard model. A military variant of the ATR 72-500 for maritime surveillance was presented at Le Bourget this year. A hybrid electric variant of ATR is contemplated by the company as an experiment for the future. It seems the family still enjoys good demand.

The other contenders in the regional turboprop market are considerably less competitive. Since Dash 8 Q400 (ex-Bombardier, now Viking since November 2018) is not yet prepared to face the competition of ATR, it would need an upgrade and a production line apt to adapt to higher output. Iliushin Il-114, expected to be revived soon is an unknown, probably in need of modern technology, while other currently used types have serious handicaps, so ATR is in strong control of the market.
The other contenders in the regional aircraft market include Japan, Russia, China and Ukraine, and were considered in the broader context of potential competitors in the airline market.

7.5 The Business Jet Market and Supersonic Prospects

The business jet market extends from the largest airliners customized for heads of state to private aircraft flown by their owners (subsection 7.5.1). The next civil supersonic transport following Concorde (subsection 7.5.2) could be a supersonic business jet (subsection 7.5.3). Hypersonic or orbital travel (subsection 7.5.4) would be farther into the future.

7.5.1 A Wide Range of Business Jets and Fractional Ownership

A small fraction of Airbus and Boeing airliner production goes into business jets, mainly in two groups:

- At the upper end the wide bodies like the A380 and A340, and B747 and B777 customized for heads of state, royal families and wealthy individuals;
- At the lower end, the corporate narrow bodies like the A320 and B737 used to transport several company officials from and to the closest airports independently of airline schedules.

Just below in size the top rank of dedicated business jets by Gulfstream aviation can have comparable speed, range and comfort in a narrower fuselage and costs that are not much lower than single-aisle airliners. The main European competitor Dassault keeps a family of efficient long and medium-range Falcon series business jets. Smaller regional business jets are produced by other manufacturers like Cessna with the extensive Citation range. Embraer has entered the market at the low end with the Phenom series, going gradually up in scale with the Embraer legacy series. This contrasts with its arch-rival Bombardier established for a longer time supplier of high-end large business jets, some doubling as regional jetliners. Some models like the Learjet, Hawker and Aero have changed ownership several times. At the very low end, some low-cost business jets are supposed to be flown by their owners. The general trend is in the opposite direction of fractional ownership with an aircraft or a large fleet shared by several owners. This may amount to flight by the hour including aircraft, engines, flight crew, maintenance and other costs.
According to the General Aviation Manufacturers Association (GAMA), three classes of business jets are identified by specific performances and price levels:

a) Light jets – for example, Cirrus SF50, Cessna Citation series lower end or Pilatus PC-24
b) Midsized jets –Bombardier Challenger, Cessna Latitude, Embraer Legacy etc class
c) Large business jets – Gulfstream, Bombardier and Falcon families

Light jets and the lower end of midsized are facing competition from turboprops and even from piston-engined models. But from a business aviation world market worth nearly $20bn yearly, only about 10% buys non-jets.
Both the number of units sold by the manufacturers each year and the money spent by customers for procuring business jets have shown strong volatility during the last decades. Any recent recession hit this industry that suffered much more than other aerospace sectors. After the record of over 1300 aircraft produced in 2008, the volumes halved in subsequent years to fluctuate later just above those numbers.
After several years of decline, the business jet market seems to show small signs of recovery: a total of 703 units were delivered in 2018 compared to 677 in 2017. However, the behaviour of each market segment was different.

Light class, very crowded as ever did show a rather encouraging increase of 16%, explained to analysts by the resurgent US market in connection with economic growth. Midsize class sales were nearly level, explained maybe by the current transition between generations.
On the contrary, the 'large' class is still suffering from the blows of the previous recession, with volumes decreased by 7%. This is probably the effect of soft demand in traditional markets like the Middle East and China. The only manufacturer who recorded an increase in deliveries in 2018 was Gulfstream, 121 units compared to 120 in 2017.
Europe is far from leading in this market. Of the total number of business jets delivered worldwide in 2018 (703 units) and billed at $17.8bn, only 60 were manufactured in Europe, billed for a total of just over $3bn. Dassault shipped just 41 Falcons (down from 49 in 2017or 95 in 2010).
The successor to the first supersonic airliner Concorde (subsection 7.5.2) could come in another category as a supersonic business jet (subsection 7.5.3).

7.5.2 The Unsurpassed Technical Achievements of Concorde

Although it was designed in the 1950s, first flew in the 1960s and ceased airline operations in the last century, Concorde as the first supersonic airliner remains an unsurpassed achievement in many areas:

- Its ogival wing combines high sweepback angle at the root and tip for a high-speed flight with lower sweepback in the middle for greater span for a low speed flight;
- The highly swept delta wing was tested at low speed in the specially designed Handley Page H.P.115 experimental aircraft, to check that it had acceptable flying qualities;
- The ogival wing was tested at high-speed up to Mach 2.2 in another experimental aircraft, the BAC 221 itself an extensive redesign of the Fairey Delta FD.2:
- The choice of a Mach 2.08 cruising speed was made to stay below the heat barrier and allow the use of a special aluminium alloy in the structure;
- The Bristol Siddeley Olympus engine grew in thrust from 4.5 tons in the series 100 in the Avro Vulcan Mk.1/Handley Page Victor Mk.1 bombers, to 9 tons in the 200 series of the Mk.2 bombers, to 13.6 tons in Concorde augmented to 16.2 tons with afterburning;
- Supersonic cruise did not require afterburning and careful aerodynamic design giving the same range in subsonic as in supersonic flight;
- Afterburning was used only on take-off and landing, with the high angle-of-attack requiring a droop nose, and flying at the 'back' of the power curve, that required special pilot training and skill;
- Sophisticated multi-ramp air intakes were needed to match the airflow to the engine over a wide range of speeds from twice the speed of sound to stalling speed;
- The motion of the centre of lift changing between subsonic and supersonic flight required fuel transfer to keep pitch trim, thus adding another flight-critical system;
- The passenger payload was only 8% of the gross weight giving a little margin for weight growth in the development of such a complex aircraft.

Technical excellence does not always equate to market success, and Concorde faced many other challenges:

- The development cost of one billion pounds for each partner country Britain and France could never be recovered;
- Only 16 aircraft were produced, 8 each for Air France and British Airways, with no further orders;
- The flights were always full of passengers willing to pay higher fares for the privilege of flying at twice the speed of sound in a unique aircraft instead of flying first class in a more conventional airplane;
- The sonic boom limited supersonic flight to overwater routes in the Atlantic, with acceleration and deceleration bins of shock wave concentration in inhabited areas in the English Channel and near Newfoundland in Canada;
- Flights between London/Paris and New York/Washington took half the time of other aircraft;
- Flights to the Middle East had a similar range at mostly subsonic flight with less time benefit;

- Paris-Conakry was also possible but not transpacific routes.
- The Concorde needed high jet exhaust speeds for supersonic flight leading to higher at take-off and landing noise than for subsonic aircraft.

New York La Guardia airport created a noise monitoring point, and millions waited for the next Concorde operation to break the noise limit and leading to a ban to use the airport. A special bank manoeuvre after take-off was developed so that the noise limit was not exceeded at the measuring point, and the demonstrators returned home with nothing to complain about. The achievements of Concorde can be seen by comparing with its attempted rivals, starting with the Tupolev Tu-144 Koncordski. Its design betrayed the role of industrial espionage in Britain and France, yet it was a failure: it needed afterburning for supersonic flight, was short on range, never carried passengers and only performed some mail-carrying flights between Moscow and Alma Ata. A more ambitious competitor was the US SST (Super Sonic Transport) funded by Congress. It would carry 300 passengers across the Pacific Ocean (instead of 108 passengers across the Atlantic Ocean) and fly at Mach 2.7 above the heat barrier (instead of Mach 2.08 below the heat barrier) requiring titanium instead of aluminium for the structure. The Boeing swing-wing design won over the Lockheed highly swept delta wing, raising some eyebrows when Boeing changed to the configuration of its rival after winning the contest. With the prospect of a 2.7 billion-dollar development cost being exceeded the U.S. Congress finally voted to terminate the program.

The cancellation of the U.S. SST left Concorde as the sole supersonic transport in existence and in the foreseeable future, allowing some discriminatory targeting of its unique features. Yet Concorde operated reliably and profitably over the Atlantic routes until suffering an accident that was not its fault. A piece of debris left on the runway by a preceding aircraft was hit by the undercarriage, projected towards the wing, puncturing a fuel tank, and causing a fire leading to a fatal crash. The protracted investigation that followed proved nothing wrong with the original design. The operations ceased not for lack of willing fare-paying passengers, but because of the difficulties of maintaining an old aircraft, with the few surviving examples cannibalized for spares. The preferred name of the aircraft was "Concord" for the British and "Concorde" for the French, and in the compromise "Concorde" the last "e" was supposed to stand for "Europe". Whether British, French or European the Concorde was a magnificent technical achievement but not a commercial success, perhaps explaining why decades have passed debating a successor that is yet to appear.

7.5.3 The Supersonic Business Jet?

The prospects for a commercial supersonic aircraft look dim:

- The sonic boom would prevent flight overland, leading only overwater routes, with the transatlantic market small and the transpacific market requiring more range;
- The overall number of aircraft, perhaps a few hundred, could hardly cover the high development cost of a supersonic airliner and a dedicated engine.

The feasibility of a supersonic transport probably depends on taking economics out of the equation. The supersonic business jet could be the right market niche with time saved and perhaps exclusive status prevailing over operating costs. Yet the supersonic business jet still faces the same challenges as Concorde. Research on sonic boom reduction has led to long-nose configurations delaying the formation of the N-shaped shock wave and leading to the lower ground overpressures. Depending on the level of ground overpressure allowed by certification authorities' supersonic flight at about Mach 1.5 might be possible overland at sufficient altitude (above 15 km). The main stumbling block may be the lack of a suitable engine:

- The existing supersonic engines were designed for combat aircraft that fly hundreds of hours per year, and have a design life of about 5000 hours;
- With civil aircraft flying up to 3000 hours per year the durability of military engines is clearly inadequate;
- Converting a subsonic civil engine to supersonic would mean an almost total redesign at a cost possibly not justified by the small niche market involved;

- Current civil turbofans have high bypass ratios (BPR) of 5 to 10 for fuel efficiency, leading to large frontal area;
- For supersonic flight, the small frontal area for acceptable area, would limit the BPR to about 1, as in the older first-generation civil turbofan.

Of all aircraft manufacturers Dassault Aviation would be best placed to design and produce a supersonic business jet:

- it has decades of experience with supersonic jet fighters;
- it has a complete range of high-end efficient business jets;
- it has researched the critical aspects of a supersonic business jet.

Yet Dassault has never come forward with a supersonic business jet proposal, perhaps because there is no suitable power plant. Several start-ups, some of which never produced even a light plane, have come and gone with supersonic business jet and small airliner designs that change configuration halfway into oblivion.

Some of the supersonic business jet or small airliner start-ups or stalwarts have sought or claimed the cooperation of major airframers like Airbus, Boeing or Lockheed with various agreements and timescales.

Recent favourable news include:

- The announcement by Pratt 8 Whitney that it could develop an engine for supersonic business jets based on the old JT-8D series of the first generation low bypass ratio turbofans;
- The Directive of the Trump Administration that the FAA develop certification rules for supersonic business jets, hat have been submitted to ICAO, and may prove controversial on environmental issues.

7.5.4 Hypersonic, Sub-Orbital and Orbital Transport

As speed increases several factors become more acute:

- The cost may grow faster than speed;
- The time saved is less in absolute terms;
- Technology and operating conditions become more severe.

To illustrate the point of reduction of travel time:

- Propeller driven airliners in the early post-war years would take over 10 hours to cross the Atlantic and might require a refuelling stop;
- jet airliners flying directly at twice the speed halve the travel time from 12 to 6 hours, that is a significant absolute time saving of 6 hours:
- Flying at twice the speed of sound in Concorde halves the flight time to cross the Atlantic to 3 hours, yet this smaller absolute time saving comes at considerable cost and complexity.

Substantial time savings at speeds higher than transonic airliners could still apply to the very long flight to the antipodes of the earth, such as Europe to Australia in 20 hours direct or with 1 stop. A Concorde successor flying at twice the speed of sound over very long ranges would halve travel time to 10 hours. A hypersonic aircraft powered by a supersonic combustion ramjet at Mach 6 would take 3 hours and a rocket orbiting a passenger capsule with atmospheric re-entry would take less than 1 hour. However, the operation would no longer be from nearby airports, adding to ground travel time. The cost also increases significantly with the technical challenges and passenger fitness might become an issue. All these problems will have ultimately to be solved for space exploration by mankind.

7.6 Markets for Helicopters and Convertibles

The helicopter market is one of Europe´s major successes. Airbus Helicopters is the world leader and Leonardo also holds a strong position on the market. They are competing against Boeing-Vertol, Bell and Sikorsky (that Lockheed-Martin sold to Boeing) from the U.S. as well as Mil and Kamov from Russia (subsection 7.6.1). The strong U.S. investment in greater hot-and-high and high-speed capabilities must be matched if Europe wants to maintain long term market share (subsection 7.6.2).

7.6.1 Stability and Volatility of the Helicopter Market

The helicopter market has some stable elements like search-and-rescue, emergency medical evacuation and law and order protection. Other elements are more volatile and vulnerable to large fluctuations:

- Oil exploration is more intense in periods of high oil prices, and can run down quickly if oil prices fall;
- Wars in inhospitable places, like hot and dusty Iraq, and high, hot and dusty Afghanistan place high demands on helicopters due to the lack of safe ground infrastructure or alternative means of transport.

The helicopter market expanded due to:

- The wars in Iraq and Afghanistan leading to high demand for rotorcraft due to the lack of local infrastructure to support rapid mobility on the ground and the risks with the proliferation of roadside bombs;
- The high oil prices fostering the off-shore oil prospecting and exploration supported by medium and heavy helicopters.

The decline in military operations in Iraq and Afghanistan and the reduction in oil exploration due to the lower oil prices caused a reduction of both the military and civil helicopter markets that are slowly recovering.

7.6.2 Greater Hot-and-High and High-Speed Capabilities

Faced with reducing order books the American helicopter industry is pressing the US government mostly through the armed forces to end decades of stagnation in helicopter technology, as the focus was on the production of existing types and derivatives. The aim is to replace production contracts by contracts to develop new helicopters that can then be produced as replacements for the existing vast fleets, even if on a reduced scale of less than one-on-one. The promises of increased performance focus on:

- Greater hot-and-high capabilities, overcoming the degradation of existing helicopters in those conditions, by using more powerful propulsion and rotor systems.
- The greater power can also be used to increase speed, range and shorten reaction time.

Although these developments are driven by the military, the results in improved performance will come to the civil market sooner rather than later.

Some threats to Europe's market leader position might come from the very ambitious US's Future Vertical Lift programme to design helicopters or tiltrotors with: twice the range; 50% higher speed; over twice the hover payload under demanding hot and high conditions, using engines with double power but similar fuel consumption, size and weight. The programme is justified by the need to counter threats from near-peer adversaries in Europe and elsewhere: hence it is relevant to the defence of Europe. The FVL contenders are the V-280 Valor tilt-rotor from Bell and SB-1 Defiant dual rotor plus pusher-propeller helicopter from Boeing and Sikorsky; Europe has analogues in the Augusta-Bell AB609 and Airbus X3, as well as competitive turboshaft engines from Safran and Rolls-Royce.

Although it is a military programme it could have civil spinoffs: (i) double-range for the off-shore oil industry; (ii) higher speed for medical emergencies and executive transport; (iii) greater payload for rescue and transport missions. All this could challenge the current position of Europe with over 50% of the world helicopter market share. The strong U.S. investment in greater hot-and-high and high-speed capabilities must be matched if Europe wants to maintain long term market share.

Russia is also funding the development of an advanced high-speed helicopter**.** The Central Aerohydrodynamic Institute (TsAGI) has confirmed on 27 November 2018 that Kamov Design Bureau started work to create a flying laboratory on the basis of the Ka-52 helicopter. The concept feature a 'delta' fixed-wing, co-axial rotor system, a side-by-side cockpit, and pusher engines in the rear similar to what is used on the Sikorsky S-97 Raider and SB-1 Defiant. The co-axial rotor system will be driven by twin engines. It is expected that new technologies will provide more speed (probably about 400 km/hr) and range and better fuel efficiency.

Europe must match the U.S. and Russian efforts if it wants to keep its leading position in the world helicopter market. Safran Helicopters is introducing a new family of turboshaft engines to compete with the advances made in two military U.S. programs. The Airbus X-3 has gained the world helicopter speed record 472 km/hr, in 2013) showing that Europe does not lack the technology or ingenuity. Airbus Helicopters has recently unveiled the aerodynamic configuration of the high-speed demonstrator it is developing as part of the Clean Sky 2 European research programme. Codenamed Racer, for Rapid and Cost-Effective Rotorcraft, this demonstrator will incorporate a host of innovative features and will be optimised for a cruise speed of more than 400 km/h. It will aim at achieving the best trade-off between speed, cost-efficiency, sustainability and mission performance. Final assembly of the demonstrator is expected to start in 2019, for a 2020 first flight.

The massive resources being put into high-speed helicopters and convertibles in the U.S. leave no room for complacency in Europe: the advances there must be matched on this side of the Atlantic in a competitive or cooperative but coordinated program. The transition from 'permissive' military applications to 'stringent' civil certification must be taken into account: although based on the Bell Boeing V-22 Osprey tiltrotor the smaller AB-609 initially a co-development taken over by AugustaWestland has struggled over a decade with civil certification.

7.7 Current UAVs Markets Demand

Under the general term of Unmanned Air Vehicles (UAVs) there is a very wide spectrum of aircraft equipment addressing a multitude of applications. For the scope of this paragraph, the discussion will cover only the large Unmanned Combat Aerial Vehicles (UCAVs).

In this sector, Europe is far from being competitive, an example not to be followed. In Europe, there is no shortage of technology, as proved in the UK-only Taranis program, the German Talarion, the Italian Hammerhead and the multi-national Neuron led by Dassault. However, none of those has reached production. The projects are at an early stage with no guarantee that leadership and nationalism issues have been resolved. The recent official abandon by France's and UK of a 2010 UCAV joint programme with no pertinent explanation is a sad example. Consequently, Europe is buying Global Hawks, Reapers and Predators from the U.S. and Herons and Hermes from Israel. The in-development US programmes using Artificial Intelligence (AI) like Loyal Wingman and Skyborg have no EU equivalent at present.

Other countries had progressed in this field, ahead of Europe. The reluctance of the United States to export armed drones has allowed China to take a leading position as the supplier of such systems in Asia and the Middle East. While during the decade 2009-2018 US exported just 15 Reapers, China exported 163 UCAVs of 5 models to 13 countries. The efforts made by the Chinese to develop a wide range of almost state-of-the-art drones and the willingness to export them at unbeatable prices creates a market advantage that will be difficult to challenge. One unit of Wing Loong II Chinese UCAV is offered at a list price between $1m and $2m, compared to $16m the price of a Reaper, only slightly superior in flight performances, but actually much better in systems and reliability. While China is working to produce competitive engines for their drones, India is working hard to develop UCAVs and Turkish Aerospace is also a player on this market with their Anka product.

It is essential to have either one common or several competitive programs that go beyond studies and prototypes into production. The development of a new MALE (Medium Altitude High Endurance) drone by France and Germany, recently joined by Spain, is the best prospect of closing this capability gap, and bringing other partners. The MALE effort is part of a larger programme including a new generation fighter and loyal wingman to replace French Rafale and German Eurofighters. A competing Tempest program led by Britain may be joined by Sweden and Italy. Thus the current three European competitors in the fighter sector, namely Rafale, Eurofighter and Gripen, could be replaced by two with different political and industrial alliances.

The key topics considered next are:

- Long-range air transport (T7.1 and T7.2);
- Airliner and Business Jet Markets (T7.3 and T7.4);
- Helicopters (T7.5 and T7.6).

KEY TOPIC T7.1 ECONOMIC ASPECTS OF THE LONG-RANGE AIR TRANSPORT

Historically, long-haul traffic has grown faster than short-haul, growing 3.4% per year since 2000 while the growth in short-haul has been 2.5% for the same period. Today's long-haul network serves a variety of market needs. People may choose to fly form a world's economic centre to another, fly to a more secondary airport or seek a connection between smaller locations. Nonstop and connecting traffic contributes to different extents to an airport's long-haul traffic volume.

Figure 7.11 shows the forecast evolution of air passenger's traffic, taking into account three scenarios:

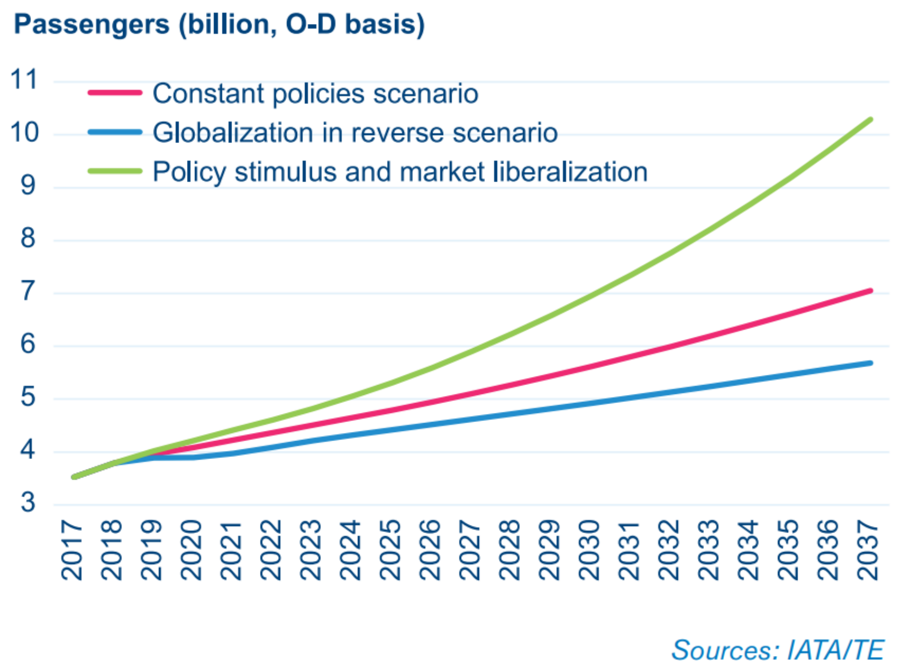

Figure 7.11– Air passengers growth scenarios 2018-2037

The long-haul traffic future growth is related to a wide range of parameters that will be analysed in detail in the following sections:

- Demand;

- Cost;
- Users;
- Operators and manufactures.

T7.1.1 Demand

In the future, long-haul flights will be operated by larger aircraft to serve the higher numbers of passengers demanding travelling long-distance. Although gradual route fragmentation may lead to more direct flights avoiding stops at busy hubs that add cost and increase environmental impact. In addition, it is expected more demand from emerging countries such as China or India as a result of their growing economy.

T7.1.1.1 Passengers Demand

According to IATA, for "constant policies scenario", passenger numbers are expected to reach 7 billion by 2037 with a 3.8% average annual growth in demand (2017 baseline year). The five fastest-increasing markets in terms of additional passengers per year over the forecast period will be China, the US, India, Indonesia and Brazil. (See figure 7.12).

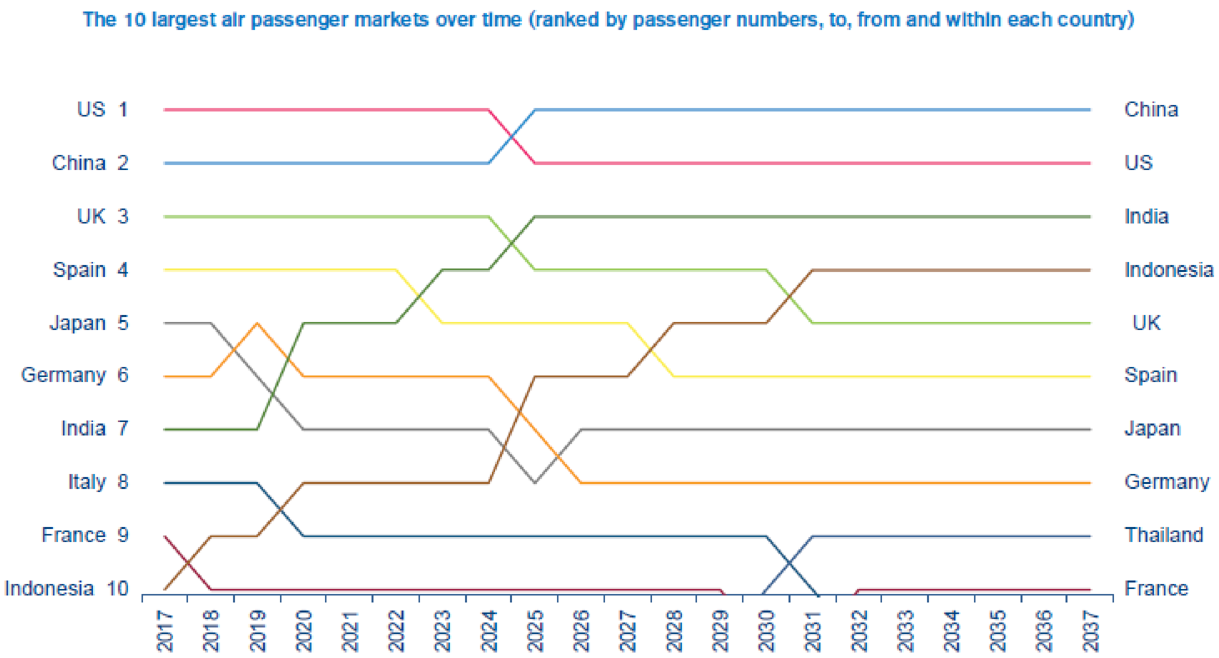

Figure 7.12– Top ten passengers markets

Source: IATA TE Long-Term Demand

In addition, passengers demand by regions will also experiment a great change, as indicated in Figure 7.13:

- Routes to, from and within Asia-Pacific will see an extra 2.35 billion annual passengers by 2037, for a total market size of 3.9 billion passengers. Its CAGR of 4.8% is the highest, followed by Africa and the Middle East.
- The North American region will grow by a CAGR of 2.4% annually and in 2037 will carry a total of 1.4 billion passengers, an additional 527 million passengers.

- Europe will grow at a CAGR of 2.0% and will see an additional 611 million passengers. The total market will be 1.9 billion passengers.
- Latin American markets will grow by a CAGR of 3.6%, serving a total of 731 million passengers, an additional 371 million passengers annually compared to today.
- The Middle East will grow strongly with a CAGR of 4.4% and will see an extra 290 million passengers on routes to, from and within the region by 2037. The total market size will be 501 million passengers.
- Africa will grow by a CAGR of 4.6%. By 2037 it will see an extra 199 million passengers for a total market of 334 million passengers.

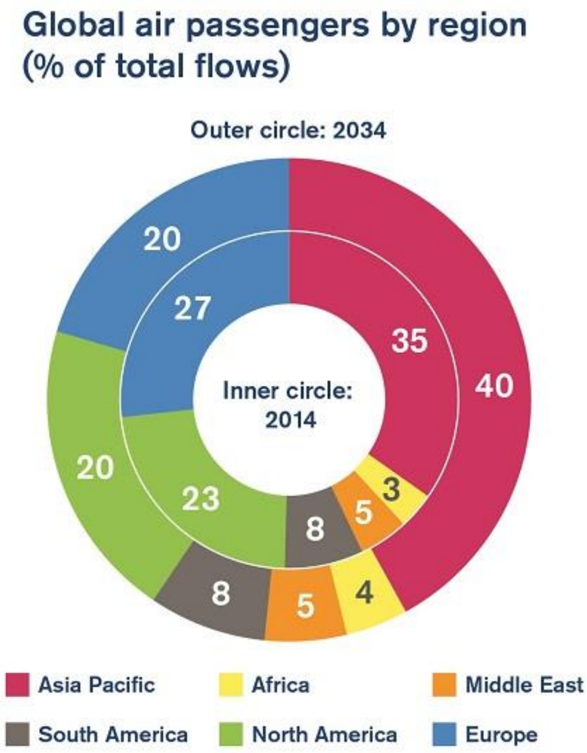

Figure 7.13– Global Air Passengers by region

Source: IATA Air Passenger Forecast Shows Dip in Long-Term Demand

T7.1.1.2 Urban Growth

Air traffic growth is much related to population growth, which in turn is related to economic growth. Nowadays, more than half of the world's population, 3.5 billion people, live in urban centres. By 2030, it is expected that 59% (5 billion people) will live in cities. During the next two decades, developing countries as China or India will absorb a significant additional urban population, 900 and 600 million city dwellers respectively.

Rates of urban growth in developing countries have been higher than that of developed countries. Cities have become the main driver of globalization and the engine of economic growth. They have quickly transformed their economies through international trade, attracting large multinational corporations, international media and foreign tourism. The rise in urban population has led to an increase in economic growth, which is a key driver for aviation. Most urban growth is projected to take place in the southern part of the world, with different degrees of urbanisation. For example, urban populations are expected to grow significantly in India, China and Indonesia. By 2030, more than half of the population of China and Indonesia and about 40% of the Indian population will live in cities.

As these countries continue growing, it will be necessary to have access to quick and efficient connections. Air transport will be the ideal solution, minimizing time, the impact on land use and cost to the government. Therefore, air transport will become a vital part of these emerging countries by providing access to global markets and facilitating the connection of people worldwide, enabling increased foreign migration and international tourism.

In 2010, emerging countries such as Brazil, Russia, India and China (BRIC countries), together accounted for 69% of world population, about 5 billion people, which explain the growth it is predicted over the next two decades. In the future, these countries together with other emerging economies will contribute an impressive 56% of the 2010-2030 world economic growth. (See figure 7.14).

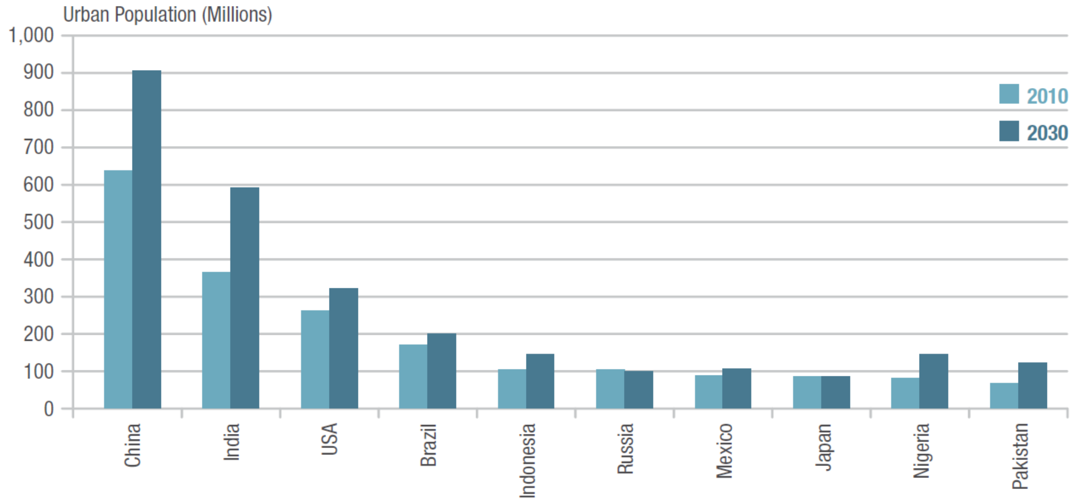

Figure 7.14 – Top 10 urban countries

Source: Airbus Global Market Forecast 2011-2030

T7.1.1.3 Long-range Routes and Traffic Flows

Forty years ago, 76% of the world's traffic flew from, to or between North America, Western Europe and Japan. Today, this tendency has changed as more people can benefit from aviation advantages as a consequence of growing economies. In 2030 it is expected that 70% of the traffic volumes will be between expanding regions.

Today, the long-haul market is dominated by three main traffic flows (see figure 7.15). The air-bridges over the Atlantic and the Pacific Ocean, as well as links between Europe and Asia, account for two-thirds of worldwide long-haul traffic. With anticipated traffic growth over the next 20 years, the clear majority of long-haul traffic will remain concentrated on these three dominant flows (see figure 7.16).

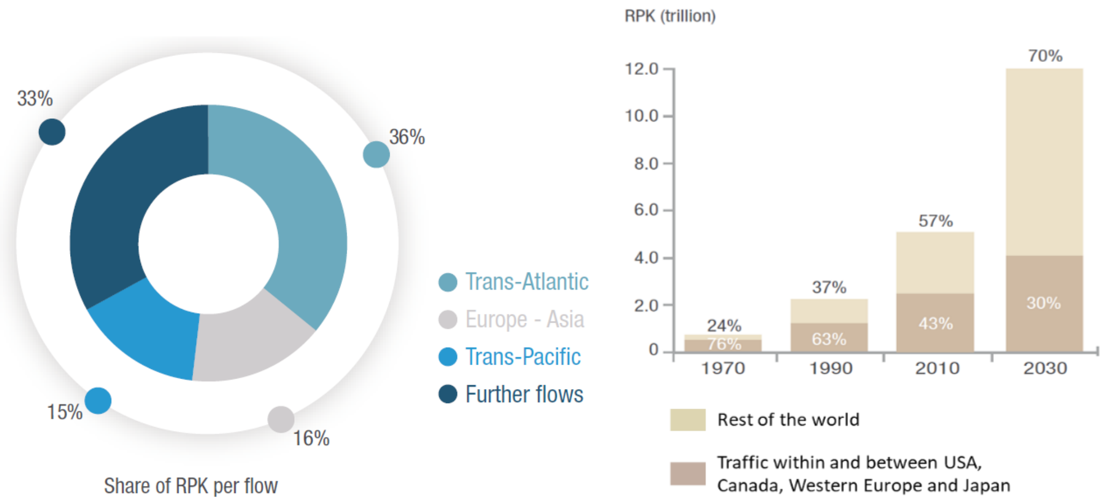

Figure 7.15 – RPK share of Trans-Atlantic, Trans-Pacific and Europe-to-Asia traffic flows on total long-haul traffic, 2010

Source: Airbus Global Market Forecast 2011-2030

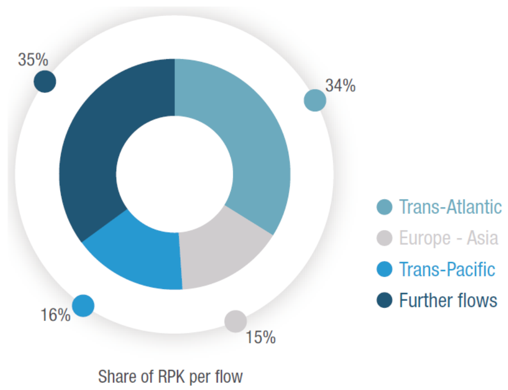

Figure 7.16 – RPK share of Trans-Atlantic, Trans-Pacific and Europe-to-Asia traffic flows on total long-haul traffic, 2030

Source: Airbus Global Market Forecast 2011-2030

In particular, the trans-Atlantic market has undergone a growth of 50 % in the last 15 years, as it can be seen in Figure 7.17.

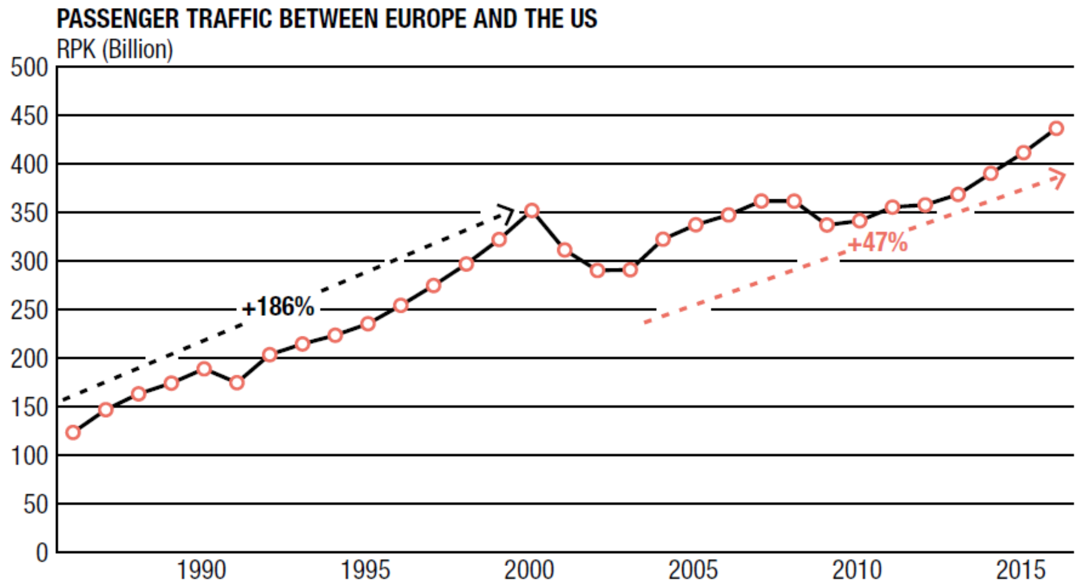

Figure 7.17 – Passenger Traffic between Europe and US

Source: Airbus Global Market Forecast

On the other hand, traffic between emerging countries is forecast to grow at 6.2% annually and will represent a growing share of air traffic, from 29% of world traffic in 2016 up to 40% by 2036. The highest growth in long-haul traffic market is expected within the triangle of Africa, Asia-Pacific and the Middle East.

The Popular Republic of China will be the main contributor to new long-haul routes in the Asia-Pacific region, which will lead world traffic by 2030, becoming this dynamic region the world's largest air travel market. For instance, traffic within the Asia-Pacific region will represent 25% of total traffic in twenty years, up from 19% in 2010. The main flows will connect China to South-East Asia, the Indian subcontinent and the Middle East.

The long-haul sector between Europe, the Middle East and Africa is dominated by traffic between Europe and Middle East, where again most of the route openings are expected, notably between the U.A.E. hubs and more secondary cities in Europe.

Finally, the Trans-Pacific will enjoy the strongest growth out of the big three long-haul flows. The main reason is the increasing weight of RPK (Revenue Passenger Kilometres) traffic to China, which will reach similar dimensions as traffic to Japan. The newest non-stop route openings are forecast between Europe and Asia, despite strong competition coming from connections via the Middle East hubs.

In figures 7.18 and 7.19, it can be seen the main flows with more volume of air traffic in 2010 and 2030.

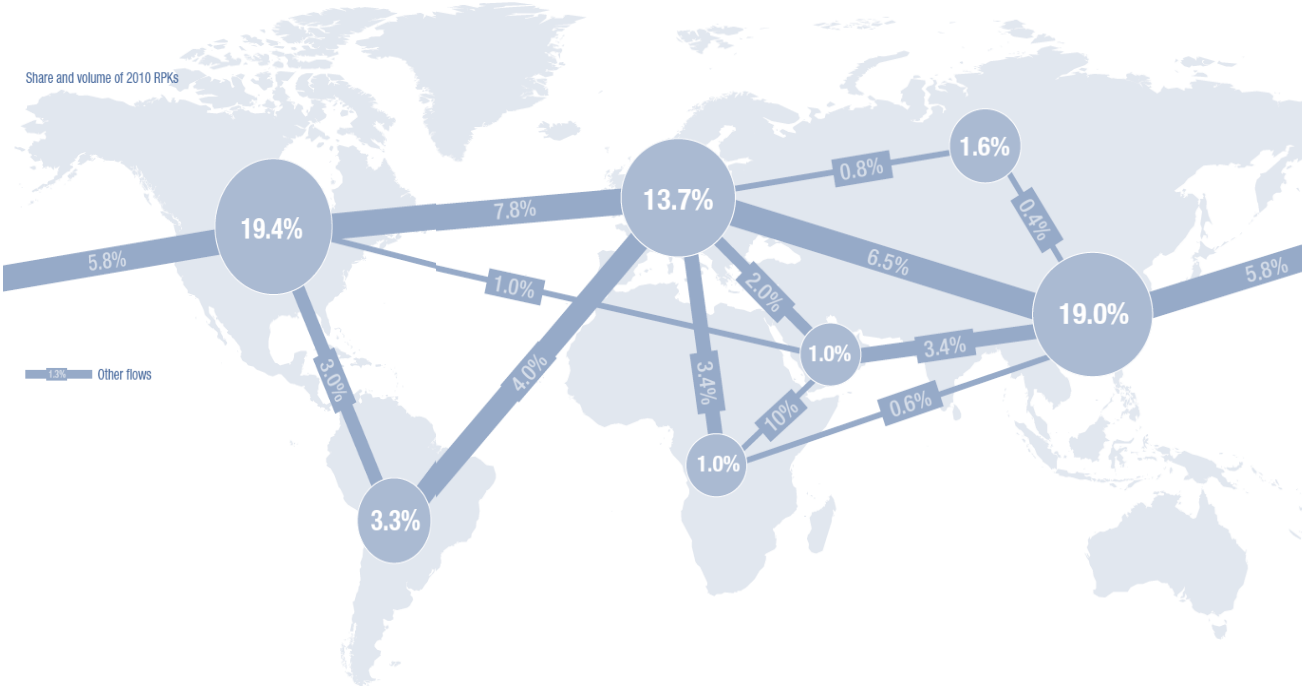

Figure 7.18 – Share and volume of 2010 RPKs

Source: Airbus Global Market Forecast 2011-2030

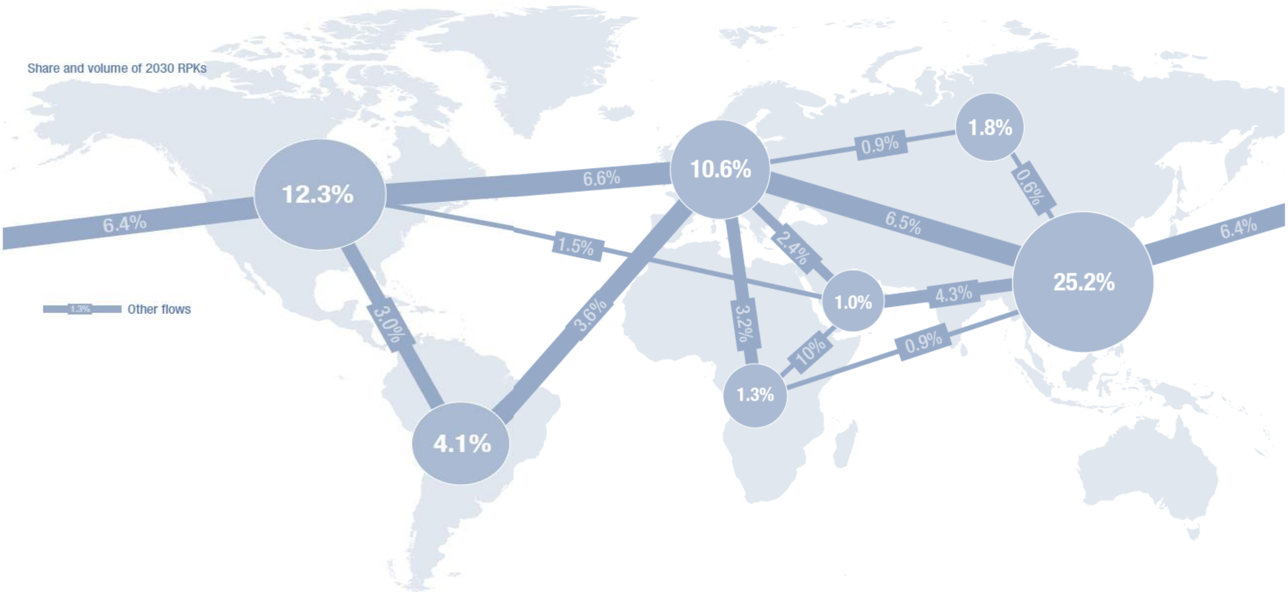

Figure 7.19 – Share and volume of 2030 RPKs

Source: Airbus Global Market Forecast 2011-2030

Finally, figure 7.20 shows the flows in which the fastest growth is expected.

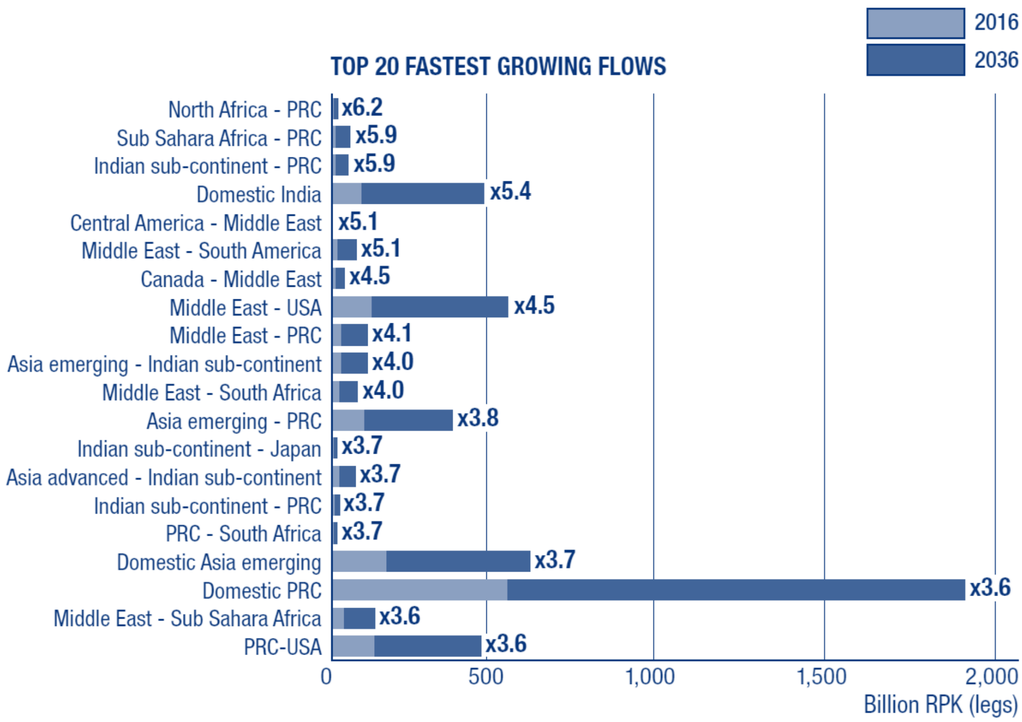

Figure 7.20 – Top 20 fastest growing flows over the next 20 years

Source: Airbus Global Market Forecast, Growing Horizons 2017-2036

T7.1.1.4 Long-range Destinations

There are cities that traditionally are centres of air transport demand, due to their socio-economic weight within a certain region. These cities, such as Tokyo, New York and London, are vital points for world trade; they are also big population centres with an enormous appeal far beyond their borders. These cities, in most of the cases, serve as a connection hub and, besides, they are places where people want to start and finish their journey that above all contributes to their weight and importance in the world long-haul network. Other points, whilst not being major population centres are very significant as aviation centres, such as the cities and airports in the United Arab Emirates and large European and U.S. transfer hubs. All these destinations are part of the long-haul network, which serves to connect flights from all over the world. Today, there are 39 cities from a total of around 350 that have a monthly throughput of at least 10,000 long-haul passengers per day and they absorb the 90% of the world's long-haul traffic. They serve as the pillars of the global long-haul network, serving as essential network crossroads and as the source of massive air transport demand. They are called aviation mega-cities.

Today, more than 90% of long-haul passengers travel either on a route between two Aviation megacities or on a route having one of them as a route start point, connecting point or endpoint.

Figure 7.21 – Long haul directs routes between the world's 2010 Aviation Mega-cities

Source: Airbus Global Market Forecast 2011-2030

By 2030, 87 cities around the world will have passed the threshold of 10,000 daily passengers, to become aviation mega-cities (Figure 7.21). The emerging regions of the world, including Latin America, Africa, the Middle East and Asia will contribute an additional 29 long-haul traffic hubs, as their economic power and wealth grow passenger traffic within these regions. Cities in Australia, Europe and North America will also benefit from a sustained long-haul traffic growth, adding a further 19 aviation megacities. However, in the next 20 years, slightly more than half of the global long-haul air transport centres will be in emerging economies. The number of cities that are considered as key gateways for long-haul flights will more than double over the next 20 years.

Nevertheless, long-haul traffic will remain highly concentrated on a relatively low number of points. In numerical terms: the 2010 top 20 long-haul gateway cities handled 55% of world long-haul traffic. Despite network evolution, the top 20 of 2030 will still account 50% of traffic. In the same way, the top 100 cities account for more than 90% of long-haul traffic, in 2010 as well as over the next 20 years.

Figure 7.22 – 2030 cities with more than 10,000 daily long-haul passengers

Source: Airbus Global Market Forecast 2011-2030

T7.1.1.5 Long-Range Network Forecast

World air traffic will grow at an average rate of 4.8% per year over the next two decades. This additional traffic volume will be accommodated on the existing route network as well as on new routes. Airbus forecasts that more than 700 new city-pairs will be added on the long-haul market over the next 20 years. This will grow today's long-haul network of about 1,600 city links by more than 40%. However, as traffic will grow twice as fast as the network, most growth will be accommodated on the world's existing city pairs. No more than 15% of 2030 passenger traffic will be on routes that are not served today, that is to say, new routes. Therefore, 85% of 2030 long-haul traffic will still be accommodated on the 2010 network. Figure 7.22 illustrates this forecast.

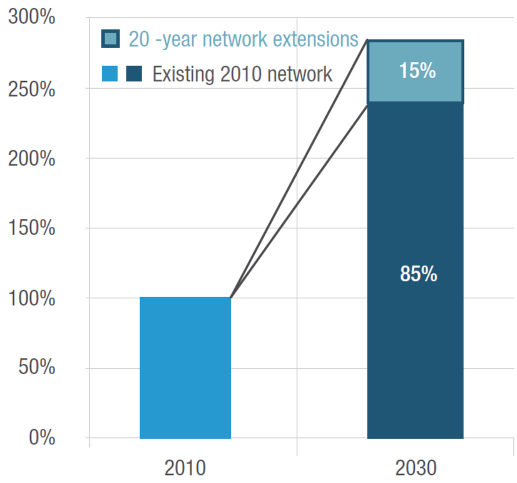

Figure 7.23 – Evolution of long -haul traffic

Source: Airbus Global Market Forecast 2011-2030

T7.1.1.6 Touristic Destinations

In figure 7.24, it can be found the main touristic destinations in 2015, with China leading the list.

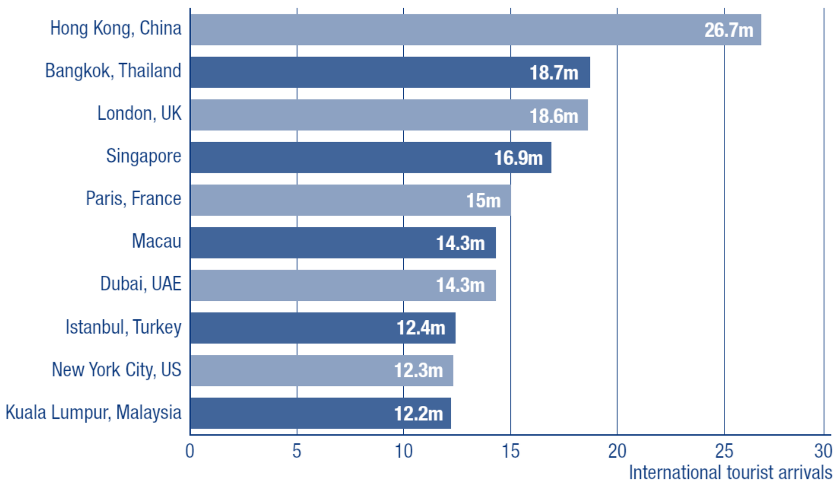

Figure 7.24 – Top 10 most visited cities in 2015

Source: Airbus Global Market Forecast, Growing Horizons 2017-2036

T7.1.1.7 Business Travel Trends

Business travels expenditure by US and European passengers have adjusted to austerity following the financial crisis and slow to recover the old spending habits; in contrast to Asia business passenger's travels expenditures, that trend growth, as indicated in figure 7.25.

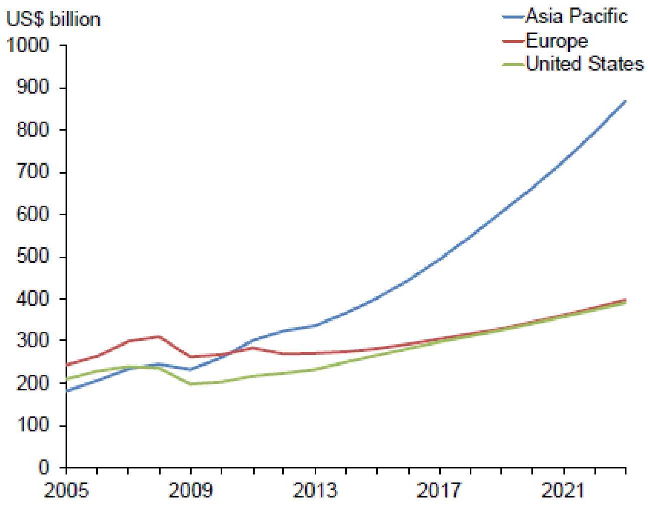

Figure 7.25 – Total business travel expenditures 2005-2023

Source: Oxford economics

A variety of mechanisms have contributed to this adjustment:

- Western companies have introduced sophisticated tools to control business expenses.
- Use of technological alternatives such as videoconferencing.
- More business trips are being planned by employees themselves or at least in-house rather than via an agent.
- Employee's empowerment by making more cost-effective decisions and/or decisions more suitable to their precise individual circumstances.
- Changes in corporate travel policies declining the yield on such travel (downshifting from business class to premium economy/economy, shorter hotel stays, changing to restricted fares or other means, etc.).

However, the effect has not been so dramatic for the long-haul segment. Premium air traffic data from IATA7 shows that long-haul (intercontinental) premium traffic recovered quicker from the financial crisis - particularly that connecting advanced to emerging markets. This difference might be explained by the fact that emerging market growth is helping to propel the latter.

As results of this later crisis several trends have consolidated:

- The emergence of the 'Premium Economy' travel class, especially in medium-haul 6-8 hour's journeys.
- Certain airlines have reinforced business class to retain or recapture business class passengers.

Regarding the future evolution of the business sector, **it seems that Asia will drive future growth in business travel**. North-East Asia alone will account for 42% of the growth in global outbound business travel expenditure over the next decade, with South East Asia accounting for a further 13%.

In particular, China is also rapidly reaching the US as the largest domestic market for business travel (see figure 7.26). European and North American business travellers will become less important globally, in proportion, but they will still be a third of outbound business travel between them and will increase their business travel to emerging markets. European business travellers are expected to be around 15% of future global revenue growth over the next decade, and North America 7% (See figure 7.27).

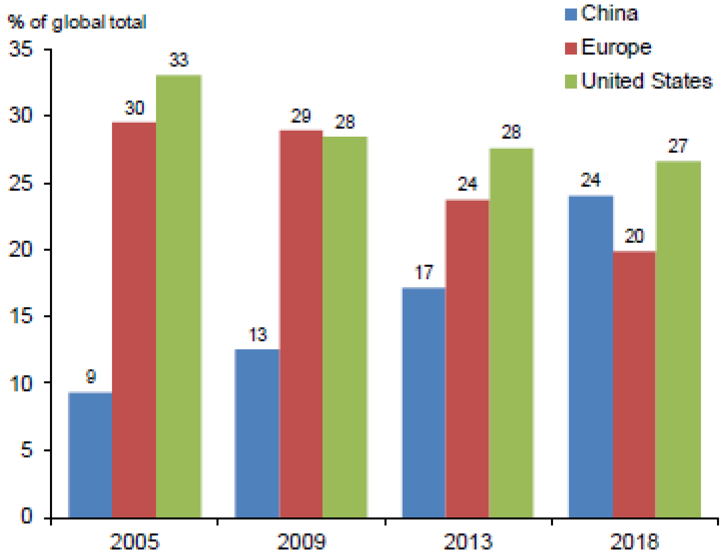

Figure 7.26 – Domestic business travel expenditure (% of global total domestic business expenditure)

Source: Oxford economics

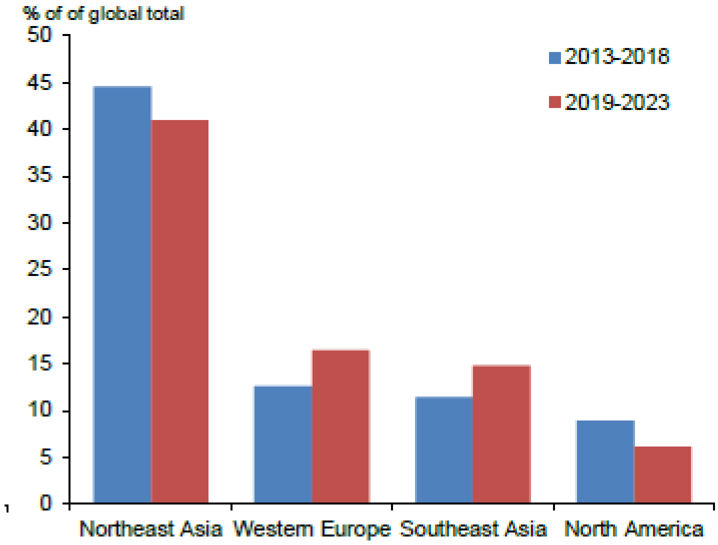

Figure 7.27 – Regional share of global growth in business travel expenditure (2013-2023)

Source: Oxford economics

A special reference needs to be done to the role of videoconferencing in this sector, as a supplement but not a replacement for business travels. Room for growth in both, videoconferencing and business travel, is expected over the next decade, in the context of globalisation and emerging markets.

T7.1.2 Cost

T7.1.2.1 Ticket Costs

Long-haul routes are highly attractive; in the United States, they account for about 40% of mainline operating revenues and over 90% of operating profits.

Normally, total ticket costs are much higher in long-haul flights than in short-haul flights (Figure 7.28). This is mainly because of the impact of fuel cost, but also because taxes, fees, and surcharges are considerably higher on long-haul routes.

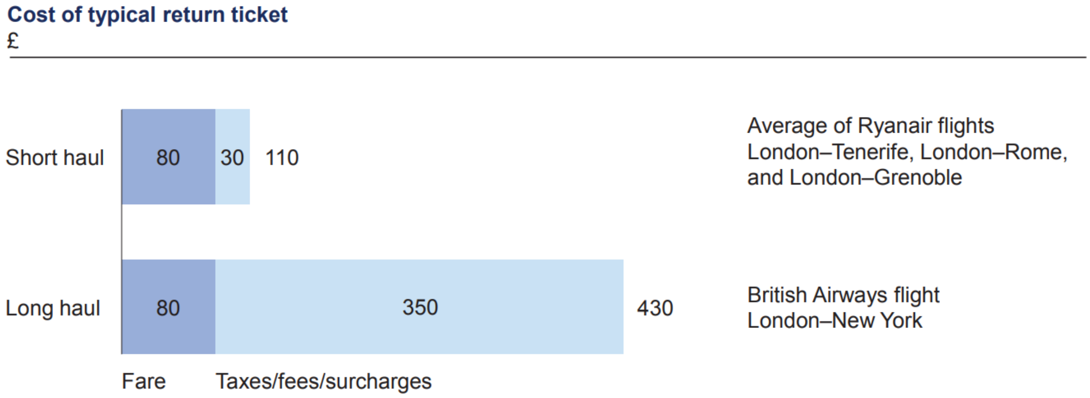

Figure 7.28 – A short life in long haul for low-cost carriers

Source: McKinsey & Company

T7.1.2.2 Costs of Operation

Normally, the cost categories of a flight include pilot, cabin crew, fuel, airframe maintenance, engine maintenance and others. The next figure 7.29 illustrates the approximate share of airplane operating costs that can be attributed to these various categories for a long-haul flight.

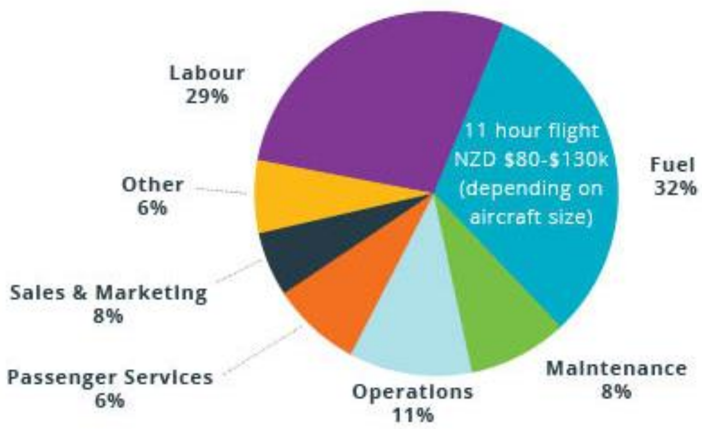

Figure 7.29 – Cost per flight for a long-haul service

Source: http://www.tourism2025.org.nz/tourism-2025-archive/grow-sustainable-air-connectivity-2/

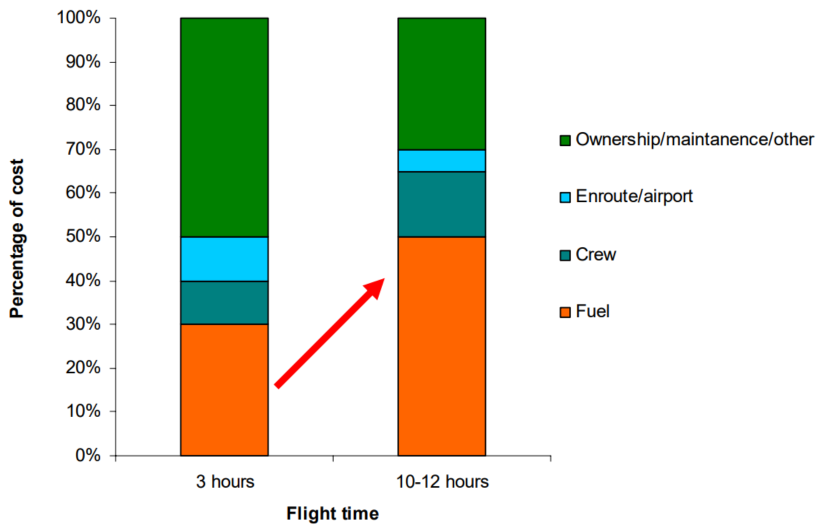

Figure 7.30 – Cost per flight time

Source: Long Haul Carriers in the modern low-cost world, Nathan Agnew

As can be seen in the previous images, the fuel consumption is the main cost component of a long-haul flight, as it must travel a great distance and, therefore, more fuel is needed. Fuel represents approximately 50% of the total LH trip cost, for every carried tonne of fuel, 0,5 tonnes of fuel will be burnt to carry it. Figure 7.31 illustrates the potential fuel savings predicted by Airframe- and Engine-manufacturer. The Airframe- and Engine-Manufacturer predict for the short-term Fuel burn savings of 2 to 4 per cent, with new technologies in the long term, estimated fuel burn savings are predicted to be in the region of 10 to 12 per cent. To buy a new aircraft and recover the capital investment, an airline requires a reduction of fuel consumption per passenger of at least 10%. This is the minimum gain in efficiency for a new generation of aircraft.

Figure 7.31– Potential fuel savings predicted by Airframe- and Engine-manufacturer (short and long term are disregarded)

Source: Airline profiler

Figure 7.32 represents the fuel consumption per distance for various long-range aircraft. As can be seen, the Boeing B787 is today one of the most fuel-efficient airplanes, therefore it is very likely that the carriers (both mainlines and low cost) will prefer to operate with this type of aircraft or similar (e.g. Airbus 350, Airbus A330 Neo, revamped B737 or A320 an extended range A321).

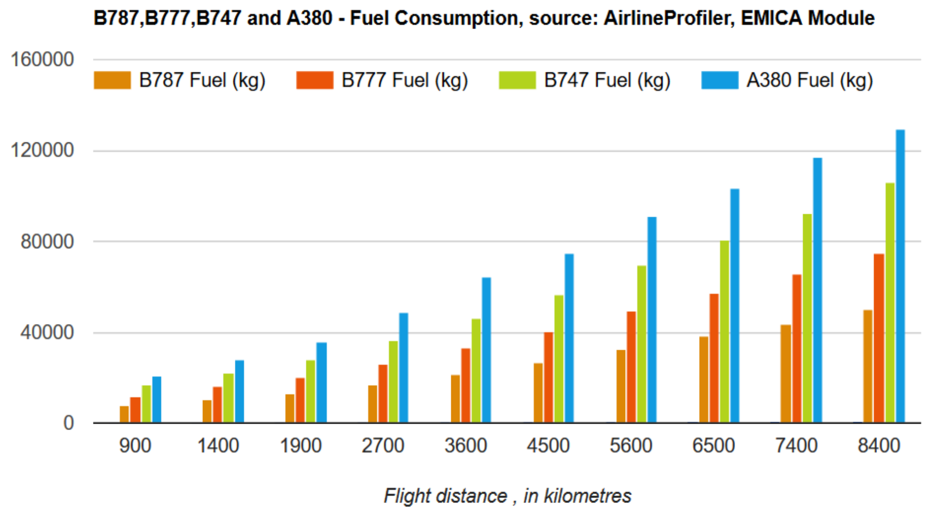

Figure 7.32 – Fuel consumption per distance

Source: Airline profiler

Figure 7.33 illustrates the breakdown of the cost of operation for the today most fuel-efficient airplane, the Boeing 787-8, as operated by different companies, a conventional air-carrier, a low-cost carrier and a charter air-carrier. The figure highlights the possible range of cost per available seat and kilometre and allows to identify where cost-saving mightily be possible.

A look at the operating economics of the 787-8 highlights cost differences.

	Mainline 247 seats[1] 3,200 nautical miles (nm); 740 km/h block speed 85% load factor		Low-cost carrier 291 seats[1] 3,200 nm; 740 km/h block speed 85% load factor		Charter 291 seats[1] 3,200 nm; 740 km/h block speed 95% load factor		
Line item	**$/BH[2]**	**Input cost**	**$/BH**	**Input cost**	**$/BH**	**Input cost**	**Unit**
Aircraft/ insurance	**2,467**	879,000	**2,467**	879,000	**2,467**	879,000	$/month
		12		12		12	BH/day
Fuel	**4,386**	1,700	**4,386**	1,700	**4,386**	1,700	Gallons/BH
		2.5		2.5		2.5	$/gallon
Maintenance	**855**	855	**855**	855	**855**	855	$/BH
		300,000		300,000		300,000	Salary/year/crew, $
Cockpit	**544**	**60%**	**411**	**20%**	**411**	**20%**	Benefit load, %
		10,000		10,000		10,000	Training cost/year/crew, $
		75		75		75	BH/month/crew
		32,000		32,000		32,000	Salary/flight attendant/year, $
Cabin crew	**390**	**40%**	**310**	**10%**	**310**	**10%**	Benefit load, %
		8		8		8	Cabin crew/aircraft
		2,000		2,000		2,000	Training cost/year/crew, $
		80		80		80	BH/month/crew
Hotel accommodation	**167**	**200**	**125**	**150**	**125**	**150**	$/crew member
		2,000		1,500		1,500	$/turn, aircraft
Airport/navigation	**831**	**2,530**	**661**	**2,530**	**679**	**2,530**	$/leg, landing and navigation
		10		5		5	$/passengers, handling
On board	**524**	**20**	**310**	**10**	**173**	**5**	$/passengers
Sales and distribution	**918**	**35**	**310**	**10**	**104**	**3**	$/passengers
General and administrative	**315**	**12**	**155**	**5**	**69**	**2**	$/passengers
Total cost $/BH	**11,396**		**9,989**		**9,579**		
CASK[3]	**6.2**		**4.6**		**4.4**		

[1]Seat counts based on announced configurations by carriers fitting the respective archetype.
[2]Block hour.
[3]Cost per available seat kilometer.

McKinsey&Company | Source: *Aircraft Commerce*; annual reports; Boeing; US Department of Transportation, Form 41; International Air Transport Association; International Civil Aviation Organization; pprune.org; McKinsey analysis

Figure 7.33 – Operation cost differences among companies for a B-787-8

Source: Airline profiler

T7.1.2.3 Fuel Prices Evolution

Oil price is an important consideration in aircraft forecasts as a result of its impact on economic activity, and the resulting impact it has on-demand for aviation. From aviation's perspective, crude oil prices and economic activity are closely correlated: strong and developing economic activity increases demand for oil, which has a positive impact on crude oil prices. Conversely, an exogenous increase of crude oil prices has a negative impact on economies, through inflation and a negative shock on global demand. Another impact of fuel cost is on the introduction of technological improvements for the aircraft to significantly decrease fuel consumption as shown in Figure 7.34.

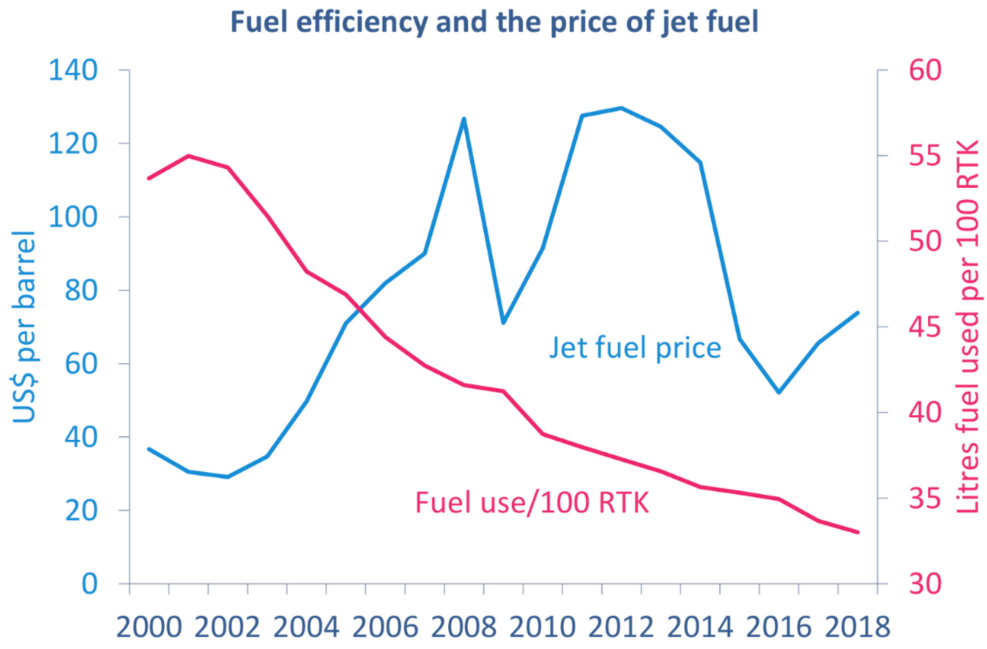

Figure 7.34 – Price of jet fuel evolution vs efficiency of the flying machine

Source: CAPA News

Air transport is generally more impacted than other sectors by increases in crude oil prices, as fuel currently represents more than 30% of airlines operating expenses. In recent years, the jet fuel price has undergone a decline, allowing improving the airline profitability during the period. Airlines had an operating result of $58.3 billion in 2016.

However, in the short to medium term, forecasts suggest that oil and jet fuel prices will continue the trend started in 2018 and recover over time, although may not reach soon the peak levels of the past.

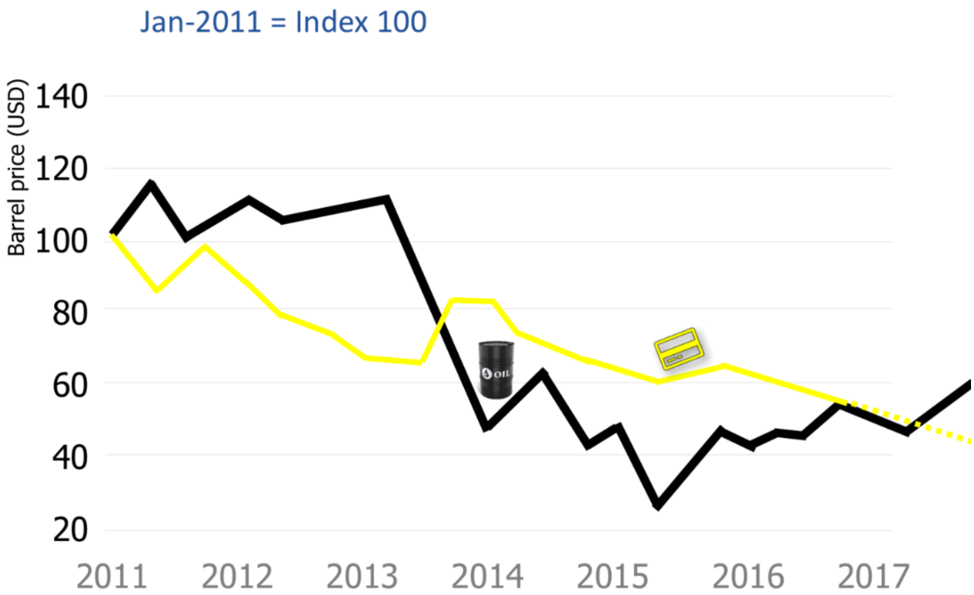

Figure 7.35 – Price of crude oil evolution

Source: CAPA News

T7.1.2.4 Costs in Relation with Distance

In addition, there is a relation between the flights costs and the distance costs increase as the distance increases because carries more fuel weight relative to pay level. Therefore, as long-haul flights must travel a greater distance, their operating costs are higher, which can be seen in the following images Figure 7.36 and 7.37 respectively for short and long-haul flights.

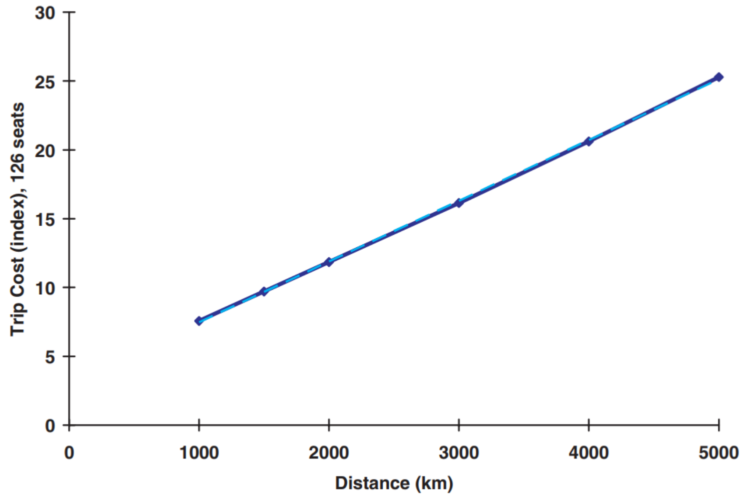

Figure 7.36 – Short-haul trip costs

Source: Aircraft trip cost parameters: A function of stage length and seat capacity, William M. Swan, Nicole Adler

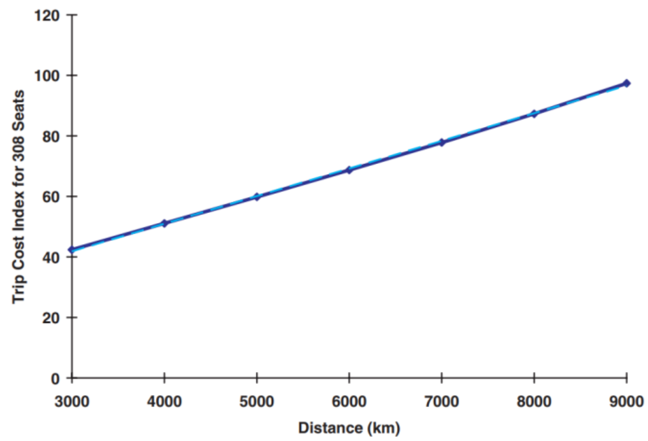

Figure 7.37 – Long-haul trip costs

Source: Aircraft trip cost parameters: A function of stage length and seat capacity, William M. Swan, Nicole Adler

T7.1.3 Long-Range Air Transport of Passengers

In relation to the growing demand for air travel, the following figures are established, according to Airbus GMF (Global Market Forecast) data (Figure 7.37):

- Revenue Passenger Kilometres (RPKs) grew 6.3% in 2016, as compared to 2015, according to ICAO figures which were preliminary at the time of writing.
- This represents an impressive 3.7 billion passengers carried by air in 2016.
- Over half of the world's tourists who travel across international borders each year are transported by air.
- Air passengers benefited from **oil prices** which remained relatively low, with airlines able to choose between stimulating the market through lower yields and therefore **ticket prices**, and their margins.

- Air traffic continues to prove its resilience to slow economic growth by outperforming global GDP, demonstrating the world's appreciation of the benefits aviation brings.
- For the next 20 years, the Airbus GMF forecasts a 4.4% global annual air traffic growth, despite some downward revision of future economic growth by a number of forecasters in several regions of the world. According to some predictions, the first decade will enjoy a 4.9% increase per year, with 4.1% average annual growth for the last decade, a lower figure but growth in those years based on absolute traffic numbers higher than today.
- One source of information is the Airbus GMF forecast. As an example, the GMF 2000 forecast continues to track the long-term trend and our latest forecast, despite significant market perturbations in the years following its production.

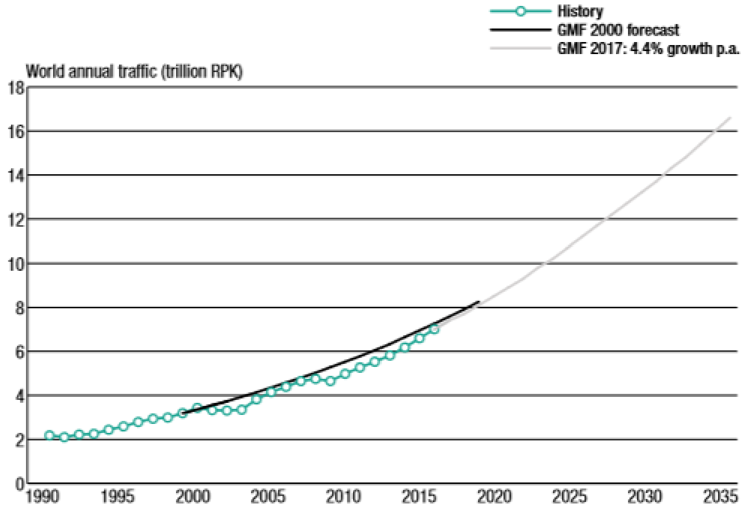

Figure 7.38 – Airbus GMF predicting long term demand

Source: Airbus GMF 2017

Furthermore, the following results are shown in the traffic forecast for 2036:

- Asia-Pacific will lead world traffic by 2036, with a threefold increase in the traffic serving this region by the end of the forecast period.
- Traffic between emerging countries is forecast to grow at 6.2% per annum and will represent a growing share of air traffic, from 29% of world traffic in 2016 up to 40% by 2036.
- Domestic China will become the largest traffic flow before the end of the forecast period. Domestic Chinese traffic is forecast to almost quadruple, with the Domestic USA increasing by 50% from an already high base.
- The three major flows connecting Western Europe are all expected to develop: Western-Europe – USA, Intra-Western Europe and Western-Europe – Middle East forecast to grow 1.8, 1.6 and 2.5 times respectively.
- Amongst the Top 20 traffic flows, 50% will involve Asia-Pacific and 25% will involve the Middle East.

T7.1.4.1 New Routes Demand ("Ultra-long-range")

Improved long-range economics are making the opening of new routes possible, as well as the resumption of old ones. So, improved fuel efficiency is therefore essential to the feasibility of ever longer air routes and this is exactly what the aircraft manufacturing industry has been delivering.

The state-of-the-art Airbus A350-900ULR (where the last three letters stand for "ultra-long-range") has a range of 8,700 nautical miles (over 16,000 Km).

It's this aircraft that Singapore Airlines is planning to use to re-launch the New York route that it previously operated with a comparatively thirstier four-engine Airbus A340-500.

It'll have competition in the form of the up-and-coming Boeing 777-8, whose first delivery is expected in 2020. This new ultra-long-range version of the popular "triple seven" will replace the Boeing 777-200LR, that's currently in use on Qatar's Doha to Auckland route.

Meanwhile, the smaller Boeing 787-9 combines an impressive range of over 7,600 nautical miles (14,000 kilometres) with operational costs low enough to enable the launch of less busy long-haul routes which were deemed uneconomic in the not-so-distant past.

Advances in aircraft manufacturing make it possible to operate profitably some very long-distance routes that were previously unthinkable. This is due to the growing global demand for air travel; since as more people fly, more city pairs meet the demand threshold required to support direct connections.

Technological improvements are also having an effect on ETOPS regulations, which set constraints on twin-engined aircraft routings by imposing a limit of maximum flight time to the closest airport in case of diversion.

With aircraft like some A350 being ETOPS-compliant for up to 370 minutes, a whole bunch of new direct routings across the oceans becomes possible, particularly in the Pacific region and across the Southern Hemisphere. The first large long-range twin design to exploit ETOPS was the B777, followed by the B787 and A350, and leading to the demise of less-efficient four-engine airliners like the B747, A340 and A380, once deemed essential for transoceanic travel.

Better long-range aircraft economics should also provide the definitive impulse to the development of a global long-haul **low-cost** airline sector. It's in this context that AirAsia X, the Malaysian airline that pioneered long-haul low-cost flights in Asia, has announced its intention to have another go at the **European market**. It tried some years ago with four-engined A340 aircraft, but dropped the flights, citing low profitability. Now AirAsia X is planning to resume them as soon as it receives new Airbus A330neo airplanes, a re-engined, more fuel-efficient version of this popular wide-bodied aircraft type.

Meanwhile, the Boeing 787 Dreamliner has found favour with Scandinavian carrier Norwegian. With a dozen 787s in service and 20 more on order, Norwegian is leveraging the aircraft to develop a long-haul **low-cost operation out of its European bases.**

An important point to keep in mind is the long-haul travellers. The most obvious limitation is the amount of time economy class passengers are willing to sit still in a cramped cabin. Also, the effects of the lack of humidity become noticeable after three hours of flight.

Despite the industry working hard to devise improved ergonomic aircraft seat designs, this is an area where pretty much the only way to get straightforward relief is to get an upgrade. Travelling in economic may have its silver lining, though.

T7.1.4.2 User Expectations for Ultra-Long Range

User expectations for long and ultra-long-haul flights will play an essential role in the development of this market. Key aspects of these expectations are discussed hereafter:

- **Saving time for business & increasing productivity**: Ultra-long-haul is perceived, by the business travel community, as a great occasion to increases productivity and available working hours. With one or two layovers, the journey from Singapore to New York can take between 24 and 30 hours with one or two intermediate stops. Professional travellers argue that direct air route will always be preferable as reduced unproductive hours on connections, and also improve traveller rest that is not interrupted by layovers. This argument can also be applicable for leisure flights, as a traveller will always to enjoy maximising its holiday time at the destination instead of intermediate airports at layovers.

- **Passenger's endurance**: Perhaps the only remaining challenge that ultra-haul flights have to overcome is how to guarantee passengers health and comfort during such a large number of hours on board. A new area of technological solutions is gaining relevance and becoming a differentiation strategy for big manufacturers as new technology will be needed to make the experience of long flights more endurable for passengers. For example, carbon-fibre-reinforced composites — such as in the Boeing 787 and the forthcoming Airbus A350-900ULR — that are not vulnerable to corrosion, permits a higher cabin humidity and higher internal cabin pressure, probably the most important factors for passenger comfort. After extensive 18-hours endurance tests at different pressures inside a mock aircraft cabin at the University of Oklahoma, Boeing has settled the 787-optimal cabin pressure equivalent to that at 6,000 ft. above the sea level, instead of the 8,000ft at conventional older aircraft.
- **Pilot health risks**: The risks of flying such long distances also distress the pilot's health. The effect of long-haul routes on pilot circadian rhythm (body clock) disruption, sleep and fatigue has not been studied, nor the risk of greater exposure to radiation. An adapted crew in-flight rest facilities must be provided onboard ultra-long aircraft. New needs appear regarding health, such to provide special cupboard to store any unexpected fatality onboard (as introduced by Singapore Airlines in its fleet of A340-500).
- **Economic sustainability**: Until now, the strategies of the operator to support the airline's higher fuel and staff costs in ultra-long-haul services, has been to stand upon high premium travellers, predominantly business travellers, willing to pay a premium for a nonstop flight. For example, the longest Singapore Airlines route, initiated in 2004 with both business and economy seats, was adapted 4 years later to uniquely business-class. The trade-off between health and comfort vs occupancy rates for economy cabin might be one of the key points for the economic profitability of ultra-long-haul operations. There seems to be a clear willingness from passengers to pay slightly more for an ultra-long-haul flight without an intermediary stop. The trade-off between this additional extra payment, the length of the flight and the evolution of the principal cost of operation will determine the progress of this new market segment.

T7.1.5 Specific long-haul business models

The long-haul market envisages various specific models of operation which utility and variability are disused hereafter.

- Intermediate Stop Operation – ISO;
- Low-Cost Business Model for Long-Haul Sectors – LHLC (Long-Haul Low-Cost);
- Ultra-Long-haul operation – ULTRA LH;
- Supersonic flights.

T7.1.5.1 ISO Intermediate Stop Operation

Intermediate Stop Operation is a model of operation that face the exploitation of the long-haul market based on the use of medium-range aircraft and intermediate stops in the route.

The economic interest of this model of operation for the airlines it closely related to a specific range of aircraft segments, travel distances and routes. Some studies[1] have shown the effect of splitting long-range routes into two segments (analysed for medium size and large wide bodies, represented by two specific payloads of 30,000 and 50,000 kg, and the splitting respecting geographic and commercial constraints). According to research:

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[1] Proc IMechE Part G: J Aerospace Engineering 227(2) 394–404, IMechE 2012 DOI: 1177/0954410011429766. Cost-range trade-off of intermediate stop operations of long-range transport airplanes. Rodrigo Martinez-Val, Emilio Perez, Cristina Cuerno and Jose F Palacin

- ISO **potential fuel savings below a certain threshold**, about 7,000–10,000 km, depending upon the detour factor, **are negligible or, even, negative**.

In routes serving very distant city pairs, with little or no detour (deviation) and almost even splitting (such as London–Sydney via Calcutta or New York– Melbourne via Honolulu), ISO fuel savings can be as high as 20%. However, in more common circumstances, ISO can scarcely cut the fuel bill by 7–10%.

Considering the overall DOC (Direct Cost of Operation) the results are less positive than considering only pure fuel savings because it is necessary to account for the extra flying time. Extra flying time brings also extra airplane depreciation, insurance and maintenance; as well as extra crew time required.

Direct Cost of Operation (DOC) will only be smaller than for the baseline nonstop flight for very long routes, above 12,000 km (6,500 NM). However, for these very long distances, the psychological effect of the stop and waiting time at the intermediate airport has a significant negative effect on the passengers. This is a serious issue of comfort now that new aircraft development allows flying very long distances without any stop, at very low operating cost.

In the best case considered, for R ¼ 15,000 km without detour and perfect route splitting, the economic saving is about 10%. In a future scenario with higher fuel prices or new taxes on fuel, the savings due to ISO would increase up to 12–13%. This saving can hardly justify the operation of this fleet for this very long market. In addition the extra landing adds airport fees and local noise and emissions.

- **Implementation of intermediate stops is not always possible** from a logistic point of view.

Intermediate stop operations can be easily scheduled in the Northern Hemisphere since it contains the clear majority of the population and the landmasses with suitable airports. Although, even with these favourable conditions, there will still be problems and problematic routes, such those linking North America to South East Asia due to the scarcity of adequate airports across the Pacific Ocean.

However, the Southern Hemisphere, with the endless uninhabited Pacific Ocean and Antarctica, poses unbeatable troubles for commercially viable ISO.

All these together means that ISO is more interesting from the point of view of fuel savings and environmental impact than on purely economic terms. Given the new long-range aircraft, highly competitive in terms of efficiency and fuel composition this model does not seem to be a sustainable model for a long-haul, but more a residual operation for medium-range companies. It is not, therefore, expected that this model will stand for a great share of the long and ultra-long market in the future.

T7.1.5.2 Low Cost Business Model for Long-Haul Sectors

Low-Cost airliners have created a very successful model for short and medium flights, however, the realization of low budget for long-haul flights had many failed attempts until now.

Low-Cost Carriers (LCCs) that succeeded in short and medium-haul profited from structural and hard-to-match cost advantages; markets with significant latent demand; and a unique value proposition that appealed to a wide range of customers. The mixture of these features has permitted LCCs to continuously under-price mainline airlines, limit retaliation, and build a loyal customer base. However, this model is difficult to replicate on long-haul routes, due to the specificities of this type of operation; that poses serious limitations to the development and consolidation of an LCC model in the long-haul market. While the long-haul market offers significant margins for a lower-priced, mainlines have the opportunity to capture it, impairing LCC to become factual new entrants in the long-haul market.

At the same time, it is true that a new concept of operation is necessary for these routes. This model, still to be developed, will have to consider the specificities of the long-distance operations, emerging aviation technologies and information technology, demand and supply-driven, flexible networks and aircraft management. On top of all that, it should be focused on customer comfort service providing a mix of premium and comfort classes.

The feasibility of Low-Cost for long-haul Sectors will depend mainly on the ability of airlines to control the operating expenses. Table 7.1 illustrates the areas LCC have demonstrated ability to influence in the short and medium range.

Cost Factors	Ability to Influence
Manpower	Possible
Air Fares	Possible
Air Traffic Management	Not Possible
Airport, Navigation, Taxes and Fees	Not Possible
Airport Handling	Possible
Cabin Design, Seat Configuration	Possible
Fleets and Aircraft Composition	Possible
Fuel Consumption, Saving Measurements (Weight reduction, winglets, airframe modifications, air traffic, etc.)	Possible
Fuel, Oil	Not Possible
Leasing Cost	Possible
Maintenance	Possible
Marketing Sales	Possible
Passenger Services	Possible
Stimulating Traffic	Possible
Technical Aircraft and Engines Improvements	Not Possible
Routes and Destinations	Possible

Table 7.4 – Areas current LCC have demonstrated ability to influence in the short and medium range

In a short-haul operation, LCCs combine lower input costs with higher productivity to achieve a 25 to 50 per cent cost advantage over their mainline rivals. However, the operating economics associated with long-haul flights are different. More optimistic estimates of the cost savings potential, if current Low-Cost Concept will be adapted for Long-Haul Sectors, are indicated in figure 7.37. Optimistic forecasts in the short term indicate that the long-haul low-cost sector will likely again double in size over the next two years and surpass a 1% share of global capacity. The fastest expansion is likely to come in Europe, driven by Norwegian, Level and Air France's Buzz. Scoot and AirAsia X are also expected to focus on expanding in Europe over the next few years – in part, a response to their new European based competitors and partially driven by the fact routes to Australia and North Asia are starting to become saturated.

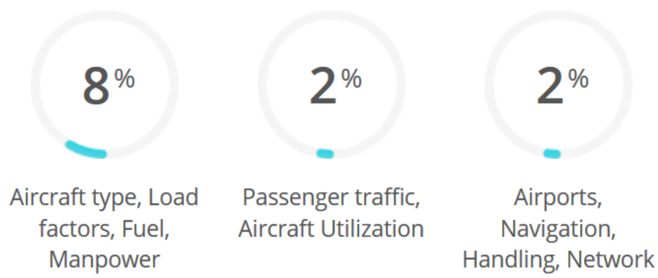

Figure 7.39 – Estimated cost savings potential, if current Low-Cost Concept will be adapted for Long-Haul Sectors

A simple cost model shows that in the long haul, half of the potential unit-cost advantage for long-haul LCCs is from higher seat count, produced by shrinking the premium cabins and making the economy sections denser. As a consequence, the 26% cost differential between LCCs and mainlines might be reduced to a slight 13% when seat density turns equivalent among them. The other half of the potential cost advantages come from input costs, which are less flexible in the long haul (Figure 7.40). For instance, on long-haul flights, fuel's share of direct operating costs grows from 30 to 50 per cent.

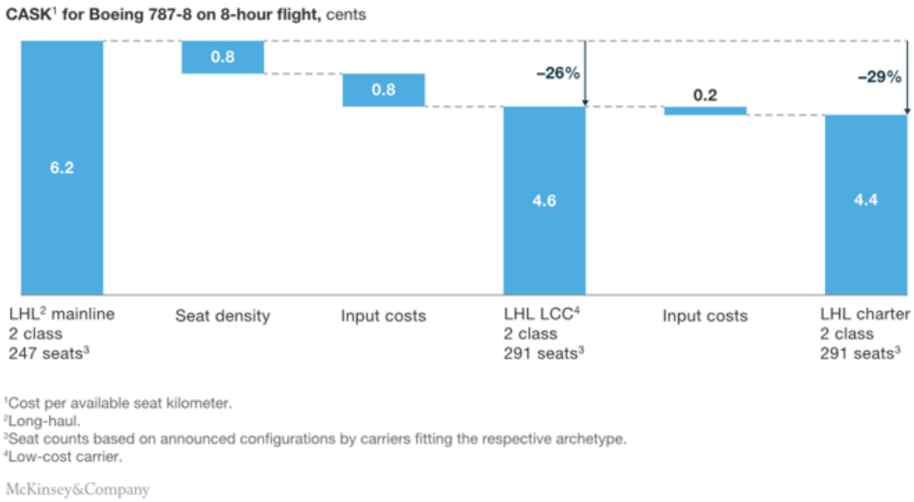

Figure 7.40 – CASK for Boeing 787 in 8 hours flight

Source: McKinsey & Company

Considering long-haul flights, the potential savings can be located mainly in the following areas:

- **Productivity**: e.g. Aircraft type, Load factors, Fuel Consumption, Manpower;
- **Performance**: e.g. Passengers traffic, Punctuality, Aircraft Utilization;
- **Operational**: e.g. Airports, Air Traffic Management, Handling, Routes, Destinations.

Key aspects of these potential savings are discussed hereafter.

- **Increasing Load Factors and Seat Densities.** Most of the gains of LCC come from high seat densities. However, this does not seem to be a differentiating factor actor between LCC and Network Airlines in the long-haul market. High Passenger Load Factors and dense Eco cabins Seat-Configurations on long haul sectors is already implemented by conventional airlines (Figure 7.41 and Table 7.5). Moreover, the Eco-Seating or Single Class Concept is increasing, business class seating is reduced and expanded by Premium Economy. The First-Class Concept is strongly reduced, and many airlines re-considering the concept or even cancel the service completely.

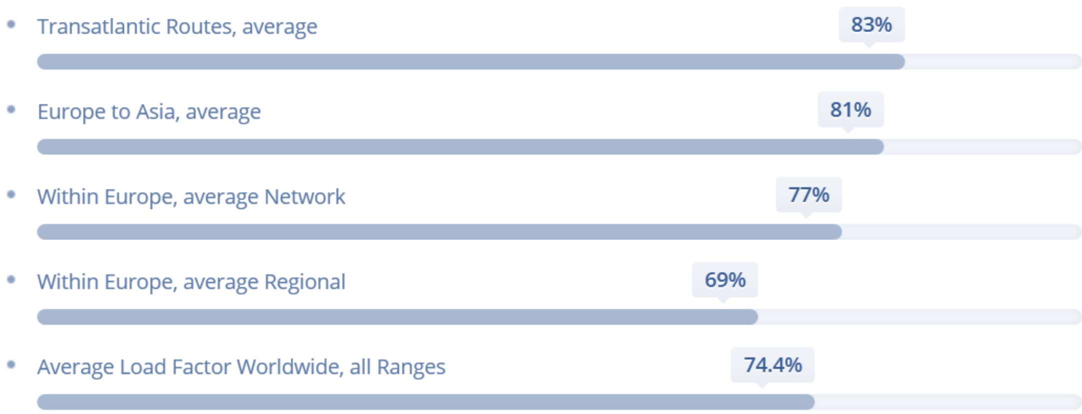

Figure 7.41 – Load factors in long haul operations

Airline	Seat Pitch in cm	Seat Width in cm
AirAsia X	81	43
British Airways	79	45
Cathay Pacific	83	45
Emirates	84	46
Japan Airlines	80	45
Jetstar	79	46
Lufthansa	86	44
Norwegian	78	44
Qantas	82	44
Scoot Airlines	81	48
Singapore Airlines	81	44
TAM	82	44
United Airlines	80	44

Airline	Aircraft	Eco-Seats	Ratio to total number of seats
AirAsia X	A330	365	97%
British Airways	B777	227	82%
Cathay Pacific	B777	268	79%
Emirates	B777	236	81%
JAL	B777	279	75%
Jetstar	A330	268	86%
Lufthansa	A330	165	75%
Norwegian	B787	259	89%
Qantas	A330	271	90%
Scoot	B777	329	82%
Singapore Airlines	B777	255	89%
TAM	B777	272	75%
United	B777	218	82%

Table 7.5 – Seat pitch, width and utilization of flight cabin by Network Airlines and Low-Cost Carrier

- **Airframe, Aerodynamic improvements, reducing fuel consumption.** High-cost reduction in LH operation will come from the utilization of aerodynamically improved airframes and more economical engines. Potential savings expected in these areas have been discussed in previous sections.
  For long-haul flights the aircraft efficiency and a lean airline fleet will play an important role. But due to the long aircraft production periods, it might take years for a Low-Cost Airline to build up an adequate fleet with enough number of aircraft to serve the required destinations with sufficient frequencies. Boeing and Airbus are working flat out and have a long waiting list for the single-aisle B737max and A320neo and twin-aisle B787/B777X and A350/A330neo, plus the A321LR for long thin routes pending competition from the Boeing MMA/FSA.
- **Passenger traffic, Punctuality and Aircraft Utilization.** On long Haul sectors, network carriers are already achieving a significant performance in high aircraft utilization, in average 13-15 hours aircraft utilization and over 80% punctual flights. The possibilities increasing flight rotations are minimum, because long-haul flights need longer turnaround times for boarding, loading, servicing and fuelling. Longer duty hours can become in conflict with duty time regulations. Flying to less congested secondary airports will not be so easy, because the necessary infrastructure; and therefore, to operate on primary international airports will not gain any savings.
- **Limits to latent demand.** LCCs' ability to drive demand by lowering prices has contributed significantly to their success in the short-haul, however, there may be limitations to this approach in the long haul:
  - Total ticket costs are higher in the long haul, and cross-elasticity of demand (that is, the ability to buy some other substantial item that a household might need or want) plays a role.

- Cross-elasticity with other modes of transport, such as rail and bus, is limited, so the reduces the opportunity to steal travellers from other modes is reduced.
- Low fares are already available in most markets. Sixth-freedom[1] options are priced significantly lower than their point-to-point alternatives and widely available.
- In many leisure markets, LCCs already exist in different forms: holiday/charter carriers serving price-sensitive travellers on leisure routes (for example, Corsair and Thomson) have a particularly strong market influence in Europe; scheduled carriers catering to the visiting-friends-and-relatives passenger segment are especially prevalent on routes with strong ethnic ties, such as the Iberian Peninsula and Latin America.

If the Low-Cost Carriers must gain market shares directly from the network airlines, because they have no evasive options, Low-cost traffic will take place (Figure 7.42) mainly between North America and Europe. Probably between Southeast Asia and Europe it will start again, attempts in the past failed (Oasis Hong Kong Airlines).

Figure 7.42 – Load factors in long haul operations

Source: Airline Profiler

T7.1.5.3 Ultra-Long-haul Operation – ULTRA LH

A more efficient new generation of aircraft, in particular, extended-range aircraft models Airbus A350-900ULR and Boeing 777-8, are helping to create a new marker in the long-range sector. These fuel-efficient technologies and cheaper oil are favouring the return of ultra-long flights, of about 19 hours non-stop flight.

Modern aircraft manufacturing technologies make it possible to operate profitably very long-distance routes. Technological improvements have overcome the limitations of maximum flight time to the closest airport in case of diversion, imposed by ETOPS regulations on the route flown by twin-engine aircraft. The advent of aircraft such as theA350, ETOPS-compliant for up to 370 minutes, open the door for new direct oceanic routes, particularly in the Pacific region and across the Southern Hemisphere. Technological and economic challenges of long-haul flying are being already tackled.

While we may have to wait a few more years for passenger flights that reach 22 hours, there are a number of ultra-long-haul flights already in operation:

- From March 2018, Singapore Airlines plans to fly an Airbus A350-900ULR non-stop flight between Singapore and Newark airport near New York.
- With its the new venture Project Sunrise, Qantas will challenge Boeing and Airbus to deliver an aircraft capable of flying regular direct services like Sydney to London, Brisbane to Paris and Melbourne to New York non-stop by 2022 as has already been shown feasible.
- The longest flight in the world is operated by Qatar Airways, using a Boeing 777-200LR to fly the 18-hour trip between Doha in Qatar and Auckland. Gulf airline Emirates flies to New Zealand's biggest city from Dubai using an Airbus A380 in an 18 hours flight.
- United Airlines Dreamliner's fly from Los Angeles to Singapore in 17 hours and 55 minutes.

- The longest flight to Hong Kong is by American Airlines. Its service from Dallas is scheduled to take 16 hours and 55 minutes. From Hong Kong to Dallas, the flying time is 14 hours and 25 minutes.

At the same time, global demand for air travel keeps growing, and more city pairs are reaching the demand threshold required to support direct connections.

It is probable that all these previous factors, together with new and better long-range aircraft economics and business models, will provide the definitive impulse to the development of a global long-haul low-cost airline sector.

The only remaining limitation to the development of this sector is coming now for the physiological challenges, particularly the one posed by the amount of time economy class passengers will accept to spend in a confined cabin.

The industry is working on improved ergonomic aircraft seat designs, but at his MMAent those improvements will not be enough for very long-distance comfort, the human body cannot be comfortable in the same position for a long time. Other factors affecting the well-being of people in indoor spaces need further improvement, such as the lack of humidity that becomes noticeable after three hours of flight; the lower air pressure in the cabin also for longer periods; the soothing effect of illumination during long flights, or how diet can influence the well-being and behaviour of passengers during long flights.

T7.1.5.4 Supersonic Flights

The Concorde, which operated at supersonic speeds since 1973, closed operations in 2003 due to high operating costs and difficulties in supporting an old airframe for lack of spares. There has been little private-sector investment since then. The ban responded to concerns about noise pollution and negative environmental impacts. However, over the past four decades, technical advances in engine design suggest that it is now feasible to produce less noisy supersonic jet engines. Moreover, some research suggests that the environmental impacts were overstated, although the sonic boom remains an issue.

To ensure a proper noise standard, initial levels can be established that are comparable to those societies already tolerates. A standard set at 85–90 decibels, for example, would be no different from lawnmowers, motorcycles, and kitchen blenders.

Aircraft speeds have stagnated over the past 40 years; the time required to fly from Los Angeles to New York or across the Atlantic Ocean are no different than they were in 1977. Addressing sonic boom concerns in the form of a standard instead of the current ban may go a long way toward achieving the economic gains of commercial supersonic travel.

Commercial supersonic flight has not been altogether forgotten as Boeing and Airbus, as well as start-ups Boom or Spike Aerospace, have all signalled supersonic ambitions. The advance in efficiency is made possible by a breakthrough aerodynamic design, state-of-the-art engines, and advanced composites. Long flights are a barrier to travel. That's why companies like Boom are trying to remove that barrier, turning 8-hours redeyes into 3-4-hour daytime flights. Excruciating 16-hour journeys become easy overnights.

Figure 7.43– Flight NYC- London in 3h 15min instead of 6h 30min

Source: Boom supersonic website

This company has created prototypes to demonstrate the efficiency of supersonic flights, like XB-1 Supersonic Demonstrator. The XB-1 demonstrates the key technologies for efficient supersonic flight: advanced aerodynamic design, light-weight materials that can withstand supersonic flight, and an efficient super-cruise propulsion system. Engineering development of XB-1 ("Baby Boom") is proceeding rapidly, with aerodynamics defined, systems ground tested, and initial structural components in fabrication. Vehicle assembly starts shortly, with the first flight planned for next year. They are grounded in physics and push technology to new heights.

About the prices, they are seeking the holy grail of the plane which can go to Mach 1 (the speed of sound; 768mph) and up to Mach 1.6 (instead of Mack 2.1 for Concorde) but do so with operational costs leaping to levels that large multinational will accept for their top executives.

Spike Aerospace is another rider in this most forward-thinking of races. This Boston-based company is currently developing the S-512 Supersonic Jet and has claimed that it could be flying by the end of the decade. This will be a 12-18 seat commercial plane that will reportedly be able to reach Mach 1.6 (about 1,100mph), although will largely be a luxury steed aimed at the private jet market.

Airbus, meanwhile, has set up a partnership with the Nevada-based Aerion Corporation, in the hope that a marriage of the latter's technological nous and the former's business clout and economic muscle may yet give birth to the new Concorde. Elsewhere, the European giant's key American rival Boeing is also looking to craft a supersonic solution. Japan has kept a steady research program on a supersonic commercial flight. A major obstacle is the availability of a suitable civil supersonic engine with high durability for several years flying several hours per day. Pratt & Whitney has indicated the willingness to develop such and engine.

T7.1.6 Impact on ACARE Goals

The following Table 7.6 shows how the long-haul travel could have an impact on the ACARE goals as well as the improvements that will be required:

Challenges	Goals	Action Area	Impact in LR	Improvements
Challenge 1: Meeting societal and market needs	1. Air traffic management system (at least 25M flights). 2. Ground infrastructure. 3. Mobility. 4. Door-to-door within 4 hours. 5. Flights arrive within 1 min off the planned arrival time.	- Understand customer, market and societal expectations and opportunities. - Design and implement an integrated, intermodal transport system. - Develop capabilities to evaluate mobility concepts, infrastructure and performance. - Provide travel management tools for informed mobility choices. - Deliver mobility intelligence: journey information, data and communication. - Provide tools for system and journey resilience, for disruption avoidance and management. - Evolve airports into integrated, efficient and sustainable air transport interface nodes. - Design and implement an integrated information, communication, navigation and surveillance platform. - Develop future air traffic management concepts and services for airspace users. - Human factors and automation support, autonomy and resilience.	-It will depend on business and tourist class. - ULR: aspects to improve - Low cost LR: competitiveness with traditional companies. - Advanced navigation technologies using new sensors. - Network congestion. -Selection, training and qualification of long-haul crews. - A **single ticket**, valid for the entire journey will be more complicated to be achieved. -Information shared between airports: processes, time, etc. -Connectivity between airports.	-Users' needs will be different in long-haul routes: punctuality, comfortability, health conditions. - New markets such as ultra-long range, low cost long-haul. -Regulatory framework in crew conditions: maximum number of hours, medical inspections. - Competitiveness of emerging markets and low-cost carriers. - Interoperability requirements and standards more complex due to a larger scale. -System robustness and resilience to face disruptions. - More accurate systems. -Better connectivity and integration. - Ground and air infrastructure availability and capacity. - Tools that allow passenger to be informed of the flight situation: scales, delays, direct flights
Challenge 2: Maintaining and extending industrial leadership.	6. The whole European aviation industry is strongly competitive. 7. High profiles in motivation process. 8. Streamlined systems engineering.	-Increase competitiveness in product industrialisation. - Develop high-value manufacturing technologies. - Embed **design-for-excellence** in the product lifecycle. - Secure continued and focused investment. - Exploit the potential of operations and **maintenance, repair and overhaul** (MRO). - Develop innovative and optimised testing.	- Digitalisation and big data, supported by cybersecurity measures. - Aviation industrialisation in the future must focus on **high-value technologies**. - By 2050, industrialisation should benefit from access to a full set of production data and capabilities. - European aviation industry will extend its industrial leadership while meeting the essential	-Access to a full set of production data and capabilities of different production sites. - Constantly increasing competition means that airlines must maximise the operating time of their fleet, reduce operating costs and minimise the number of unscheduled flight cancellations. - European airline industry increased airport efficiency and capacity and is developing new services and products. - New models.

		- Establish new business/enterprise models and initiatives. - Lead the development of standards. - Streamline certification.	societal challenges of climate change and security.	- The use of tools for **automated** analysis and design.
Challenge 3: Protecting the environment and the energy supply	9. 75% reduction in CO_2 emissions in 2050. 10. Aircraft movements are emission free when taxing. 11. Designed to be recyclable. 12. Europe like a centre of excellence. 13. Environmental action plan.	-Develop air vehicles of the future: evolutionary steps. - Develop air vehicles of the future: revolutionary steps. - Increase resource use efficiency and recycling. - Improve the environmental performance of air operations and traffic management. - Improve the airport environment. - Provide the necessary quantity of affordable alternative energy. - Understand aviation's climate impact. - Adapt to climate change. - Develop incentives and regulations.	- In the mid-term: new engine options or other system changes. - In long- term: more radical concepts and technologies. - On-board aircraft systems must support new operations and air traffic management concepts for reduction of emissions and noise. - New designs, new energy sources and capabilities of operations. - New operational concepts based on multiple aircraft/fleet interaction. - The increasing availability and use of (RPAS) must be carefully managed. - The use of environmentally-friendly chemicals need to be generalized at airports. - Aviation as a global business has a strong need for internationally harmonised rules, in terms of both design and operational requirements.	- Airframes: lightweight materials. - Propulsion: higher thermal and propulsive efficiency and new lightweight structures and high-temperature materials for engine cores. - Health monitoring must apply to all elements. - An eco-design approach - The operational gains resulting from these research activities will induce a reduction of between 250kg and 500kg of fuel (800kg to 1600kg of CO_2) per flight - 5-10% of the total). - Specific research for the airport environment will permit significant improvement in air quality and reduction of noise annoyance at European airports. - Use of recycling materials in order to achieve less environmental impact - Optimised trajectories that minimize fuel burn as well as noise and CO_2 emissions

Challenge 4: Ensuring safety and security	14. European air traffic system has less than one accident/10M aircraft. 15. Risks properly mitigated. 16. Manned and unmanned vehicles operate safely in the same airspace. 17. Efficient boarding and security measures. 18. Resilience to external and internal threats. 19. High –bandwidth data resilient to cyberattacks.	- Collaborate for safety. - Optimise human and organisational factors for safety. - Build and exploit safety intelligence. - Ensure operational safety. - Design, manufacture and certify for safety. - Collaborate for security. - Engage aviation personnel and society for security. - Build and exploit security intelligence. - Ensure operational security. - Design, manufacture and certify for security.	- Intermodal safety governance is aimed at the future. - Europe will operate an air transport system in which safety governance and practice is effective, able to keep up with and stay ahead of a rapidly changing environment. - Ensuring the highest degree of safety. - Gathering, processing and exploiting the data will provide vital information that will make the air transport system safer. -Ensuring high levels of operational safety is the culmination of all safety efforts. - Early warning and alerts will facilitate incident prevention and response system-wide, thereby maintaining security across the entire aviation spectrum. - Real-time security capability.	- Human factors will be essential in long-haul to ensure safety as the flights will be longer: it is necessary to change crews considering fatigue, flight hours, etc. -Crew must be trained adequately to long-haul requirements. -Improve survivability of people in long-haul flights. -Improvement of data exploitation for the benefit of safety. -Analysing the great amount of data to identify safety hazards. -All the processes inside the airports must be safe. -A safety radar is required to detect safety hazards such as weather events, one of the main disruptions in long-haul flights. -High level of maintenance will be required to ensure safe operations. -It is necessary compatible risk management methods between regions.

				-Monitor staff and passengers to detect erratic behaviours and security threats.
Challenge 5: Prioritising research, testing capability and education	20. European research and innovation agenda. 21. Industry- Research-Academia clusters. 22. Test, simulation and development facilities. 23. Young talent and women in aviation.	-Maintain awareness with an effective technology watchtower. -Develop an inclusive research strategy covering the entire innovation chain. -make the right investment choices with robust selection processes. -Develop and maintain state-of-the art test infrastructure. -Establish sustainable network of operators for test infrastructure. -Provide world-leading education in aviation. -Stimulate the involvement of stakeholders in education. -Make aviation attractive to ensure inflow educational programmes.	- The technology watchtower will promote harmonisation of evolutions in aviation with other relevant sectors. -New processes are needed to help capture and import technology from other sectors. - Systematic feedback from exploitation and operations into early research will ensure more effective technology development and reduce waste. - Develop **metrics** and goals to support the selection of projects and investments. - The aviation sector needs a coordinated and shared approach to the development, maintenance and operation of a broad range of infrastructure. - A dynamic network of operators of strategic European test infrastructure will ensure up-to	-European aviation industry will be a support to **SMEs** with key knowledge and visibility of emerging technologies. - Engaging all stakeholders in a common approach will ensure that future trends are properly accommodated. - The **network** will bring together the expertise of all major operators and serve as the counterpart to potential users in discussions on future needs and trends. - Utilisation of the **dynamic network** will increase and redundancy will be reduced. - European aviation **education** will remain world-leading and provide excellent support to the aviation sector. - Involving industry and research establishments in **educational**

			date, relevant equipment, efficiently operated. - Workforce with excellent education.	**programs** will ensure that students are better prepared for a career in aviation. - Development and investment of new infrastructure required for simulation and virtual testing

Table 7.6 – ACARE Goals

KEY TOPIC T7.2 COMMERCIAL AND BUSINESS AVIATION

T7.2.1 Introduction

Related to the air traffic evolution, which includes long-haul trips, the growth of air traffic has suffered remarkable variations in the past and it is likely to also suffer remarkable variations in the future. As can be seen in the following figure 7.44, the air traffic has grown steadily through the years, but it also had decreasing periods, coinciding with economic recessions and security issues as World Trade Centre attacks in 2001.

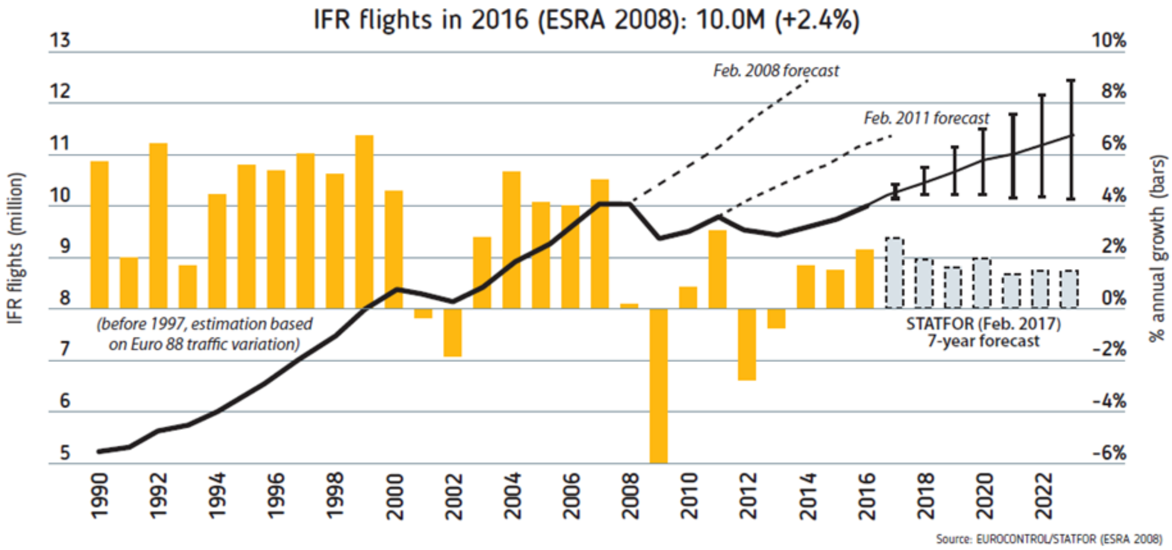

Figure 7.44– Evolution of European IFR flights (1990-2023)

Source: EUROCONTROL Annual Report 2016

However, there has been a positive trend during the last three years, in which a 2% annual growth has been reached in 2016. Based on this positive trend, even though it is not expected that previous annual growth rates (about 6%) are reached, it is expected that air traffic continues growing as much as new technologies are able to accommodate the future demand. If and when integration of UAVs in the airline traffic network is achieved additional capacity will be needed depending on the scale of UAV operations.

Considering EUROCONTROL forecasts, three different scenarios are proposed:

- First scenario (Figure 7.45): a low but steady growth occurs, establishing almost a 1% annual growth. This forecast agrees with the slow but sustained development of the air traffic framework, both technological and regulatory framework. This growth would allow accommodating only part of future demand.

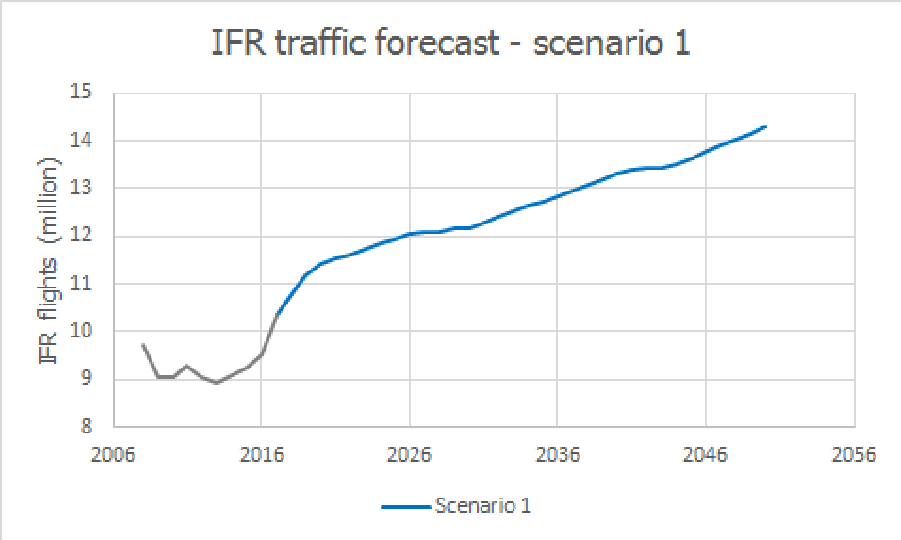

Figure 7.45– IFR traffic forecast - scenario 1

- Second scenario (Figure 7.46): the growth is not steady over the years and it presents decreasing periods due to issues that are likely to occur, such as economic recessions or the non-viability to accommodate the demand based on the technology developed in the next decades. This forecast set a 1.25% overall annual growth rate and it would allow to accommodating only part of the future demand.

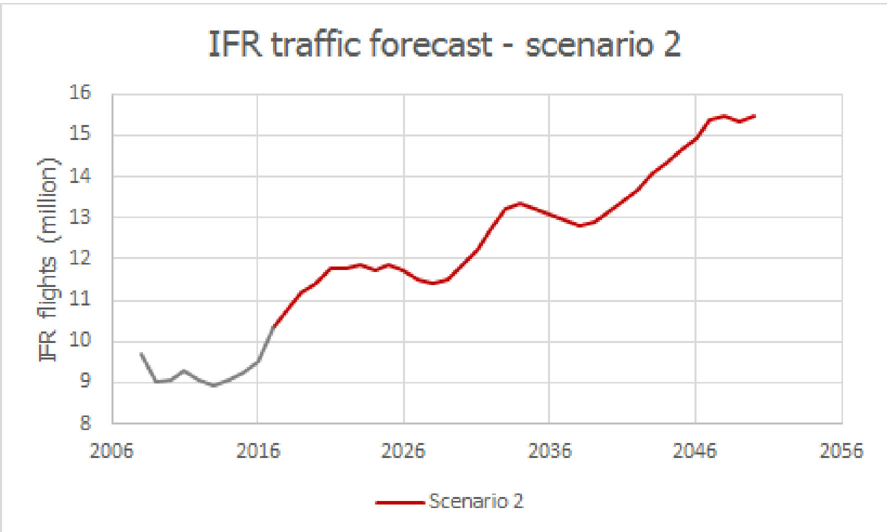

Figure 7.46 - IFR traffic forecast - scenario 2

- Third scenario (Figure 7.47): the following figure shows the optimal growth that would allow the accommodation of the expected demand within the air traffic network. This forecast set a 2,7% overall annual growth rate, reaching the 25 million flights in 2050.

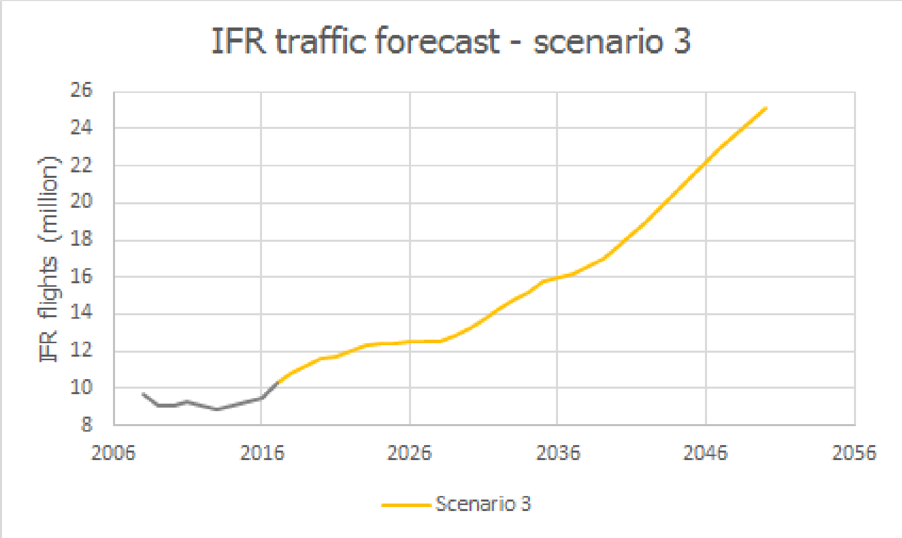

Figure 7.47 – IFR traffic forecast - scenario 3

T7.2.2 Airline Traffic

Focusing on long-haul trips, the demand for them is characterized by its elasticity, mainly owing to that ticket prices for long-haul flights are very high and, therefore, these flights decrease the most during the economic downturns.

During the last few years, Europe's economy has grown (Europe's GDP grew by 1.9% in 2015), thus Europe's air travel market has remained strong, including long-range travel. For example, air passenger flows grew by 15% between 2010 and 2015 in connections between North America and the European Union. The routes between these two continents are traditionally one of the most profitable ones, thus it is unsurprising such a big growth.

However, the highest growth rate since 2010 was observed in passenger flows between Europe and the Near & Middle East (+49%) due to the strong expansion of Middle Eastern carriers. In contrast, North Africa's share in passenger flows decreased by 21% during 2010-2015, mainly driven by a series of multiple terrorist attacks and political instability in many North African countries.

As can be seen in figure 7.48, approximately 54% of the total passengers from/to Europe were related to long-haul flights in 2015. The main destination was North America with almost 20% of the share, whilst the Middle East set almost 13% of the share with the highest growth rate.

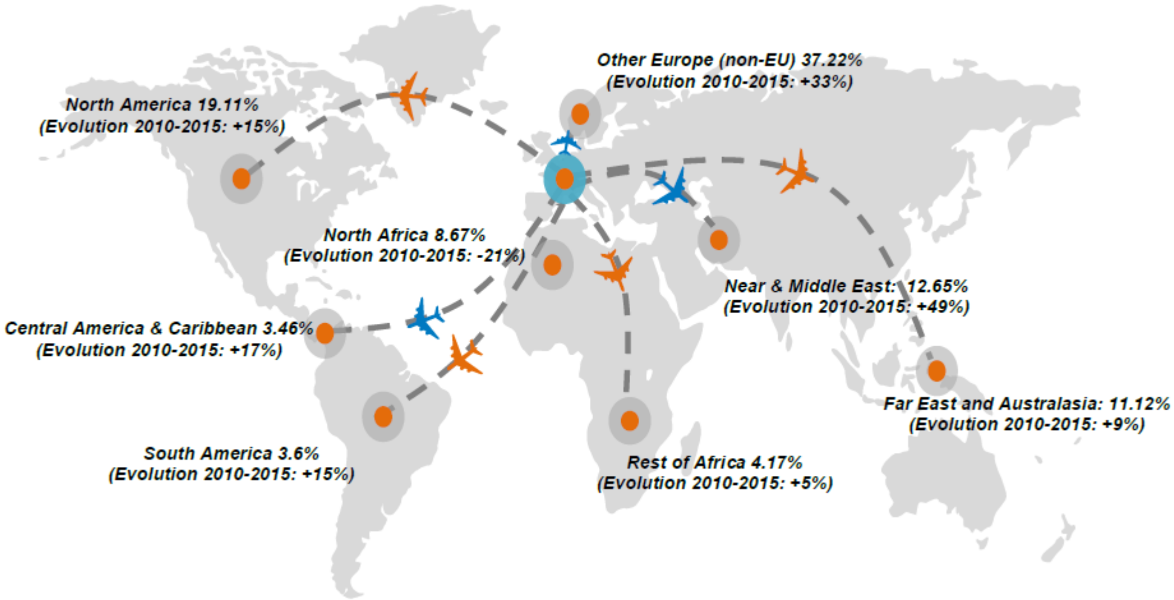

Figure 7.48 – Air passenger flows in 2015. Shares and historic evolution from/to Europe (EU28)

Source: Annual Analyses of the EU Air Transport Market 2016

Concerning airlines, its operations in Europe continue to evolve with the launch of new ventures, routes and business models. Perhaps the most striking strategic development in Europe during the last few years has been the rapid rise of the low-cost long-haul (LCLH) business model. For example, Norwegian Air Shuttle continues to expand its low-cost long-haul carrier operations, adding bases in Paris and Barcelona for service to North America and recently initiating the first low-cost service from London to Singapore. As a response to that, network airlines are establishing LCLH operations in their LCC subsidiaries: Lufthansa subsidiary EuroWings is expanding the LCLH operations it initiated last year, Level from International Airlines Group began operations during past June, and Air France-KLM's Boost has announced plans to initiate LCLH operations in 2018. The North Atlantic has been a primary flow for LCLH service additions to and from Europe, with Norwegian, EuroWings, Level, Iceland-based LCC Wow air, Canadian LCC WestJet, and Air Canada LCC subsidiary Rouge increasing their LCLH service between Europe and North America by over 250 peak operations per week during summer 2017 [1].

European operators have been on the forefront of this trend, with 96 long-haul routes introduced since 2012 (the most of any region). The introduction of more efficient aircraft has helped European carriers both to improve their load factors, but also to increase their RPKs (Revenue Passenger Kilometres) and ASKs (Available Seat Kilometres) as they fly routes of longer length.

Focusing on the future, intercontinental traffic is further impacted by the general tendency of network airlines to focus less on short-haul point-to-point traffic while increasing hub operation. In this context, South and South-East Asian destinations are expected to benefit from Middle Eastern airlines, which are expanding their transfer traffic from European airports, via Middle Eastern hubs to these markets. European network carriers in contrast, largely focus on long-haul operations to North, Central and South American regions.

As can be seen in the following figure 7.39, air traffic flows within Europe are projected to increase by 3.2% between 2016 and 2035. Intra-European traffic development is particularly driven by the continuous expansion of low-cost short-haul point-to-point traffic. On the other hand, long-haul traffic is expected to present a higher growth than short-haul traffic as traffic to South America is expected to increase by 5.3% and traffic to the Middle East is expected to increase by 5.4%.

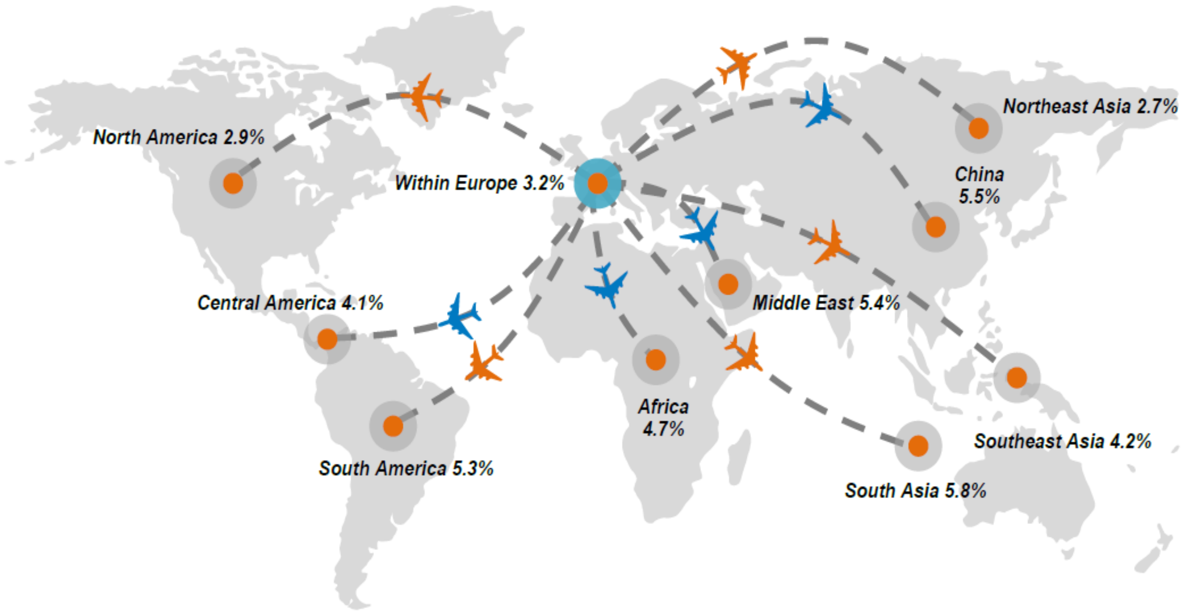

Figure 7.49 – Air traffic flows from/to Europe growth projections for 2016-2035

Source: Annual Analyses of the EU Air Transport Market 2016

T7.2.3 Business Jet Traffic

Firstly, business aviation should be put in context. Business flying is defined by International Business Aviation Council (IBAC) as "that sector of aviation which concerns the operation or use of aircraft by companies for the carriage of passengers or goods as an aid to the conduct of their business, flown for purposes generally considered not for public hire and piloted by individuals having, at the minimum, a valid commercial pilot license with an instrument rating" [2]. Different subdivisions are inherent in this definition:

- Commercial: "The commercial operation or use of aircraft by companies for the carriage of passenger or goods as an aid to the conduct of their business and the availability of the aircraft for whole aircraft charter, flown by a professional pilot(s) employed to fly the aircraft". [2]

- Corporate: "The non-commercial operation or use of aircraft by a company for the carriage of passengers or goods as an aid to the conduct of company business, flown by a professional pilot(s) employed to fly the aircraft". [2]

- Owner Operated: "The non-commercial operation or use of aircraft by an individual for the carriage of passengers or goods as an aid to the conduct of his/her business". [2]

Corporate and owner-operated subdivisions are located within general aviation, which is defined as "all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire" [2]. The position of these subdivisions within general aviation can be seen in Figure 7.50.

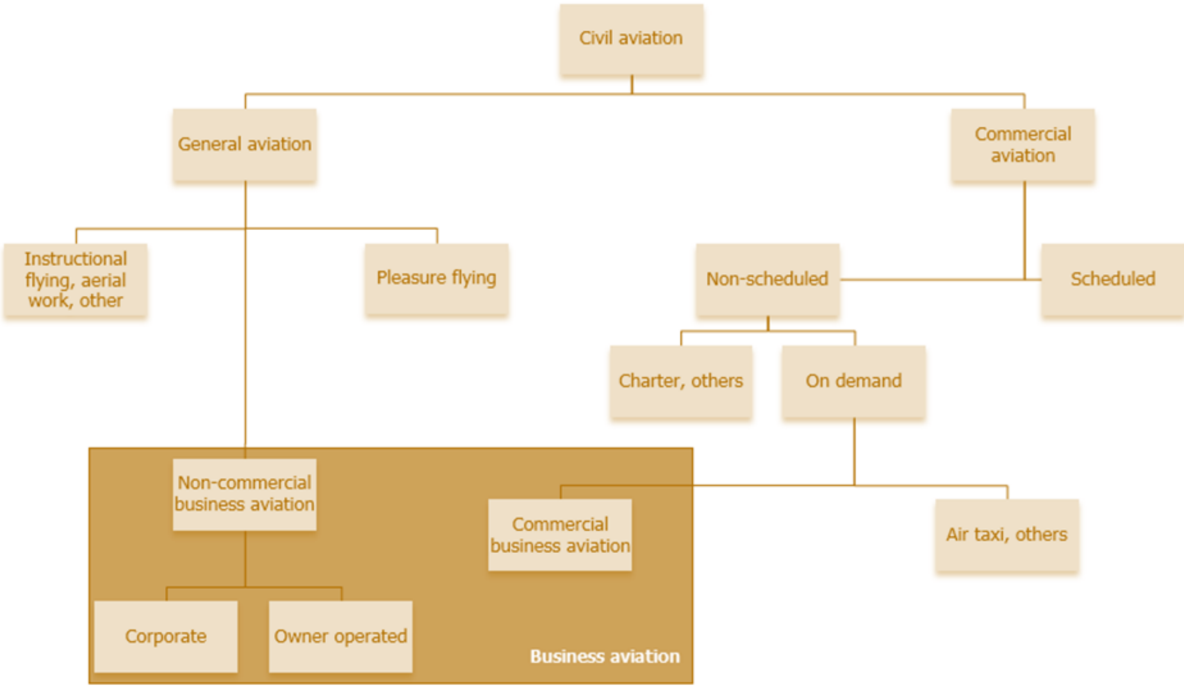

Figure 7.50 – Business aviation within aviation network

In this context, business aviation is the third-largest market segment in Europe, after the traditional scheduled and low-cost segments. While being a much smaller market segment in comparison with commercial air travel, it nevertheless has a significantly positive economic impact as it generates jobs and, indirectly, stimulates commerce. Compared to the main market segments, business aviation flies from smaller airports and is characterized by a very large number of routes focusing on city pairs where there is no daily scheduled service.

Business aviation has suffered variations along the years at the same time as air traffic has changed and it has contributed to the total growth of flights in Europe. At the beginning of the 21st century, business aviation enjoyed a rapid expansion from 2002 to 2009, then it suffered a sharp 14% contraction and it went back to around 2005 levels. This 14% contraction in 2009 was the largest percentage decline of the major market segments in Europe: all-cargo and charter came close with declines of 13%. As a result, the market share of business aviation fell back from its peak of 7.7% of flights in 2007 to 6.9% in 2009. In fact, business aviation began to contract sooner than the rest of the industry, which managed a little growth in 2008. [3]

However, it recovered in 2010 (+5%) and 2011 (+2.4%) but declined again by 1.2% on average between 2012 and 2015 (Figure 7.51). Therefore, over the last 10 years, the market share of business aviation has fluctuated around 7% of all flights (variations between 7.7% in 2007 to 6.7% in 2016) which states that business aviation is being a steady sector in Europe.

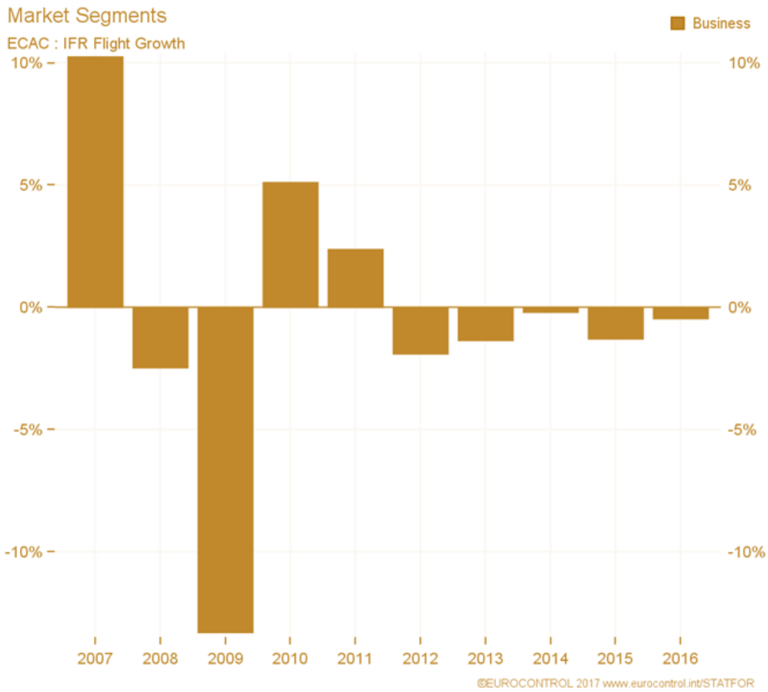

Figure 7.51 – Business aviation growth along the years

Source: Business aviation: An expanding sector

Concerning the recent trends and upcoming challenges, the sector started to show promising signs of strength at the end of 2016, which was confirmed by 6% growth recorded during the first quarter of 2017, compared to the same period in 2016. This is mainly due to robust increase inflows within Europe, with France and UK contributing most to this growth, in such a way that Eurocontrol forecasts an average annual growth rate of +2.3% for the period 2017-2023.

One of the key factors for the growth of business aviation is the evolution of its fleet in Europe. Whilst business aviation set negative growth rates since 2012, the European fleet has maintained positive growth rates during the last few years, reaching more than 3000 aircraft in 2014 as can be seen in the following figure 7.52.

Figure 7.52 – European business aviation fleet 2010-2014

Source: EBAA Annual Review 2014-2015

This growth has allowed the European fleet to maintain its position as the second biggest in the world behind the United States, hoarding around 18% of the total global fleet. It can be also stated that a large category of business aircraft has suffered a growth during the last decade. This means that an increase in long-range operations has occurred.

Both the number of units sold by the manufacturers each year and the money spent by customers for procuring business jets have shown strong volatility during the last decades. Any recent recession hit this industry that suffered much more than other aerospace sectors. After the record of over 1300 aircraft produced in 2008, the volumes halved in subsequent years to fluctuate later just above those numbers.

Fleet forecasts show that it will continue to grow in the following years. For example, Bombardier has forecasted a total of 8300 deliveries until 2025 which are divided into 3100 deliveries of light aircraft, 2800 deliveries of medium aircraft and 2400 deliveries of large aircraft. Although the number of deliveries of large aircraft will be the lowest one, taking into account the retirements of the old aircraft, large aircraft will set the highest growth percentage in the following years. The following figure 7.53 illustrates how, whilst the light aircraft market share decreases, the large aircraft market share increases which mean that long-haul trips within business aviation will grow in the next decade.

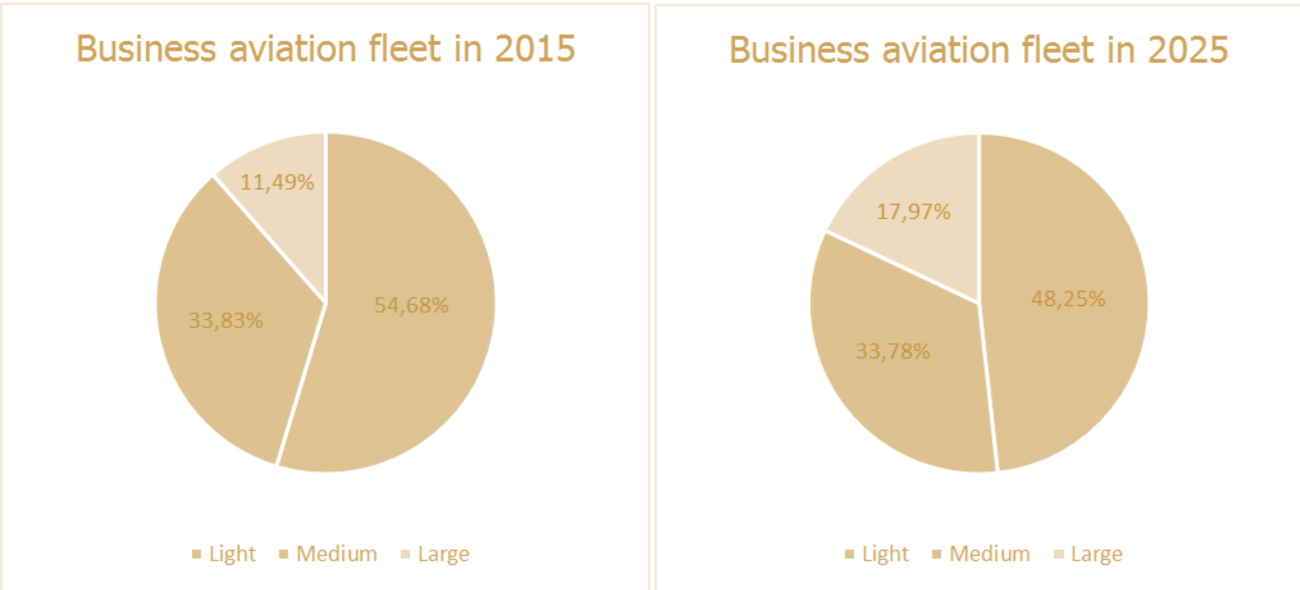

Figure 7.53 – Business aviation fleet 2015 vs 2025

For the moment, the volumes of business jets delivered seems to have stagnated, as Figure 7.54 illustrates. A total of 703 units were delivered in 2018 compared to 677 in 2017. However, the behaviour of each market segment was different. Light class, very crowded as ever, did show a rather encouraging increase of 16%, explained by analysts by the resurgent US market in connection with economic growth. Midsize class sales were nearly level, explained maybe by the current transition between generations.

On the contrary, the 'large' class is still suffering from the blows of the previous recession, with volumes decreased by 7%. This is probably the effect of soft demand in traditional markets like the Middle East and China [18]. The only manufacturer who recorded an increase in deliveries in 2018 was Gulfstream, 121 units compared to 120 in 2017.

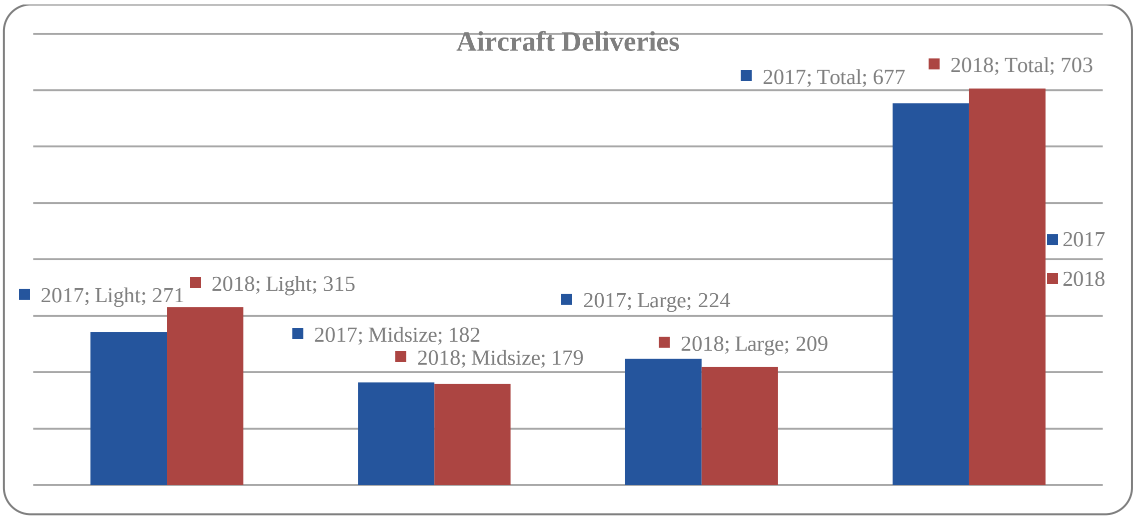

Figure 7.54 – Business aviation deliveries 2018 vs 2017

If a recession will be expected before the beginning of the third decade of the century, the volumes of purchased business aircraft will further decrease. An important factor in business aviation has been the growth of traditional or shared ownership and leasing.

T7.2.4 Airline Fleets

Firstly, prior to stating any conclusions, it is necessary to compare current air traffic figures with future air traffic expectations.

During 2017 there were more than 10 million IFR flights within ESRA08 (EUROCONTROL Statistical Reference Area). These IFR movements can be split into internal flights, departures and arrivals (e.g. respectively going to or departing from a non-ESRA country) and overflights (e.g. flights for which both departure and arrival aerodromes are outside the region). The figures for each subdivision of IFR flights are collected in Table 7.7.

Departures	**1.087.220**
Arrivals and Departures	**1.087.562**
Internal	**8.075.186**
Overflight	**143.256**
Total	**10.393.224**

Table 7.7 – IFR movements in 2017 (ESRA08). Source: STATFOR

It is adequate to gather both arrival and departure flights in other to establish a classification, differencing between flights from/to Europe and flights within Europe. In this manner, internal flights are those that are carried out within Europe, whilst arrival flights, departure flights and overflights are those that are carried out from/to Europe or from/to another country or continent different to Europe. The percentages corresponding to each part are shown in figure 7.55.

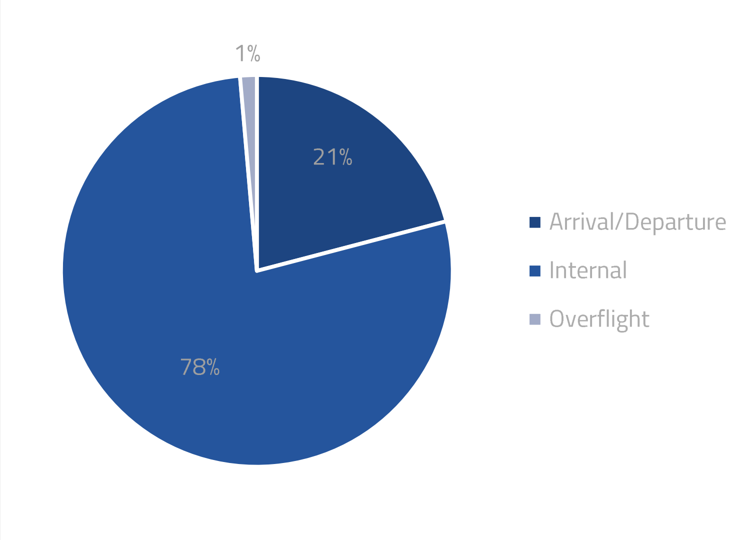

Figure 7.55– IFR movements in 2017

As can be seen, internal flights hoard most of IFR movements (78%) whilst flights with origin or destination out of Europe, in which most of them can be considered as long-distance flights, gather 22% of overall.

As well as global air traffic, it is also expected growth of the number of long-distance flights in Europe. For example, it is forecasted (Figure 7.56) 14,4 million of IFR flights in 2035 [2], within which the short-haul flights are expected to decrease up to 69% and medium and long-haul flights are expected to grow up to 31% [4].

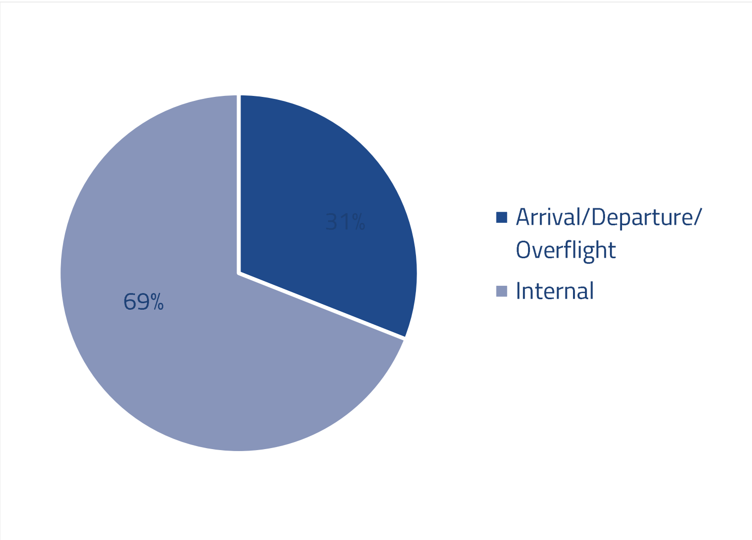

Figure 7.56 – IFR movements in 2035

On the other hand, it is necessary to compare the previous figures with fleet forecasts. For example, Boeing states (Figure 7.57) that there were approximately 22,510 jet airplanes in service in 2015, a number that is expected to double over the next 20 years to an in-service fleet of 45,240 airplanes. To achieve that, 39,620 new airplanes will be needed owing to that 5,620 airplanes that are in service nowadays will be maintained in service [5].

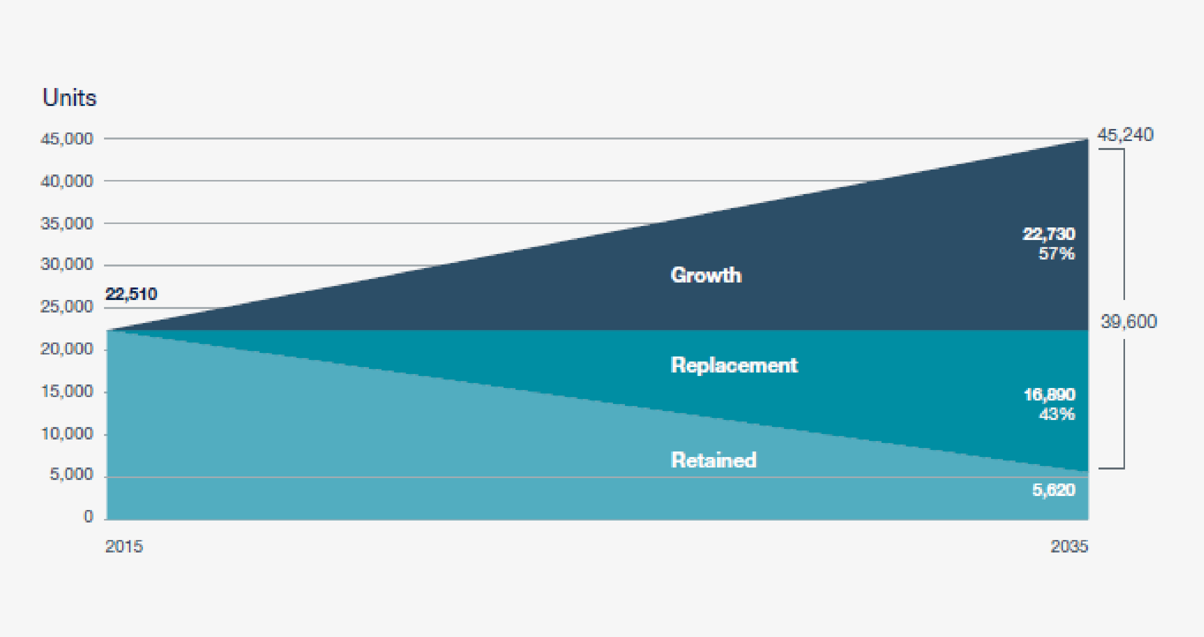

Figure 7.57 – Boeing fleet forecast 2015-2035

Source: Current Market Outlook 2016-2035

If the number of aircraft is split into categories (single aisle and widebody), it can be seen in the next figure that (Figure 7.58) 22% of overall were correspondent to widebody in 2015. This means that the percentage of widebody aircraft is exactly the same as the percentage of arrivals, departures and overflights of IFR movements in 2017. This connection between both IFR movements and aircraft shows that nowadays both are growing together and that the offer meets the demand for long-range aircraft.

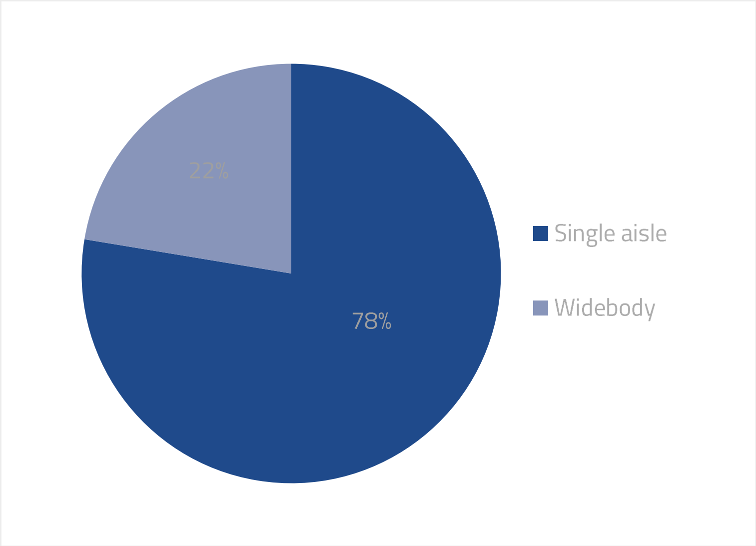

Figure 7.58 – Aircraft classified by type in 2015

On the other hand, Boeing forecasts that, from the 45.240 airplanes that will be in service in 2035, 23% of them will correspond to wide body aircraft, which means that, the share for any type of aircraft will be pretty similar to nowadays (see figures 7.58 and 7.59). If this became true, it could mean that there was a big difference between the expected percentage of medium and long-distance IFR movements (31%) and the expected percentage of wide body aircraft (23%). This difference could mean that the offer cannot meet the demand for long-range aircraft in the future and, hence, it could become a problem for the development of long-haul flights.

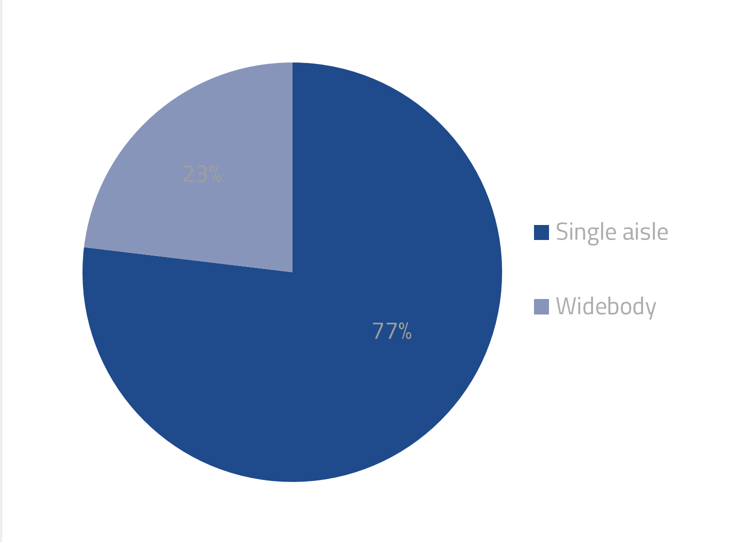

Figure 7.59 – Aircraft classified by type in 2035

T7.2.6 Airliner Market

As was seen in the last section, there might be a difference between the expected growth of air traffic and the expected growth of fleet within the long-distance sector. In this manner, there might be a shortfall of long-range aircraft from now until 2035, when it is expected that medium and long-distance flights account for 31% of all flights whilst long-range aircraft are expected to account for 23% of the entire fleet, according to Boeing forecasts.

The analysis of Boeing – Airbus forecasts is complicated, owing to the lack of apples-to-apples comparisons with previous years for a number of reasons: Airbus' integration of the A220 at the bottom end of its forecasts; Airbus' removal of the X-Large category at the top of its forecasts following the sunsetting of the A380 program; and Boeing and Embraer's proposed integration, where the two airframers are officially still putting out separate statistics with markedly different headline numbers.

Airbus hasn't officially updated its market forecasts for 2019, but chief commercial officer Christian Scherer revealed a few high-level numbers at a pre-briefing before the Paris Air Show. "Our global market forecast sees over the next 20 years a little bit more than 37,000 commercial aircraft delivered into this market, of which about 28,500 are single-aisle. The medium category we see about 5,500, and in the larger category about 3,300 aircraft," Scherer said.

Boeing's published 2019 market forecast, meanwhile, forecasts a market some 15% larger: a total of just over 44,000 aircraft. It splits the market into four categories:

- 90 seats and below, for which Boeing forecasts 2,240 aircraft
- 90 seats and above: 32,420 aircraft
- Widebody: 8,340 aircraft
- Freighter widebody: 1,040 aircraft

Comparing these numbers is complex given the overlaps between Airbus' "small" and "medium", Boeing's two narrow body categories. Boeing provided details on certain sub-markets and cross-markets at Le Bourget suggesting a middle-of-the-market category comprising between 4,000 and 5,000 airplanes. Editor John Walton, Runawaygirl Network

Although this difference of percentages may seem excessive, it is necessary to clarify that the percentage of 31% correspond to those flights covering distances longer than 2000 km. Long-haul aircraft tend to be used in routes longer than this, say over 3 000, 4 000 or 6 000 Km, so the definition should be viewed with caution. This means that part of medium distance flights, which cover distances between 1500 and 4000 km [7], are included within this percentage. Therefore, although the difference between percentages is significant, the part concerning long-distance flights is lower than it could seem.

The separation between short and long-haul can be placed at a distance of 2 000 Km or greater. Single-aisle aircraft fly up to 6 000 Km with A321XLR going much further, and twin-aisle aircraft are mostly used beyond the range of single aisle. The choice of a boundary between short and long-haul makes the comparison with aircraft fleets more uncertain.

Focusing on the growth of the fleet, which it is expected to be composed of 23% of widebody aircraft and 77% of single aisle aircraft in 2035, it is interesting to address the economic impact that it will drive globally. Even though the number of widebody aircraft will be significantly lower than single-aisle aircraft, widebody aircraft will account for about half of the total market value as forecasts carried out by Airbus and Boeing show.

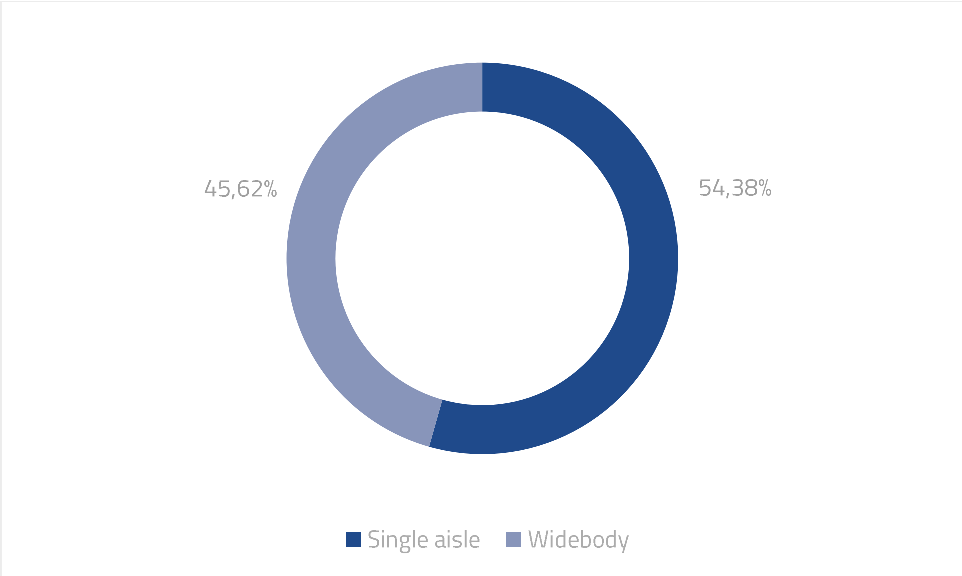

Figure 7.60 – Billing by type of aircraft forecasted by Boeing

On the one hand, Boeing forecasts (Figure 7.60) that 45,62% of the total billing will correspond to widebody aircraft, which means that the airlines will spend around US$ 2760 billion on widebody aircraft. Therefore, if the difference between the percentage of long-distance traffic and the percentage of long-range aircraft became true, it would result in a shortfall of revenue that aircraft manufacturers could have reached if the offer had met the actual demand of widebody aircraft. In economic terms, this would result in the non-income of up to US$ 944 billion.

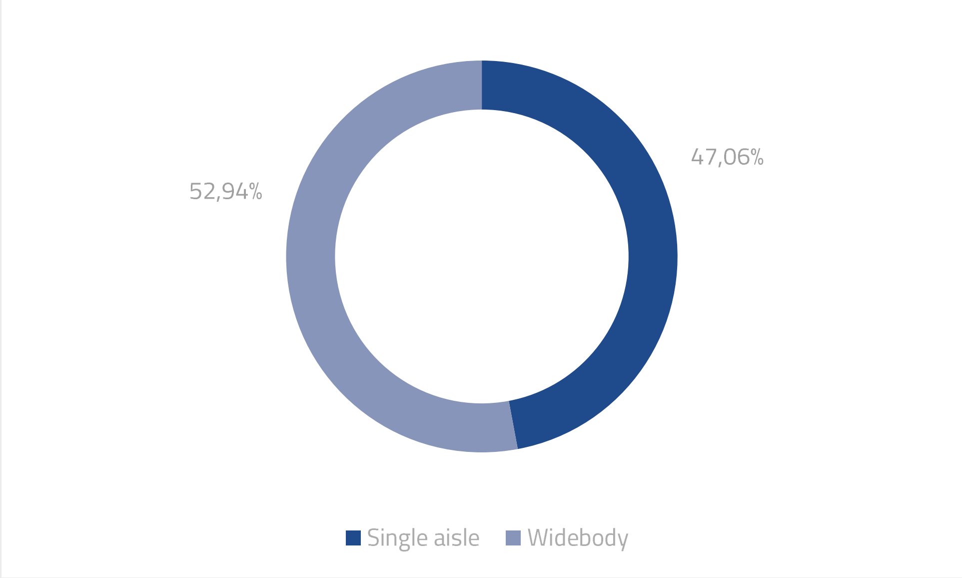

Figure 7.61– Billing by type of aircraft forecasted by Airbus

On the other hand, Airbus forecasts (Figure 7.61) that almost 53% of the total billing will correspond to widebody aircraft, this is translated into airlines spending around US$ 2700 billion on widebody aircraft which is pretty similar to the figure forecasted by Boeing (US$ 2760 billion). In this case, if the difference between the percentage of long-distance traffic and the percentage of long-range aircraft became true, it would result in the non-income of up to US$ 924 billion.

Boeing and Airbus can adjust their production rates to aircraft demand, and also use delivery dates to ensure that the market is fully served correcting for any inaccurate estimates.

As both companies forecast a similar number of widebody aircraft to be delivered, the gap between revenue and possible non-income is also similar (US$ 944 billion vs US$ 924 billion). However, the most important thing about this figure is the fact that in becoming true, it would mean a potential economic growth of 34% not achieved due to, although it is expected the manufacturing of over 9000 widebody aircraft, it would be necessary more than 12000 widebody aircraft in order to cover the medium and long-distance traffic (31% out of total traffic) forecasted for 2035.

T7.2.7 Desirable Future Evolution

Firstly, the long-distance traffic situation should be put in context. The cluster of short, medium and long-distance flights shape the global air traffic network and, within it, long-range flights have a fundamental role due to they allow the connections between continents in such a way that displacements of people and goods from one part of the world to another are possible in a few hours, whilst other modes of transport, as maritime transport, the same displacements have a duration of days.

Similarly, since we are part of a globalized world in which the speed of connections with countries far away is increasingly important, long-range traffic is a key factor for the development of air traffic. Likewise, all the measures designed to allow the development of air traffic will have a direct impact on long-distance traffic.

Therefore, measures designed to achieve the increase of airspace capacity, the reduction of the environmental impact of air traffic and the reduction of air traffic management costs are necessary. Some of these measures address the development of equipment, systems and procedures which would allow, for example, improve the flexible use of airspace which would optimize the available airspace for commercial operations. On the other hand, other measures address the development of aircraft systems which would allow, for example, to reduce separation minima, always taking into account the main principles of any air navigation system: accuracy, availability, continuity and integrity. A clear example of the previous part is the

Performance-Based Navigation (PBN). As states the PBN Navigation Strategy 2016 by FAA, PBN comprises RNAV and RNP and describes an aircraft's ability to navigate in terms of performance standards. On the one hand, RNAV enables aircraft to fly on any desired flight path within the coverage of ground- or space-based navigation aids, within the capability of the aircraft equipage or a combination of capabilities. On the other hand, RNP is RNAV with the addition of onboard performance monitoring and alerting capability. A defining characteristic of RNP operations is the ability of the aircraft navigation system to monitor the navigation performance it achieves and informs the pilot if the requirement is not met during an operation. The performance requirements of PBN for particular airspace are communicated to pilots through navigation specifications published in navigation charts. Common PBN specifications include RNAV 1, RNAV 2, RNP 0.3, RNP 1, as well as RNAV (GPS) and RNAV (RNP) approaches, as can be seen in the following figure 7.62.

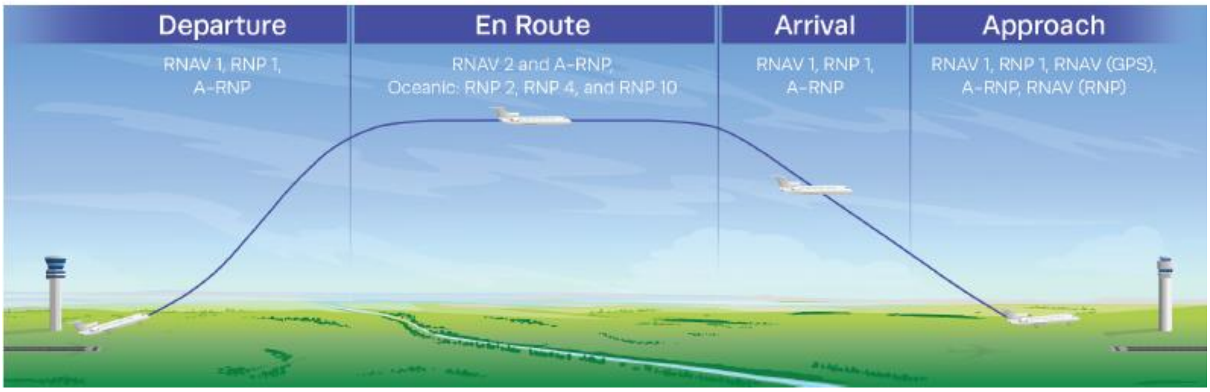

Figure 7.62 – Various PBN procedures are used at each phase of flight

Source: FAA PBN Navigation Strategy 2016

The main advantages are that the PBN framework enables a safer and more efficient design of airspace and procedures within the airspace by [9]:

- Segregating traffic between airports, arrival and departure paths, and routes in close proximity.
- Increasing efficiency of sequencing, spacing and merging when integrated with communication, surveillance and controller decision support tools.
- Allowing for reduced divergence between departure operations, resulting in increased departure throughput.
- Providing safe access to airspace near obstacles and terrain.
- Improving access to airports during poor weather conditions, especially for general aviation (GA) operations.
- Reducing pilot-controller voice communication by using text-based messages, allowing controllers more time to plan or handle emergencies and abnormal situations.
- Providing pilots with vertical guidance, resulting in more stabilized approaches and landings.
- Reducing flight track distance, fuel burn and emissions due to more direct flight paths and optimized vertical descent profiles.
- Improving predictability to better inform airline operators for schedule and gate management.
- Reducing reliance on and investment in ground-based navigational aids and the conventional procedures dependent on them.

As an example of the benefits of PBN navigation procedures, non-radar track separation was reduced from 100 nautical miles (NM) to 30 NM laterally and longitudinally using RNP 4 procedures over the Atlantic and the Pacific, as can be seen in the following figure 7.63.

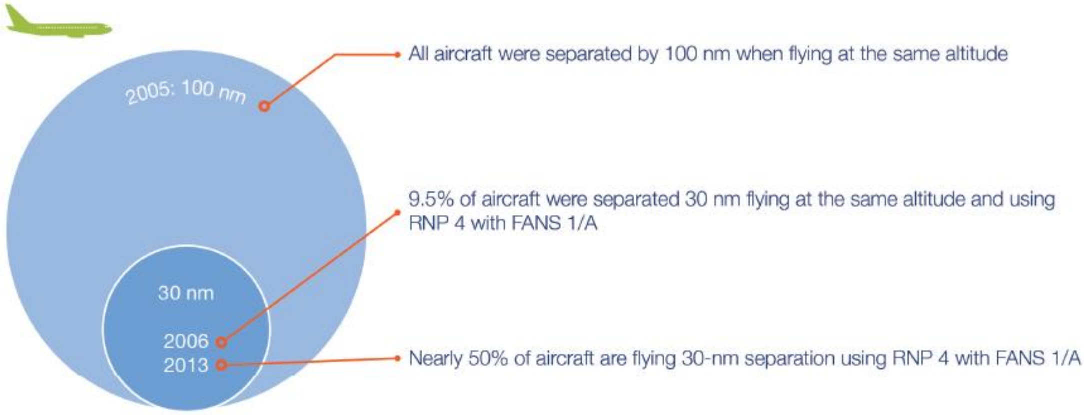

Figure 7.63 – Reduced spacing has substantially increased the capacity of non-radar oceanic environments
Source: FAA PBN Navigation Strategy 2016

Likewise, technological improvements and increases in operator equipment will continue to enable new worldwide PBN applications instead of conventional procedures. This transition from conventional procedures to PBN procedures increases predictability, reliability and flight efficiencies while continuing to ensure safe operations. As PBN capabilities evolve and emerging advancements in surveillance and communication become widely available in Europe, it is vital that aviation stakeholders continue to innovate and integrate navigation technologies [9].

However, these improvements may not be enough to match the expected growth of air traffic and it is possible that available capacity becomes a bottleneck. In this manner, constraints can become true both at airports (regarding runways, terminals or processes saturation) and in air traffic management (regarding en route sectors and TMAs saturation).

Therefore, proper measures should be taken in order to predict and solve these bottlenecks before they arise, hence research and development will be essential for the aviation industry. In that case, the European Union should provide institutions, companies and other stakeholders with the tools needed for successful development.

KEY TOPIC T7.3 AIRLINER MARKET

T7.3.1 Introduction

Our age of globalization is unique in that it is now far cheaper and faster than ever to transport people, which has made it possible to travel back and forth between distant places as never before. This is the direct consequence of the expansion in air travel. Of course, it was possible to travel long distances before air travel, but the cost was so high and travel time so long that few actually did, and those who did, for the most part, would not travel frequently. Now, for the first time in human history, the whole world is effectively connected in a global network that enables a constant flow of people between countries and continents far apart.

The technological evolution of commercial airplanes enabled greater and greater distances to be covered: from the Boeing 707, which started flying transatlantic routes in 1958, to the Boeing 747 ("Jumbo Jet"), which enabled, for instance, the route between San Francisco and Sydney which, at just under 7500 miles, became in 1976 the longest regularly scheduled non-stop flight in the world.

The Boeing 747-400 started commercial operations in 1989; by 1990 there had already been over 100 units delivered, and the 747-400 went on to become the best-selling subset in the 747 family, with more than 1400 units delivered. A few years later, in 1993-94, Airbus introduced its A330 and A340 models, which made the company into a serious competitor for Boeing; the A330/A340 have combined to sell more than

1800 units. Finally, in 1995, the Boeing 777 family went into operation, eventually delivering nearly 1500 planes. These plane models made ULH flights substantially cheaper because they combined long ranges with much improved fuel efficiency. The 747-400 family was about 20% more fuel-efficient than the preceding best-selling family of twin-aisle planes, from the early 1970s, and the 777 pushed that gain further to a total of about 30%.

The number of long-haul flights (above 4500 miles) goes up sharply right after 1989, and this is largely pushed by the range below 6000 miles. This is in turn driven by Boeing aircraft, matching the introduction of the 747-400. Airbus then enters the long-haul market in 1993, exactly as the A330 and A340 come into the picture, and the increase in its presence is overwhelmingly in the below- 6000 range as well.

The introduction of the Boeing 747, in 1970, brought about the era of “ultra-long-haul” (ULH) commercial aviation. There is no single definition of what constitutes ULH, but a common practical one singles out flights that take longer than 12 hours. Given customary speeds, a 12-hour flight translates into about 6000 miles, corresponding to the distance between London or Paris and Tokyo. The distinction is apparent in the range of modern commercial aircraft by Airbus and Boeing: there is a set of aircraft models designed to fly up to 4000 nautical miles (about 4600 miles), and another designed to fly at least 6000 miles. The crucial import of the ULH distinction is not in the technical feasibility of flights by different kinds of aircraft – in fact, the shorter-haul planes cannot fly the 9-12 hours range anyway. Instead, the 12-hour threshold is meaningful because of its impact on the cost of a given flight, as very long flights impose requirements on the availability of pilots and crew. For instance, the US Federal Aviation Authority (FAA) had required since the 1950s that a two-pilot crew could fly at most 12 hours within a 24-hour period: flights above that limit require at least three pilots and an additional flight crew member (“double augmentation”), as well as “adequate sleeping quarters” on the plane. Similarly, European regulators adopted in 1991 a daily maximum of 13 hours for a flight crew member’s “flight duty period” working in a basic (“un-augmented”) crew. Since the regulator also imposed that pre- and post-flight duties included in that period could not be less than one hour, there would necessarily be additional crew in any flight of more than 12 hours. The cost patterns documented by the US FAA show that, for long-haul planes (wide-body, 300-plus seats) in passenger air carriers, crew corresponds to about 36% of non-fuel costs (11% of total costs). On top of that, additional crew and sleeping quarters imply less space and weight available for carrying a payload, thus reducing revenue potential.

T7.3.2 Foreseen Development of the Long-Range Air Transport Demand

Demand for air transport is the driver for traffic growth. Demand is heavily influenced by the economy and demographic evolution. The growth of air transport exhibits a strong positive trend, even though this is inhibited to some extent by various factors, such as environmental concerns, infrastructure, perceived inconvenience, and so on. In the presence of these constraints, however, the evidence indicates that overall demand does not reduce, but instead adapts - and spreads. As constraints influence demand, then so, in turn, demand influences supply. If air traffic growth is constrained (e.g., by capacity limits or regulation and/or by price increases), then demand changes and supply adapts and restructures.

The development of competition between airlines, which followed air transport deregulation, coupled with more efficient and less costly aircraft technologies, has brought about the democratisation of air transport. Tourism is an important contributor to air transport growth. About 69% of air journeys made by Europeans are leisure trips. Demand for leisure-driven air transport will probably continue to grow.

Regarding the characteristics of air travel demand in 2025, a recent study has identified the following trends (Eurocontrol, 2009):

- increase in the level of air travel demand for the purpose of Visiting Friends and Relatives;
- increase in the level of air travel demand for retired people;
- increase in the demand for individualised travel;

- use of travel as a way to escape from the very fast rhythm imposed by society;
- increases in airfares or regulatory measures limit supply levels and reduce demand for air travel.

Long-term demand analysis requires further exploration and monitoring of several societal indicators (Eurocontrol, 2009):

- total cost of travel, including the cost of living at the destination;
- household consumption of leisure air travel;
- holiday departure rates according to socio-professional categories;
- number of retired and emigrated people impacting the number of trips for the purpose of Visiting Friends and Relatives (VRF);
- opposition between environmental issues and the emergence of "the right to travel".

Professional mobility, second to tourism and leading to migration flows, remains an important driver of air transport demand. Moreover, professional mobility is supported by the EU as a channel for developing the future European economic model.

Emerging economies attract business activities, which act as a catalyst for more transport and travel movements until levels of wealth begin to reach toward those in developed nations. In the future, there is likely to be very strong growth along these lines, comparable with the doubling of air traffic every 20 years as observed in the West. The areas with outstanding growth are Asia (especially China and India), Russia, and Latin America. These are emerging economies seeking access to the same travel modes and behaviours as the developed countries. This may lead to significant growth in demand, especially for long-haul connections, that is, unless environmental constraints impede this growth.

The main macro-economic trend is the exceptional growth over the past four years. Global GDP increased by 4% yearly. This represented an annual 8% growth in global air transport demand. From 2008 onward, following the "sub-prime" crisis, global GDP growth will slow slightly to stabilise at around 3% for the next five years (forecast made early 2008). This equates to a 6% growth in global air transport demand. This figure has actually been the standard for the last 60 years. Air transport growth over the long-term, then, has exhibited a stable trend, even though economic stagnation and recession. Although economic forces have exerted a negative impact on demand in special circumstances (for instance, the 1970s oil crisis and 1991 terrorist attacks) traffic is seen, historically, to rebound after negative events.

T7.3.3 Long-Range Air Transport Cost

T7.3.3.1 Aircraft

An aircraft can operate on different ranges. According to the ICAO definition, the long-haul flights are the flights on routes longer than 4 000 km (ca. 2160 NM). However, it is generally assumed that long-haul flights are carried out on routes longer than 6,000 km (ca. 3 240 NM). Aircraft that can handle such routes are mainly produced by two world leaders in the aircraft production: the AIRBUS consortium and the Boeing Company. Table 7.8 contains a summary of the long-range aircraft currently in service, indicating the maximum capacity of each type, the number of aircraft currently in use and the approximate unit cost. The payback-range characteristic of three classes of airliners appears in Figures 7.64 – 7.67).

Some of the aircraft not included in the table have a range close or a little greater than 3200 NM. This is their maximum range. However, aircraft rarely fly on routes with a length close to their maximum range, therefore it was assumed that they do not fly on long-haul distances.

Type	Max. Seating no.	Max. range, nm	In service/in order (2016)	No. of operators	Unit Cost Million USD
Airbus A300-600(R)	298	4 150	23	9	N/A
Airbus A310-200/300	280	4 350	35	15	N/A
Airbus A330-200	380	7 250	501/42	91	238.5
Airbus A330-300	440	6 100	619/99	71	264.2
Airbus A340-200	300	8 000	2	3	87 (1989)
Airbus A340-300	440	7 400	120	33	238 (2011)
Airbus A340-500	375	9 000	5	8	261.8 (2011)
Airbus A340-600	475	7 900	72	10	275.4 (2011)
Airbus A350-900	366	9 700	36/564	39	317.4
Airbus A380-800	853	8 200	195/124	19	445.6
Boeing 737-7	170	4 200	0/60	-	90.2
Boeing 757-200	228	3 995	357	63	65 (2002)
Boeing 767-200/200ER	255	6 385	19	23	N/A
Boeing 767-300/300ER	350	5 500	481	84	197.1
Boeing 767-400ER	375	5 365	37	2	N/A
Boeing 787-8	291	7 355	304	41	224.6
Boeing 787-9	290	7 635	141/432	41	264.6
Boeing 787-10	330	6 430	0/153	9	306.1
Boeing 777-200	440	4 240	70	10	N/A
Boeing 777-200ER	313	7 065	363	49	277.3
Boeing 777-200LR	317	8 555	55	12	313.8
Boeing 777-300	550	5 045	53/3	10	N/A
Boeing 777-300ER	396	7 370	669/126	40	339.6
Boeing 777-8	355	8 700	0/53	-	371
Boeing 777-9	406	7 600	0/243	-	400

Type	Max. Seating no.	Max. range, nm	In service/in order (2016)	No. of operators	Unit Cost Million USD
Boeing 747-400(ER)	500	7 635	187	43	N/A
Boeing 747-8I Intercontinental	581	7 730	32/9	5	379.1

Table 7.8. Long-range aircraft

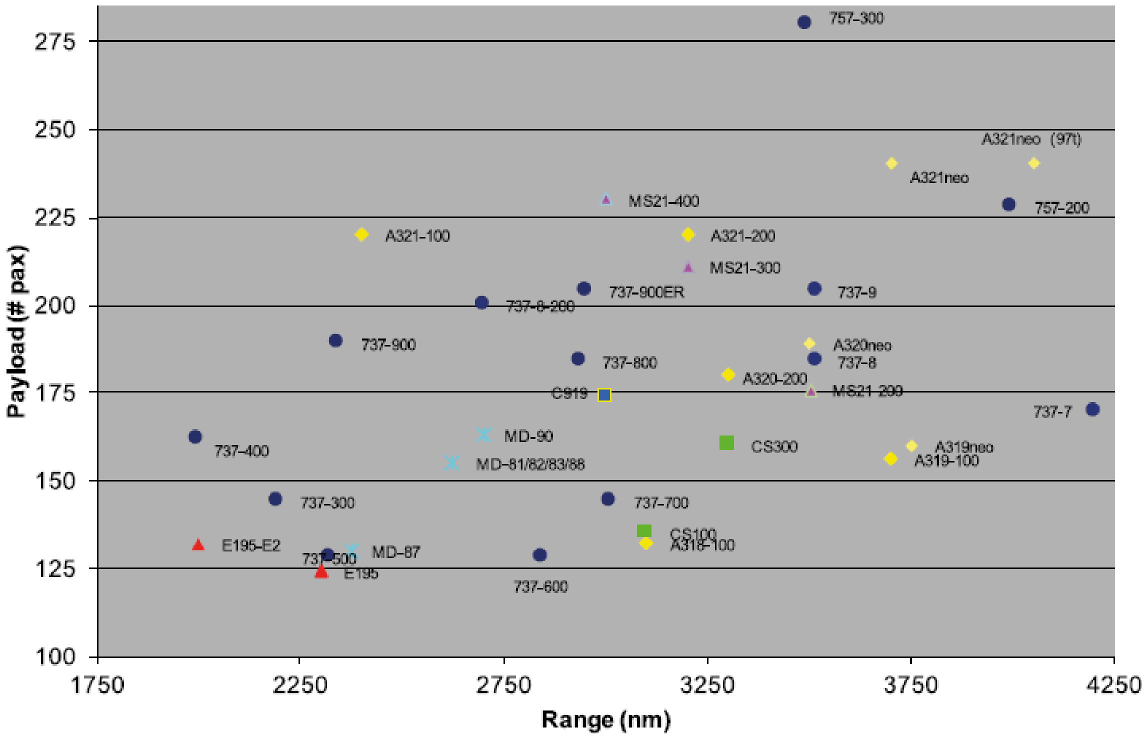

Figure 7.64 Narrow-body Payload-range (single class cabin configuration) (Leeuwen, 2016)

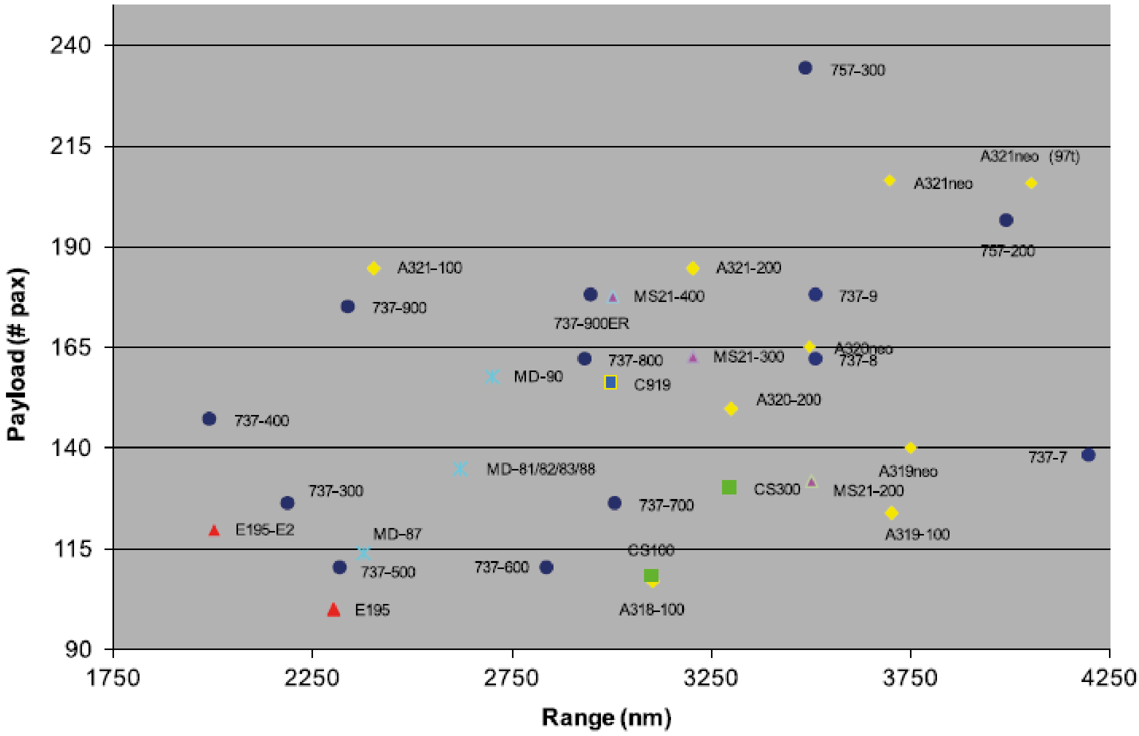

Figure 7.65 Narrow-body payload-range (dual class cabin configuration) (Leeuwen, 2016).

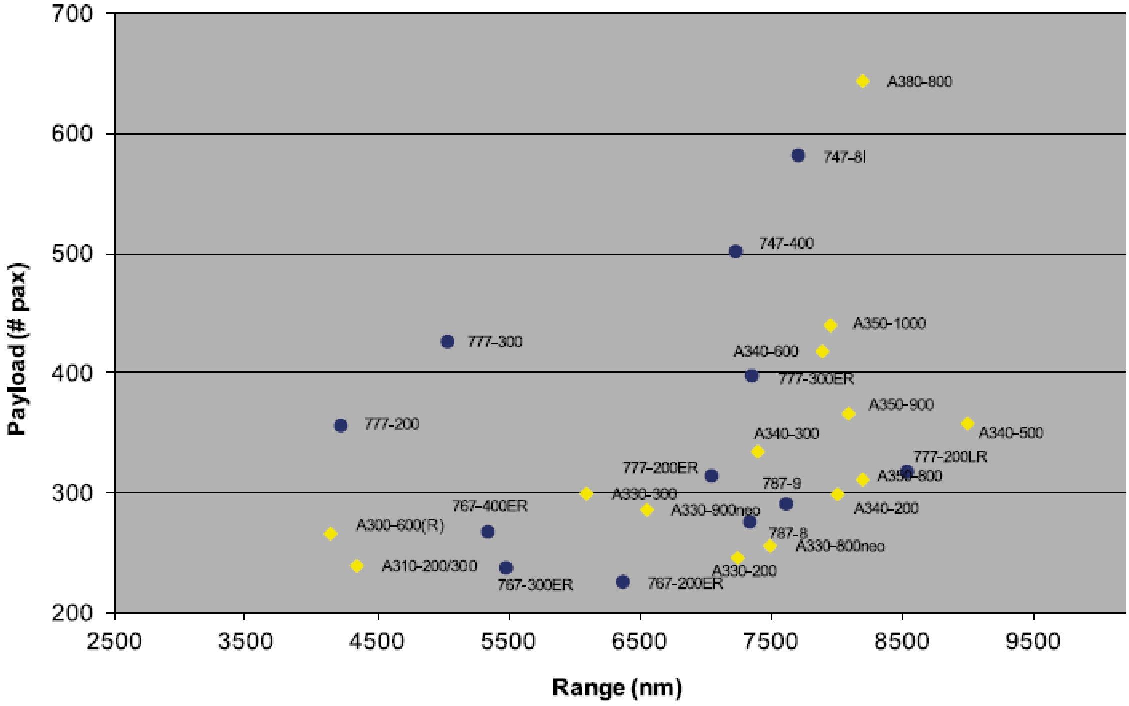

Figure 7.66 Widebody payload-range (dual class cabin configuration) (Leeuwen, 2016).

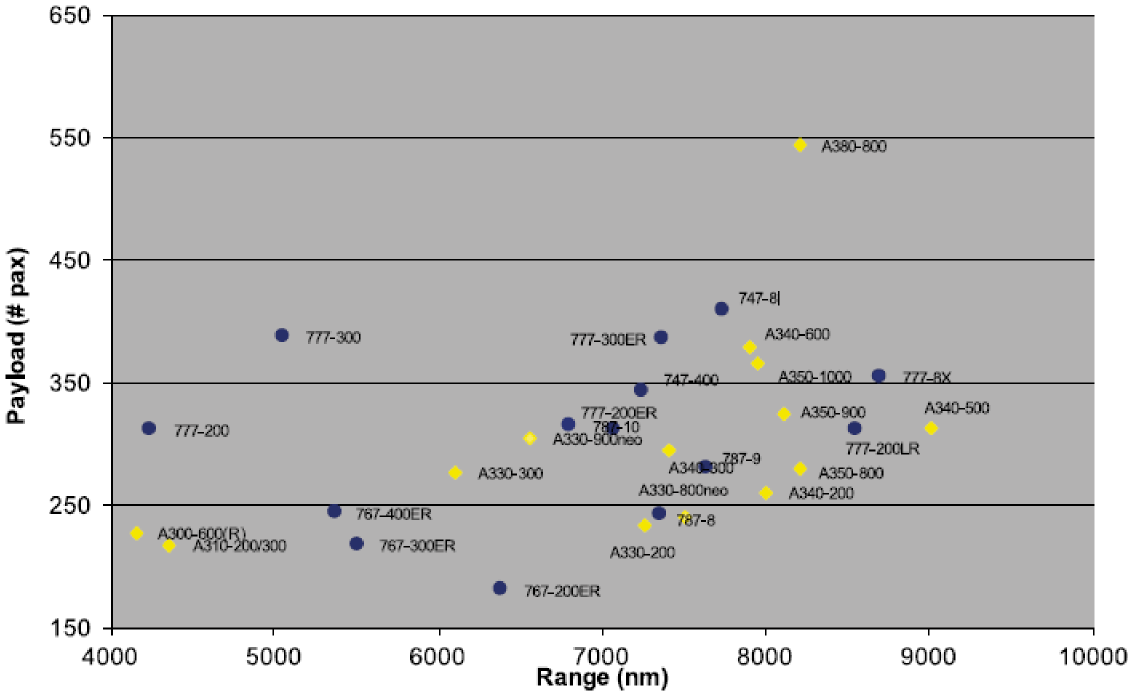

Figure 7.67 Widebody payload-range (triple class cabin configuration) (Leeuwen, 2016

T7.3.3.2 Fuel

One of the main factors affecting the economic efficiency of air transport is the amount of fuel consumed. The indicator showing the amount of fuel consumed is fuel efficiency expressed in fuel/passenger-km.

The analysis compares the fuel efficiency of newly delivered aircraft on two metrics, namely fuel per passenger-kilometre and ICAO's metric value (MV). The fuel/passenger-km metric denotes the amount of fuel burned per passenger-km flown, as measured from the departure gate to arrival gate ("block fuel"). This metric includes all fuel consumed for the taxi, take-off, cruise, approach, and landing stages.

ICAO's metric value (MV) was developed within ICAO's Committee on Aviation Environmental Protection (CAEP) as part of the effort to establish a CO2 emission standard for new airplanes. The most important difference from the fuel/passenger-km metric is that MV considers only the cruise performance and ignores other flight phases of an aircraft such as landing, take-off, and climb.

Figure 7.68 presents historical changes in fuel efficiency for commercial jet aircraft from 1960 to 2014, with the 1968 value as the baseline, using both fuel/passenger-km and ICAO's metric value. The figure shows that the average fuel burn of new aircraft fell approximately 45% from 1968 to 2014, or a compounded annual reduction rate of 1.3%. But the rate of reduction varied significantly. During periods of rapid improvement such as the 1980s, fuel efficiency improved by 2.6% annually due to the aggressive adoption of new technologies and efficient aircraft design principles. In contrast, little net improvement was seen during the 1970s.

Reductions in average aircraft fuel burn slowed noticeably after 1990 and largely halted around 2000. After 2010, average fuel efficiency began to accelerate on both metrics and has now returned to the long-term average improvement of 1.1% per annum on a fuel/ passenger-km basis. Acceleration in improvement rate is expected in the foreseeable future due to the introduction of new, more efficient aircraft designs such as the A320neo, 737 MAX, and 777X. Over the long term, fuel efficiency improvements on the fuel/passenger-km and ICAO's cruise fuel metric were found to be comparable (Figure 7.60). Periodic deviations between the two are partly attributable to the fact that the ICAO metric provides limited crediting for improved structural efficiency (e.g., the use of lightweight materials).

ICAO estimates the potential for a 40% improvement in fuel efficiency for new single-aisle and small twin-aisle aircraft in 2020 relative to 2000 levels. This goal was compared with a fuel burn trend projection of new single-aisle (SA) and small twin-aisle (STA) aircraft types under ICAO's metric value plotted by the year they enter service (EIS). Figure 7.61 presents this comparison, showing a 12-year time lag between the projected fuel burn improvement and the time needed to reach ICAO's goals.

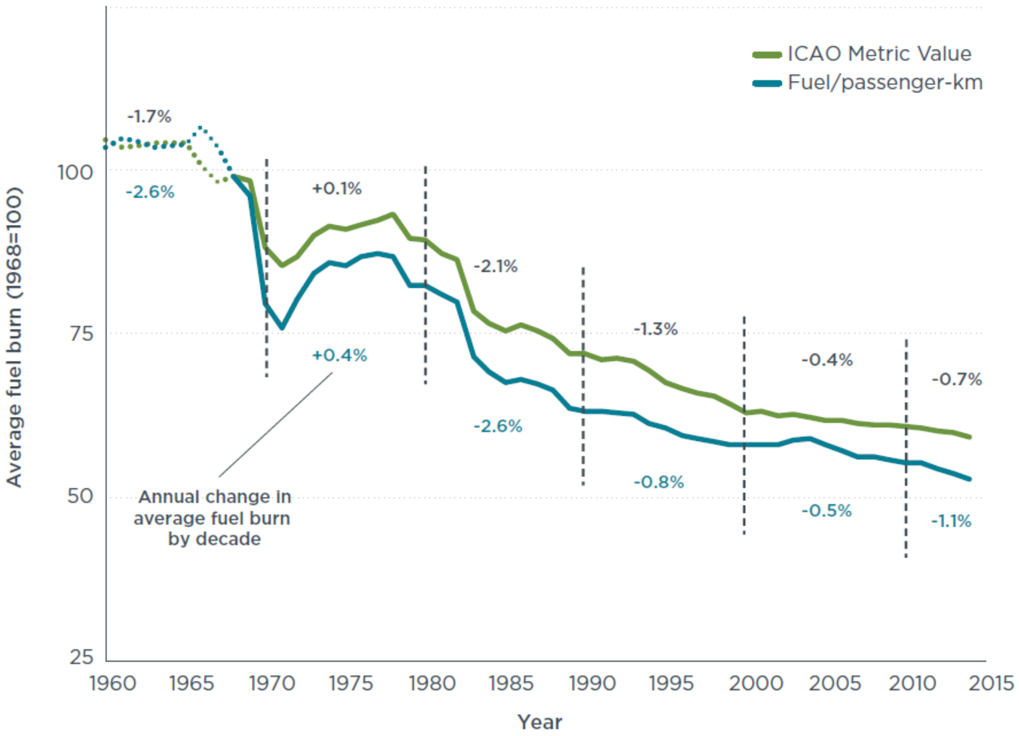

Figure 7.68 Average fuel burn for new commercial jet aircraft, 1960 to 2014 (since 2015) (1968=100) (Kharina et al., 2015)

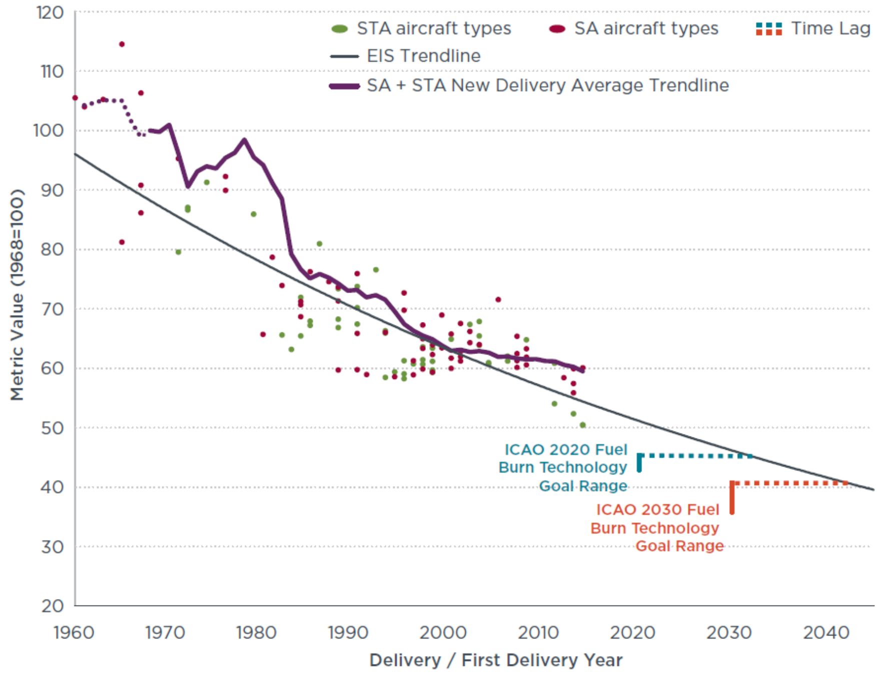

Figure 7.69 New single-aisle and small twin-aisle jet aircraft metric value vs. ICAO fuel burn technology goals (Kharina et al., 2015)

There are several expected drivers of the recent trends in new aircraft efficiency. One is fuel cost. Figure 7.70 overlays the trend in real jet fuel prices (EIA, 2015), normalized via the Consumer Price Index to 2015 values, from 1975 to January 2015 over the average fuel burn data (fuel/passenger-km metric) from Figure 7.68 to Figure 7.70 highlights the high volatility of jet fuel prices, especially in the last decade.

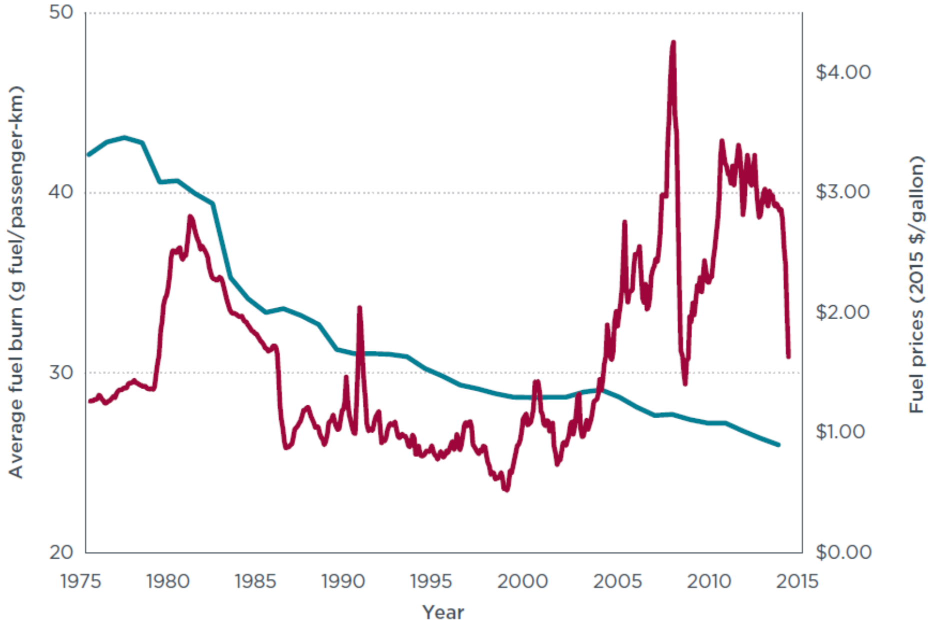

Figure 7.70 Average fuel burn for new commercial jet aircraft and real jet fuel prices (2015 dollars) (Kharina et al., 2015)

Over the long term, aircraft average fuel burn trends are largely driven by the introduction of new, more efficient aircraft types. Within an aircraft type, there are limited means of reducing fuel burn through the introduction of incremental improvements in technology; prominent examples include Performance Improvement Packages (PIPs) that are incorporated into Airbus and Boeing's products over the course of their production lives.

The average fuel burn trend assuming annual improvement on all aircraft types after their EIS (Entry Into Service) dates follows the original trend quite closely, with gaps widening in the 1970s and narrowing back in the 1980s, and again widening in late 2000. In fact, the annual average fuel burn reduction for the sensitivity analysis between 2010 and 2014 falls to 0.9%, lower than the annual improvement for the trend assuming no annual improvement (1.1%).

T7.3.3.3 Fuel Price

Over the long-term, the biggest concern for the air transport industry is the cost of fuel. Profitability, reduced costs and return on investment are the key factors that govern organisations like Airbus, Boeing, and other airlines. For the financial well-being of a commercial air transport operator, fuel cost is the greatest issue, as this represents the main part of its operating costs. This depends on fuel price and fuel burn. Ever since its beginning, air transport has been fuelled by oil derivatives.

Alternatives to fossil fuel were known and tested some 20 to 30 years ago. There has been hydrogen- and natural gas-fuelled aircraft. There is a growing interest in sustainable aviation fuels (Chapter 17), due to environmental concerns, even if their cost is higher than that of fossil fuels.

Demand and availability of oil will be important factors for air transport evolution as these drive fuel prices. The oil price will increase as, in the long-term, oil demand is likely to increase faster than supply. Oil price is not yet driven by scarcity. Global oil reserves for the next 80 years are probably greater than the estimations, and oil availability does not mean actual physical limitations for air transport. After all, air transport accounts for 3% of global fuel consumption, and if doubled would still only represent 6%. Special fuels, like high-octane aviation gasoline have become much less available. The price of aviation fuel is mostly driven by global demand beyond the control of the aeronautical users.

T7.3.3.4 Ticket Price

Today, the cost of air travel may well be at its lowest ever. Competition between airlines is driving ticket prices down, which, in turn, sustains air transport growth. The ATM community is creating an increasingly efficient system. Airlines are becoming far more efficient in the way they operate their businesses and have reduced overhead costs significantly.

However, fuel price and tax increases may well drive prices up again. We are probably at the bottom of the curve of disposable air ticket prices, without knowing where air ticket prices will be 20 years from now. In Europe, the political signs are that air travel is considered too cheap; this could potentially have a strong negative impact on demand.

In the long term, a quick economic analysis using the elasticity of demand to GDP and ticket-price (which will increase because of oil) shows that even with very conservative assumptions but taking into consideration the demography which plays an important role in the growth of air transport, we can still expect a 2.5% growth per annum until 2025.

- The elasticity of demand to ticket price is -0.5 (i.e., if the price reduces by 1% then demand increases by 0.5%). This is a reasonable assumption, since, in general, such elasticity is deemed to be -0.4 in the long term.
- The elasticity of demand to GDP is 0.8. This is an appropriate value for developed economies. In China, however, the value would be nearer 2.0.

Let us consider a scenario where the oil price goes from USD 50 in 2005 to USD 200 in 2025 (USD in constant value). This is seen as a realistic hypothesis because the oil price will remain driven by demand rather than by scarcity.

We can then make a projection of how much ticket prices could increase by 2050.

- Take a ticket price of 100 in 2005, 25% of this covers fuel cost, i.e., 25.
- In 2025, fuel cost is multiplied by four. There is a slight decrease due to productivity gains (-0.5% per year). The ticket price is then 167.5.

Assuming that global GDP increases annually by 4% between 2005 and 2015, the annual increase between 2015 and 2025 is 3%, and global GDP is then multiplied by two in 2025. In this hypothesis, the growth in demand by 2025 would represent a 34% increase, i.e., 1.5% per year. If demography is included, this would go up to 2.5% per year. This is far from the commonly accepted 4% per year. The hypotheses are therefore pessimistic, but still, they indicate that demand will grow.

T7.3.4 Aircraft Operators

It is likely that aircraft fleets operating in the 2020s will be dominated by evolutions of current aircraft (for example B777, B787, A330, A350 in the long haul) and that new technologies being matured now will reach operational use after 2030. A350 and the B787 were conceived with the development logic of the long-haul point-to-point system as an alternative to the hub system. This is based on the idea that 13 Chinese capitals will constitute marketplaces of more than 10 million inhabitants. These capitals are bound to deal directly with European capitals independently of one another. Flying farther and faster with a quick turn-around time is a factor that contributes to efficient aircraft operation. There are two factors to consider when designing and building aircraft: size and speed. Contrary to the Hub and Spoke concept, the concept of point-to-point, such as Lyon to Salt Lake City, emphasises speed and distance. The large market between hubs, e.g., Paris and New York, emphasises size and distance. The two modes of operation will probably co-exist. Business development might not be based on frequency anymore, but a strategy of «productive» growth using larger aircraft. However, the macro-economic trend of a 6% growth in the demand for worldwide air transport over the next five years is a concern, because this implies that most of the large European hubs will be saturated in the future.

The concentration of legacy airlines will continue. This will reduce competition, which is often detrimental to the environment and to the economic performance of the operators: several departures at the same time for the same destination, small modules, and high frequencies, more fuel usage, and more space utilised. The air transport model evolves toward a trust of three worldwide alliances between three European and three American poles: American Airlines alongside British Airways, United Airlines alongside Lufthansa, and Delta North West alongside Air France. At the NMAent, intra-American flows, intra-European flows, and European-American flows represent 54% of worldwide flows. Airlines from other parts of the world will probably enter some of these three alliances.

KEY TOPIC T7.4 BUSINESS JET MARKET

T7.4.1 Introduction

According to the General Aviation Manufacturers Association (GAMA) 2016 General Aviation Statistical Databook & 2017 Industry Outlook, Textron Aviation (Cessna Aircraft) delivered in 2016 178 business jets, Bombardier Business Aircraft came 2nd at 163, Embraer Executive Jets sold 117, Gulfstream Aerospace sold 115, Dassault Falcon Jet sold 49, Honda Aircraft Company sold 23, ONE Aviation Corp. (prev. Eclipse Aero) sold 8, while Boeing Business Jets sold 4 and Airbus Corporate Jets sold 1.

T7.4.2 Leading Business Jets Manufacturers in 2016

According to the GAMA world-leading business jets manufacturers are:

Textron Aviation (Cessna) – is the general aviation business unit of the Textron group. It was formed in March 2014 following the acquisition of Beech Holdings which included the Beechcraft and Hawker Aircraft businesses. The new business unit includes also, the Textron-owned Cessna. The company sells Beechcraft and Cessna branded aircraft. While no longer selling new Hawker airplanes, Textron Aviation still supports the existing Hawker aircraft fleet through its service centres.

http://txtav.com/

Bombardier Business Aircraft, as part of Bombardier Inc. – it is the world's third-largest aircraft manufacturer. The company's involvement with aircraft started with its acquisition of Canadair in 1986. Bombardier makes a wide range of jets to suit different purposes. The Learjet series is made up of light jets capable of carrying around eight or nine over short distances, whilst the popular Global 6000 – previously known as the Global Express XRS – can carry almost twice as many passengers and is able to make much longer journeys. The company newest aircraft is the follow on to the highly successful Global 5000/6000, with the Global 7000/8000 scheduled to enter service in 2017/2018. The company currently offers: Learjet 70 and 75, Challenger 350 and 650, Global 5000, 6000, 7000, 8000.

https://www.businessaircraft.bombardier.com/en/aircraft

Embraer Executive Jets - Brazilian-based Embraer entered the aerospace market-making reliable turboprops. The Legacy 600, available as a shuttle version with 16-37 seats and an executive version with 10-16 seats, flew for the first time in 2001. With the Legacy continuing to cement its reputation as an immensely popular mid-sized aircraft, in 2006 Embraer embarked on a tour across the US to showcase mock-ups of its new Phenom 100 business jet as well as the Phenom 300. The following year the Phenom 100 entered service, just three months before the much larger Lineage 1000, which achieved FAA Certification in 2009.

Having started in the business by building executive versions of airliners in the early 2000s, Embraer is now aiming to have a model in each of the size and weight categories. First came the Phenom 100 and Phenom 300, but Embraer soon closed the gap between the Phenom 300 and the Legacy 650 with the introduction of the mid-size Legacy 450 and Legacy 500. Embraer decided to give the aircraft the Legacy name rather than the Phenom name to give the new range the feel of the larger aircraft family.

http://www.embraerexecutivejets.com/en-us/pages/compare-aircraft.aspx

Gulfstream Aerospace - Although Gulfstream has developed a number of popular medium-sized business jets, such as the G200 and G450, the Georgia-based company has built its reputation almost entirely from building large business jets. Having always specialised exclusively in corporate aircraft, Gulfstream Aerospace grew out of Grumman Aircraft Engineering Co., a manufacturer of military aircraft. Gulfstream's biggest coup came partway through 2014 with the simultaneous introduction into the market of two new models. Long talked about as the mysterious-sounding 'P42', Gulfstream managed to keep both the G500 and G600 secret until the day they launched. During the launch at the manufacturers Savannah home-base, Gulfstream wowed many by having the G500 taxi into view under its own power. The company currently offers: Gulfstream G650ER, G650, G600, G500, G550, G280.

http://www.gulfstream.com/

Dassault Falcon Jet – Dassault has produced a number of medium-sized business jet models as well as the larger Falcon 7X, which features three engines and has a range of almost 6,000 nautical miles. Dassault's latest models, the Falcon 5X and Falcon 8X were introduced in 2013 and 2014 respectively, but whilst the Falcon 8X is a one-meter stretch of the 7X with an additional 500 nm range, the 5X is a clean sheet design that could become the platform for later, larger models.

https://www.dassaultfalcon.com/en/Pages/Home.aspx

Honda Aircraft – Honda Aircraft Company is a wholly-owned subsidiary of American Honda Motor Co., Inc. Founded in 2006, Honda Aircraft's world headquarters is located in North Carolina. The HondaJet is Honda's first commercial aircraft, incorporates many technological innovations in aviation design (e.g. Over-The-Wing Engine Mount (OTWEM) configuration that improves performance). The OTWEM improves fuel efficiency by reducing aerodynamic drag, cabin sound, minimizes ground-detected noise. The HondaJet is powered by two highly fuel-efficient GE Honda HF120 turbofan jet engines. The HondaJet is a light, seven seat jet, with a range of 1,223 nautical miles and 422 knots cruising speed.

http://www.hondajet.com/

Boeing Business Jets - All three versions of BBJ remain popular types of aircraft amongst private jet owners and operators, and between 1996 and 2014, there were a total of 164 aircraft delivered to customers. The company's latest development came in August 2011 when the Boeing board approved the launch of the 737MAX series of aircraft, almost a year after Airbus launched the A320neo family that the 737 competes with. Designed to replace the current in-production series of 737 airliners, the BBJ versions of the aircraft were finally launched in April 2014 with an order from an undisclosed customer for a single BBJ MAX 8.

Like Airbus Corporate Jets, Boeing Business Jets are often used by heads-of-state, governments and corporate clients, and because of a great number of airlines operate Boeing aircraft, it is easy to find maintenance.

http://www.boeing.com/commercial/bbj/

Orders and deliveries include all BBJ, BCA and BDS Aircraft delivered new into VIP service since 1996 appear in Table 7.9

Orders & Deliveries	737	BBJ	MAX	757	767	777	787	747-4	747-8	TOTAL
Orders	16	169	17	5	8	11	15	3	11	**255**
Deliveries	16	163	0	5	8	11	12	3	11	**229**
In Service	15	159	0	5	8	8	4	3	6	**208**

Table 7.9 Boeing Orders & Deliveries Source: http://www.boeing.com/commercial/bbj/#/aircraft/overview/

Airbus Corporate Jets - Airbus has besides the two main manufacturing facilities, one at Toulouse and the other in Hamburg, also one in China and one in the U.S. The most popular business jets built by Airbus are corporate ACJ318, ACJ319neo, ACJ320neo and ACJ321. These versions typically seat between 15 and 50 passengers. Airbus Corporate Jets are often used by heads-of-state, governments and corporate clients, and because over 300 airlines operate Airbus aircraft, it is easy to find maintenance.

http://www.airbus.com/aircraft/corporate-jets.html

ONE Aviation Corp. (prev. Eclipse Aero) - formed in 2015 to merge the aircraft manufacturers Eclipse Aerospace and Kestrel Aircraft. The new company initially produced the Eclipse 550, which had been in production at Eclipse Aerospace, and intends to complete certification of the Kestrel K-350. In March 2017 the company announced that Eclipse 550 production would end to concentrate production on the new Eclipse 700 model of the aircraft.

https://www.oneaviation.aero/

Reference state in 2010 and progress up-to-now

According to the General Aviation Manufacturers Association (GAMA) worldwide business jet shipments by the manufacturer in years 2010-2016 are given in Table 7.10:

Company	2010	2011	2012	2013	2014	2015	2016
Airbus Corporate Jets	15	10	9	6	5	4	1
Boeing Business Jets	12	8	12	7	10	11	4
Bombardier Business Aircraft	150	182	179	180	204	199	163
Cirrus Aircraft	0	0	0	0	0	0	3
Dassault Falcon Jet	95	63	66	77	66	55	49
Embraer Executive Jets	145	99	99	119	116	120	117
Gulfstream Aerospace Corp.	99	99	94	144	150	154	115
Honda Aircraft	0	0	0	0	0	2	23
ONE Aviation Corp.	0	0	0	0	12	7	8
Textron Aviation (Beechcraft)	73	52	32	6	0	0	0
Textron Aviation (Cessna)	178	183	181	139	159	166	178
SUM:	767	696	672	678	722	718	661

Table 7.10 Source: 2016 General Aviation Statistical Databook & 2017 Industry Outlook

The worldwide business jet shipments by manufacturer and type of aircraft in the years 2003-2016 is presented in Table 7.11.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Airbus	**0**	**0**	**9**	**11**	**13**	**11**	**13**	**15**	**10**	**9**	**6**	**5**	**4**	**1**
Airbus Corporate Jet (all models)	0	0	9	10	12	9	11	-	-	-	-	-	-	-
ACJ318	-	-	-	-	-	-	-	2	2	2	1	0	1	0
ACJ319	-	-	-	-	-	-	-	8	6	6	4	1	1	0
ACJ320	-	-	-	-	-	-	-	3	1	0	0	4	1	0
ACJ321	-	-	-	-	-	-	-	-	-	-	1	0	0	0
ACJ330	-	-	-	-	1	1	1	1	1	1	0	0	1	1
ACJ340	-	-	-	1	0	1	1	1	0	0	0	0	0	0
Avcraft (prev. Fairchild)	**9**	**9**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Envoy 3	9	9	1	-	-	-	-	-	-	-	-	-	-	-
Boeing Business Jets	**7**	**3**	**4**	**13**	**7**	**6**	**6**	**12**	**8**	**12**	**7**	**10**	**11**	**4**
Boeing Business Jet	4	2	3	12	7	3	3	4	8	2	5	3	4	1
Boeing Business Jet 2	3	1	1	1	0	1	0	2	0	2	1	2	1	0
Boeing Business Jet 3	-	-	-	-	-	2	1	4	0	0	0	0	1	0
Boeing 737-800	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Boeing Business Jet 747	-	-	-	-	-	-	-	-	-	8	0	0	0	0
Boeing Business Jet 767	-	-	-	-	-	-	1	0	0	0	0	0	0	0
Boeing Business Jet 777	-	-	-	-	-	-	1	2	0	0	0	1	1	1
Boeing Business Jet 787	-	-	-	-	-	-	-	-	-	-	1	4	4	0
Bombardier Business Aircraft	**70**	**130**	**188**	**213**	**224**	**247**	**173**	**150**	**182**	**179**	**180**	**204**	**199**	**163**
Learjet 31A	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Learjet 40/XR	-	17	21	26	57	48	33	16	24	24	1	-	-	-
Learjet 45/XR	17	22	28	30										
Learjet 60/XR	12	9	18	15	23	26	13	12	19	15	10	1	0	-
Learjet 70/75	-	-	-	-	-	-	-	-	-	-	18	33	32	24
Challenger 300/350	1	28	50	55	51	60	33	29	37	48	55	54	68	62
Challenger 604/605	24	29	36	29	35	44	36	38	43	34	32	36	25	26
Global 5000	-	4	17	18	46	52	51	49	53	54	62	80	73	51
Global 6000/Express	14	20	13	22										
CL 850/870/890	-	1	5	18	12	17	7	6	6	4	2	0	1	0
Cirrus Aircraft	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
SF50	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Dassault Falcon Jet	**49**	**63**	**51**	**61**	**70**	**72**	**77**	**95**	**63**	**66**	**77**	**66**	**55**	**49**
Falcon 50EX	8	5	5	5	2	1	-	-	-	-	-	-	-	-
Falcon 900C	3	3	1	-	-	-	-	-	-	-	-	-	-	-
Falcon 900EX	6	1	-	-	-	-	-	-	-	-	-	-	-	-
Falcon 900DX	-	-	2	4	10	4	1	3	-	-	-	-	-	-
Falcon 900EX EASy	4	14	16	16	18	19	17	17	1	-	-	-	-	-
Falcon 900LX	-	-	-	-	-	-	-	4	11	7	11	8	-	-
Falcon 2000	12	11	6	6	1	-	-	-	-	-	-	-	-	-
Falcon 2000DX	-	-	-	-	-	3	1	-	-	-	-	-	-	-
Falcon 2000EX	16	10	-	-	-	-	-	-	-	-	-	-	-	-
Falcon 2000EX EASy	-	19	21	30	33	24	3	-	-	-	-	-	-	-
Falcon 2000LX	-	-	-	-	-	-	23	30	20	22	8	-	-	-
Falcon 2000LXS	-	-	-	-	-	-	-	-	-	-	3	18	-	-
Falcon 2000S	-	-	-	-	-	-	-	-	-	-	12	13	-	-
Falcon 7X	-	-	-	-	6	21	32	41	31	37	43	27	-	-
Falcon 2000S/2000LXS/900LX/7X/8X	-	-	-	-	-	-	-	-	-	-	-	-	55	49
Embraer	**13**	**13**	**20**	**27**	**36**	**38**	**122**	**145**	**99**	**99**	**119**	**116**	**120**	**117**
Phenom 100/E	-	-	-	-	-	2	97	100	41	29	30	19	12	10
Phenom 300	-	-	-	-	-	-	1	26	42	48	60	73	70	63
Legacy 450	-	-	-	-	-	-	-	-	-	-	-	-	3	12
Legacy 500	-	-	-	-	-	-	-	-	-	-	-	3	20	21
Legacy 600/650	13	13	20	27	36	36	18	11	13	17	21	18	12	9
Lineage 1000/E190 Head of State	-	-	-	-	-	-	5	5	3	2	4	3	3	2
Shuttles (ERJs and E-Jets)	-	-	-	-	-	-	1	3	0	3	4	0	0	0
Emivest (prev. Sino Swearingen)	**0**	**0**	**0**	**1**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
SJ30-2	-	-	-	1	1	0	2	0	0	0	0	0	0	0
Gulfstream Aerospace Corporation	**74**	**78**	**89**	**113**	**138**	**156**	**94**	**99**	**99**	**94**	**144**	**150**	**154**	**115**
G100/150 (prev. IAI Astra) G200 (prev. IAI Galaxy)	24	22	26	42	59	68	19	24	21	11	23	33	34	27
G300/350/400/450 (prev. GIV/GIVSP) G500/G550 (prev. GV/GVSP), G650	50	56	63	71	79	88	75	75	78	83	121	117	120	88
Honda Aircraft Company	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**23**
HA-420 HondaJet	-	-	-	-	-	-	-	-	-	-	-	-	2	23
ONE Aviation Corp. (prev. Eclipse Aero)	**0**	**0**	**0**	**1**	**98**	**161**	**0**	**0**	**0**	**0**	**0**	**12**	**7**	**8**
Eclipse 500	-	-	-	1	98	161	-	-	-	-	-	-	-	-
Eclipse 550	-	-	-	-	-	-	-	-	-	-	-	12	7	8
Textron Aviation (Beechcraft)	**100**	**115**	**141**	**140**	**162**	**160**	**98**	**73**	**52**	**32**	**6**	**0**	**0**	**0**
Premier I/A	29	37	30	23	54	31	16	11	11	3	-	-	-	-
Hawker 400XP	24	28	53	53	41	35	11	12	1	-	-	-	-	-
Hawker 750	-	-	-	-	-	23	13	5	7	-	-	-	-	-
Hawker 800XP	47	50	58	8	-	-	-	-	1	-	-	-	-	-
Hawker 850XP	-	-	-	56	35	15	3	1	0	-	-	-	-	-
Hawker 900XP	-	-	-	-	32	50	35	28	22	17	-	-	-	-
Hawker 4000	-	-	-	-	-	6	20	16	10	12	6	-	-	-

Table 7.11 Source: 2016 General Aviation Statistical Databook & 2017 Industry Outlook, GAMA

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Textron Aviation (Cessna Aircraft)	**196**	**181**	**247**	**307**	**388**	**466**	**289**	**178**	**183**	**181**	**139**	**159**	**166**	**178**
CE-510 Citation Mustang	-	-	-	1	45	101	125	73	43	38	20	8	8	10
CE-525 Citation CJ1	22	20	14	-	-	-	-	-	-	-	-	-	-	-
CE-525 Citation CJ1+	-	-	4	25	34	20	14	3	2	-	-	-	-	-
CE-525 Citation M2	-	-	-	-	-	-	-	-	-	-	12	46	41	38
CE-525A Citation CJ2	56	27	23	1	-	-	-	-	-	-	-	-	-	-
CE-525A Citation CJ2+	-	-	-	36	44	56	21	17	15	19	15	2	-	-
CE-525B Citation CJ3	-	6	48	72	78	88	40	20	22	21	15	6	-	-
CE-525B Citation CJ3+	-	-	-	-	-	-	-	-	-	-	-	10	23	25
CE-525C Citation CJ4	-	-	-	-	-	-	-	19	48	44	33	28	33	29
CE-550 Citation Bravo	31	25	21	18	-	-	-	-	-	-	-	-	-	-
CE-560 Citation Encore	21	24	13	12	-	-	-	-	-	-	-	-	-	-
CE-560 Citation Encore+	-	-	-	-	23	28	5	5	4	-	-	-	-	-
CE-560 Citation Excel	48	23	-	-	-	-	-	-	-	-	-	-	-	-
CE-560 Citation XLS	-	32	64	73	82	72	7	-	-	-	-	-	-	-
CE-560 Citation XLS+	-	-	-	-	-	8	37	22	27	31	31	22	21	19
CE-680 Citation Sovereign	-	9	46	57	65	77	33	16	19	22	5	-	-	-
CE-680 Citation Sovereign+	-	-	-	-	-	-	-	-	-	-	8	28	18	11
CE-680A Citation Latitude	-	-	-	-	-	-	-	-	-	-	-	-	16	42
CE-750 Citation X	18	15	14	12	17	16	7	3	3	6	-	-	-	-
CE-750 Citation X+	-	-	-	-	-	-	-	-	-	-	-	9	6	4
Total Number of Airplanes	**518**	**592**	**750**	**887**	**1,137**	**1,317**	**874**	**767**	**696**	**672**	**678**	**722**	**718**	**661**
% Change	-23.4%	14.3%	26.7%	18.3%	28.2%	15.8%	-33.6%	-12.2%	-9.3%	-3.4%	0.9%	6.5%	-0.6%	-7.9%
Total Billings for Airplanes ($M)	**8,616**	**10,404**	**13,161**	**16,555**	**19,347**	**21,948**	**17,443**	**18,000**	**17,235**	**17,108**	**21,058**	**22,015**	**21,877**	**18,353**
% Change	-17.4%	20.7%	26.5%	25.8%	16.9%	13.4%	-20.5%	3.2%	-4.2%	-0.7%	23.1%	4.5%	-0.6%	-16.1%

Table 7.12 (continuation) Source: 2016 General Aviation Statistical Databook & 2017 Industry Outlook, GAMA

The latest data from the GAMA show that there was a slight increase in business jet deliveries in the third quarter of 2017 when compared to the same period in 2016. Overall the industry delivered 138 aircraft in the third quarter of 2017 (137 in the same period in 2016).

Highlights during the quarter include the continuing success of the Challenger 350 (13 deliveries) and the Citation Latitude (also 13 deliveries). At the smaller end of the scale, the Citation M2 just reached double-digit deliveries for the first time this so far in 2017. The light jet delivery contest won Embraer with nine Phenom 300s versus the six HondaJets. In the large-cabin business jet sector, Gulfstream continued its dominance with a mixture of 21 G450s, G550s and G650s delivered.

Overall, despite the lower quarter on quarter numbers, deliveries for the first nine months are up by 1.4%.

Two new aircraft:

- Gulfstream was able to deliver a single G500 into its demonstration team (however his will now take place in the first quarter of 2018),
- Pilatus Aircraft delivered the first Pilatus PC-24, but the certification for the type is on-track, with the first customer aircraft for US fractional operator PlaneSense almost completed.

T7.4.3 Market Forecast

According to ***Bombardier Business Aircraft Market Forecast 2016-2025*** in 2015, the business jet industry was stable, having been supported by the developed economies. As the emerging economies return to strong growth levels from 2016 to 2017, world GDP was forecasted to reach 3% growth, translating into higher-order intake and stronger business aviation activity.

Bombardier Business Aircraft (Table 7.11) forecasts 8,300 new business jet deliveries (representing $250 billion USD in industry revenues) from 2016 to 2025 in the Light, Medium and Large aircraft segments.

Business jets in region	Fleet in 2015	Deliveries	Retirements	Fleet in 2025
North America	10 355	3 930	1 390	12 895
Europe	1 435	1 530	130	2 835
Latin America	2 015	790	305	2 500
Greater China	405	700	10	1 095
CIS	595	400	15	980
Middle East	410	350	30	730

Asia Pacific	435	200	50	585
South Asia	155	200	10	345
Africa	380	200	60	520
	16 185	8 300		22 485

Table 7.12 Source: Bombardier Business Aircraft Market Forecast 2016-2025

According to ***Honeywell's Global Business Aviation Outlook***, released on 8th October 2017, global economic and political uncertainty, combined with low commodity prices and stiff competition from the used-jet market, will restrain new aircraft deliveries. Mr Ben Driggs, President Aftermarket Sales, Americas, Honeywell Aerospace, said "*Declining used aircraft prices, continued low commodity prices, and economic and political uncertainties in many business jet markets remain as near-term concerns for new jet purchases*". He also pointed *'(...) there are several new and exciting aircraft models coming to market which will drive solid growth in new business jet purchases in the midterm and long term*."

Honeywell estimates up to 8,300 new business jet deliveries (valued at $249 billion) will take place in the next 10 years.

Other highlights of the report estimated:

- Large-cabin airplanes will account for about 57% of new business jet deliveries and 85% of revenue in the next five years;
- Russia, India, and China have seen a significant drop in demand for new business jets, while Brazil is a "bright spot";
- Asia, as a whole, has seen a significant drop in business jet demand due to increasing regional tensions;
- The Middle East and Africa forecast for new sales is down, due to low oil prices;
- Europe saw an 11% decline in new business jet purchases in 2017 compared to the previous year due to sluggish economic growth, concern about Brexit, and political turmoil;
- North America, which accounts for 61% of global demand for new business jets, is expected to see a 9% reduction in new business jet purchases to roughly the same levels as 2014 and 2015;
- In the used-jet market, asking prices declined by about 7% this year and are still falling. Used jet inventory has dropped, but sales remain soft.

"We expect roughly similar delivery levels in 2018 compared with 2017," Mr Ben Driggs said. All these predictions are called into question by the COVID-19 Pandemic (Chapter 16).

KEY TOPIC T7.5 HELICOPTERS AND LONG-HAUL OPERATION

T7.5.1 Current Utility of Helicopters

The smaller the size of the helicopter, the smaller the fuel tank, and naturally the reduced distance it can travel. For those serious about owning a helicopter and integrating this method of travel into their day to day planning, it's essential to not have to think about fuel stops every hundred or so miles.

A typical mid-range design will be able to fly for 2.5 hours at 135 knots, for 300-350 miles (500/560 Km) without refuelling. To put that into perspective, that kind of speed and fuel efficiency will get you from London to Paris in 90 minutes. A larger model, like the Sikorsky S92, can seat up to 16 people and reach 160 mph for over 600 miles.

Just like planes, helicopters must abide by a similar set of rules laid out by the Civil Aviation Authority, also bad weather can result in blanket bans on helicopter flights if the conditions are deemed too unsafe. Even the best-outfitted helicopters have their access restricted when conditions are at their worst.

T7.5.2 Technological Evolution

Helicopters were once billed as an alternative to fixed-wing aircraft, especially as a short-haul airliner; but noise, vibration and fuel-efficiency got in the way.

When helicopters first appeared in our skies in the 1950s, they were touted as the transport of the future; an aircraft which could take off and land in a car park or the roof of a building and fly us high above our traffic-clogged streets.

Congested roads and airways would be a thing of the past, the thinking went. Fleets of helicopters could whisk us safely and efficiently to our destinations. But helicopters proved to have their drawbacks. They are much less fuel-efficient than planes. They are noisy, and vibrations make them uncomfortable to travel in.

In the meantime, fixed-wing aircraft won out. Conventional planes can carry larger loads faster and further than helicopters, and in more comfort for passengers. But they require long runways and therefore, bigger airports.

At London's Heathrow, for instance, a plane uses the runway every 30 seconds or so. Airports like these are bad neighbours; noisy and polluting and have to be situated some way outside city centres, adding to travel time. And we need more and more of them.

If helicopters can be re-designed, then they might provide an alternative, cutting congestion and opening the skies to us all.

Nowadays, NASA designers are using tilt-rotor technology to design a machine that will carry around 90 passengers and travel 1,000 miles (1,600km).

The Large Civil Tilt Rotor (LCTR) looks like a plane, but with two huge rotors at the end of each wing instead of small propellers. For take-off and landing, those rotors are parallel to the ground just as in a helicopter. Then during flight, they swivel forwards to act like huge propellers. The LCTR is designed to work using existing infrastructure. That means it could use airports, but not clog up runways. Short and medium-length trips could be taken on a tilt-rotor, leaving just the long-haul flights using large fixed-wing aircraft.

The Agusta tiltrotor demonstrates at a smaller scale the technology of the larger V-22 developed to the military.

Another major drawback of helicopters has been their speed, or rather lack of it. Compared to fixed-wing aircraft, helicopters are the snails of the sky.

The limit for a conventional helicopter, big rotor on top, small rotor at the back, is somewhere around the 170-190 knots (315-350km/h or 185 to 220 mph). The LCTR is designed to fly at 300 knots (555 km/h), which is a significant increase in speed. New technologies and designs will increase speeds above 400Km/h that have already been demonstrated.

The way conventional helicopters are built makes it almost impossible for them to fly very fast. Their spinning blades slice through the air and work like the wings of a plane, generating lift. Unlike wings, however, the blades don't provide an equal lift on both sides. As a blade on one side moves forward, a blade on the other side is moving backwards. When a helicopter starts to speed up, this difference becomes more serious. The air passing over the blade moving in the same direction as the helicopter travels faster than it does over the opposite blade. It is a problem known as retreating blade stall

But with a radical redesign, helicopters are capable of being speed demons. Sikorsky, a helicopter maker based in the USA, held the record for the fastest helicopter flight until recently it was beaten by Airbus. Its X2 concept flew at over 250 knots (460 km/h) in 2010. The X2 uses two counter-rotating rotors, meaning two rotors stacked on top of each other, spinning in opposite directions. That means there is an equal amount of lift being generated on each side. Next speed record, 472km/hr, was achieved in 2013 by another Airbus Helicopter experimental machine, the X3

Another advantage of the design is that engineers can remove the tail rotor, which is needed to stop the helicopter spinning around. That gave them extra room for a propeller at the back. Other helicopter configurations can provide similar performance.

Advances in computing and 'fly-by-wire' flight systems have made the craft much easier to fly, and the proof of the design is in the world speed record. The double rotors mean no retreating blade stall and a much smoother and quieter ride. Now the team is working on a next-generation helicopter incorporating the technology, in order to get safety, efficiency and comfort. Contra-rotating rotors have been used for a long-time, as most Kamov designs are of this type. The contenders for high-speed helicopter competition (FVL) held by the U.S. Army include contra-rotating rotors, tilt-wing, pusher propellers and fixed wings.

T7.5.2.1 Kind of Helicopters

- Civil helicopters (Figure 7.71). They are designed to fly safely in all types of situations at the lowest possible cost. From single- and twin-engine light and medium rotorcraft to those in the eleven-ton-class.

Figure 7.71 – Civil helicopters (H125, H130, H175)

Source: Various manufactures

- Military helicopters (Figure 7.72). They are for transport, armed scout, utility, attack, combat, rescue, naval, maritime and special operations.

Figure 7.72 Military helicopters (H145M (Airbus), AS565 MBe (Airbus))

Source: Various manufactures

- Corporative helicopters (Figure 7.63). The Dedicated Private and Business Aviation Helicopter.

Figure 7.73 - Military helicopters (H145 (ACH), (ACH) Latest model)
Source: Various manufactures

T7.5.2.2 Helicopters in The Future

The conventional design of a helicopter is based on the use of the main rotor motor for the lift and a tail rudder, on which an anti-torque rotor works that prevent the helicopters from turning the opposite direction to the main rotor. Although the advantages of vertical take-off and landing are obvious, this design limits the maximum speed, since above 160-170 knots blades become unstable and stall. This is due to the difference in the lift of the blade that advances against that is trailing and the high speed that is reached at the tip of the blade.

There are several helicopter types in service with coaxial rotors, or interlaced rotors, which do not use the anti-torque rotor because the main rotors cancel the total torque.

Another approach is the tilt-rotor V-22 Osprey convertiplane developed by Bell and Boeing, which is an example of the combination of a helicopter and an airplane, which was pioneered by the military

It offers the capacity of landing and vertical take-off of one and the high speed of the other, being its main characteristic that the wings of which have at the ends two engines that tilt along with the rotors, which vertically allow to take off and land like a helicopter, but in horizontal they act like those of a conventional plane. The V-22 tilts the engine nacelles and rotors together with the wing, it is possible in other designs to keep the wing fixed and tilt only the engine nacelles and rotors, or only the rotors.

The main helicopter suppliers are Airbus and AugustaWestland in Europe, Bell and Sikorsky in the USA and Mil and Kramov in Russia. As an example, Sikorsky helicopters are used by the five branches of the Armed Forces of the United States, as well as by international armed forces and commercial companies in 40 nations), launched the development of a tactical helicopter prototype, called S-97. It consists of a combination of cutting-edge technologies, as it employs a one-piece fuselage made of composite materials, fly-by-wire control system and active systems for vibration reduction. The first fly-by-wire helicopter is the European multinational NH90.

The configuration of the cabin is two seats side by side and identical command posts; it also has a compartment to accommodate up to six soldiers, weapons and fuel. The "Skyrider" (Figure 7.74) has an estimated cost of 15 million dollars per unit.

Figure 7.74 Corporate helicopters (S-97 "Skyrider")

Source: Various manufactures

These models have been improved and for the future a parallel model to the American one is proposed, called Advanced Concept Engine (ACE), according to which the options are evaluated to develop a new high-performance engine, which can be installed in both the current helicopters as in those that emerged from the Future Vertical Lift (FVL) program. It is estimated that this program will be ready by 2035. Participating companies include GE Aviation and ATEC formed by Honeywell and Pratt & Whitney.

Europe Airbus helicopter and AgustaWestland, have a high-speed helicopter concept or prototypes as advanced as the United States, and the main European helicopter engine supplier, the former Turbomeca now part of Safran delivers equally competitive turboshafts.

KEY TOPIC T7.6 HELICOPTERS AND ENVIRONMENTAL IMPACT

In comparison to studies concerning airplanes, fewer references concerning the impact of helicopters on the environment are available. Therefore, the gas emissions due to helicopter operation are even more difficult to assess than for airplanes. A methodology to define a metric for assessing the gas emitted by the helicopters in operation has been proposed by Eurocopter [7]. In particular, the metric is obtained on the basis of the consumed fuel volume, or mass of emitted CO2 reproducing the specificity of rotorcraft operational aspects. It is quite evident that the helicopter traffic is only a few per cent of the entire air transportation and hence also the correspondent contribution is a very small fraction (about 1%) of the global CO2 emission associated to air transport.

The CO2 emission rate is not published by engine suppliers nor by helicopters manufacturers. Moreover, due to the peculiar capability to hover of the helicopters as required in rescue or medical missions, the fuel consumption cannot be obtained from the average consumed fuel per km and travelled distance. In addition, the fuel consumption may depend on the atmospheric conditions. Therefore, a metric dependent on hourly consumed fuel is more appropriate than the evaluation based on kilometric fuel consumption. Such dependence is illustrated in Figure 7.67 where the hourly fuel consumption at take-off under three different atmospheric conditions (See Level International Standard Atmosphere, SL ISA+20, 1500m ISA+20) is presented for four types of helicopters: one Light Single motor (like for example, AIRBUS H130, BELL 505, ENSTROM 280FX, LEONARDO SW 4, ROBINSON R44 II, ...), one Light Twins (like AGUSTA WESTLAND AW 109, AIRBUS H135, EUROCOPTER EC 135, ...) one Medium Twins (like AIRBUS H160, Bell 214ST, EUROCOPTER AS332, SIKORSKY S76 C++, ...) and one Heavy Twins helicopter (like AIRBUS H225, BOEING CH47, EUROCOPTER EC 225, SIKORSKY H92, ...).

The results are represented with respect to those concerning the helicopter with Light Single engine. It can be observed (Figure 7.75) that the consumed fuel does not exhibit appreciable variability with weather conditions. Moreover, as it concerns the consumed fuel, the medium twins require 1.5 times the amount of fuel of a light single motor helicopter, whereas the heavy twins exhibit a consumption figure of about 3.5 times that of the reference single motor.

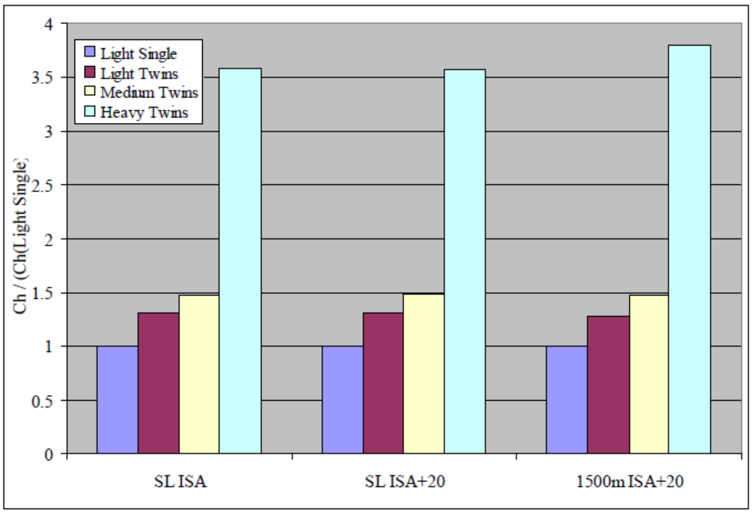

Figure 7.75

Source F. Verlut, ; N. Dyrla, N., 2010, "Definition by Eurocopter of a green metric to assess gas emitted by helycopters in operation", DSpace - Digital Repository, https://dspace-erf.nlr.nl/xmlui/browse?value=Verlut%2C+F.&type=author

In order to evaluate the consumption of a typical profile in terms of time percentages spent for each phase of the helicopter mission, has been defined. The considered phases include the specific characteristics of a helicopter i.e. the hover phase, the Best Endurance Speed (Vbe), characterizing the observation ability from above and a forward flight condition at a given speed. In particular, in order to have a greater uniformity between different helicopter types a speed of 120 knots (about 220 km/h) is considered. In Figure 7.76 the results concerning different time distribution for four types of helicopters (Light Single, Light Twins, Medium Twins, and Heavy Twins) is depicted. The average fuel consumption has been computed taking into account varying distribution of the different phases.

As can be evidenced by the results shown in Figure 7.76 the different mission profiles do not influence significantly the fuel consumption for any helicopter type.

In order to fix a metric to compare helicopter consumption the counter-part of transported persons adopted for aircraft should be chosen. By considering that helicopters may transport both persons or loads, a valid solution can be the fuel consumed divided by the useful load, so that the metric is expressed in terms of kilogram fuel per hour per kilogram of useful load. In particular, the following expression is adopted for useful load, UL:

UL = Min (MTOW - EW - Pilot; MTOW - mAGW)

where:

- MTOW is the Maximum Take-Off Weight given in the flight manual;
- EW is the Empty Weight standard given mostly in the Tech Data;
- mAGW is the Minimum Approved Gross Weight given in the flight manual.

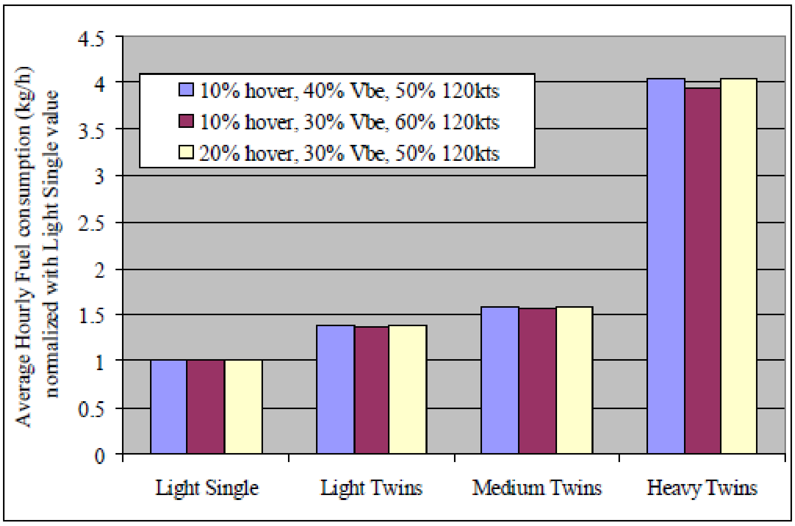

Figure 7.76

Source F. Verlut, ; N. Dyrla, N., 2010, "Definition by Eurocopter of a green metric to assess gas emitted by helycopters in operation", DSpace - Digital Repository, https://dspace-erf.nlr.nl/xmlui/browse?value=Verlut%2C+F.&type=author

An emissions scale can be defined to rank current and future helicopters. In particular, helicopter emissions are classified with a letter on a scale from A+, which represents long-term high-efficiency objectives (according to ACARE and Clean Sky goals), to E (less efficient models). The proposed scale is shown in Figure 7.77. The second column of the Table represents the fuel consumption, the third column shows the emitted CO2.

	Green Metric (kg fuel / h / 100kg UL)	**Green Metric (kg CO_2 / h / 100kg UL), *approximate***
A+	**≤ 9**	**≤ 28**
A	**]9; 12]**	**]28; 37]**
B	**]12; 15]**	**]37; 47]**
C	**]15; 18]**	**]47; 56]**
D	**]18; 21]**	**]56; 65]**
E	**> 21**	**> 65**

Figure 7.77 Classification of helicopters on the basis of emissions

Source F. Verlut, ; N. Dyrla, N., 2010, "Definition by Eurocopter of a green metric to assess gas emitted by helycopters in operation", DSpace - Digital Repository, https://dspace-erf.nlr.nl/xmlui/browse?value=Verlut%2C+F.&type=author