PERSPECTIVES FOR AERONAUTICAL RESEARCH IN EUROPE

Perspectives for Aeronautical Research in Europe
2019 Report

CHAPTER 12

Evolution of the Chinese Aircraft Industry

Final Version

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Table of Contents

List of Figures

List of Tables

Chapter 12 – Evolution of the Chinese Aircraft Industry

12.1 Introduction

The evolution of the Chinese aircraft is particularly difficult to predict due to the combination of conflicting trends and factors some favourable and other not, creating a large domain of uncertainty of what will prevail in each time frame. The three main factors can be collected:

- A large internal market and almost unlimited resources at some levels;
- The need to close a large gap competence and experience in several key technological sectors;
- The role played by domestic initiatives and international partnerships in overcoming current obstacles and bottlenecks.

12.1.1 Internal Market and Resources

China has a large internal aviation market that could, by itself almost support an aircraft industry: a strong domestic base can also support a competitive export drive.

The Chinese are actively aware that their strong export surplus is based on a very large number of products with low values. When the prospect of EU taxes was raised to counter alleged 'dumping', the Chinese Government remarked that "a single aircraft is worth 200 million t-shirts"; clearly China would like to move towards products with higher added value, to replace 'expensive' imports and generate an export surplus based on quality more than on quantity.

The centralised capitalist management of China is able to direct resources in a way that western democracies cannot, out of respect for the freedom of choice of individuals and fairness of competition of free enterprise. It is reported that there are 200 000 aerospace engineering students in Chinese universities. The Chinese Government can create or merge research institutes and manufacturing industry as it sees fit to pool resources or develop new areas.

Perhaps the highest priority in aerospace technology in China is to support a steady growth of capabilities as a military superpower with reach increasing from regional to global. The commercial value of civil aviation as an internal and external market is an important added value. It could reinforce the internationalisation efforts of China as a provider of gifts/loans around the developing world as far as Africa and Latin America. The limit seems to be not the number of resources but rather their quality.

12.1.2 Integration of Advanced Technologies

Aeronautics is a synthesis of advanced technologies, and China is far behind in several keys areas. Designing and producing a modern jet engine is more difficult that developing the aircraft, it will power. The engineer that developed the first Chinese jet engine received the highest decoration in the country; yet that engine is reportedly suffering from poor reliability, even by the less intensive use of its current military applications. Although some Chinese companies are successful in consumer electronics, advanced avionic systems are a bigger challenge. China still relies on imported engines and avionics for most of its aircraft.

China is famously adept at reverse engineering and unlicensed production, to the extent that some suppliers like Russia, only sell sufficiently large batches in the expectation that 'copying' will follow. Airbus has an A320 final assembly line in China using components imported from Europe. Airbus plans to increase local content, by using Chinese components, were not well received by Chinese airlines, and had to be dropped on the grounds of customer satisfaction.

The quality control issues that affect some Chinese products may become more acute at higher technology levels, prompting the Chinese to prefer foreign if they can afford it. The integration of advanced technologies is an even bigger challenge explaining why some Chinese aircraft programs take up to a decade without reaching international certification. In those cases where domestic certification is sufficient to secure a few hundred orders, production bottlenecks become the next hurdle: the yearly production capacity of the largest Chinese civil airframers is less than the monthly production capacity of Airbus or Boeing.

12.1.3 Internal and Cooperative Initiatives

Chinese aircraft developments depend on an international supply chain to the same or higher extent that Boeing and Airbus do. For many components, local production will depend on joint ventures with international suppliers. There are limits to what can be expected from such collaborations: the help of foreign suppliers has not been sufficient for the Chinese to obtain international certification for regional (ARJ21) or single-aisle (C919) airliners. The collaboration with Russia (CR-929) was seen as the access route to twin-aisle airliners.

The dependence of foreign components and suppliers mean that aircraft production costs in China cannot be much lower than elsewhere. However, the distinction between cost and price must be made, and in a centralised economy, the price can be an instrument of government policy as much as currency exchange rates. The potential for market distortion of combined prices and exchange rates can be considerable.

The substitution of imports, when feasible to provide essential services, can become a priority somewhat insensitive to cost, and more akin to another indirect form of taxation. The objective of foreign influence, already demonstrated by gifts and loans, can be furthered by sales to indebted partners that hardly have a choice. China may take time, one or more decades, to be more able to integrate and certify an airliner, but when it does the large internal market, the almost unlimited human resources and the many options of centralised government policy and export incentives can create a watershed of major proportions.

12.2 KEY TOPIC 12.1 - What If Study 1: Chinese Aircraft Industry

Executive Summary

In the last 40 years, the aeronautical industry has managed to move from a specialized sector to a worldwide leading industry. Companies, governments and associations from all over the world acknowledge the importance of the aviation industry in supporting the global development of the economy. Aviation improves local access to global markets, creates opportunities for social interchange and development, and supports humanitarian responses to emergencies. Prospects for the growth of this sector are optimistic. Main aircraft manufacturers, like Boeing, Airbus, Bombardier, etc., foresee an increase in the air travel demand per year for the next 20 years.

Despite the positive perspective for the market, many challenges populate the road towards this upcoming future. To succeed, the aeronautical industry must keep innovation as one of its main assets. It must master a wide range of technologies and then collaborate to integrate them into an aircraft design and development program. A collaborative approach to innovation is the key to achieve these goals. Breakthrough and emerging technologies will continue to be the main development differentiator, and sustained efforts in R&D are essential to ensure sustainable growth. Strategic responses are being prepared by governments and international institutions.

Within the international efforts to cope with these challenges is where PARE comes along. The overall objective of PARE (Perspectives for the Aeronautical Research in Europe) is to trigger collaboration between European stakeholders to support the achievement of the 23 Flightpath 2050 goals. As part of this process, the project has the task of identifying the actions required in the coming future for the proper development of the aerospace research sector, which can benefit from a detailed and rigorous analysis of possible political, social and industrial scenarios by carrying out, among other works, some "What if" analysis.

The "What if" case studied in this text is based on the perspective of the growth forecasts of the air transport sector in the medium and long term that characterizes the Asian emerging economies, and in particular China, as the ones with the highest growth in air transport. In this regional growth context, China is developing a powerful aerospace industry, whose ability to consolidate will condition the worldwide aerospace industry scenario.

In recent years there have been several attempts to develop and certify aircraft; such as the regional jet ARJ21, certified by the CAAC after years of delays; the C919 in the single-aisle segment, whose certification has been postponed from years, or the future development of a wide-body model, the C929. How the success of all this attempt will effectively affect the Airbus/Boeing leadership in the industry is going to be one of the big issues in the industry in the upcoming years.

The methodology of this study is double. On the one hand, a study of the market has been developed, by using qualitative and analytical methods that will be enough to provide information about how the market could react to the Chinese irruption. On the other hand, a game theory analysis has been performed to evaluate the results of the entry of a new competitor and its implications for a market currently dominated by the duopoly composed by Airbus and Boeing. The objective of this analysis is to evaluate the possible strategies to face the Chinese company COMAC in the single-aisle market, considering a medium and long-haul.

The SA market in China is scrutinised. Although there are more than 40 airliners in CHINA, 30 are part of the "Big Four" airlines and competition has been the same between 1994 and 2012. The 3 biggest

companies are state-owned and are included among the 20 biggest airlines in the world. By May 2019 A320 family in service in China totalled some 1658 aircraft (55% of the SA market), against 1353 of the B737 family that stands for the 45 % of the Chinese SA market. Additionally, in April 2019 Airbus has signed a deal for 300 aircraft with the state agency China Aviation Supplies Holding Company worth an estimated $US35 billion at list prices.

China is on its way to becoming one of the world's largest aviation markets, accounting nearly 20% percent of the global traffic by 2037. Traffic is expected to increase in China by 6.2 % annually. To cope with that increase the fleet will grow by a 4.5 % annually, doubling the fleet by 2038 and accounting for a market value around 1.190 Billion of dollars. By itself, China will receive 7690 deliveries, 31% of which will correspond to the replacement of existing airplanes. Out of the 7690 deliveries, 5730 will be single aisle leading to a total fleet of 6100 airplanes at the end of that period. Single-aisle airplanes will represent 71% of the total fleet in China, and it is expected that the flexibility in size and range of this fleet will enable fast growth in point to point markets within China and bordering regions.

The evolution of commercial aviation in China has also been analysed, and particular attention has been devoted to the structure of the industry and to the aviation research network structures. The size of Chinese industrial players is large, with 152 enterprises, spread over 22 provinces. However, the benchmark on the number of employees might point out at potential inefficiencies and redundancies that Chinese industry still has to polish. The aeronautical landscape is spearheaded by 3 large state-owned conglomerates: AVIC, COMAC, and AECC, representing respectively 31% (47), 4% (6) and 9% (13) of all Chinese aeronautical companies. Output and employment in China's commercial aviation manufacturing industry have been increasing, but domestic sales, not exports, have been the primary driver. The leading sub-sector in the Chinese aviation industry is aircraft parts, both manufacture and repair. The consolidation of the aviation industry in CHINA is contributing to a more global, more fragmented, more competitive industry that will give Western companies major short-term cost-reduction opportunities that they must capture. A dynamic view of the emergent economies and their role in the aerospace industry suggests that emerging economies will accelerate changes in the value chain.

COMAC consortium and its aircraft programs are also analysed. Although COMAC stands out as a company with heavy support from the Chinese government, both political and financial, this support might not be unlimited. One major improvement made by the Chinese industry is the acquisition and production of technology and know-how, which will allow them to improve in the production of their aircraft models. Despite the improvements they have made so far, they still have a long way to go to even meet the production and quality levels of the incumbent players on the market.

C919 is benchmarked with respect to their western competitors A320 and B737. The supply chain of the three models has analyzed as well as the technological innovation level of the C919, and the number order received so far. A total of 16 foreign suppliers are involved in the C919 program including GE, Honeywell, Safran and CFM, Rockwell Collins, GE Aviation, Eaton, United Technologies Corporation, Hamilton Sundstrand, Leonardo, Parker Aerospace and Liebher; with joint ventures covering avionics, flight control, propulsion system, electric power generation and distribution, composite materials, fuel and landing gear systems. To date, COMAC boasts just over 1,000 commitments for the C919 from Chinese airlines and lessors. However, according to Air Finance Journal Fleet Tracker database, firm orders number might be fewer than 400. The promise C919 selling price, half the price of its competitor, is also analysed.

On the other hand, the difficulty to get certified by the FAA or the EASA is still a major hold back on COMAC and the Chinese aspirations on gaining the MoM. Using their great and growing domestic market and their political influences with countries attracted by their dumping strategy can, still, develop their new models. However, not being able to go in the US or the EU is a major issue in order to compete with Airbus or Boeing. Another related issue is that, whenever they are able to certify their models, these won´t be a state-of-the-art product, which can be a great problem to cope with the competition of the market in that time period.

Special attention has also been devoted to some key factors that will impact C919 program and delivery timescales, including: 1. development learning curve, 2.certification hurdles, 3. system integration skills, 4. engines industry, 5. avionics, 6. composite materials, 7. possible customer countries, 8. production capacity constrains including estimation pf production curves, and finally 9. Shortage of skills

Added to this, the incumbent players already have built up over the years a commercial image that transmits some sort of assurance to the market that their products and services are the first quality aircraft available. COMAC does have to prove this. This gives Airbus and Boeing a network of subsidiaries and the ability to get financial support from private entities easily than COMAC.

Additionally, the policies deployed by the Chinese government to impulse its commercial aviation industry are analyzed in detail and recommendations are derived for those companies willing to develop its aviation activities in China. This analysis is backed up with a detailed SWOT analysis covering the aspects of technology, labour, finance and marketing.

All in all, the results from this research are directed to assess the possible problems that the future market may hold and, furthermore, to help Europe fulfil its main objectives regarding Flightpath 2050. Al the previous considerations have helped us to define and analyse 5 relevant scenarios: 3 short-medium term and 3 long term scenarios.

Scenario 1A: C919 certified only by Chinese CAA with entry into service by 2021 with a conservative production learning curve. C919 performance lags behind B737 and A320 and final selling price is half of the price of the B737 and A320 aircraft. In this case, C919 will be sold primarily in CHINA by governmental influence on the 4 big Chinese Airlines. Demand for the C919 is estimated as a percentage of the overall deliveries of the 4 Big Chinese airlines, between a conservative 10% and a more optimistic 30%. A conservative realistic approach of roughly 400 firm orders is also considered. The resulting Chinese market share will be 60% for the A320, 25% for the B737 and 14% for the C919. This approach is equivalent to considering that 20% of the 4 big SA deliveries will be covered with the C919. A maximum production rate of 8 units per assemble line has been estimated, similar to those achieved by western manufacturers when the assembly line is fully operational. However, attending to the Tianjin experience with both A320 and A330, the Chinese's industry still will take time to get to this optimum production rate. This production rate will deliver 1260 C919 units in 20 years with only one production line. COMAC could satisfy the foreseen demand with one single line. If COMAC were able to put in place two production lines, their delivery capability would be higher than Boeing's expected demand, but it will require high efforts and investments.

Scenario 1B: Similar to scenario 1A but C919 is additionally sold in countries where the Chinese government have political or economic influence. This market will be small and somehow anecdotic. The number of A320 and B737 that currently are operated by Airlines registered at those third countries potential buyers for the C919 ascends to 863, 18% on the single-aisle fleet in these regions. The possible political and economic influence of Chinese companies in these countries will hardly justify big orders from their airlines. Considering orders and exports of Chinese aviation industry this hypothetical demand is estimated between 1 and 3% of the single aisle operating in those countries, what means and additional demand between 22 and 65 additional aircraft. As expected, the figures are minimal and do not change significantly the results of the analysis in scenario 1A.

Scenario 2: C919 grants FAA and /or EASA certification with entry into service by 2025 with a conservative production learning curve. C919 performance lags behind B737 and A320 and the final price will be half of the price of B737 and A320. C919 will be sold primarily in China by governmental influence on the 4 bid Chinese Airlines, but it could be sold worldwide. Its lower price will favour its position in a market niche despite its lower performance. Internal Chinese demand will not be significantly different from the one in scenario 1A. However, C919 demand from external countries might vary between 5% of the market for a high fuel prices scenario and 10% for a low fuel prices scenario. The reaming single-aisle demand to be shared between Boeing and Airbus is not significantly affected. By 2037, C919 would have obtained a demand of less than the 9% of the total SA deliveries over the total period 2018-2037, this is 2657 out of 31175. However, in this case, the C919 selling might be enough to justify economically the investment in the C919 program. To take full advantage of this window of opportunity the Chinese industry should focus its efforts on improving its production curve, expanding its production chain as quickly as possible without affecting reliability.

Scenario 3A and 3B are a classical example of the new entrant problem with 3 players.

Scenario 3: COMAC produces a new upgraded version of C919 equivalent in terms of technologies and performance to its contemporary Boeing and Airbus models. By that time Boeing and Airbus will have probably also made evolve their current 737 and 320 models. The competition will take place under free-market rules with fuel efficiency guiding airlines buying decisions. Incumbent manufacturers will either maintain its product line with only minor modification and minimal performance improvements; re-engineer them to improve its performances significantly or bet for a new clean-sheet design to improve even more its performances. Two alternatives are contemplated below:

Scenario 3A: COMAC produced a new aircraft with performance equivalent to those of Airbus or Boeing re-engineered models. In this case, the new entrant would only be able to capture 50% of the market from two stagnant incumbents. Based on the work by [1], this scenario presents an of-symmetric equilibrium, in the case Boeing develops a new clean sheet improved design to maintain 50% of the single-aisle market while Airbus and COMAC split the remaining 50% of the market with models slightly inferior in performance to the Boeing one. In this scenario, COMAC will only receive positive payoff if neither incumbent develops a new aircraft.

This result indicates that if COMAC would seek to maximise profits could decide not to produce a new model if it's only as good as the re-engined A320 and B737 families. In this situation, incumbent manufactures will not be concerned with new COMAC single-aisle designs unless there is a high probability that the new models could match or exceed the performance of the incumbent new aircraft.

Scenario 3B: COMAC produced an aircraft with performance equivalent to those of Airbus or Boeing new clean-sheet design. The results illustrate that equilibrium might be possible in which one incumbent chooses to maintain while the other decides to re-engineer. The greater investment required by Boeing to reengineer results in an of symmetric equilibrium. The superior performance of the new COMAC's aircraft will be able to capture a significant market share while Airbus attempts to maintain market position by re-engining A320 latest models. In this situation, Boeing's optimal strategy is to avoid investment and maintain its current aircraft. Once the competitors' new and re-engineered aircraft enter service in stage 2, Boeing suffers from a greatly reduced market share, but it will continue to make small profits due to its unit production cost advantage while harvesting its existing product line. The new entrant has a positive expected net present value in each possible outcome, except if both of the incumbents develop a new aircraft.

These results suggest that there may be rents available in the single-aisle market, providing an incentive for increased competition if new entrants are able to overcome the significant entry barriers to develop an aircraft that can compete with the incumbents' new aircraft option.

Finally, an additional assessment can be made to determine the appropriate time for such a decision. The results show that if the new COMAC Aircraft is as good as the new Airbus or Boeing ones, the payoffs for a move first or delay are very close, with payoffs that are sensitive to the assumptions of the aircraft program valuation model. However, if the new COMAC aircraft will only match the performances of the Airbus or Boeing re-engined aircraft, both manufacturers will have an incentive to develop a new clean-sheet design aircraft as soon as possible. An early decision by an incumbent manufacturer would reduce COMAC's market share up to a point that might not have a positive NPV. This suggests that an early movement of the incumbent manufacturers could prevent the COMAC impulse to evolve C919.

"What if" study recommendations

The "what if" study has led to the following set of 41 recommendations relevant to the PARE project objectives.

Recommendation 1. Research and innovation policies should keep incentivising investment in innovation during the persistent situation of duopoly and dominance of big commercial aircraft manufacturers to avoid decreasing efforts in research in favour of increasing profits for manufacturer's best in class products.

- **Rationale:** Single-aisle market has become a global duopoly where Airbus and Boeing divided the marketplace. None of the probable scenarios considered in the study for the emergence of a single-aisle competitor in China will seriously endanger or hurt, in the short or medium term, the actual dominance of incumbent manufacturers. In the short and medium-term neither Airbus nor Boeing will feel pressured enough by the threat of the first version of the C919 as to significantly deviate from the exploitation of their current bestselling products. In this scenario, there is a risk that both producers may collude explicitly or tacitly or reach an agreement in order to reduce their risks for investment and new product development.
- **Justification:** What if analysis 1: "China's new airliners", section 12.2.2.4.

Recommendation 2. Assure that European education system and aviation industry will have guaranteed access over long periods to the high level of expertise required to develop new aircraft.

- **Rationale** In the long run single-aisle competition would likely see the development of new clean-sheet aircraft by incumbent manufacturers to compete with evolve versions of C919. New aircraft development requires a high level of expertise over long periods of time.
- **Justification**: What if analysis 1: "China's new airliners", sections 12.2.2.4, 12.2.9.19 and 12.2.10.

Recommendation 3: The development of new skills and competence are demanded from aeronautical professionals, engineers and managers to succeed in the new commercial, organisational, production and research environments created by emerging aviation markets as China.

- **Rationale:** In the last decades, aircraft, components and parts manufacturers have initiated delocalised processes to favour increase share in relevant or emerging aviation markets, spreading geographically their facilities and opening new factories or final assembly lines close to the final market, and setting joint venture with local companies.
- **Justification**: What if analysis 1: "China's new airliners", section 12.2.9.10.

Recommendation 4: Incumbent manufacturers need to find the right balance between harvesting the competitive unit cost advantage of maintaining models with long production runs, A320 and B373, and the need to innovate with new or re-engineered aircraft to keep a dominant position in the market.

- **Rationale:** Production learning effects result in unit costs drop on the order of 20% every time the quantity produced doubles. This gives a competitive unit cost advantage to the models with long production runs, like A320 and B737 that makes them extremely hard to bit by the new C919. The cost of developing a new aircraft is very elevated, between $3 to $14 billion, depending on the aircraft size and technology level; and new aircraft development requires a high level of expertise over long periods. On the other side, experience shows that firm producing new and more competitive aircraft gain higher market share.
- **Justification**: What if analysis 1: "China's new airliners", section 12.2.2.4.

Recommendation 5: Empower large commercial jets supply chain, not only at the high-end integration and delivery level but also through all components and structure levels in the value chain levels, by reinforcing broad-based application-oriented research and development activity that might contribute to its competitiveness.

- **Rationale:** Large commercial jets are now about 60% of total industry output by value, not just at the final delivery level but also through most of the component and structures supply chain.
- **Justification**: What if analysis 1: "China's new airliners", section 12.2.2.4.

Recommendation 6: Closely track the evolution of recent single-aisle orders deceleration in such a growing market as the single-aisle segment, to anticipate changes in any key driver affecting the sector.

- **Rationale:** Traditionally, the market has followed a cyclic pattern: a growing period of roughly seven years followed by a dropping period of approximately three years with deliveries falling by 30-40%, or more in the bad period. However, Industry experiences a continuous growth since 2004, and for the very first time, jetliner market will have a 16-year growth cycle, and possibly longer, over twice as long as the usual seven-year boom. Some consultants estimate that the segment generates a vast majority of the profits, as they represent the bulk of the historic volumes delivered (around 10,500 for Boeing and 8,500 for Airbus) and of the existing orders (4,763 for Boeing and 6,536 for Airbus), according to the data provided by manufacturers. The 12,000 jetliners on the backlog at Airbus and Boeing alone is estimated to be worth over 7-8 years of production. However, the order rush seems to have decelerated in 2018. As the strong cyclicality of the industry is still to come, and the growing cycle is becoming longer than ever it will be highly recommendable to closely track the evolution of recent single-aisle orders deceleration in such a growing market as the single-aisle segment, to anticipate changes in any key driver impacting the sector.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.2.3.

Recommendation 7: To keep the competitiveness of the commercial jet industries strategic decision should adopt a holistic approach that provides solid grounds for three key factors affecting airliners production capabilities: 1) strong financials; 2) powerful science and 3) engineering resources and efficient industrial organisation.

- **Rationale:** The significant achievements of airliners production are based on three ingredients. 1) **Strong financials:** it is well beyond the possibilities of a normal size company to spend the multi-billion dollars necessary to develop a new type of airliner. Producing such machines is an act of large-scale economics, so it needs to be supported, more or less explicitly, by governments. This happens mainly because the private capital is reluctant to approach very large investment with a rather long recovery horizon (they prefer early repayment profiles)[2][1]. The capital markets are also less inclined to take the risk of failed projects and assume its painful consequences. 2) **Powerful science and engineering resources:** resources that need to be based on an existing wide base of STEM (Science, Technology, Engineering, and Mathematics) education output, on a systematic experience accumulated in any of the contributing fields, as well as on a good capability of invention and innovation. 3) **Efficient industrial organisation:** developing a product means also proper industrialisation. Reaching appropriate production volumes at competitive costs and quality levels to satisfy the market demand is probably the most difficult task. It requires a rather rich experience, a strong discipline, a quality approach well implemented, a science of managing a large supply chain. Every such component of the industrial system is to be built and maintained using a careful design and proof process.
- **Justification**: What if analysis 1: "China's new airliners" section 12.2.2.4.

Recommendation 8: Strategic measures need to be taken to protect the industry from aggressive price competition situations.

- **Rationale:** Due to the intense competition within the sector, it is quite usual that manufacturers apply price discounts in their products to gain more market share. This is especially applied for the commercial launch of a new airplane in order to get more orders from airlines. This seems to be the cause of the C919, which is announcing a selling price, half of its competitors, despite the high development cost and the high learning curve that C919 exhibits.
- **Justification:** What if analysis 1: "China's new airliners" sections 12.2.2.4 and 12.2.2.5.

Recommendation 9: European Industry should maintain and increase if possible the dominant Airbus position in China's single-aisle market.

- **Rationale:** Despite the large air transport liberalization process started by China in 2005, competition has been the same between 1994 and 2012. The market is dominated by the "Big Four", namely Air China, China Eastern, China Southern, HNA Group, and although there are more than 40 airliners in CHINA, 30 are part of the "Big Four" airlines. The first 3 big, are controlled by the Chinese government and are among the 20 biggest airlines in the world. Airbus has today an advantaged position in the Chinese market, currently A320 family represents a 55% of the flying fleet market against the 45 % of the B737. Airbus is also ahead in terms of orders, industrial inclusion and local production.
- **Justification**: What if analysis 1: "China's new airliners" section 12.2.2.5.

Recommendation 10: The growth and health of commercial aviation in the next 20 years will be strongly linked to the expected development of air transport in China, as it will be the growth, profits and economic wellbeing of aircraft manufacturers and OEM industry. To benefit from this impulse, western aviation companies should strength collaboration with Chinese commercial aviation industry at all levels while maintaining technological and competitive advantages.

- **Rationale:** According to Boeing market outlook for the period 2018-2039, socioeconomic changes in large emerging markets such as China will be primary drivers of both global GDP growth and demand for air travel. The number of air passengers in China has increased at an average rate of more than 10 percent each year since 2011, and it is becoming the first largest commercial aviation market. China is on its way to becoming one of the world's largest aviation markets, accounting nearly 20% percent of the global traffic by 2037. Drivers for this increase are a strong economy, increasing urbanisation, the development of the middle classes and a dramatic increase in propensity to travel. The global worldwide fleet will double to nearly 48,000 by 2037, with more than 42,700 new deliveries. By 2037, the fleet will more than double in China and by itself, China will receive 7690 deliveries. 31% of the deliveries will correspond to the replacement of existing airplanes. Out of the 7690 deliveries, 200 (3%) will be a freighter, 1620 (21%) will be wide-bodies, 5730 (74%) will be single-aisle and 140 (2%) Regional jets. Single-aisle airplanes will represent 71 percent of the total fleet, and it is expected that the flexibility in size and range of this fleet will enable fast growth in point to point markets within China and bordering regions.
- **Justification**: What if analysis 1: "China's new airliners", section 12.2.3.1.

Recommendation 11: Analyse the keys for the success of aircraft manufacturers in the Chinese market to derive lessons for others aviation sectors, such as airport and infrastructures development and operation, Air Navigation and Air Traffic Management.

Recommendation 12: Airport and ATM industry will benefit from a strategy orchestrated with a sectorial perspective and institutionally supported, to explore Chinese market opportunities for increasing the return of its current investments in research, innovation and operation improvements. Increase collaboration, promotion of networking, alliances and partnerships will be key to configure a joint and solid Airport and ATM front capable to break access barriers in this emergent aviation market.

- **Rationale:** The development of the Chinese commercial aviation market is not only an opportunity for aircraft manufacturers, but it can be it also for subsidiary industries and for other air transport areas, in particular airports and aeronautical infrastructures, air navigation and air traffic management. However, airport and ATM-related companies either are, either too oriented and immersed on the European regional market or too small, to envisage China as a potential market through which they could increase the return of investments done to satisfy and to solve the problems of the European market. Airport and ATM are fragmented sectors that lack today the structural organization, critical size and global projection needed to compete effectively in emerging markets. Airbus and Boeing have acknowledged the relevance and the potential of China as the largest aircraft market. Both have achieved a deep level of penetration into the Chinese market that can hardly be envisaged by other air transport-related companies.

- **Justification**: What if analysis 1: "China's new airliners" sections 12.2.2.5 and 12.2.4.

Recommendation 13: An effective way for incumbent manufacturers to reduce even more the cost of production and integration of its products in China will be to reinforce and improve Chinese company and project management skills, which are weaker than manufacturing and engineering skills, through their joint ventures.

- **Rationale:** Chinese suppliers have become increasingly proficient at process technologies. Chinese machinists and workers are proficient, and design and engineering talent rate very high. However, the benchmark on the number of employees in the Chinese aviation industry points out at potential inefficiencies and redundancies that Chinese industry still has to be polished. With 152 companies' Chinese aviation industry employs directly 325 000 people, there are on average 2138 employees per company. In comparison, France had in 2017 350 000 employees working in over 3000 aeronautical companies: roughly an average of 117 people per company. The hierarchical management style of Chinese state-owned enterprises and the weaknesses of Chinese project management skills are behind these inefficiencies. Deficiencies in corporate and project management impose substantial costs on the overall process.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.1.

Recommendation 14: To consolidate and further exploit the best immediate opportunity for foreign companies in supplying parts for China's commercial aircraft fleet.

- **Rationale:** The leading sub-sector in the Chinese aviation industry is aircraft parts, both manufacture and repair. China's import market for aircraft parts and components exceeded $2.19 billion in 2016 (30% from the US). The best immediate opportunity for foreign companies will be in supplying parts for China's commercial aircraft fleet, as this is the largest and best-established segment of China's aviation market and is currently dominated by western aircraft with western suppliers. China's demand for aircraft parts can be attributed to a number of factors including increasing capacity utilization rate, the ageing and expansion of China's aircraft fleet, and the domestic production and assembly of aircraft.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.1.

Recommendation 15: Western companies must capture major short-term cost-reduction opportunities provided by the development of emergent strong commercial aviation manufacturing in China, but also other countries such India or Russia, through global sourcing, manufacturing, and engineering.

- **Rationale:** The consolidation of the aviation industry in CHINA is contributing to a more global, more fragmented, more competitive industry. New Boeing and Airbus aircraft involve a high percentage of parts from China. This creates complex management, coordination, and design integration challenges, but at the same time, these new models have reduced cost and increase sells in emerging countries. However, despite the global nature of air transport industry globalization in commercial aviation, design, development and production remains in its infancy. Lower labour cost in emerging countries, on average three to five times lower than in the developed world, can provide major economic savings and advantages, even considering transportation, the coordination complexity and supply chain management, supply disruption risks, etc… Lower labour cost makes these economies also interesting for labour-intensive maintenance and repair services. China and other emergent economies have the potential to increase amounts of low-cost manufacturing and engineering capacity for the aerospace industry. These changes represent a major opportunity for Western players to improve their cost performance through global sourcing, manufacturing, and engineering.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.1.

Recommendation 16: To keep its current dominant opposition, both suppliers and existing original-equipment manufacturers (OEMs), will be required to identify and further specialise in those areas where they could provide either a unique value to add or compelling cost advantage.

Recommendation 17: Winning in the commercial aviation industry of the future will require incumbent's aircraft manufactures and OEMs to outshine at developing globally its business. For that aim, these organisations will need to excel and make a leap forward to:

- Integrate, organise and manage aircraft production as a global supply chain;
- Successfully transfer of production flexibly to emerging markets;
- Refocus on higher-value-added activities;
- Re-engineer new collaborative models, and
- Form and manage global alliances and partnerships

- **Rationale:** A dynamic view of the emergent economies and their role in the aerospace industry suggests that emerging economies will accelerate changes in the value chain. Growing demand in low-cost economies such as China will lead to more offset of production toward these countries and a continuous reduction on the risks involved, as long as technology and skills are being transferred. In parallel, higher local government investment in the aerospace industry will help to increase and consolidate these low-cost high technology production capacities. Western manufacture can take advantage of this low-cost production and could direct its core activity towards higher added-value work increasing its specialization and value in the production chain. Further specialization in design, manufacturing and assembly is likely among both current and emergent players in commercial aviation. Specialization should necessarily go, hand in hand, with more extensive collaboration, placing a premium on an organization's coordination and integration capabilities. New collaborative models between economies will allow low-cost countries to develop their own programs, which will increase competition. The competition will place additional pressure over cost efficiency and added-value work and specialization.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 18: Further analysis and benchmark of the capacity of the European aviation research networks, in comparison with other regions, to master key aerospace technological areas and to innovate within them.

- **Rationale:** The competitiveness of the aerospace industry depends on mastering cutting-edge technologies and management procedures in an extensive range of 11 technologies. Since the substandard mastery of only one of these technologies can cripple an aircraft design and doom its market prospects, it is imperative to remain at the forefront of all 11 technologies to avoid being caught off guard by a competitor. In addition, these technologies must be ready for integration into new competitive products at any time deemed necessary to maintain market leadership in a new development program.

  The capacities of an aviation research network to master these key technological areas and to innovate within them have been analysed from scientific publications and patents. Significant strengths but also weaknesses have been identified, leading to recommendations for improvement. These initial be analysis must be expanded to cover others research some innovation indicators with an aim to further improve the performance of current research and innovation network structure in aviation.

- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 19: Reinforce the global character of the European aerospace collaboration structures and their ability to cooperate worldwide effectively and aggregate the knowledge and efforts that have gone into the innovation path.

- **Rationale:** Aviation is a complex system involving highly interrelated technologies whose relations can be mapped as a network. The structure of this technology network, if mapped with precision, can help us to understand the properties and research of these technologies.

- **Justification**: What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 20: Further detailed research networks in the USA and China to identify strong links and opportunities for innovation and collaboration. Specific analysis of China's research may provide the insight necessary to develop a competitive EU aerospace innovation policy.

Recommendation 21: Favour the development of strong connections with the research developed in China and other Asian economies. Promote a better interconnection and correlation between European and Chinese research institutions, as well as joint research and publications between European and Chinese universities and research centres.

- **Rationale:** A technology network analysis from patents and publications shown higher publication frequencies in both China and the USA, and also a high level of correlation between their research topics. European countries have very weak connections with the research carried out in China and other Asian economies. Research in the USA plays a pivotal role in the research infrastructure connecting the major players.

The elevated number of publications in the USA and China, as well as the highly correlated topics between the two research networks, suggests the need for further analysis of the details of both research networks. Particularly, due to the weak connections between European clusters and Chinese publications, the specific analysis of China's research may provide the insight necessary to develop a competitive EU aerospace innovation policy.

- **Justification**: What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 22: European policy should support cluster's continued excellence in different subfields, and at the same time must facilitate the aggregation of the diverse experience and knowledge in each subfield into a shared platform for the aviation industry.

- **Rationale:** Research capabilities and knowledge are homogeneously spread within Europe, with a clear geographical correlation, into four highly specialized clusters. However, national aerospace technological capabilities may not be easily collectivized. Therefore, aviation needs to pursue a dual policy of promoting excellence in the different aerospace subfields while also aggregating their information. On one side, research policy should support every cluster's continued excellence in different subfields. On the other side, research policy must facilitate the aggregation of the diverse experience and knowledge in each subfield into a shared platform for the aviation industry. It has to be considered that although national technological capabilities of aerospace engineering may not be collectivized, information and experience may differ in this regard. Therefore, innovation creation policy should reinforce the spread of knowledge while maintaining its mission orientation. Implementation of multi-objective innovation measures, both diffusion-oriented and mission-oriented, will be more suitable for maintaining excellence in aviation than single-objective policies.

- **Justification**: What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 23: Promote collaborative studies between key aerospace research areas lacking common research and thus losing potential synergies that could foster innovation.

- **Rationale:** Concurrence analysis of aerospace publications allows to identify the current main aerospace subfields of research within the international scientific collaboration network:
  1. Mechanical engineering, including biomedical engineering, robotics, and manufacturing,
  2. Physics, automation, telecommunications, electric-electronics, and computer science,
  3. Materials science optics, nanoscience, and remote sensing,
  4. Energy and polymer science,
  5. Acoustics, thermodynamics, environmental studies, and geology.

  Mechanical engineering, telecommunications, electrical and electronics engineering, instrumentations, astronomy and astrophysics, optics, and mechanics have the highest frequency of co-occurrence with aerospace engineering in the literature, evidencing the areas in which aerospace engineering publications are concentrated. However, these areas are not highly interconnected, evidencing a lack of common research, thus losing potential synergies that could foster innovation. This lack of common research is particularly evident between physics, computer science, and material engineering. These are three fields in which collaboration is required to boost aviation innovation. To fill this gap, it will be necessary to promote collaborative studies between these areas as part of the aerospace innovation funding policy.

- **Justification**: What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 24: Applied research and transfer of basic research and innovation results to the industry should be pursued in key areas for future aviation such as human factors, that today exhibits low rates of patents.

- **Rationale:** The greatest patent growth is taken place in the categories of operations and physics. Second in growth, named medium classes, are electricity, mechanical engineering, and chemistry. In contrast, the area of human factors has experienced very low growth, and the area of textiles has experienced practically no growth.
- **Justification**: What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 25: Carefully monitor the use of patents to protect technology in emerging aviation industries as China and define and encourage strategies to counteract its progressive development into barriers that reduce the ability of non-Chinese agents to access the domestic market.

- **Rationale:** China is observed to be the country with the most patents in aviation, showing a strong dynamic in the field of patents. Only one among the 20 top firms is European, and the remaining companies are American or Chinese. The volume of patents filed in China has quadrupled in the last five years. The data reflect how Chinese agents protect their intellectual property through patents, regardless of whether it was received through technology transfers or generated autonomously. Some authors have regarded this situation as replicating the strategy applied by the government and the Chinese industry in the railway sector; that is, the progressive development of barriers that are put in place to reduce the ability of non-Chinese agents to access the domestic market. The high attrition rate should not be considered in isolation, as sometimes it is a consequence of governmental policies and effectively decreases when incentives are no longer applicable.
- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 26: Improve patents production rates by European universities and research centres and deploy other strategies that help to improve their capacity to translate basic research into products and industrial innovation.

Recommendation 27: Encourage and promote research publication and patents registration as effective ways to formalise and spread innovation in basic research and knowledge transfer to the industry, as well as to protect technological innovation and IPR.

- **Rationale:** The global institutional collaboration network shows that while there is a significant dominance of universities and research centres worldwide in the publication network, there are only a few universities among the top 20 firms by the number of patents, and all of them are Chinese universities. This highlights the lack of capacity of universities in Europe, as well as in the USA, to translate basic research into products and industrial innovation. Future innovation and research policies should contribute to closing the existing research and innovation gap between academia and the aeronautical industry. They should encourage the integration of academic research and applied research to promote the development of the subject and the level of the aerospace industry.
- **Justification:** What if analysis 1: "China's new airliners" section 12.2.4.2.

Recommendation 28: Western manufacturers need to consider how to counterbalance a possible COMAC's long-term competitive advantage derived from the success in managing and empowering complex global aeronautical supply chain with high presence of foreign companies as COMAC has.

- **Rationale:** The industrial model of COMAC is comparable to Airbus and Boeing, focusing on the design and assembly of parts and systems procured from the global aeronautical supply chain. COMAC might be struggling today with the management of such a complex structure of suppliers in its early stages. However, the experience gained in managing and empowering such a complex supply chain might suppose a long-term competitive advantage over its competitors.

  A total of 16 foreign suppliers have been involved in the C919 program including GE, Honeywell, Safran and CFM, Rockwell Collins, GE Aviation, Eaton, United Technologies Corporation, Hamilton Sundstrand, Leonardo, Parker Aerospace and Liebher; with joint ventures covering avionics, flight control, propulsion system, electric power generation and distribution, composite materials, fuel and landing gear systems.

  When comparing the supplier list of A320, B737 and C919, the A320 presents the best balance of countries out of the 3 aircraft: 1/3 US, and approximately 12-14% each for France, Germany, and the U.K. The next countries fall rapidly below 2% (only Spain is above, at 3,4%). The B737 sees an overwhelming representation of US suppliers, snatching two-thirds of the aircraft's suppliers; the following order of countries after the US are the same: France, Germany, UK, thus accrediting the significance of the aerospace supply chain in these countries. Canada also stands out, being on par with Germany (3,4% each). All other countries are at 1% or lower. The C919 is somewhat in between the A320 and B737: strong US suppliers (approx. 50%), but with an important percentage from France/Germany/UK (adding up to 20%). The biggest difference lies however with the very striking presence of China, representing 15,1% and thus taking hold of 2nd place as supplying the country.

- **Justification**: What if analysis 1: "China's new airliners" chapter 8.

Recommendation 29: Western manufacturers and OEMs must maximize the industrial development opportunities offered by the aeronautic policies implemented by China to develop its own aerospace industry. The Chinese government is fully engaged in a global strategy to create an indigenous commercial aviation manufacturing industry a priority.

The set of strategies adopted by aviation global player that has proven to be more effective for aviation manufacturer to expand its footprint in China, pivot around the global idea of competing in this market while contributing to the development of the local industries. Companies willing to benefit from the wellness and growth of commercial aviation in China should look at 1) setting up local manufacturing centres and build a local supply chain; 2) focus on aftermarket opportunities, and 3) engage in contracts involving technology transfer.

- **Rationale:** Chinese government envisaged the designing and manufacturing of a commercial passenger jet as a symbol of the nation's technological progress and as a source of economic growth and technological spin-offs. The Chinese government has employed several policies that might benefit the interest of both parties:
  - Targeting orders to foreign manufacturers with assembly operations or suppliers in China. The government encourage foreign commercial aviation product manufacturers

to purchase Chinese components and to set up joint ventures in China. This operation benefits both parts. For example, the opening of Airbus's assembly operation in 2005 coincided with a dramatic increase in sales of Airbus aircraft to Chinese Airlines. Since this assembly operation, Airbus has passed from a lower market share in China, to more or less split the Chinese market with Boeing. Additionally, as a consequence of these agreements, both Airbus and Boeing track purchases of components from Chinese companies have increased. More than half of all Airbus planes contain components manufactured in China. Chinese manufacturers are the sole source providers of a number of parts made of composite materials for the B787, including the rudder, the fin, and fairings. These purchases are seen as important for continued sales.

  - Stipulating that foreign suppliers enter into joint ventures with Chinese partners. Joint ventures are designed to help Chinese firms acquire technologies, managerial know-how, and production experience. The foreign partner typically supplies production design and management expertise. Chinese partner provides the facility and labour and gains an opportunity to learn how to efficiently produce a line of products it did not previously have the capability to produce. Manufacturing joint ventures are often effectively controlled by the foreign partner, which steer the venture toward its product areas of interest.
  - R&D joint venture is seen as good opportunities for the Chinese partner to learn not just how to produce a specific line of products, but how to design and develop entirely new product lines. This might be the next step in this policy.
  - Local production is a requirement for foreign suppliers to the C919 program in high technology areas such as advanced materials and flight control systems where Chinese technology is lagging. In areas of less concern, the Chinese are content with traditional subcontracting or other work-share arrangements.
- **Justification:** What if analysis 1: "China's new airliners" section 12.2.6.1.

Recommendation 30: Some companies might benefit also from the Chinese strategy of acquiring foreign competitors with increased investment and expansion of manufacturing capabilities otherwise not possible.

- **Rationale:** Compared to other sectors where Chinese companies have been more aggressive, the global aviation industry accounts for a relativily low number of Chinese acquisitions that has been focused on smaller and less technology-significant companies. All these acquisitions are targeted at building up of expertise in GA, composites, and assemble and integration technologies. They constitute a serious push to integrate the global supply chain as well as securing technology for its aircraft programs. This international strategy is in line with the development of indigenous commercial aircraft, and the recent consolidation of the Chinese aerospace value chain (AECC, AVIC Cabin Systems). Based on the feedback available in open-source literature and press releases, impact on employment in the US and Europe has mostly been positive, with increased investment and expansion of manufacturing capabilities otherwise not possible.
- **Justification**: What if analysis 1: "China's new airliners" section 12.2.6.1.

Recommendation 31: Innovation, continuous improvement of performance and exploitation cost of Western aircraft, as well as competitive selling prices, would be key in the final decision of the CEOs of the three main state-owned Airlines will purchase aircraft that ensure the continued success of their operations, regardless of pressure to purchase Chinese products.

- **Rationale:** The study of the effectiveness on Chinese government industrial developments policies in 3 key industries during the last decades shows that at industries where the customers are state-owned companies (wind power generation and railway sector) are very much sensible to Chinese government policies to drive purchases. However, where the buying decision depends on final consumers, as in the automotive industry, the situation differs.

  In the first case, the Chinese government has been able to induce firms to buy products manufactured by Chinese companies, even when products are available from joint ventures with foreign manufacturers. The state-owned purchasers have not been concerned about disputes about ownership of the technologies underlying these products. In the second case, foreign brands manufactured by joint ventures dominate the market. The automotive brand has been able to maintain and control their intellectual property better than other industries and has made optimum use of their reputation for safety and reliability. They have also created a dealership network and have invested in marketing in China to back up their position in the market; and have been able to compete in cost, by spreading R&D cost over their global operations and reducing the cost per vehicle of developing a new model.

  The commercial aviation manufacturing industry falls somewhere between the previous cases. On one side, the Chinese government influences the choice of aircraft purchased by China's state-owned airlines; but Chinese airlines are subject to competition and travellers are very sensitive to price with low brand fidelity.

- **Justification**: What if analysis 1: "China's new airliners" chapter 10.

Recommendation 32: Western governments should seek and promote global policies that protect the western companies' investment and natural slow shift in component manufacturing to China from being distorted by protectionist Chinese industrial policies.

- **Rationale:** The increase of joint ventures to support the C919 project together with Chinese policies to maintain aircraft and aircraft components in that large market are implying a slow shift in component manufacturing to China. This natural tendency could be distorted by Chinese industrial policies. Several authors have pointed out a set of measures that both, United States and UE governments might consider reducing such distorting effects.
  - Concerted effort to reduce the use of purchases of components from local manufacturers as a marketing tool in sales negotiations with CASC by Airbus and Boeing.
  - Push Chinese government for more transparent and open tenders for purchases of new aircraft by Chinese state-owned airlines, to avoid situations like the last commitments by Chinese airlines to purchase the C919, not made after open tender solicitations for new aircraft in this category.
  - Limiting the eligibility for EASA or FAA certification of products using illicitly obtained technologies. That will require to involve FAA and EASA in the process of ensuring that Chinese aircraft components submitted for certification do not incorporate intellectual property taken from other companies.

- Building a record of influence on investment decisions as a consequence of Chinese industrial policies that could support future bilateral discussions and WTO proceedings.
- Carefully monitor the evolution of the C919 and successive aircraft and intervene promptly with formal proceedings if WTO rules in this industry are violated.
- Continue to press the Chinese government in bilateral forums and at the WTO to give out industry-specific industrial policies.

However, all these measures will only mitigate some of the effects of China's industrial policies but will not be enough by themselves to create a level playing field in China for Western manufacturers. In the long-term health of the U.S. and European aviation industries will depend on continued technological innovation and the ability of the home countries to provide a competitive environment for manufacturing aviation products.

- **Justification**: What if analysis 1: "China's new airliners" chapter 11.

Recommendation 33: Shorten or improve the development cycle of future large passenger aircraft targeting by focalising investments and innovation efforts in four major target areas of cycle time reduction: a) reducing engineering person-hours; b) reducing tooling hours; c) reducing test activity; d) implementing process and information technologies.

Recommendation 34: Reinforce strategies that allow manufacturers to minimize costs and pass a portion of those savings on to the buyers, as well as maintain profit as the level of competition rises

- **Rationale:** It will be very important aircraft manufactures in the Chinese market, particularly for COMAC, to maintain a constant or increasing rate of production over time in order to benefit from the decreased unit costs resulting from learning economies. Even small variations in production rates (especially in early years) can have dramatic effects on realized learning economies, and hence on net profits.

  Learning economies are one important benefit of cycle time reductions, reducing production costs and increasing profits. However, learning economies depreciate over time when they are unused. Getting to market earlier means that the company will have more opportunities to dominate a particular market segment before a competitor can react. If a company can lock in more customers, it has a better chance of both producing more units and smoothing the production run over the product's life cycle and thereby realize its learning economies. By getting to market faster, the forecast for the product and the expected profitability of the program are more likely to be realized. Airbus access to the single-aisle Chinese market is an example of this.

- **Justification**: What if analysis 1: "China's new airliners" chapter 12

Recommendation 35: Research incentive policies in aviation should considerer the risks that increased return to adoption model and the effect of the dominant firm dictate the strategies of incumbent manufacturers in the next 10 15 years and might lead to firms underinvest in R&D and delays in the introduction of new superior technology.

- **Rationale:** Increased return to adoption model and the effect of the dominant firm risk to dictate the strategies of incumbent manufacturers in the next 10, 15 years, as the first version of C919 risks not to be high competition for neither Boeing nor Airbus in the next years. Both firms will have an incentive to invest in the existing technology, as increasing returns to adoption are present in the Chinese market. Large learning curve effects on production costs incentivize the production more of an existing design, rather than introduce new technology that would cause higher costs associated with the beginning of the learning curve. Additionally, as that dominant firms in the Chinese market, incumbent manufacturers will be reluctant to make technological leaps forward because they do not wish to compete with their existing and successful product lines. This is known as the effect of the dominant firm. As a result of these two effects, firms may underinvest in R&D, even up to technology demonstration and validation and delay the introduction of new superior technology**.**

- **Justification:** What if analysis 1: "China's new airliners" chapter 12.1

Recommendation 36: It will be on the interest of all parties that western safety regulation authorities and China CAAC will continue to strengthen cooperation and collaboration agreements, and achieve a common ground of criteria and regulation requirements for aircraft parts and components that facilitates economic exchanges in aviation as well as sustained and safe aviation growth.

- **Rationale:** China has strengthened its relationship with Europe and EASA in different areas over recent years. This dialogue has been formalised in the discussions for the signature of the future Bilateral Air Safety Agreement (BASA), which is currently under negotiation between China and the EU. EU-China Aviation Partnership started in 2017 the Aviation Partnership Project (APP) led by EASA to promote:

  - Exchanges between regulatory authorities;
  - Support to the political aviation dialogue;
  - Specific technical cooperation activities, including training, placing short-term experts and addressing technical questions through dedicated working groups and conferences.

  The project covers a wide range of areas of joint interest such as: cooperation at ICAO level, ramp-inspections, validation of products from both Europe and China, development of the General Aviation (GA) sector, airworthiness certification, safety promotion activities and Air Traffic Management (ATM) modernization, drones standards, Airports and security, advances and technological trends in passenger transport etc...

- **Justification**: What if analysis 1: "China's new airliners" chapter 12.2

Recommendation 37 Western manufacturers should not rely on certification as an entrant barrier.

- **Rationale:** Certification is not a permanent barrier to entry for competitors. COMAC is learning how to get through the certification process with the FAA, EASA and the Civil Aviation Administration of China. Once Chinese companies master this process, they will be better placed to develop into global suppliers.

- **Justification:** What if analysis 1: "China's new airliners" chapter 12.2

Recommendation 38: Foreign customers of China's aviation components must keep the pressure on Chinese suppliers to become more efficient, improve manufacturing technologies and quality control.

- **Rationale:** Joint ventures have created opportunities to learn how to efficiently manufacture new product lines and to acquire the know-how from repeatedly manufacturing the same component and to meet Western quality standards. Foreign customers of Chinese components have forced Chinese suppliers to become more efficient, improve manufacturing technologies and quality control. In manufacturing joint ventures, the foreign partner typically supplies the production design and management expertise, while the Chinese partner provides the facility and labour. As the Chinese partner gains experience, its engineering and management skills tend to improve.

- **Justification:** What if analysis 1: "China's new airliners" chapter 12.

Recommendation 39: European aviation institutions and stakeholders should figure out and develop a solid legal, commercial and technical strategy that contribute to a level playing field for aviation companies in China that incentive its developments while protecting their technological assets and IPR

- **Rationale** Concern about the theft of intellectual property is a disincentive factor for aviation companies to extend in China. Once Chinese competitors have mastered technologies, the companies fear they will lose some of their competitive advantages.
- **Justification:** What if analysis 1: "China's new airliners" chapter 12.

Recommendation 40: Chinese universities and technical schools, which have achieved high levels of competence and excellence, offer a playground for collaboration and partnership that western academic institutions must capitalize through common academic programs, mutual titles recognition, long-life learning projects, and teaching and mobility agreements.

Recommendation 41: European universities can obtain a new impulse for their PhD programs from qualified scientific and engineers pursuing to develop a research carrier in aerospace. They should design attractive, long term and bespoke programs that could capture bets qualified Chinese researchers and research investment.

- **Rationale:** Chinese universities and technical schools are turning out substantial numbers of well-trained technicians and engineers. The Chinese national and provincial governments are highly involved in improving the quality of Chinese engineering and technical schools, providing the necessary funding to create and support the aeronautical engineering and technical programs needed to teach these skills.
  Institutions of higher education have also improved the quality of their staff, recruiting expatriate Chinese engineers and professors to return to China to teach in these institutions. State support in the form of higher salaries and attractive benefits packages have been important to provide these inducements to attract these individuals

  Europe is suffering the lack of highly qualified scientific and engineers liking to continue their university studies with a PhD and pursuing research carreers in aerospace. The high quality of Chinese aerospace engineering programs, the elevated number of graduates; the interest of Chinese government in promoting long term research carrier in aerospace and the economic wellness to support those carriers, might be an opportunity for European universities to fill the actual gap of PhDs and researches.

- **Justification**: What if analysis 1: "China's new airliners" chapter 12.

12.2.1 Introduction to the What if Study

The PARE project assess progress, gaps and barriers, and propose suitable measures to close the remaining gap to support the achievement of the Flightpath 2050 goals in a broad variety of key areas of aeronautical research which are essential for the development of the aerospace sector in Europe.

As part of this process, the project has the task of identifying the actions required in the coming future for the proper development of the aerospace research sector, that can benefit from a detailed and rigorous analysis of possible political, social and industrial scenarios by carrying out What if analysis.

The experience of the consortium and its capabilities, as well as the work realized in analysing the state of the art, future forecasts and needs in each of the project's areas of interest, have allowed the identification of two highly relevant case studies for the evolution of the sector.

The first case is justified from the perspective of the growth forecasts of the air transport sector in the medium and long term that identify the Asian emerging economies, and in particular China, as the one with the highest growth in air transport. Coupled with the booming economic development of these regions, we are witnessing the growth of the potential powerful aerospace industry in China. The capacity of this thriving industry to consolidate will undoubtedly condition the worldwide scenario of aviation.

In recent years we have witnessed several attempts by the Chinese industry to develop and certify large transport aircraft, such as the regional jet ARJ21 certified by the CAAC after years of delays, the C919 in the single-aisle segment whose certification has been postponed from years, or the future development of a wide-body model C929. How the success of all these attempts will effectively affect the Airbus/Boeing leadership in the industry is going to be one of the big issues in the industry in the upcoming years.

China's ability to certify and produce commercial aircraft efficiently, economically and on time to take advantage of the country's anticipated development could greatly influence the international scenario and could have a major impact on the current balance of the aerospace industry.

Keys in that future will be the capacity of the Chinese industry to certify its current aircraft developments, produce on a large scale, gain the confidence of the airlines and acquire a significant share of the market. All these aspects are raised and developed in a first case study that aims to shed light on how the possible scenarios can influence the development of the European air transport industry and how Europe can react in each case with the best political, regulatory, research, educational and industrial strategy.

The second case focuses on the analysis of competition among the main aircraft manufacturers in a segment that has captured the attention of both in recent years, the Middle of the Market segment.

The middle of the market is often abbreviated MoM, and the potential new aircraft that could serve this market are referred also as MMA which stands for 'Middle of the Market Aircraft'. It represents the airliner market between the narrow-body and the wide-body aircraft as well as between the short and the long-range and has become a market segmentation used by Boeing Commercial Airplanes since at least 2003. These aircraft can fly ranges of approximately 3,000 to 6,500 nautical miles and carry passenger loads of approximately 180 to 300 people in both single and twin-aisle configurations.

Both Airbus and Boeing produce aircraft that serve this segment. In the range of 2,500 to 4,000 nm, 120-169 seats narrow-body airplanes are mainly used,170-229 seats narrow-body jets (A321, 737-

900ER, 757, etc.) and 230-399 wide-body jets (A330, 767/787, etc.) are operated too. In the upper band of this range, partly because the route distance is longer, relatively larger airplanes, such as 170-229 seats narrow body and 230-399 wide-body jets are used more actively in this distance range than for 3,500-4,500 nm range. In the range of 4,500 nm or more, 310-399 seat jets (A340, 777, etc.) are mainly operated, followed by 230-309 seats jets (A330, A350, 787, etc.), 500-800 seats jets (A380), and 400-499 seat jets (747). 400-499 seats airplanes have declined in number due to the recent decrease in the number of 747 and A380 jets orders.

B737 and A320 are the best seller products with more than 10,000 and 8,500 deliveries respectively. B737 is in its third generation since 1969s and A320 in its second generation since the 1980s. However, this third 737 has less stress potential than the A320, and the 737 MAX 9 has been beaten soundly by rival Airbus' A321neo in the 170-229 seats market segment by a ratio of nearly 8:1, looking purely at current firm orders. There is a 100-seat gap between the 737 and the 787, where Boeing needs a product to compete with the A321 and get profit from the 757 and 767 replacement opportunities. The issue has become more burning since Boeing began studies for the development of an MMA, named today as 797. Up to now, the company has been delayed the decision about whether to move forward with the 797 programmes and later announced that, probably, a decision will be made in 2019. On the other hand, forecasts of traffic growth are especially optimistic for this sector. This has led the industry to focus strategies, in recent years, on the real volume of the MMA market and how large manufacturers value its potential developing strategies to lead it.

Because of all these reasons, the second case addresses the analysis of the NMA issue and the best and most probable Airbus and Boeing strategies to succeed in this market.

Objectives

The objective of this study is to analyze the potential of the emerging commercial aviation industry and its possibility of affecting, at a long and medium-term, the actual duopoly run by the European Consortium Airbus Group and the American company Boeing Corporation. Done this, this project will provide with a set of conclusions and recommendations within different fields, in order to maintain appropriate competitiveness in the sector.

China's first airliner, COMAC C919, is expected to compete with the narrow-body, single-aisle aircraft Boeing 737 and Airbus A320. This project will analyse the impact of this aircraft's entry on the market and will estimate quantitatively the market share that will take from the current duopoly. To do so, the study will analyse several questions in both technical and business fields, such as:

1. A study about the single-aisle sector and its relevance nowadays, together with future perspectives of the sector. The objective is to identify why this sector has become so relevant for the airlines nowadays and how it is expected to evolve in the next 30 years.
2. An insight on the new Chinese COMAC C919 aircraft, including the evaluation of its features and timeframe, in order to assess its potential competitiveness with the incumbent models. To do so, the study will provide technical data regarding the design of the aircraft as well as the production capacities and business intentions of the Chinese company.
3. An analysis of the possible market share that the new aircraft may get. This will be supported by considering different scenarios within certification possibilities, and will answer these two main questions: If the aircraft achieves FAA/EASA certification, how this will affect to Airbus and Boeing orders and deliveries? On the other hand, if the aircraft is only certified in China and in some of

its commercial partner countries, will that cause a long-term domestic substitution of the aircraft orders in these territories?

This study will develop a SWOT analysis of the new aircraft and will be supported by different scenarios in both the short-term and long-term. The analysis of these scenarios will provide with a global vision of the evolution of the Chinese airline market within different external situations.

Scope

In order to achieve the objectives mentioned in the previous chapter, this study will consider the following aspects:

- **Certification problems.** The Chinese regional jet ARJ21 has obtained certification from CAAC after years of delays. Although, without international certification by the FAA or the EASA, it is operated by Chinese airlines in domestic routes. Several incidents have led to the CAAC to impose restrictions on operations. The C919 is an A320/B737 competitor whose certification has been postponed for several years. After failing to agree on certification with the FAA, CAAC is trying with the EASA, which should not make much difference. Further into the future is the project of a wide-body airliner, the C929, to be developed with Russia using Russian engines. In the meantime, Chinese airlines have no choice but to buy Western aircraft. Will this change?
- **Domestic market.** The domestic market is by itself sufficient to justify the development of new airliners. The ARJ21 shows that the CAAC is willing to certify for internal use aircraft not certified by EASA or the FAA. If they certify the C919 by mid-2020s and the C929 later in the 2020s, what would be the effect on the domestic market? How would the sales of Airbus and Boeing in China be affected? What would be the effect on global Airbus/Boeing sales and prospects?
- **Production cost.** The Chinese aircraft use Western engines and avionics so the production cost cannot be much lower. How much lower realistically? China has been many times accused of "dumping" a variety of products, mostly of much lower value than airliners. When faced with anti-dumping measures by the EU, the Chinese replied that an airliner is worth 200 million T-shirts. If the Chinese airliners obtain EASA (or FAA) certification is there a risk of dumping? What effect could it have in international markets and Airbus/Boeing global prospects?
- **Production capacities.** The Chinese regional jet ARJ21 is already on service and in production after being certified by the CAAC. The Chinese airlines' intention seems to be of using this aircraft for domestic routes, in substitution of the options of the two main Western regional jets manufacturers, Embraer and Bombardier. The aircraft has received a total of 302 orders by August 2018, most of which are from Chinese airlines, as well as 31 from other countries, such as the Republic of Congo or Laos. COMAC's industrial plans were to achieve a production rate of 20 aircraft a year by 2018, but they only managed to deliver 6 units up to date, which puts in doubt its capacities to satisfy a high-growing demand. Even if the Chinese company achieve international certification for its airlines, will they be able to produce at the same rate than its Western competitors? Will this also affect to the C919 sales and orders?
- **Customer countries.** China has developed close relations with several developing world countries, including some with questionable human rights records (like China) and dubious business practices. In fact, some of the countries not eligible for EU or US assistance due to domestic issues, find in China an alternative partner that does not raise such concerns. Could China use these countries as customers preferring its airliners even if not the most efficient (like the satellite countries of the Soviet Union in the past)? How much market share could be obtained in this way, possibly combined with dumping at unbeatable prices?

- **Domestic substitution.** China is still unable to supply major aircraft elements, such as engines or avionic systems that function together. The engineer that developed the first modern Chinese jet engine received the highest decoration in the country. The military variants of that engine are already in use, with reports of poor reliability. China is investing strongly in aerospace technology, with 200,000 students taking university courses in this area. What are the prospects for domestic Chinese development of major aircraft systems? Which and when? Is the most or all Chinese airliner a prospect? In which time frame? Would the international market rely on Russian/Chinese engines and systems? Given the poor record of some countries (like Russia) in spare and after-sales support would China be better (including the C929R)?

Methodology

In this chapter, the methodology of the "what if" analysis will be discussed. The methodology proposed is double. On the one hand, a study of the market will be developed, by using qualitative and analytical methods that will be enough to provide answers to the questions and cases raised in the objective and scope of this study. Additionally, the "what if" analysis is complemented with the application of game theory to evaluate the results of the entry of a new competitor and its implications for the market which is currently dominated by the duopoly composed by Airbus and Boeing. The outcome of the games will evaluate the possible strategies to be applied by Airbus and Boeing in order to face the Chinese company COMAC in the SA market, considering a medium and long-term horizon. Besides, the game theory will allow performing sensitivity analysis to consider the impact of the various uncertainties that influence the case.

Information and analysis coming from the first part of the analysis will be used to define the structure of the competitive games in the second part of the analysis and the possible scenarios; as well as to synthesize the possible strategies of the three players and to construct the aircraft valuation model for the estimation of the payoffs. Figure 12.1 illustrates the main steps in the whole process.

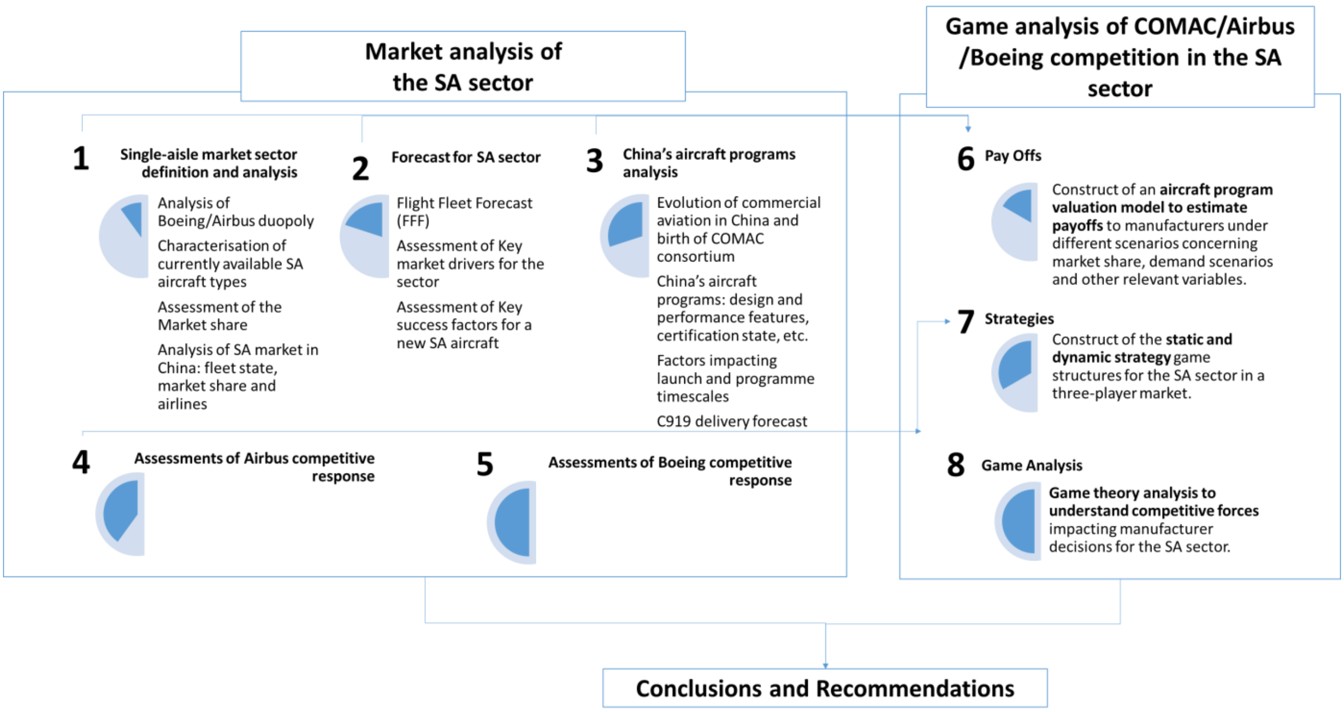


Figure 12.1 - Methodology for the "what if" study on the China case.

As can be seen from the figure above, the initial market analysis consists of five main steps. The first step comprises the definition and analysis of the single-aisle market, which is currently dominated by the Boeing/Airbus duopoly. The competition between these companies is analysed in this step and it is also included a characterization of the SA aircraft models that both companies have currently available, in terms of design and performance features. Finally, an analysis of the SA market in China is performed, through an evaluation of the current fleet state, its main operators and airlines. This analysis will allow the quantification of the Airbus and Boeing market share in the region, which is an essential aspect in order to understand how the presence of a new competitor could affect the great influence of both companies in the country.

The second step is composed of the following main topics: i) Flight Fleet Forecast (FFF); ii) identification of key market drivers for the sector; iii) identification of key success factors for a new SA aircraft; iv) performance of a SWOT analysis for the single-aisle market. Traffic and fleet forecast will be a critical element to evaluate the market share that COMAC could absorb from Airbus and Boeing in the country.

The third step involves a deep analysis of China's aircraft programs, starting by a brief description of China attempts to manufacture commercial aircraft, resulting in the birth of COMAC consortium as a commercial aircraft manufacturing company. Then, the models that this company has currently available, or is already committed to developing, are analysed in detail in terms of design, cost, certification and performance features. It is also included a valuation of the different factors that could affect launch and programme timescales, which will serve as inputs for the definition of scenarios. Finally, the delivery date and rate of the C919 aircraft will be provided to estimate the market share it may get, considering different situations that could stimulate or damage the sales landscape.

The last steps, 4 and 5, are dedicated to outline and evaluate the Airbus and Boeing reaction as well as their possible strategies to compete with COMAC in the single-aisle market, with the goal of not losing market share, in China and internationally.

Additionally, as can be seen in Figure 12.1, a game competitive research approach is three staged (steps 7, 8 and 9). In step 7, static and dynamic game structures for a three-player SA market are constructed. In step 8, using the outcomes of previous study sections, an aircraft program valuation model is implemented to estimate payoffs of manufacturers under different market share and demand scenarios. The purpose of this model is not to determine aircraft manufacturers' profitability precisely but to estimate the rank of payoffs to determine how changes in the market structure may change the equilibrium game outcome. It has to be noticed that this analysis will be hindered by the proprietary nature of aircraft program economic data. The consortium uses reusable assumptions based on publicly available data sources. These assumptions will also be subject of a sensitivity analysis to determine the impact of the assumptions and proxies on the study's funding. Finally, at step 9, a game theory analysis is used to model competitive forces impacting manufacturer decisions.

The results of the whole process will allow understanding how competition can affect manufacturers' decisions, as well as to understand how the entry of a new rival in the market could imply changes in the duopoly composed by Boeing and Airbus. This understanding and the derived conclusions and recommendations may assist policymakers in developing regulatory and incentive mechanisms to improve aviation and inform expectations of the introduction of a new competitor into the global aviation market. The whole approach will also allow testing policy options to determine their outcomes in a competitive market, based on the assumptions from the valuation model.

12.2.2 – Single-aisle sector definition

Single-Aisle aircraft is a widely accepted term for referring to narrow-body airliners used for short- and medium-haul flights. This Chapter focuses on the characterization of this market bod. It will review the current Single-Aisle models as well as the market structure and the lessons learned from the competition between Airbus and Boeing in the past.

12.2.2.1 Single-aisle current models

The Boeing B737 is in its third generation since the 1960s and the Airbus 320 in its second since the 1980s. The third generation B737 has less stretch potential than the second-generation A320. The new generation of more efficient engines has turned the A321 into more than its designers could originally have hoped, able to cross-continents and some oceans. Additionally, Boeing’s 737 requires more engineering work to re-engine than Airbus’s A320, which could provide a re-engined advantage to Airbus, as a smaller investment and less technical risk is required, if needed.

With more than 10000 deliveries of the B737 and 8500 of the A320, they are the numeric best sellers in the Boeing and Airbus fleets. Considering current backlogs numbers might exceed 12000 or even reach 15000 sales. At this point, both manufacturers are harvesting the profits of their more successful products, and plan to do so in the short and medium-term. The C919 might be a challenge to this long-term duopoly situation, or at least an extra impulse for a new competition in the market.

In the following sections, we analyse in detail the current models produced by Airbus and Boeing in this segment. Table 12.1 summarises the models and their main characteristics.

Aircraft model	First Flight	Length (m)	Wingspan (m)	Range (nm)	Capacity (two-class configuration)	Maximum capacity	Total Orders	Total Deliveries	List price (USD millions)
A319neo	2017	33.84	35.80	3700	120-150	160	35	0	101.5
A320neo	2014	37.57	35.80	3400	150-180	194	4143	641	110.6
A321neo	2016	44.51	35.80	3600	199	230	2327	184	129.5
A321neo LR	2018	44.51	35.80	4000	206	240			
A321XLR	2023	44.51	35.80	4500	206	240			
B737-800	1997	39.47	35.79	2935	160	189	4991	4979	102.2
B737-900ER	2000	42.11	35.79	2950	177	220	505	504	112.6
B737 MAX 8	2016	39.52	35.90	3550	178-193	210	2590	330	121.6
B737 MAX 10	2019	43.80	35.90	3300	188-204	230	579	0	134.9

Table 12.1. Current Airbus and Boeing single-aisle models for short –medium haul.

A321-200N (NEO)/A321-200NX (NEO LR)

Background

The Airbus A321 is the largest member of the Airbus A320 family. It is a narrow-body, short to medium range, commercial passenger twin-engine jet airliner manufacturered by Airbus. It entered service in 1994 and it was offered in two versions: the basic -100 and the longer-range -200 variant. The A321-200 was the first direct competitor to the Boeing 757-200. While not as range-capable as the Boeing 757-200, the A321-200 became a strong competitor on medium routes, such as US coast-to-coast.

In December 2010, Airbus launched the 'New Engine Option' (or "NEO") for the A320 family. The baseline A320-200N (NEO) entered service in 2016 and the longer A321-200N followed in May 2017. These versions were re-engined with the CFM International LEAP-1A or Pratt & Whitney PW1000G engines, which provide a 15% fuel burn advantage over their previous versions. With a backlog of around 2000 aircraft, the A321-200N is a very successful programme for Airbus.

In October 2014, Airbus revealed a new long-range variant of the A321neo. Initially, this version was unofficially called the A321neo LR. The new version will have a new door-configuration, called "Airbus Cabin Flex" (ACF) which results in up 20 more seats, bringing the total of passengers on an A321-200N to 240 (high density). As this new door arrangement is a structural change to the original A321's fuselage, a new type certificate was needed, making it a new version of the A321-200N, called the A321-200NX.

This new version is clearly aimed at the 757-200 replacement market. It will have a range of 4000nm, 200nm more than the Boeing 757-200 (some of which are used on long-range trans-Atlantic routes) and 400nm more than the standard A321-200N. Intended markets are North America to Europe, Europe to Africa, North America to South America and S.E. Asia to Australia. With newer engines and more modern design, the A321-200NX will have 27% lower fuel burn than the 757-200. It is expected its introduction to the market in 2019.

A321-200 N Technical specifications and performance metrics.

DIMENSIONS

Overall length	44,51 m
Wing span	35,80 m
Height	11,76 m

CAPACITY

Typical seating	206 (two-class)
Max	244

ENGINE DATA

Take-off thrust	44,51 m
Weight	35,80 m
Number of engines	11,76 m

PERFORMANCE

Range
Maximum take-off weight
Operating empty weight

COST MODEL INPUT PARAMETERS

Average stage length
Speed (miles per block hours)
Utilization (block hours per day)
Gallons per block hour

Order book

As illustrated in Figure 12.2, the A321neo is a very successful programme which has accumulated a great number of orders since its introduction. By December 2018, the A321neo has received 2075 orders, composed by 122 deliveries and a backlog of 1953. In spite of its recent introduction into the market, the perspectives of this model are very promising as it has achieved to outsold its previous version the A321ceo as well as several models of the Boeing 737 MAX generation.

Orders	Deliveries	Backlog
2075	122	1953

Data as of December-2018

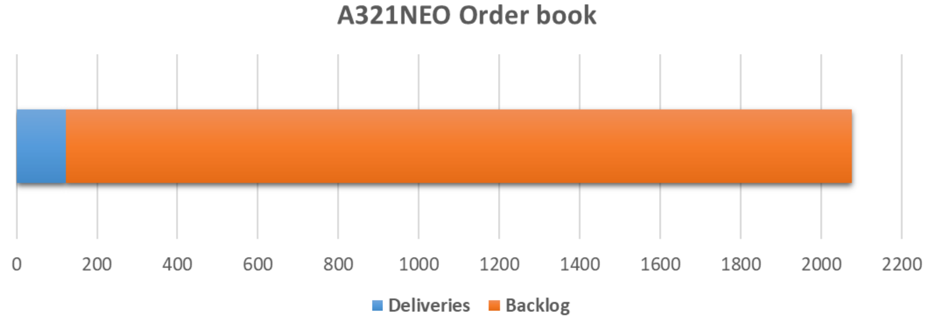


Figure 12.2. A321neo order book by December 2018.

Market share

The routes market share shown in Figure 12.3 belongs to the A321neo variant. As can be seen, almost 60% of the routes flown by this model are less than 1000 nm in length. The rest is distributed in the range between 1000 and 3000 nm, in such a way that as the distance increases, the number of routes is reduced. As of a length of 3000nm, there are no routes flown by the A321neo, although its maximum range corresponds to around 3600 nm.

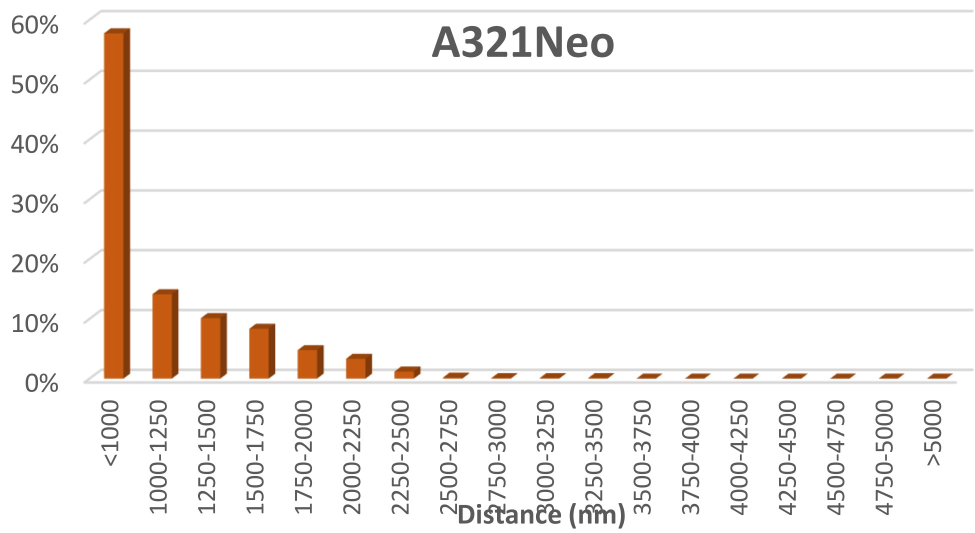


Figure 12.3. A321Neo routes market share

Boeing 737-800/737 MAX 8

Background

The Boeing 737 is a short to medium range narrowbody developed and manufactured by Boeing. It was initially introduced in 1968 and till date, it has developed into a family of thirteen passenger models with capacities from 85 to 215 passengers. It is currently Boeing's only narrowbody airliner in production, with the 737 Next Generation (-700, -800, and -900ER) and the re-engined and updated 737 MAX variants in use.

The Boeing 737 Next Generation (NG) was introduced in the 1990s, with a redesigned, increased span wing, upgraded "glass" cockpit, and new interior. The 737 NG comprises the 737-600, -700, -800, and -900 variants. The 737-800 is considered commercially very successful, with more than 4000 aircraft in active service and over 24 on order backlog, the Boeing 737-800 is seen as the most liquid commercial aircraft in the market today. But the introduction of the A320neo with its efficient specifications and high sales figures put pressure on Boeing to react more quickly with a more modern and efficient 737NG successor.

Therefore, in August 2011 Boeing presented the 737 MAX aircraft type, which succeeds the Boeing 737 Next Generation (NG) and represents the fourth generation of the Boeing 737. The most important new feature of the 737 MAX was the introduction of the new CFM International LEAP-1B engine, which provides an improvement in fuel burn. In addition, fuel efficiency is improved by some aerodynamic modifications on the fuselage (a new tail cone) of the 737 MAX and the introduction of a new winglet design, called the Boeing Advanced Technology ("AT") winglet. The range of the 737 MAX has increased by 400-540nm compared to the 737NG. Aircraft types belonging to the MAX family so far are designated 737-7, 737-8, 737-8-200, 737-9 and 737-10.

As the 737-8 is considered as the successor of the 737-800 and considering its high sales, it is the only version of the 737 MAX family analysed in the study. The 737-8 is a narrow-body short to medium range airliner. It can carry between 178 and 210 passengers and it has a range up to 3550nm. The first flight took place in 2016. The 737-8 competes against its arch-rival the A320neo. So far, 2,556 orders have been placed for the 737-8 variant, making it the most popular 737 MAX variant.

As there are still a large number of 737-800 in operation, it is expected that the 737 MAX 8 will replace a high part of this fleet, especially considering its order book, which is very promising.

B737 MAX8 Technical specifications and performance metrics

DIMENSIONS

Overall length	39,52 m
Wing span	35,9 m
Height	12,3 m

CAPACITY

Typical seating	178 (two-class)
Max	210

ENGINE DATA

Take-off thrust	
Weight	

PERFORMANCE

Range	3550
Maximum take-off weight	
Operating empty weight	

COST MODEL INPUT PARAMETERS

Average stage length	
Speed (miles per block hours)	
Utilization (block hours per day)	
Gallons per block hour	

Number of engines

Order book

The B737 MAX 8 is a very successful programme which has accumulated a great number of orders, as in the case of the A321neo which is its main rival. By December 2018, the MAX 8 has received 2590 orders, composed of 330 deliveries and a backlog of 2260 (Figure 12.4). Taking into account that it is expected that the 737 MAX 8 will replace a part of the 737-800 fleet, its future perspectives are very optimistic, despite the A321neo is absorbing part of its market share.

Orders	Deliveries	Backlog
2590	330	2260

Data as of December-2018

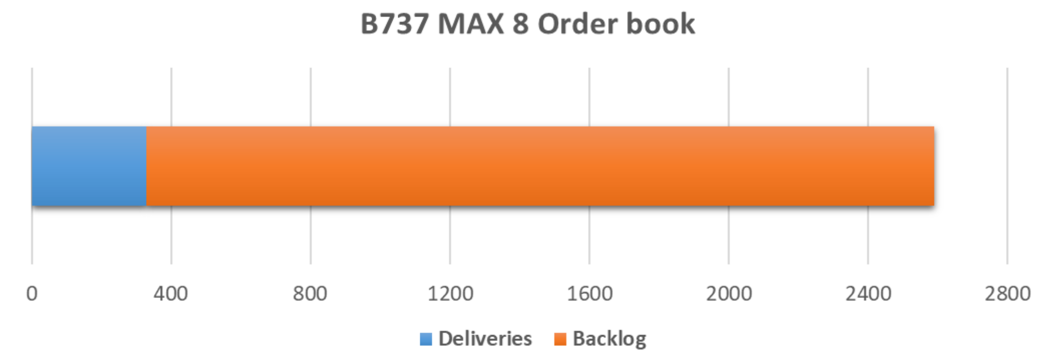


Figure 12.4. B737 MAX 8 Order book

Market share

The routes market share shown in Figure 12.5 belongs to the B737-800 variant since the B737 MAX 8 has just entered the market and there are few routes flown by this model. In addition, as the MAX 8 is expected to be the successor of the B737-800 variant, it is very likely that the routes of both models will be very similar when there are more units of the MAX 8 in the market. The figure shows a distribution very similar to the A321neo variant, its main rival. That is, more than 70% of the routes flown by this model are less than 1000 nm in length. The rest is distributed in the range between 1000 and 3000 nm, in such a way that as the distance increases, the number of routes is reduced, and as of a length of 3000nm, there are no routes flown by the B737-800.

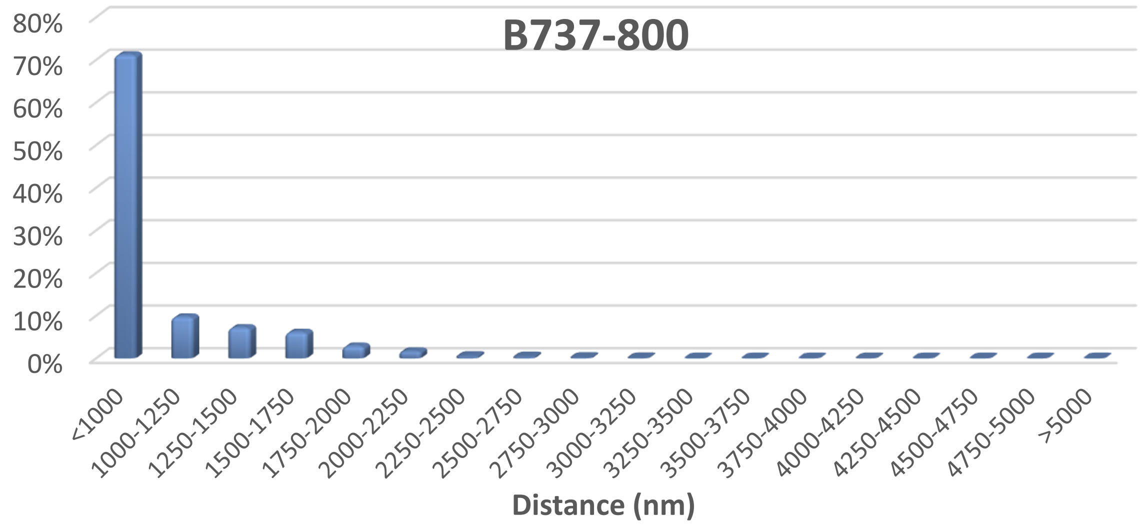


Figure 12.5. B737 MAX 8 routes market share

12.2.2.2 Single-aisle market structure

The single-aisle market is integrated by narrow-body aircraft with more than 100 seats, which operates on short and medium-haul routes. In the past, this market was split between various manufacturers: Boeing, McDonnell-Douglas, Lockheed and Airbus. Boeing's 727-200, with 150-185 seats, dominated the short-medium range market, until 1980 when the MD-80 entered in service with a 37% fuel burn improvement. Boeing and Airbus response was Boeing's 737-400 and Airbus's A320 in 1998 that offered significant performance improvements over the MD-80, and since then, both manufacturers have been updating these products lines. Finally, with Boeing's acquisition of McDonnell-Douglas in 1997, the market has become a global duopoly, where Airbus and Boeing divided the market. **Error! Reference source not found.** illustrates this situation with the evolution of seat market shares and fuel burn performance of the three manufacturers in the period 1980-2009.

In this sector, incumbent manufacturers are protected from new competition by large entry barriers:

- The cost of developing a new aircraft is very elevated. Experts estimate it between $3 to $14 billion, depending on the aircraft size and technology level.
- New aircraft developments require a high level of expertise over long periods.
- Production learning effects result in unit costs drop on the order of 20% every time the quantity produced doubles. This gives a competitive unit cost advantage compared to the models with long production runs [3].
- Airlines are more and more exigent demanding lower operating cost and lower prices.
- Airlines switching cost are significant and tend to maintain the airlines locked into one product family. Fleet commonality also reduces operating and maintenance cost increasing the reluctance of an airline to switch manufacturer. To gain market share the new manufacturer needs to offer a product with significant performance improvements to overcome the switching cost or any other advantage that compensate for the switching cost.

In order to maintain market share, manufacturers must develop aircraft with equivalent performance to the ones already established. If a manufacturer wants to gain market share needs to produce an aircraft with significant performance improvements to overcome the airlines switching cost. If one manufacturer develops a superior aircraft, its competitors risk losing market share. That, lead manufacturers to an action-reaction game, where each one responds to other's moves to prevent an inferior aircraft in a market segment from losing market share and profit potential. This reaction might imply a re-engineering of existing airframes, or even the development of a new, clean-sheet design.

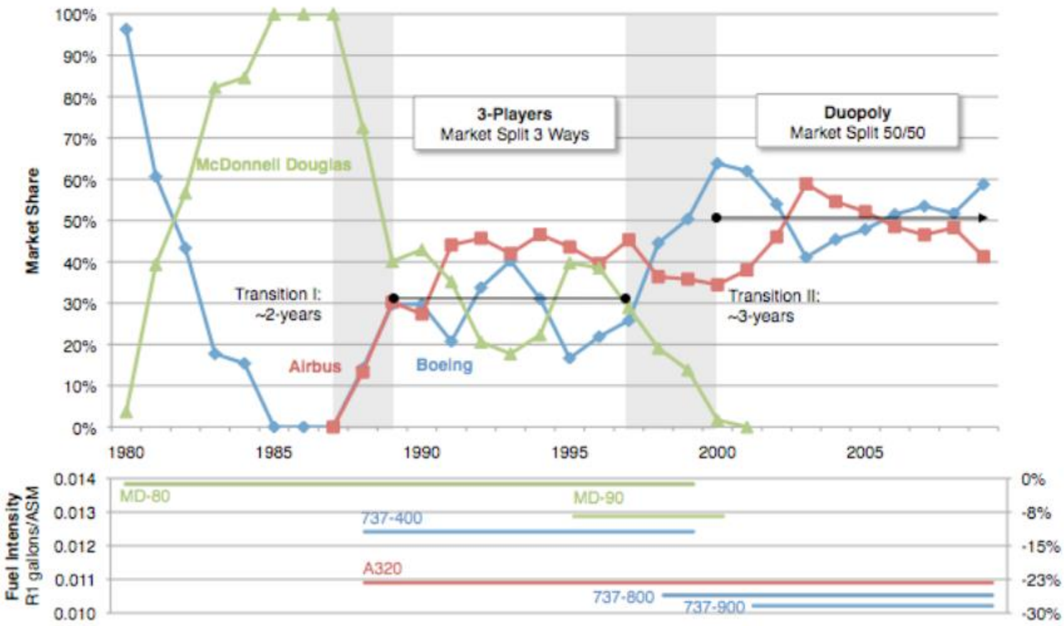


Figure 12. 6. Single-aisle, 150-185 Seat Market Shares and Fuel burn Performance, 1980-2009.

12.2.2.3 Lessons learned from past Airbus- Boeing competition in the single-aisle market

As indicated in 12.2.2.1, the competition between Airbus and Boeing has been characterized as a duopoly in the large jet airliner market since the 1990s. In fact, the world aircraft industry today is increasingly controlled by Airbus and Boeing. The prize of this competition is the dominant position on a market in continuous growth. A total backlog of 14816 aircraft [4] is currently distributed mainly between the "Two Big", representing 89% of the total industry (**Error! Reference source not found.**).

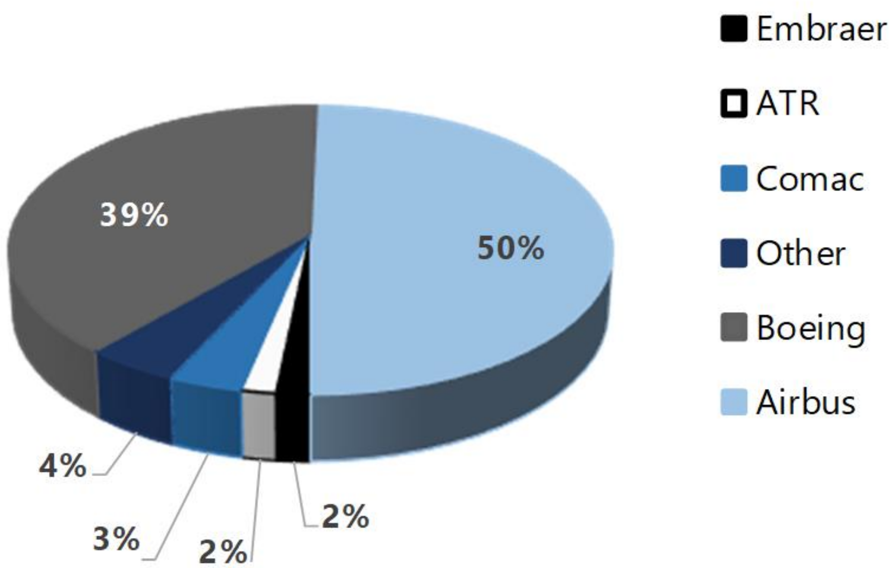


Figure 12.7 - Commercial aircraft order backlog by the manufacturer.[4]

Large commercial jets are now about 60% of total industry output by value, not only at the final delivery level but also through most of the component and structures supply chain. The reasons for this duopoly are multiple:

- Airbus and Boeing absorb a greater share of the industry. In 2018, Airbus acquired Bombardier's C Series with a new line of 110/130-seat jets, provisionally known as the A220-200 and A220-300. Boeing is creating a joint venture with Embraer covering Embraer's E-Jet series, spanning 75-120 seats.
- Extremely high entry barriers.
- Extreme concentration at the top of the market in terms of major revenue-producers.

History in jetliner competition is characterised by certain significant examples of competition between these two companies. Since the early '80s, the other mirrored every move of one competitor. As it can be observed in **Error! Reference source not found.**, nearly each of the airplane types in the portfolio of Boeing had, and probably will have a counterpart in Airbus, and vice versa.

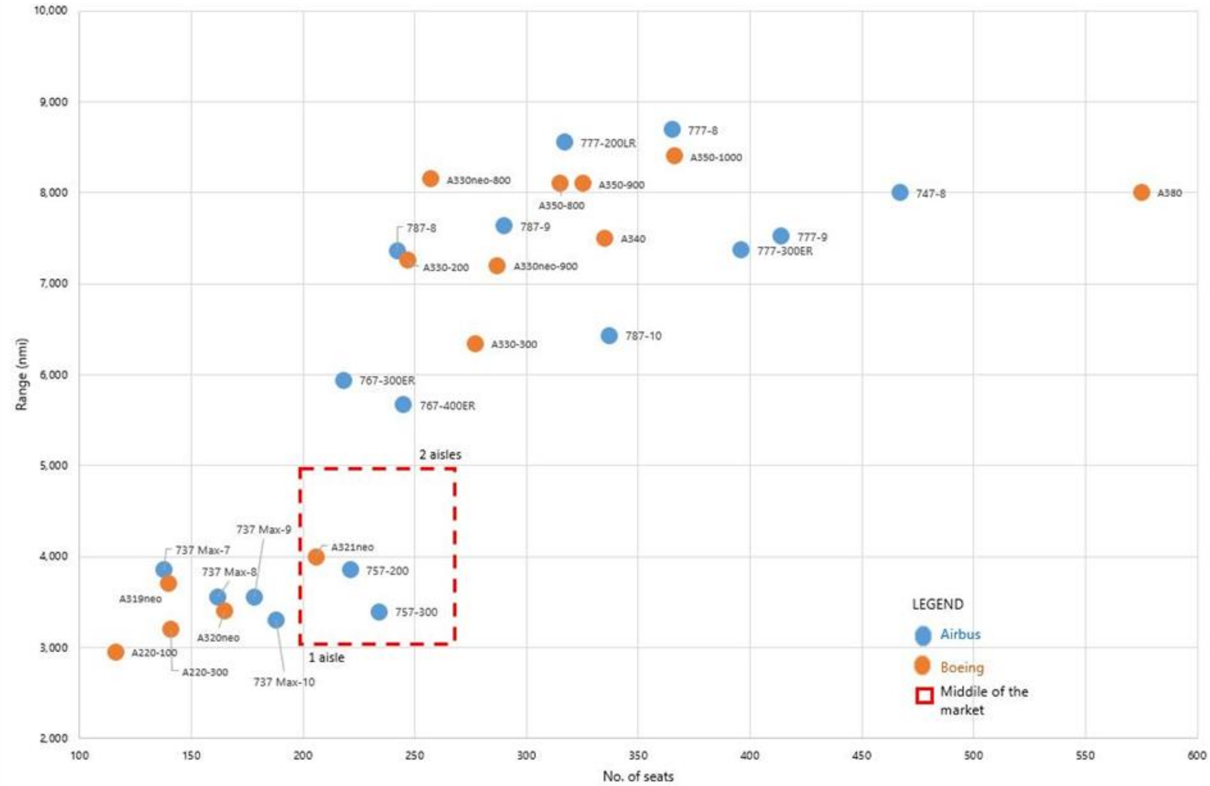


Figure 12.8. Boeing and Airbus payload-range diagram.[5]

A review of the Boeing and Airbus duopoly can bring hindsight of what was relevant for the dominance of the single-aisle market in the past and might be also in the future.

Traditionally the market has followed a cyclic pattern: a growing period of roughly seven years followed by a dropping period of approximately three years with deliveries falling by 30-40%, or more in the bad period. However, Industry experiences continuous growth since 2004, slow down during 2016-2017 parenthesis (single-aisle deliveries pause before A320neo and 737MAX deliveries ramp-up). The expectations call for continued growth through 2020, at least. Long-term demand drivers include a strong passenger traffic growth trend projected over the next 2 decades but a slowdown in market demand for new aircraft by carriers, industry OEMs (original equipment manufacturers) and industry value chain ramping up production to deliver on the huge accumulated order backlog. The 12,000 jetliners on the backlog at Airbus and Boeing alone is estimated to be worth over 7-8 years of production. The A320 family is on course for 63 planes per month, with the 737 headed for 57 per month. Considering these figures, for the very first time, the jetliner market will have a 16-year growth cycle, and possibly longer, over twice as long as the usual seven-year boom.1

[1] Assuming the new rates were achieved in 2023, the single-aisle segment would have seen 450% growth (by value of deliveries) over 19 years, in constant year dollars. More single-aisle jets will have been delivered between 2010 and 2024 than were delivered in the first 51 years of the jet age, 1958-2009.

Some consultants estimate that the segment generates a vast majority of the profits, as they represent the bulk of the historic volumes delivered (around 10,500 for Boeing and 8,500 for Airbus) and of the existing orders (4,763 for Boeing and 6,536 for Airbus), according to the data provided by manufacturers[6][7]. However, as shown by the data in **Error! Reference source not found.**, the order rush seems to have decelerated in 2018. As the strong cyclicality of the industry is still to come, and the growing cycle is becoming longer than ever it will be highly recommendable to closely track the evolution of recent single-aisle orders deceleration in such a growing market as the single-aisle segment, to anticipate changes in any key driver affecting the sector.

Model	Deliveries		Net orders		Backlog 2018
	2018	2018/2017	2018	2018/2017	
A220	20	n/a	135	n/a	480
A320ceo	240	63.7%	10	7.8%	165
A320neo	386	213.3%	531	57.3%	5,981
Total Airbus	646		676		6536
737NG	324	n/a	-24	n/a	88
737 Max	256	56.3%	699	53.3%	4,675
Total Boeing	580		675		4763

Table 12.2. Airbus and Boeing 2018 orders.[6][7] [8]

Both companies still keep a BB ratio (book-to-bill ratio, the ratio of orders received to the amount billed for a specific year) at a value higher than 1, which is characteristic of a boom period. In addition, B737 and A320 families, with their latest versions, are the models with a higher backlog, illustrating the success of the single-aisle segment.

Historically, Boeing's 737 first entered service in 1968. A variety of derivative aircraft based on the initial design, with different ranges and seating capacities, have been produced over the years. Airbus, after being successful with A300 series, planned its narrow-body family starting in 1978 as Jet 1 and Jet 2, a project targeted to compete with B737 and DC-9, the uncontested leaders of the market at the time[5]. The engineering capacity freed by the completion of the first project (A300) was put to work for the second.

The consortium introduced its A320 family into service in 1988. It was the first airliner conceived with fly-by-wire controls. The aircraft's fuselage has been stretched and shrunken to fill different market niches with the introduction of the A321, A319, and A318. A variety of engines have been used on the Airbus airplanes allowing for incremental improvements in fuel efficiency. As an answer, Boeing launched the members of the Next Generation 737 family in the late 1990s and early 2000s with updated engines, cabin interiors, and flight deck avionics as well as winglets and changes to the airframe.

Categorically, within the vintage generation, the Boeing 737-600 competes directly with the A318; the Boeing 737-700 competes directly with the A319; the Boeing 737-800 competes directly with the A320, and the Boeing 737-900 competes directly with the A321.

The battle between both companies continued with the introduction of the Airbus Neo generation and the Boeing MAX generation. On the one hand, the 737 MAX series is offered in four lengths, typically configured for 138 to 230 seats and a 5,954 to 7,084 km. The 737 MAX 7, MAX 8 and MAX 9 replace, respectively, the 737-700, -800 and -900. Additional length is offered with the further stretched 737 MAX 10 (scheduled to be delivered from 2020). On the other hand, Airbus neo series is offered in three variants, which are based on the previous A319, A320 and A321. The passenger capacity varies between 140 to 244 seats and a range of up to 7,400 km. (**Error! Reference source not found.**).

Model	No of seats	MTOW (t)	Range (nm)	List Price (MUSD)
A220-100	116	60.80	2,950	79.5
A220-300	141	67.60	3,200	89.5
737 MAX 7	138	80.30	3,850	96.0
A319neo	140	75.50	3,700	101.5
737 MAX 8	162	82.19	3,550	117.1
A320neo	165	79.00	3,400	110.6
737 MAX 9	178	88.31	3,550	120.2
737 MAX 10	188	92.00	3,300	129.9
A321neo	206	97.00	4,000	129.5

Table 12.3. Narrow-body current market. [9][10]

The prices' list for two competing models belonging to rival families are comparable and the discount policies of both companies are similar (sometimes even 50-60% discount on the list price)[11].

In today's aerospace market, the MAX and the Neo are the best-selling products for both manufacturers. These models are more fuel-efficient, longer-ranged, enhanced passenger interior and enhanced passenger comfort than previous B737/A320 families, both of which have sold very well since their introductions. A comparison of the evolution of the order backlogs for each of the competing families as per September 2018 is shown in **Error! Reference source not found.**.

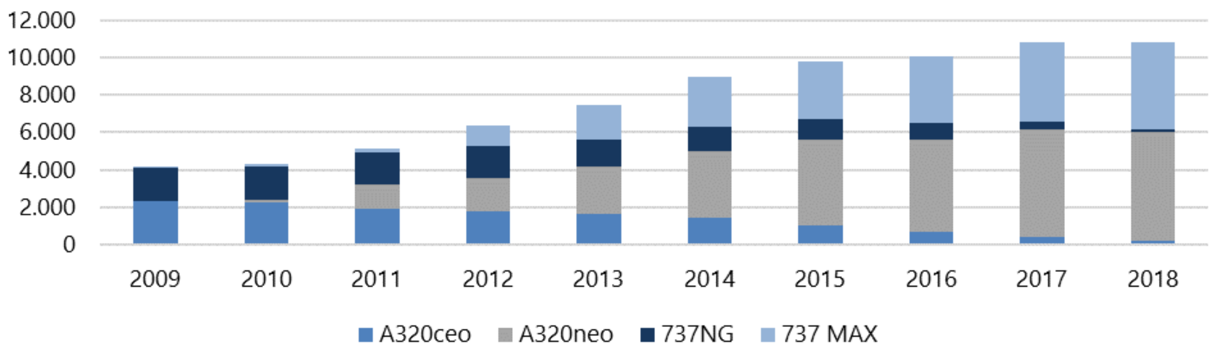


Figure 12.9 - Evolution of order backlogs. [12]

From this representation, it can be easily understood that the attraction of the new generations (3rd for Boeing and 2nd for Airbus) was causing the slow extinction of the previous one and that Airbus managed to absorb a larger proportion of the market demand growth. Comparing both families in terms of total orders, Airbus rules the market of re-engined single aisle, with 60% of the market. It is certainly possible that Airbus will maintain the 60-40 advantage in the following years, but this scenario may change in the upcoming years.

12.2.2.4 Relevant competition factors in the past that might be also in the future

The continuous Boeing-Airbus rivalry has been in place during decades, since Boeing began, in the late 80s and early 90s, to take seriously the challenge of the small outsider established in 1970. The only notable competitor at that moment for Boeing, on the commercial airliner market, was McDonnell Douglas, manufacturer of both narrow bodies and wide bodies. However, McDonnel was strongly affected by the recession in the early 90s and was to be merged into Boeing in 1997. Some analysts even consider that the Airbus presence on the market accelerated the decline of McDonnel and its absorption by Boeing[2]. For a better understanding of the development circumstances of the duopoly, a short review of the conditions in the industry is useful.

The significant achievements in aerospace industry (and here the airliners production is relevant) are based on three ingredients:

1. **Strong financials:** it is well beyond the possibilities of a normal size company to spend the multi-billion dollars necessary to develop a new type of airliner. Producing such machines is an act of large-scale economics, so it needs to be supported, more or less explicitly, by governments. This happens mainly because the private capital is reluctant to approach very large investment with a rather long recovery horizon (they prefer early repayment profiles)[2]. The capital markets are also less inclined to take the risk of failed projects and assume its painful consequences.
2. **Powerful science and engineering resources:** resources that need to be based on an existing wide base of STEM (Science, Technology, Engineering, and Mathematics) education output, on a systematic experience accumulated in any of the contributing fields, as well as on a good capability of invention and innovation.
3. **Efficient industrial organisation:** developing a product means also proper industrialisation. Reaching appropriate production volumes at competitive costs and quality levels to satisfy the market demand is probably the most difficult task. It requires a rather rich experience, a strong discipline, a quality approach well implemented, a science of managing a large supply chain. Every such component of the industrial system is to be built and maintained using a careful design and proof process.

The absence of any single one of these three ingredients spoils any chance of contemplating the entrance on this market. This means that high entry barrier prevents outsiders to threat the incumbents' positions. Any tentative to steal a fraction of the market from the "Big Two" by an outsider not strong enough in all three ingredients is doomed (as the case of Bombardier, despite the active support of the Canadian government).

Finally, it is worth to mention that in the recent history of the industry there are several relevant factors and lessons learned that can be extracted and that should be considered in the future in order to maintain competitiveness in the market. Here are some examples:

Competition between the two producers. A duopoly is a market situation in which only two producers exist. The decisions and actions of one producer affect and are affected by the decisions and actions of the other producer. An example of this situation is reflected in the Airbus/Boeing duopoly, in which both companies have maintained an aggressive competition over time. As a result, manufacturers must pay close attention to the actions and reactions of its competitor as well as to respond to each other's moves to prevent an inferior aircraft in a market segment from losing market share and profit potential. This scenario generally fosters relatively high innovation, high production and low prices in order to maintain an advantage in the market. However, there is also a risk that both producers may collude explicitly or tacitly or reach an agreement in order to reduce their risks for investment and new product development.

Price competition. Due to the intense competition within the sector, it is quite usual that companies such as Airbus and Boeing apply price discounts in their products to gain more market share. This is especially applied for the commercial launch of a new airplane in order to get more orders from airlines. In fact, both companies have accused each other several times of carrying out this type of practices. However, price war hurts the profits of all the companies in a well-established industry and, for that reason, companies should avoid it.

Innovation. Innovation is a key factor that has been used by Boeing and Airbus in their strategies to achieve success, which has enabled both companies to develop products that attract very high demand in the market. Innovation normally implies the use of advanced technologies to develop new products with the objective of seeking performance advantages in their products. Developing modern technologies is a very positive factor that helps to advance the industry, allowing to obtain more modern and efficient aircraft. As an example, the Boeing 787 Dreamliner was the first large airliner to use composites for most of its construction.

Commitment to deliveries. In the industry, there have been cases in which manufacturers have been unable to comply with promises made regarding aircraft deliveries. An example is the Airbus A380 case, a superjumbo jet which has received to date 331 firm orders. This aircraft had several delivery delays that caused dismay from its buyers as well as a drop in the earnings expected. In addition, Airbus had to negotiate compensation with its customers for postponing deliveries. Therefore, to be able to fulfil delivery commitments is an important factor as, in case of not achieving it, it would lead to disappointment and distrust of the company.

Customer-oriented strategies to reach success. Both Boeing and Airbus carefully research customer needs and strive to satisfy them since they represent a competitive and successful factor for a company. In addition, the airplane purchasing decision criteria of airlines include not only load and range factors and operating costs but also passenger comfort. Airbus has been quite competitive and successful in recent years as a result of developing a clear empathy with its customers, encouraging a two-way flow of views, ideas and technical feedback on its aircraft in service around the world.

At present, Boeing and Airbus appear equally competitive. Both companies must understand their customer's needs and buying behaviour, anticipate how customers' needs will evolve over time, keep a close eye on the competition, be innovative in creating customer value, and strive to deliver total customer satisfaction. The company that can consistently and efficiently do all of these will be the winner in the end.

12.2.2.5 SA market in China

Airlines and operators

Development of the airline industry in China is commonly divided into 5 periods [13], [14]:

- The Pre-Reform Tight Regulation (1949-1978).
- The Transitional Stage (1979-1987).
- State-led consolidation and privatization (1988-2004).
- Market-Driven Consolidation and deregulated competition (2005-2012).
- A New wave of deregulation (2013-today).

The actual picture of air transport airline industry in China was conformed during the third period, as a consequence of the consolidation impulse by the CAAC which significantly reduced the number of airlines: 21 in 1994 vs 10 in 2004. This triggered the emergence of the "Big Four", namely Air China, China Eastern, China Southern, HNA Group. The first three are state-owned while the fourth one HNA Group (which owns Hainan Airlines) is a mix of private and municipal, and it is currently struggling with economic problems.

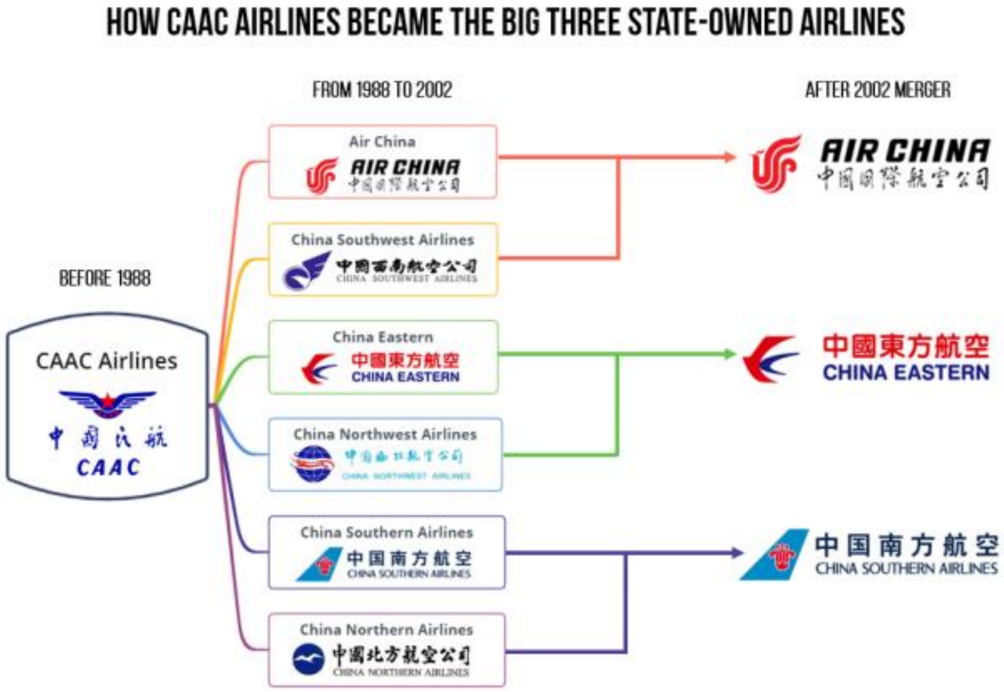


Figure 12.10 - CAAC Split-up and later mergers

In 2013, it started a further liberalization, with the relaxation of minimum price regulation on 31 routes. This was a strong incentive for the Low-Cost Carrier (LCC) and a way to compete with China's new high-speed rail network. In 2015 and 2018 the CAAC relaxed again airfare enabling airlines to increase ticket prices. The deregulation concerned 101 domestic routes in 2015 [15], and 306 highly competitive domestic routes in 2018 [16]. Additionally, in 2018, they relaxed the "one route, one airline" policy from 2009, favouring more internal competition between Chinese carriers, enabling new private companies to enter the competition. The CAA also approved a second wave of private airlines.

Although there are more than 40 airliners in CHINA, 30 are part of the "Big Four" airlines and competition, according to (Wang, Bonilla, & Banister, 2016), has been same between 1994 and 2012. Privately or locally owned airlines tend to fly mostly in routes with less demand in central and western provinces, where local governments are eager to support regional carriers. Tough monopolistic air routes decline in number, most of them today are operated by such airlines. Many experts adventure that the LCC model has a strong potential in China, due to the extreme price-sensitivity of the air transport market and the quasi non-existence of airline-loyalty].[17]. **Error! Reference source not found.** presents the size of Low-Cost airliners in China.

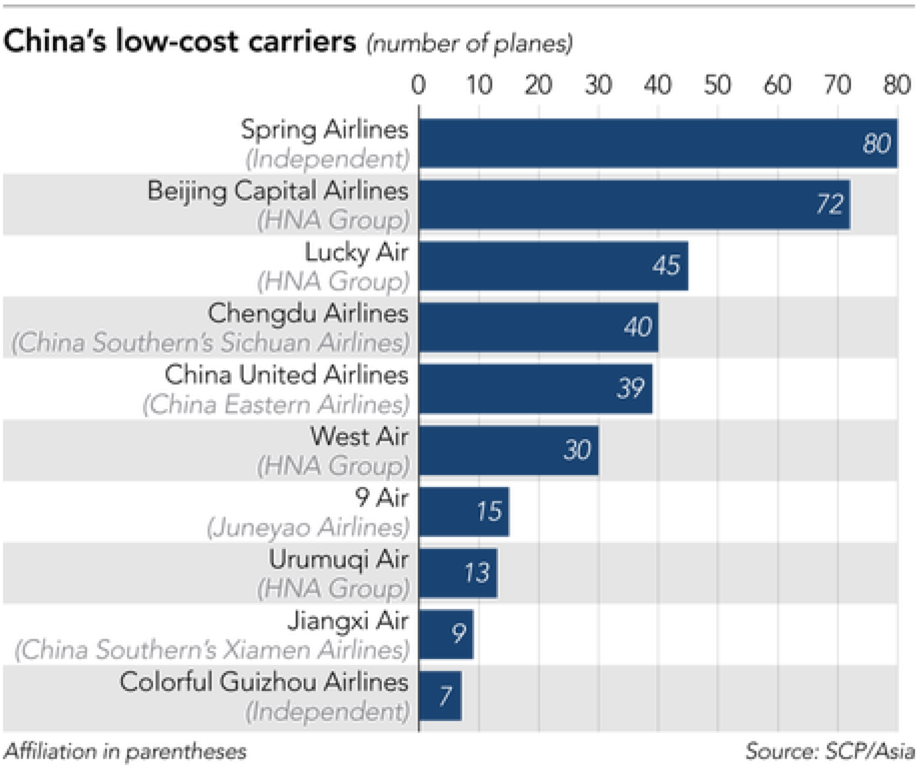


Figure 12.11 - Chinese LCCs by fleet size in 2018 (graph from [14])

Single-aisle fleet in China

In this section, we analyse the fleet of the biggest Chinese airlines[18]. According to Business Insider, the big 3 were among the 20 biggest airlines in the world [19]:

- Air China is number 10 with a capacity: of 90,531,776 seats and a fleet size of 418 aircraft.
- China Eastern Airlines is number 7 with a capacity of 122,917,175 seats and a fleet size of 525 aircraft.
- China Southern Airlines is number 6 with a capacity of 131,972,745 seats and a fleet size of 597 aircraft.

Air China: Air China, founded in 1988, is the flag carrier and one of the three major airlines in China. It is headquartered in Beijing. Beijing Capital International Airport, Chengdu Shuangliu International Airport and Shanghai Pudong International Airport are its hubs. Air China, Air China Cargo, Dalian Airlines, Air China Inner Mongolia share the same logo. Air China has 298 airlines, including 71 international airlines, 15 regional airlines and 212 domestic airlines. Passengers can take Air China to 31 countries and 154 cities, among which are 104 domestic cities, 50 international cities and regions. **Error! Reference source not found.** and **Error! Reference source not found.** summarises the structure of the group and the fleet matrix respectively.

Air China Group	
Airline Full Name	China National Aviation Holding Company
Country	China
Airline Founded	11 Oct 2002
Subsidiaries / Group Airlines	Air China (415 aircraft) Air China Cargo (15 aircraft) Air China Inner Mongolia (7 aircraft) Air Macau (22 aircraft) Beijing Airlines (4 aircraft) Dalian Airlines (12 aircraft) Henan Airlines Kunming Airlines (26 aircraft) Shandong Airlines (124 aircraft) Shenzhen Airlines (184 aircraft)
Headquarters	Beijing
Fleet Size	808 Aircraft (+ 15 On Order/Planned)
Average Fleet Age [1]	6.8 Years
Official Site	http://www.airchinagroup.com/

Table 12.4. Air China Group Fleet Details and History

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A300			8		8
Airbus A319	45		6	12.1 Years	51
Airbus A320	144	5	12	6.4 Years	161
Airbus A321	76		6	6.8 Years	82
Airbus A330	65			7.2 Years	65
Airbus A340			6		6
Airbus A350 XWB	1			0.7 Years	10
Boeing 737	401	9	142	6.3 Years	552
Boeing 747	13		24	11.6 Years	37
Boeing 757	4		10	22.9 Years	14
Boeing 767			15		15
Boeing 777	36		10	5.1 Years	46
Boeing 787 Dreamliner	14	1		2.4 Years	15
Bombardier CRJ-100 Series			12		12
Bombardier CRJ-700			2		2
British Aerospace BAe 146/Avro RJ			4		4
Embraer ERJ-190			5		5
Saab 340			3		3
Tupolev Tu-204			1		1
Total	**808**	**15**	**266**	6.8 Years	**1089**

Table 12.5. Air China Fleet Matrix.

China Eastern Airlines: China Eastern Airlines, founded in 1988, is a major Chinese airline operating international, domestic and regional routes. Its main hubs are at Shanghai Pudong International Airport and Shanghai Hongqiao International Airport, and its secondary hubs at Kunming Changshui

International Airport, Xian Xianyang International Airport and Nanjing Lukou International Airport. With the center of Shanghai and Yangtze River Delta, China Eastern Airlines is well linked with China domestic destinations and international destinations. At present, China Eastern Airlines has been serving 177 countries and regions, 1052 destinations. **Error! Reference source not found.** and **Error! Reference source not found.** summarises the structure of the group and the fleet matrix respectively.

China Eastern Airlines Group	
Country	China
Subsidiaries / Group Airlines	China Cargo Airlines (9 aircraft) China Eastern Airlines (550 aircraft) China Eastern Airlines Executive Air (5 aircraft) China United Airlines (49 aircraft) Shanghai Airlines (102 aircraft)
Fleet Size	716 Aircraft (+ 11 On Order/Planned)
Average Fleet Age [1]	6.1 Years

Table 12.6. China Eastern Airlines Group Fleet Details and History

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A300			13		13
Airbus A310			5		5
Airbus A318	1			11.5 Years	1
Airbus A319	35		13	6.2 Years	48
Airbus A320	204		26	7.6 Years	230

Aircraft Type	Current	Future 2	Historic	Avg. Age	Total
Airbus A321	77			5.9 Years	77
Airbus A330	56		10	5.6 Years	66
Airbus A340			10		10
Airbus A350 XWB	6			0.4 Years	6
Boeing 737	297	10	74	5.5 Years	381
Boeing 747	3		2	15.7 Years	5
Boeing 757			13		13
Boeing 767			10		10
Boeing 777	26			4.6 Years	26
Boeing 787 Dreamliner	7	1		0.5 Years	8
Bombardier CRJ-100 Series			10		10
British Aerospace BAe 146/Avro RJ			13		13
Embraer ERJ-145	4		11	6.0 Years	15
Fokker F70 / F100			10		10
McDonnell Douglas MD-11			10		10
McDonnell Douglas MD-80			16		16
McDonnell Douglas MD-90			9		9
Total	716	11	255	6.1 Years	982

Table 12.7. China Eastern Airlines

China Southern Airlines: China Southern Airlines, founded in 1988, is an airline headquartered in Guangzhou. Its main hubs are Guanzhou, Baiyun International Airport and Beijing Capital International Airport. Its secondary hubs are Chongqing Jiangbei International Airport and Urumqi Diwopu International Airport. Along with Air China and China Eastern Airlines, China Southern Airlines is China's "Big Three" airlines. Every day, there around 2000 flights to more than 40 countries and regions, 195 destinations. Cooperating with SkyTeam, China Southern Airlines' network is linking with 177 countries and regions, 1052 destinations.

China Southern Airlines		
CHINA SOUTHERN AIRLINES		
IATA **CZ**	ICAO **CSN**	Callsign **CHINA SOUTHERN**
Airline Full Name		China Southern Airlines Co., Ltd.
Country		China
Airline Founded		Mar 1995
Group / Part of		China Southern Air Holding
Base / Main Hub		Guangzhou Baiyun (CAN / ZGGG)
Fleet Size		616 Aircraft (+ 16 On Order/Planned)
Average Fleet Age [1]		7.1 Years
Official Site		https://www.csair.com/

Table 12.8. China Southern Airlines Fleet Details and History

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
ATR 42/72			5		5
Airbus A300			6		6
Airbus A319	23		18	13.9 Years	41
Airbus A320	136	2	24	8.1 Years	162
Airbus A321	124	2		6.7 Years	126
Airbus A330	48		2	6.5 Years	50
Airbus A350 XWB		3			3

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A380	5			7.6 Years	5
Boeing 737	215	8	80	6.4 Years	303
Boeing 747	2			17.0 Years	2
Boeing 757			32		32
Boeing 767			6		6
Boeing 777	24		10	5.3 Years	34
Boeing 787 Dreamliner	21	1		3.1 Years	22
Embraer ERJ-145			6		6
Embraer ERJ-190	18		2	7.1 Years	20
McDonnell Douglas MD-80			23		23
McDonnell Douglas MD-90			13		13
Total	616	16	227	7.0 Years	859

Table 12.9. China Southern Airlines

Hainan Airlines: Hainan Airlines, founded in 1993, headquartered in Haikou, is the fourth largest airline in terms of fleet size in China. Its main base is Haikou Mailan International Airport and its hubs are Beijing Capital International Airport and Xian Xianyang International Airport. Hainan Airlines is one of the seven Asian airlines rated as five-star by Skytrax. It serves nearly 500 domestic and international routes and flies to more than 90 cities. International routes can reach Asia, like Bangkok, Phuket, Male, Almaty; Europe, like Paris, Brussels, Berlin, Moscow, St. Petersburg; and the Americas, like Seattle, Toronto, Chicago, Boston, etc.

Hainan Airlines Group	
HNA	
Country	China
Subsidiaries / Group Airlines	Air Changan (11 aircraft) Air Guilin (11 aircraft) Capital Airlines (89 aircraft) China West Air (35 aircraft) China Xinhua Airlines (5 aircraft) Deer Jet (3 aircraft) Fuzhou Airlines (18 aircraft) Grand China Air (3 aircraft) GX Airlines (27 aircraft) Hainan Airlines (238 aircraft) Hong Kong Airlines (43 aircraft) Hong Kong Express (24 aircraft) Lucky Air (54 aircraft) Shan Xi Airlines (1 aircraft) Suparna Airlines (26 aircraft) Tianjin Air Cargo (3 aircraft) Tianjin Airlines (96 aircraft) Urumqi Air (17 aircraft)
Fleet Size	704 Aircraft (+ 28 On Order/Planned)
Average Fleet Age [1]	5.9 Years

Table 12.10. Hainan Airlines Group Fleet Details and History

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A319	28		5	10.7 Years	33
Airbus A320	160	2	1	4.9 Years	163
Airbus A321	32			2.1 Years	32
Airbus A330	81	6		5.8 Years	87
Airbus A340			3		3

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A350 XWB	10	11		1.1 Years	21
Boeing 737	276	6	41	6.6 Years	323
Boeing 747	4			20.7 Years	4
Boeing 767			5		5
Boeing 787 Dreamliner	40	2		2.7 Years	42
Bombardier CRJ-100 Series			2		2
Bombardier CRJ-700			1		1
COMAC ARJ21		1			1
Dornier Do-328			29		29
Embraer ERJ-145			25		25
Embraer ERJ-170			4		4
Embraer ERJ-190	70			7.1 Years	70
Gulfstream Aerospace G-V Gulfstream	3				3
Hawker Beechcraft Hawker 4000			1		1
Total	704	28	117	5.9 Years	849

Table 12.11. Haina Group Fleet Matrix

Sichuan Airlines: Sichuan Airlines is a regional airline headquartered in Chengdu, operating mainly domestic flights out of Chengdu Shuangliu International Airport, Chongqing Jiangbei International Airport, Kunming Changshui International Airport, Hangzhou Xiaoshan International Airport, etc. It has 160 routes to 79 destinations. International flights can reach Hong Kong, Taiwan, Moscow, Sydney, Kathmandu, Soul, Maldives, Phuket, Saipan, Djakarta, Ho Chi Minh, Vancouver, Melbourne, etc.

Sichuan Airlines		
SICHUAN AIRLINES		
IATA **3U**	ICAO **CSC**	Callsign **SICHUAN**
Country		China
Airline Founded		19 Sep 1986
Started Operations		14 Jul 1988
Base / Main Hub		Chengdu Shuangliu (CTU / ZUUU)
Fleet Size		152 Aircraft (+ 8 On Order/Planned)
Average Fleet Age [1]		5.5 Years
Official Site		http://www.scal.com.cn/

Table 12.12 - Sichuan Airlines Fleet Details and History

Aircraft Type	Current	Future [2]	Historic	Avg. Age	Total
Airbus A319	23		1	9.9 Years	24
Airbus A320	58	2	13	5.7 Years	73
Airbus A321	54	3	6	3.9 Years	63
Airbus A330	13	3	1	4.6 Years	17
Airbus A350 XWB	4			1.8 Years	4
Boeing 737			1		1
Embraer ERJ-145			5		5
Total	152	8	27	5.5 Years	187

Table 12.13 - Sichuan Airlines Fleet Matrix

Single-aisle market share in China

Error! Reference source not found. presents the A320 and B737 fleet currently operating in Chinese airliners, both at cargo and passengers operations, according to actualised data at [18]. **Error! Reference source not found.** presents the actual market share for the A320 and B737 family's models considering both cargo and passengers aircraft. By May 2019 A320 family in service in China totalled some 1658 aircraft corresponding to 212 A319, 997 A320 and 448 A321. B737 aircraft totalled 1353. A320 family represents 55% of the market against the 45 % of the B737.

Additionally, in April 2019 Airbus has signed a deal for 300 aircraft with the state agency China Aviation Supplies Holding Company worth an estimated $US35 billion at list prices. The two signed a general terms agreement in Paris during the visit of Chinese President Xi Jinping for 290 single-aisle A320 family planes and 10 widebody A350 XWB aircraft.[20]

	ACTUAL FLEET				
Airliners Group	**Airbus A318**	**Airbus A319**	**Airbus A320**	**Airbus A321**	**Boeing 737**
Air China Group		45	144	76	401
China Eastern Airlines Group	1	35	204	77	297
China Southern Airlines		23	136	124	215
Hainan Airlines Group		28	160	32	276
Sichuan Airlines		23	58	54	0
Air					18
Air Travel		3	4	2	
CCB leasing group			2		
CEFC China Energy Company Limited		1			
Chengdu Airlines Fleet Details and History		4	30		
China Express Airlines			9		
China Postal					22
Dehong South Asian Airline					1
Donghai Airlines					23
Evergrande Real Estate Group		1			
Joy Air					1
Juneyao Airlines			41	27	
Longhao Airlines					6
Longjiang Airlines			1	2	
Loong Air			39		3
Nanshan					1
Okay Airways					29
PLAAF - China Air Force		3			14
Qingdao Airlines			19		
Ruili Airlines					19
Sany Group		1			
SF Airlines (ShunFeng Airlines)					17
Shan Xi Airlines					1
Sichuan Airlines		23	58	54	
Sino Jet					2
Spring Airlines			86		
Tibet Airlines		22	6		
YTO Cargo Airlines					7

TOTAL	**1**	**212**	**997**	**448**	**1353**

Table 12.14. - Actual Single-aisle Fleet at Chinese Airliners.

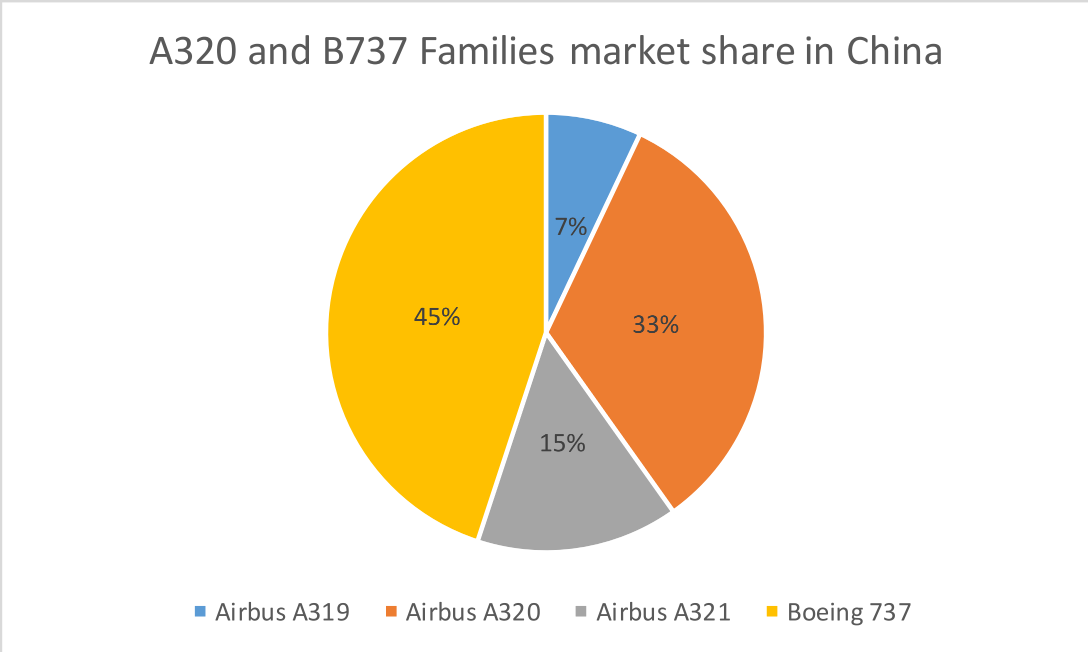


Figure 12.12 - A320 and B737 current families market share in China Airliners (passengers and cargo aircraft included)

12.2.3 Forecast for Single-aisle sector

12.2.3.1 Flight Fleet Forecast (FFF)

Forecasting the number of airplanes demanded by airlines and passengers in the future is a complex problem affected by important uncertainties. Although a number of approaches and methodologies have been developed by the academia and the industry, the accuracy of any fleet demand forecast relays very much on a deep knowledge of the industry and on reliable data about the evolution of the various markets and segments.

A selected group of companies, including manufacturers, consultancies and governmental agencies, produces regular updates of short, medium- and long-term forecast that are considered a reference for any market study in aviation. In particular, Boeing and Airbus, both release each year twenty-five-year market forecasts for aircraft demand, which provides some insight into the qualitative nature of the market demand and how the two major producers expected demand to evolve over the coming two decades.

In this chapter, we analyse the worldwide studies produced by Boeing and Airbus to understand how the potential market for Chinese aviation industry might evolve in the next 20 years. The aim of this study is not to build an additional forecast, but to integrate the best publicly available long-term forecasts, as well as hypothesis and trends highlighted by reference reports about credible expected evolution of airplane fleets demand, production, retirement and delivery. All these inputs about the expected long-term evolution of the global world fleet market will be used to dimension the size of the possible Chinese aviation industry, in particular, the market for the C919. That way, the current study will benefit from the best knowledge in the market and will integrate the most optimist and also conservative approaches and hypothesis about the global commercial aircraft market.

Airbus Market outlook 2018-2035

Every year, Airbus [21] delivers its market prospects for the following 25 years. In this market forecast, the company estimates the evolution of air traffic over the next years using an econometric model based on the GDP growth, wealth and middle-class share growth estimations.

The main driver for the air transport demand is the wealth effect of people owning higher wages and increasing their predisposition to travel, and so increasing the air transport demand. The evolution of the middle-classes is an excellent proxy for this relationship. In 2002, about a quarter of the world's population could be described as "middle class", today it's considered to be around 40% and by 2037, Airbus forecasts it to be around 57%.

Business models are an important part of the evolution of air transport. Airlines evolve over time to meet the requirements of passengers, to take advantage of the opportunity and to respond to competition. The low-cost model has helped to deliver additional growth, through the provision of low fares and new city pairs largely. In recent years, the low-cost model has evolved including ultra-low-cost modalities and started offering seats in the long-haul segment. This has made air transport more accessible to the middle class.

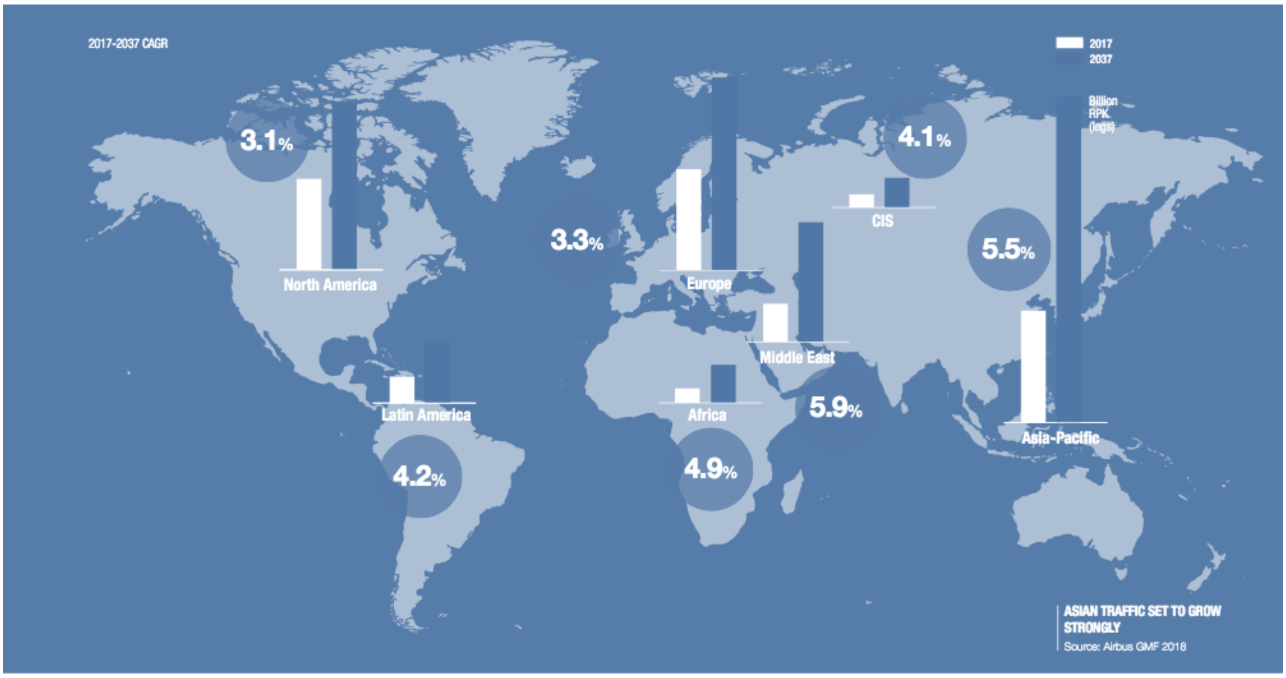


Figure 12.13. Airbus' air traffic growth forecast. Source: Airbus GMF 2018. [21]

Error! Reference source not found. shows the estimations of air traffic growth in the following 20 years made by Airbus. It can be seen that Asia-Pacific, Middle East and Africa will be the regions with the biggest growth percentage by average. Tourism is playing an increasing role in Asia, which has grown by nearly 270 million since 1990. Asia-Pacific broke a new record in foreign arrivals in 2017, topping a cumulative count of 636 million visitors to the region, according to a report by the Pacific Asia Travel Association (PATA). Traffic from these emerging countries will rise at a rate of 5.5% per year according to Airbus' report. Passengers travelling between emerging countries (intra-regional and domestic traffic) is forecast to grow at 6.0% per annum and inter-regional traffic is expected to grow at 4.7%. This will represent a growing share of air traffic, from 29% of world traffic in 2017 up to 40% by 2037.

Looking into more detail to the prospects for the Asia-Pacific region, Airbus foresees that although India is now outpacing China in economic growth, Asia-Pacific remains firmly connected to China and its transition to a service/domestic consumption-based economy. The worst fears on slowing Chinese economic growth have eased, although this has been replaced to some extent with trade concerns, as new manufacturing hubs such as Vietnam and Indonesia are emerging in Asia as China's cost competitiveness evolves. China will experiment a big growth, especially in domestic traffic. According to Airbus, Chinese domestic traffic will multiply by a factor of 3.5 over the next 20 years. Indian subcontinent and domestic flights inside India will carry 5.9 times more passengers than in 2017. It also highlights that India will experiment with the fastest growth at a rate of 5.4% per year. In Asia, domestic sources of growth, particularly private consumption, will play a larger role in the coming years. Asia-Pacific will continue to lead world economic growth with expected average real GDP growth of +3.9% per year over the next 20 years.

According to fleet forecast, Airbus remarks the increase of the single-aisle fleet, which evolved much faster than the wide-body fleet over the last ten years. This is due to a higher number of seats in this family of planes and longer-range capabilities that opened new routes. The average distance flown by single-aisle aircraft was 422 NM with 140 seats on average back in 1999 and 586 NM with 169 seats on average. Airbus forecasts 36,563 new deliveries on the following 20 years, composing a global fleet of 45,265 aircraft, comparing to the 2018 global fleet of around 19,000 aircraft. This refers to 100+ seats aircraft and does not include Russian models.

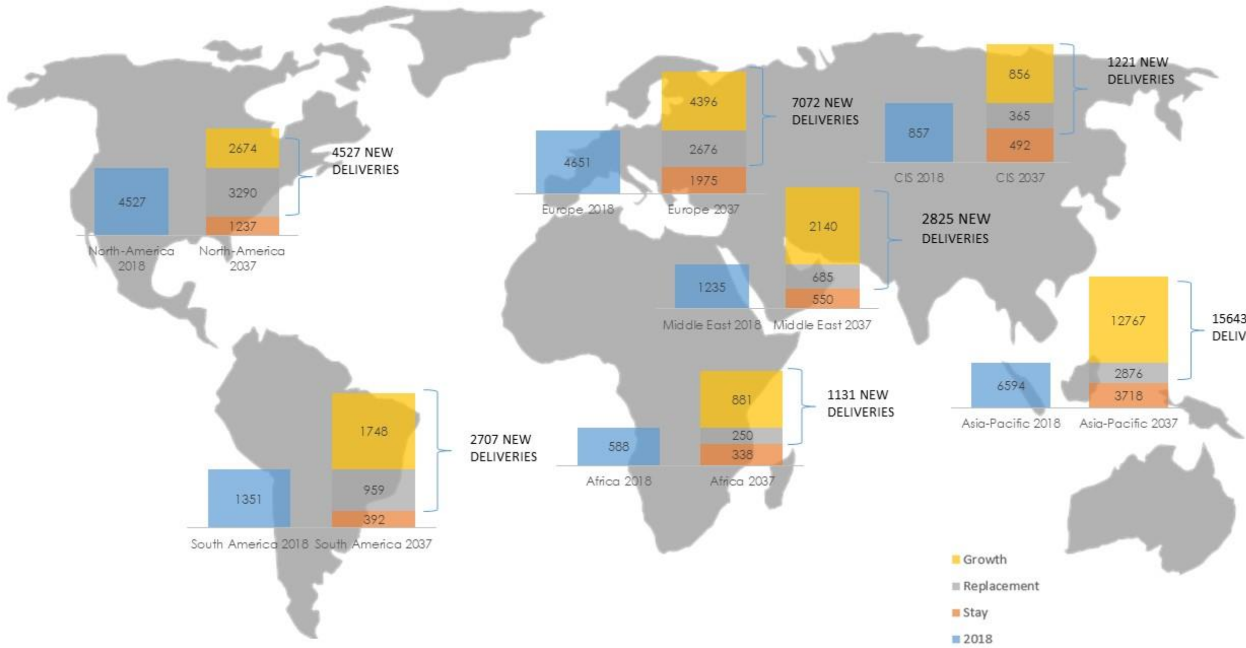


Figure 12.14. World fleet evolution 2017-2037 according to Airbus GMF 2017-2037

Error! Reference source not found. shows the fleet evolution regionally over the next twenty years. It is clearly seen that Airbus forecasts the Asia-Pacific countries as the main drivers of the aerospace sector, with more than 15,643 deliveries representing a growth of almost two times the actual fleet, and around the 40% of the world fleet. A factor helping to characterise the intra-regional Asia-Pacific market is the large population centres and relatively large distances between them. More in detail **Error! Reference source not found.** indicates the evolution of the fleet in service expected for the Asia-Pacific region. By segment, new deliveries will be distributed as indicated in **Error! Reference source not found.**. The Middle East will multiply its fleet by a factor of 2.7, and other developing regions such as South America, Africa or the Commonwealth of Independent States will duplicate its air fleet. On the other hand, North America, the region that had boosted air transport on its early beginnings will no longer dominate the market, and its fleet growing perspectives are around 50% of the current fleet, according to this Airbus report.

According to Airbus, small aircraft such as the Airbus A320 or the Boeing 737 will dominate the market, representing 76% of the deliveries worldwide, and 54% of the value.

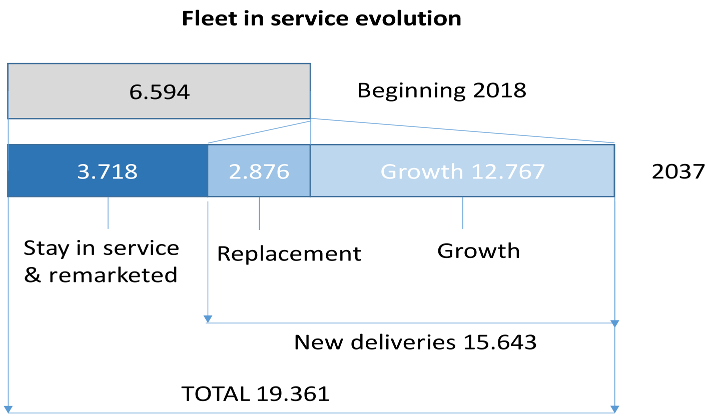


Figure 12.15. Fleet in service evolution in the Asia-Pacific region according to Airbus for the next 25 years.

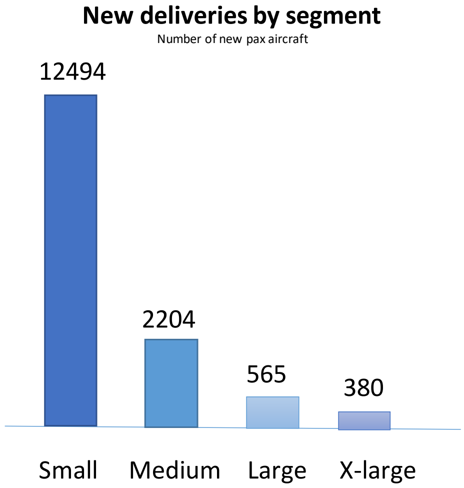


Figure 12.16. New deliveries distribution by segment for the Asia-Pacific region according to Airbus for the next 25 years.

Boeing Market outlook 2018-2035

Like its European competitor, Boeing also delivers its own market forecasts yearly. In this commercial aviation outlook, the US manufacturer points out the three macro-environment dimensions that drive airplane demand. [22]

- On the one hand, there is the underlying **demand for air travel**, which is lead fundamentally by economic and income growth. The **growth of the world GDP** is mainly composed by the changes in large emerging countries like China or India. This growth causes bigger support for air travel due to higher **consumer spending.** Economies like China are transitioning to a more service-based economy due to higher automation relative to manufacturing worldwide, which will support air travel in the future. The higher incomes will lead to more predisposition to travel, as tourism becomes a growing part of consumer spending.
- Air travel demand is followed by the **regulatory, infrastructure and technology environment**. The increasingly **liberalized markets** have been an important asset to the

commercial airline industry. Another key driver for the future demand will be **the airport infrastructure and congestion.**

- Besides economy and infrastructure, the **products and strategies followed by the airlines** are also the main drivers of the sector. Low fares boost demand with strategies like fleet standardization (single aisle), lower yield and higher load factor, ancillary revenues… etc. New trends like ULCCs (ultra-low-cost carriers) are expected to arise in the future, and also the entry of LCC into long-haul routes. **Network airlines** such as IAG will also be important in the future, with products spanning in the low cost, long-haul sector, like LEVEL.

With these three environments identified as the main boosters of demand, Boeing forecasts a 4,7% average annual passenger traffic growth in the next 20 years. Asia-Pacific region will be the one contributing most to passenger growth, with an average rate of 5,7%.

According to Boeing market outlook for the period 2018-2039, socioeconomic changes in large emerging markets such as China will be primary drivers of both global GDP growth and demand for air travel.

The number of air passengers in China has increased at an average rate of more than 10 percent each year since 2011, and it is becoming the first largest commercial aviation market (see **Error! Reference source not found.**). The middle classes in China have developed as well, and their propensity to travel has increased dramatically.

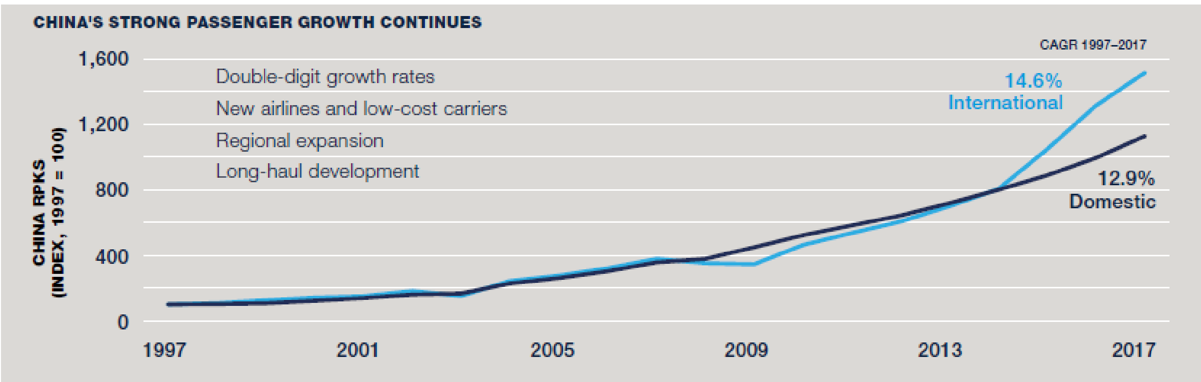


Figure 12.17. Continuous strong passenger growth in China in the last 11 years.

An insight made by Boeing into this region shows that China is on its way to becoming one of the world's largest aviation markets, accounting nearly 20% percent of the global traffic by 2037. Drivers for this increase are the strong economy and the increasing urbanisation. China's GDP is estimated to grow at a rate of 4.8% annually in the next 20 years. This will increase China's share from 13% of total GDP today to 19% in 2037. The share of people living in cities in China has grown by 25 percentage points during the last 20 years and now is close to 60%.

Traffic is expected to increase in China by 6.2% annually. To cope with that increase the fleet will grow by a 4.5 % annually, accounting for the market value for 1.190 Billion of dollars (see **Error! Reference source not found.**).

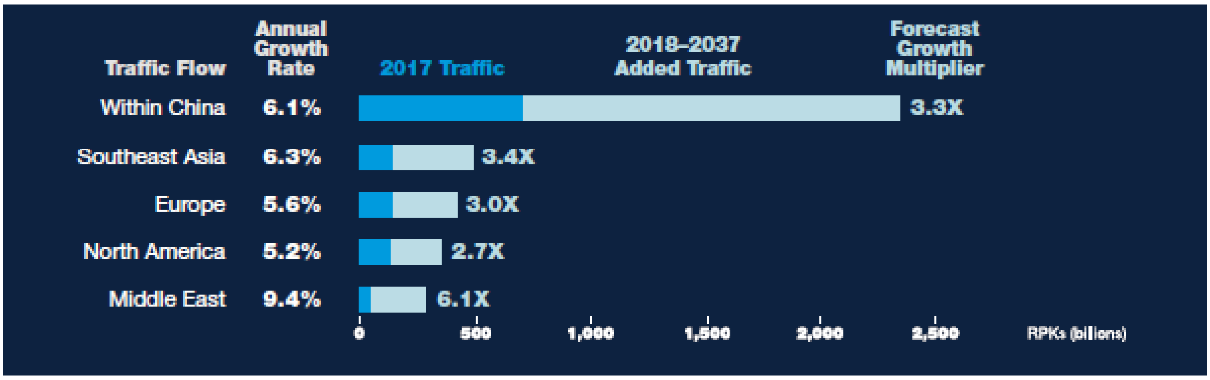


Figure 12.18. China traffic flows growth for 2018-2037

Southern-Asian developing countries such as India that will quadruple its fleet will follow Chinese traffic growth. Africa, on the other hand, is the region with the highest growing rate in the world, with 6% per annum by average. The US company forecasts African connectivity will be improved over the next 20 years resulting in a great increase in the transport. Nevertheless, it will continue being the region with the least developed aviation sector. The following map shows the growth rate of every region listed by Boeing in its Commercial Market Outlook.

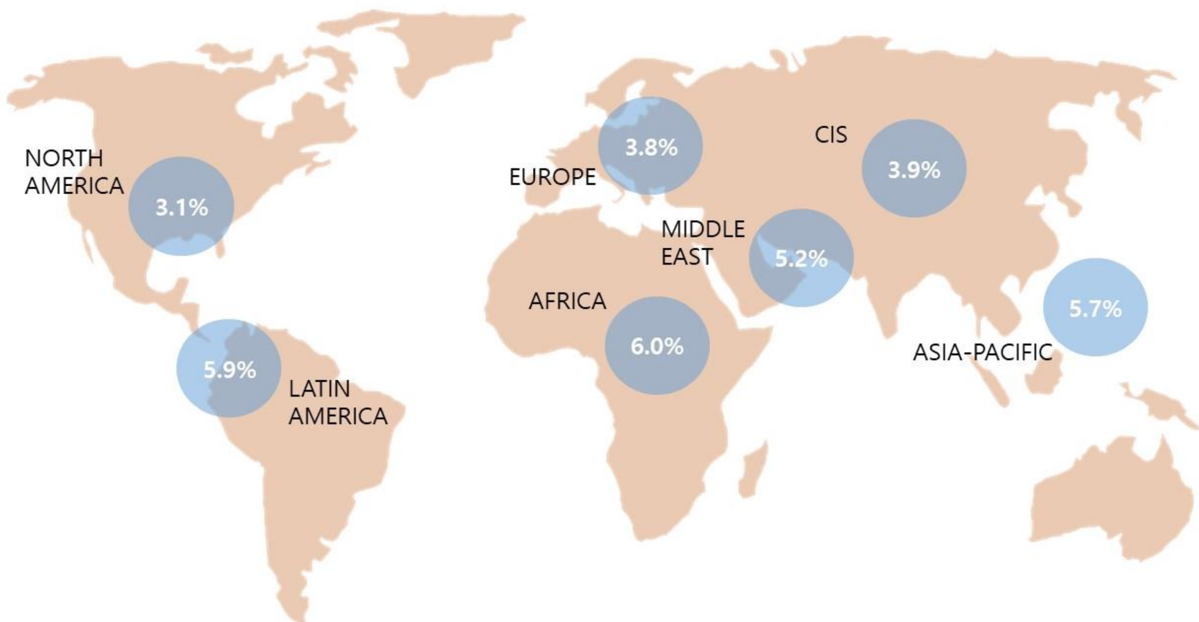


Figure 12.19. Boeing's traffic growth forecast by region.

Unlike Airbus, Boeing considers a wider range of aircraft for its Commercial Market Outlook. The US company also considers the regional jet fleet, which sums up a global fleet of 24,000 at the beginning of 2018, a bigger size than the 21,000 aircraft considered by Airbus in its forecast. Boeing forecasts the global fleet to double to nearly 48,000 by 2037, with more than 42,700 new deliveries. Most of these deliveries will account to single-aisle aircraft, alongside more than 9,000 new wide-body aircraft. Asia-Pacific region will receive more than 40% of these new aircraft, as well as an additional 40% to be delivered to Europe and North America. The remaining 20% will satisfy the demand of Russia and Central Asia Regions, Middle East, Latin America and Africa.

By itself, China will receive 7690 deliveries distributed as indicated in Figure 12.20. By 2037 the fleet will more than double in China. 31% of the deliveries will correspond to the replacement of existing airplanes. Out of the 7690 deliveries, 200 (3%) will be freighter, 1620 (21%) will be wide-bodies, 5730 (74%) will be single-aisle and 140 (2%) Regional jets. Single-aisle airplanes will represent 71 percent of the total fleet, and it is expected that the flexibility in size and range of this fleet will enable fast growth in point to point markets within China and bordering regions. Figure 12.21 summarizes the fleet composition in 2017 and the expected fleet composition by 2037.

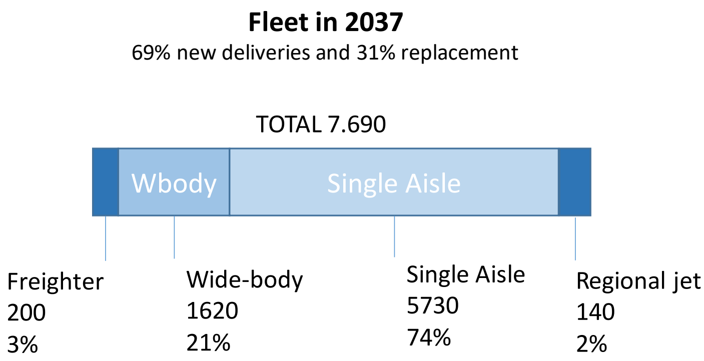


Figure 12.20. Deliveries in China for the period 2018-2037.

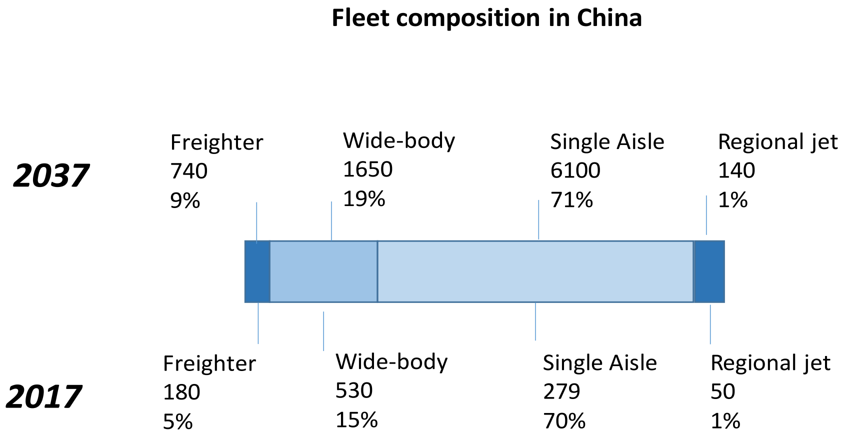


Figure 12.21. Fleet composition in China by 2018 and 2037.

By 2017, Boeing's data shows that 69% of the global fleet was composed of single-aisle airplanes, whereas in 2037 it will account for around 74%. Boeing states that the long-haul market will be dominated by smaller wide-body airplanes due to clients' preferences. The irruption of the single-aisle aircraft into transatlantic routes will also make a turn into the market since the aircraft average size will become significantly smaller.

Error! Reference source not found. shows the global fleet by end 2017 and the forecast of the distribution of the fleet around different regions of the world in 2037. Developing regions such as Asia-Pacific, Latin America, Middle East and Africa will more than double their current fleet, whereas, for Europe and North America, the number of aircraft will increase at a lower rate.

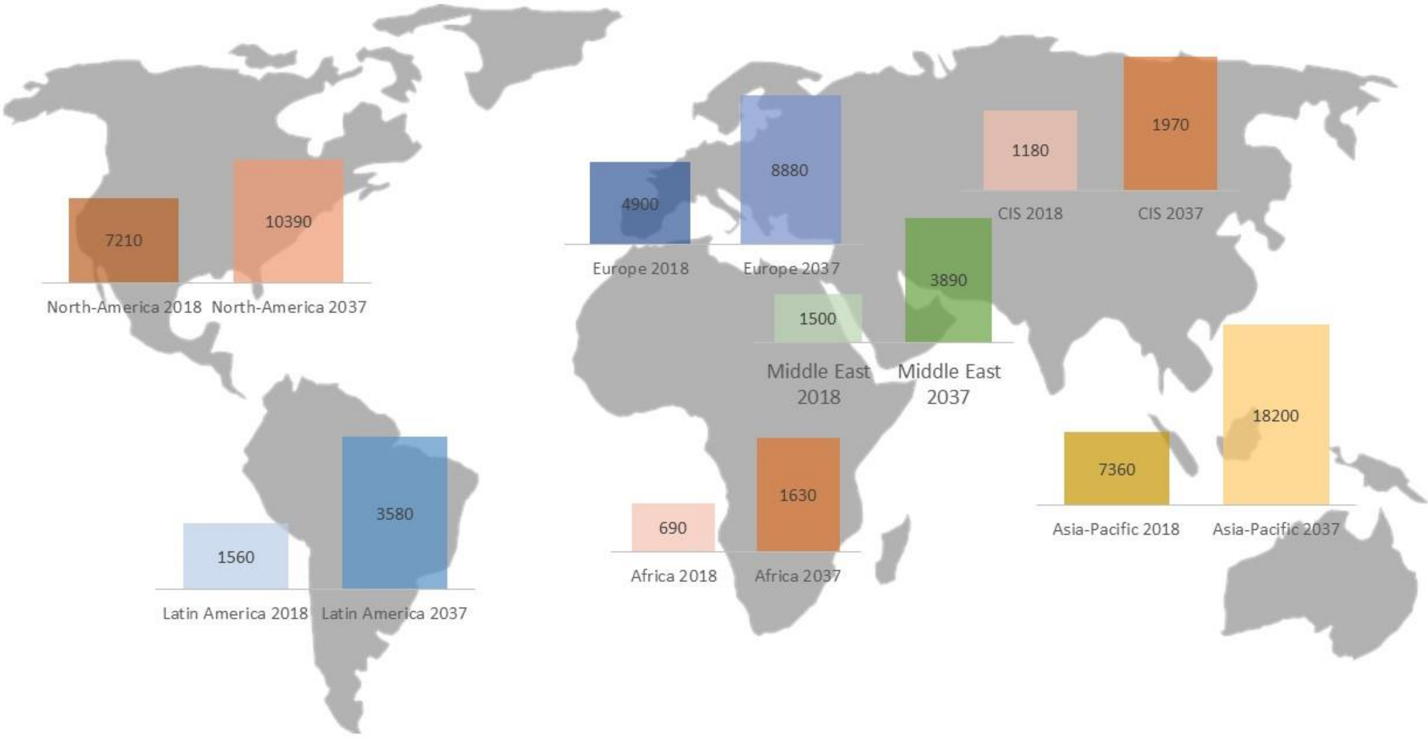


Figure 12.22. Boeing's global fleet forecasts

Single-aisle fleet forecast in China

Based on the two previous analysis, this section summarizes the expectations of both manufactures for the single-aisle market in China. It has to be noticed that market outlooks produced by Boeing and Airbus are not directly comparable, as each one used slightly different market segmentation and present data with dissimilar aggregated statistics. Therefore, the forecasts are taken as an envelope of what the single-aisle market could be in the following 20 years, and these envelopes will help us to estimate the size of the possible market for the C919.

Error! Reference source not found. and **Error! Reference source not found.** summarises the expected traffic growth in the region. As can be seen, Boeing expects a higher increase in the domestic market, but also high increase in the connexion between China and the Middle East and Southeast Asia. Flows with Africa are not considered significant to be detailed in the table, and the manufacturer included it in the overall others categories.

On the other side, Airbus estimates a similar value for the domestic market growth (6.4%) but a lower value with the Middle East. Growth of the flow between China and North America will be higher according to Airbus that estimates 7.1% versus the 5.2% estimated by Boeing. It can be seen that Airbus desegregates a little bit more traffic flows and provides figures for the evolution of the flows with India, Africa and Russia.

Boeing Commercial Market Outlook 2018-2037

Regional Traffic Growth (RPKs in billions)	Average Annual Growth 2017 - 2037
China--China	6.1%
China--Europe	5.6%
China--Middle East	9.4%
China--North America	5.2%
China--Northeast Asia	4.0%
China--Oceania	5.0%
China--Southeast Asia	6.3%

Table 12.15. Regional traffic growth for China according to Boeing Commercial Market Outlook 2028-2037

Airbus Commercial Market Outlook 2018-2037

Regional Traffic Growth (CAGR based on non-oriented leg RPKs values)	Average Annual Growth 2017 - 2037
China—Asia Developed	6.5%
China—Asia Emerging	7.2%
China--Domestic	6.4%
China—Central Europe	4.6%
China—Western Europe	4.4%
China--India	8.9%
China—Middle East	7.3%
China-North Africa	9.4%
China - Pacific	5.7%
China- Russia	5.8%
China- South Africa	9.5%
China - USA	7.1%

Table 12.16. Regional traffic growth for China according to Airbus Commercial Market Outlook 2028-2037

Error! Reference source not found. summarises the forecast of Boeing for the single-aisle segment in the Asia-Pacific region with a detailed view of the figures expected for China's market. Boeing estimates that the region will demand 5730 new aircraft in this segment by 2037, leading to a total fleet of 6100 airplanes at the end of that period.

Boeing Commercial Market Outlook 2018-2037

	Asia-Pacific	China
Total Market Size		
Deliveries	16,930	7,690
Market value ($B)	2,670	1,190
Average value ($M)	160	150

Boeing Commercial Market Outlook 2018-2037		
Unit Share	40%	18%
Value Share	42%	19%
	Asia-Pacific	China
Single-aisle Market		
Deliveries	12,570	5,730
Market Value ($B)	1,410	630
2017 Fleet	5,270	2,790
2037 Fleet	12,880	6,100

Table 12.17. Boeing forecast for the single-aisle segment in China and the Asia-Pacific region.

Statistics by Airbus are aggregated in a way that is more difficult to clearly determine how big the single-aisle market will be for China. Airbus does not specifically differentiate the single-aisle market but considers a different category segmentation that makes difficult the comparison.

In 2018 Airbus has introduced a new market segmentation in its 2018 forecast. It has changed the segmentation methodology dividing segments into categories ranging from 'Small' to 'Extra Large', blurring the traditional boundaries between aircraft types. This new classification redefines the traditional distinction between single-aisle or narrow-body jets and double-aisle or wide-body jets, and between the various types of long-haul aircraft. The "small" aircraft market goes up to 230 seats and ranges up to 3.000 NM. "Medium" category is between 230 and 300 seats and range up to 5.000 NM; and "Large" between 300 and 350 seats and range up to 10.000 NM.

Error! Reference source not found. shows the correlation between aircraft and market segmentation between both manufacturers. As can be seen, the model's direct competence of the C919 is classified by Airbus as small.

For the sake of comparison, we took the estimation made by Airbus for the Small category, although it has to be noticed that Airbus also includes in this category what Boeing separate as regional, so the correspondence between the Airbus small category and the Boeing single-aisle category is not exact.

Boeing classification	Aircraft	Airbus classification
Regional	Antonov An-148, -158	Small
	AVIC ARJ-700	Small
	Bombardier CRJ	Small
	Embraer 170, 175, 175E2	Small
	Mitsubishi MRJ	Small
	Sukhoi Superjet 100	Small
Single-Aisle	Boeing 737-700, -800, MAX-7, MAX-8	Medium
	Boeing 737-900ER, MAX 9, MAX 10	Medium
	Boeing 757 -200, -300	Medium
	Airbus **A318**, A319, A320, A319neo, A320neo	Small
	Airbus A321, A321neo	Medium
	Bombardier CRJ-1000	Small
	Embraer 190, 190E2, 195, 195E2	Small
	Comac C919	Small
	UAC MS 21-200/300	Small
	Tupolev TU-154, -204, -214	Small/Medium
Wide-Body	Boeing 747	Extra-Large
	Boeing 767	Large
	Boeing 777, 777X	Large/Extra-Large
	Boeing 787	Large
	Airbus A330	Large
	Airbus A340	Large
	Airbus A350	Large/Extra-Large
	Airbus A380	Extra-Large
	Illyushin IL	Large

Table 12.18. Passenger's aircraft segments according to Boeing and Airbus. Aircraft in bold are no longer in production. Sources: Boeing, Airbus.

Airbus forecast for the small segment is presented in Data are presented for the Asia region but not specifically detailed for China.

Airbus Commercial Market Outlook 2018-2037

	Asia-Pacific
Total Market Size	
Deliveries Pax	15.643
Deliveries Freight	2520
Total units	15.895
2017 Fleet	6912
2037 Fleet	20163
Small aisle Market	
Deliveries PAX	12.494
Deliveries Freight	0
Market Value ($US billion)	1.424

Table 12.19. Airbus forecast for the single-aisle segment in the Asia-Pacific region.

12.2.4 Evolution of commercial aviation in China

As discussed in previous chapters, the great development, especially during the last 10 years, of the domestic flight market in China is supporting the Chinese will to set up an indigenous civil industry. This is reflected in multiple high-level policy papers, such as the "13th Five-Year Plan", and "Made in China 2025".

More than 200 airports operate in China and the number of aircraft has tripled in the last 15 years. Only in 2014, the country took 20 percent of all aircraft deliveries. Demand among China's rising middle class for air travel means that the country is likely to displace the United States as the world's largest aviation market (measured by traffic to, from and within the country) by the mid-2020s.

The prospects for the industry are extraordinarily good. According to IATA, China will account for 1.6 billion passengers annually by 2037 for a total of 1.5 billion in the United States. According to Airbus and Boeing, China will account for 17% of the 40,000 global airplane deliveries expected during the next 20 years. Airbus and Boeing expect China to buy somewhere in the range of 7,500 new aircraft over the next 20 years. China is considered the largest market, valued at 1 trillion US$ cumulatively. **Error! Reference source not found.** illustrates the foreseen aircraft deliveries in China for the next 20 years.

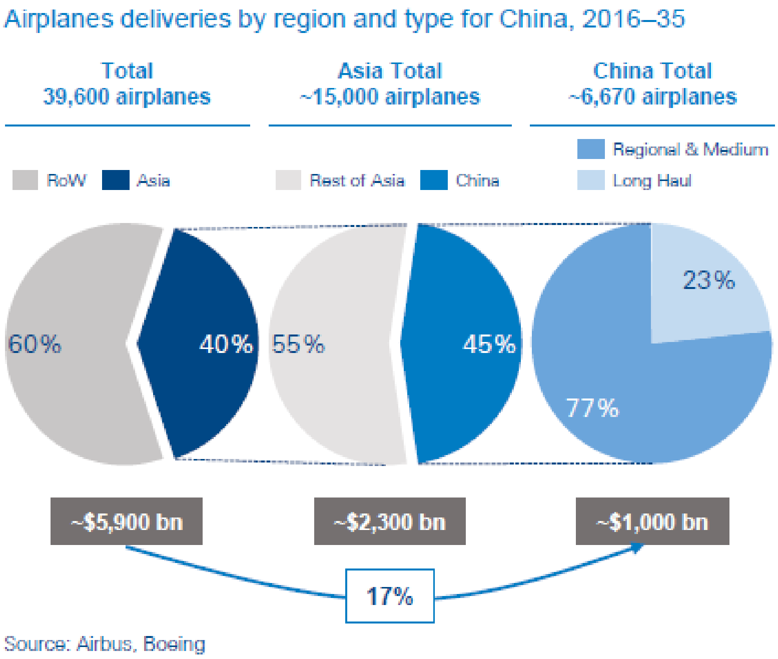


Figure 12.23. Foreseen aircraft deliveries by region and type for China, period 2016-2035.

This playground will be the scenario for incumbent airframes competition to increase market share and China's emerging aviation homegrown alternative to reduce dependency on imported aircraft.

To take advantage of this future growth, the Chinese government decided to structure a domestic commercial-aircraft manufacturing industry capable of reducing its dependence on foreign suppliers and, in the long term, of competing with established OEMs on a global scale.

History of Chinese made passenger aircraft is summarised in the timeline in **Error! Reference source not found.**. Between the 1950s and the early 1980s, the Chinese aeronautical industry mainly focused on the development of military aircraft and a few unsuccessful attempts at manufacturing commercial jet aircraft (e.g., Shanghai Y-10).

In 1985, the partnership established with McDonnell Douglas represented a major turning point, accelerating the Chinese industry's learning process through the joint manufacturing of the MD-82.

The creation of the Aviation Industry Corporation of China (AVIC) in the 1990s and the Commercial Aircraft Corporation of China (COMAC) in the 2000s initiated a phase of consolidation for Chinese industrial capabilities, aimed at developing a full range of commercial jet aircraft. In parallel with developing COMAC as the domestic OEM, the Chinese government invested in building a local supply chain and requested Western players that were willing to capture contracts in China to partner with the local industry, operating transfers of know-how and technologies.

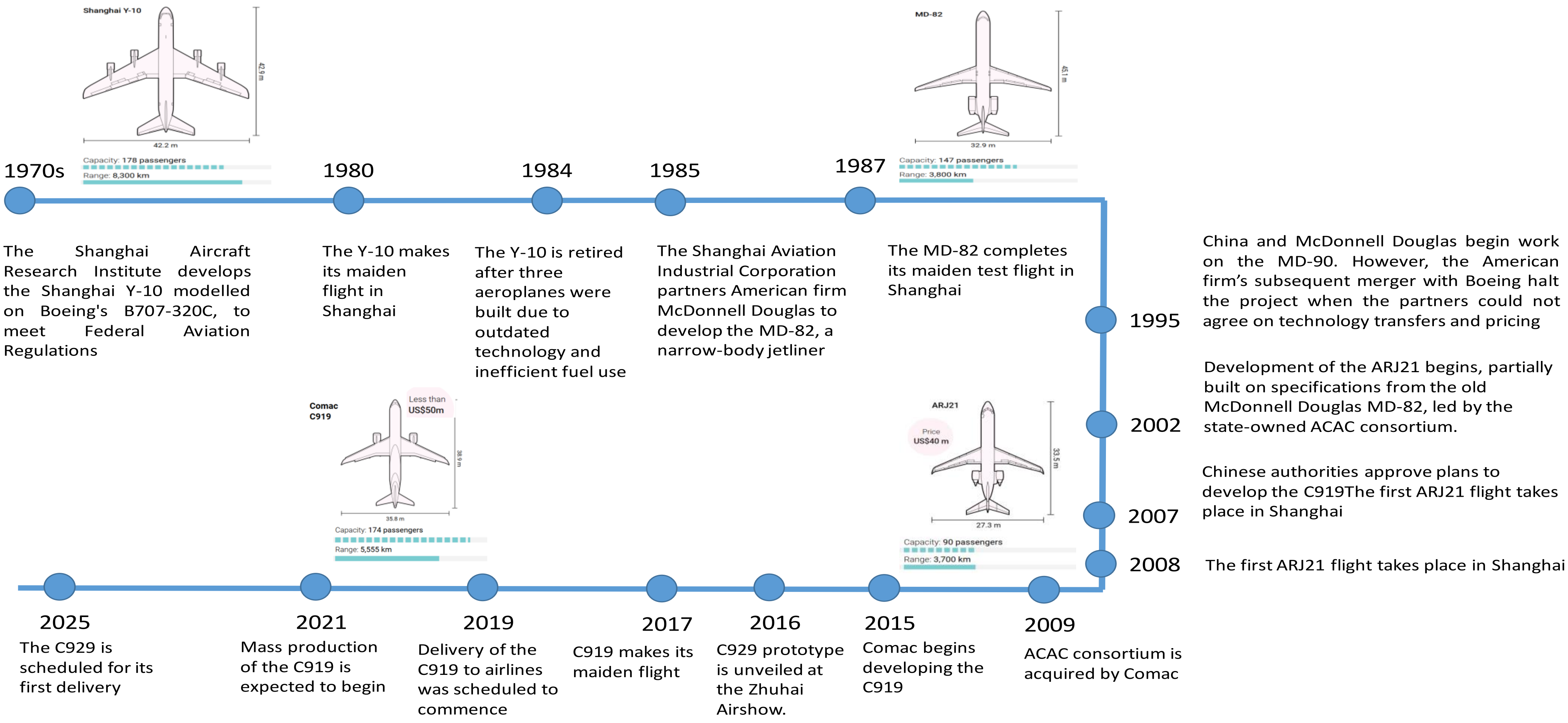


Figure 12.24. A timeline history of Chinese made passenger aircraft [23]

12.2.4.1 Snapshot of the Chinese aviation industry

The first results of the global Chinese strategy are visible in the aerostructures market, where AVIC has developed into a leading tier-1 [2]supplier to all major OEMs. On top of aerostructures, the Chinese government recently started to invest in Aero Engine Corp. Of China (AECC) to develop domestic industrial capabilities for the manufacturing of aircraft engines. To a lesser extent, it also invested in the joint venture between AVIC and GE (AVIAGE Systems) to develop avionics systems.

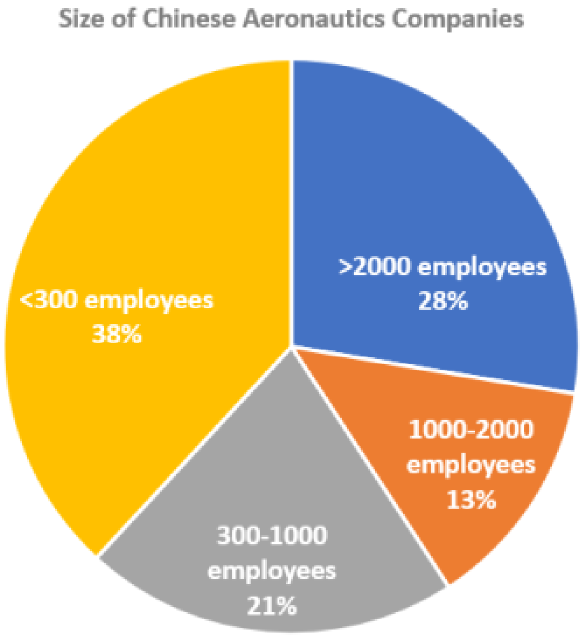
The Chinese aviation industry in 2016, according to the China Civil Aviation Report in 2017 [24], was **composed of 152 enterprises, spread over 22 provinces** (out of the 34 in China). As indicated in **Error! Reference source not found.**, many major aeronautical firms are located in coastal regions, but in general, the industry is well spread over the country. Top Provinces in terms of civil aeronautics revenue are Tianjin (41,9%), Guangdong (20,6%), and Shaanxi (11%). In the Western region, the aviation industry is strongly concentrated in a handful of areas, namely Chengdu, Xi'an, and Guizhou.

Figure 12.25. Distribution of China Aeronautical industry over the country.

Considering their current position in the global aeronautics market, the **size of Chinese industrial players is large**, as can be seen in **Error! Reference source not found.**. However, the **benchmark on the number of employees might point out at potential inefficiencies and redundancies** that Chinese industry still has to polish [25][26]. Total employment in commercial aviation manufacturing has increased from 234,390 in 2005 to 254,844 by 2010, a 9% overall increase and numbers that rival employment in this industry in the United States and other major countries with a large commercial aviation manufacturing industry (see **Error! Reference source not found.**). The absolute numbers

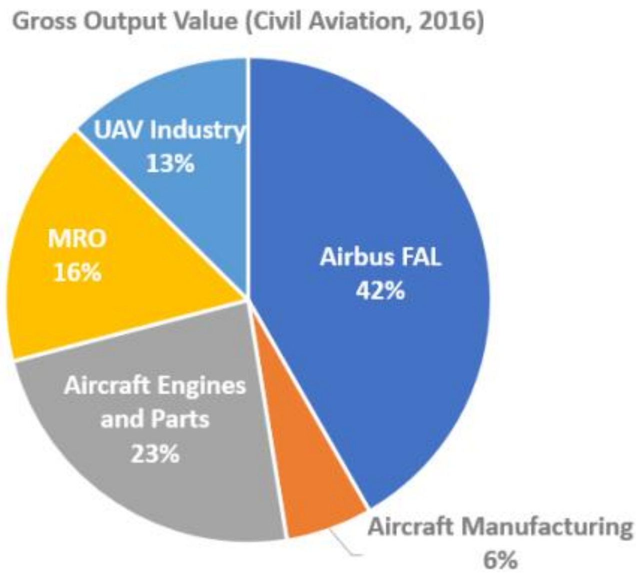
[2] Suppliers in manufacturing industries are often categorized as Tier I, Tier II, and Tier III. Tier I suppliers provide complete modules to original equipment manufacturers for final assembly into the product. Tier II suppliers provide components or submodules to Tier I suppliers. For example, a Tier II supplier might provide the hydraulic assemblies for landing gear manufactured by a Tier I supplier. A Tier III supplier provides parts to Tier I or Tier II suppliers rather than subassemblies or modules.

and shares of employees who are engineers/technicians or are recorded as working in research and development activities have increased in recent years. With 152 companies, Chinese aviation industry employs directly 325 000 people, on average 2138 employees per company. Out of them, 250,000 workers are employed in the civil aviation sector. In comparison, France had in 2017 350 000 employees working in over 3 000 aeronautical companies: roughly an average of 117 people per company.



.Figure 12.26. Distribution of Chinese aeronautical companies per size.

Most of the Chinese aviation industry is turned towards the defence industry: only a third (roughly) of the industry's revenue is generated by civil aeronautics. In 2016, from a total of 247.83 Billion RMB of total revenues generated by both civil and military aviation industry, the civil activity accounted for the 32.4% (80,29 Billion RMB) only. Moreover, a **very significant amount of civil revenue comes from Airbus China (FAL in Tianjin).** The rest is shared among the following (in decreasing order): aircraft parts and aircraft engine manufacturing, MRO, UAV/UAS industry, and indigenous aircraft manufacturing, as indicated in the **Error! Reference source not found.**.



.Figure 12.27. Chinese Civil Aviation Industry gross output value

The aeronautical landscape is spearheaded by 3 large state-owned conglomerates: AVIC, COMAC, and AECC, representing respectively 31% (47), 4% (6) and 9% (13) of all Chinese aeronautical companies. The industry is immersed in an important reorganization. Only in 2015, AVIC was still composed of 63 subsidiary companies, just before the creation of AECC. The same can also be said about COMAC, which was split off from AVIC in 2008. **Revenues are less significant than expected**, due to the dwarfing effect of Airbus China: 15.1%, 4.5% and 4% of the total industry respectively for AVIC, COMAC and AECC.

Output and employment in China's commercial aviation manufacturing industry have been increasing. Between 2005 and 2010, total industry sales increased from $6.8 billion (as measured in 2005 U.S. dollars) to $16.0 billion in 2010. Industry sales (including parts sold to non-Chinese manufacturers) totalled about $16 billion in 2010. By contrast, in 2010, the United States, with 477,000 workers, generated over $171 billion in output in aviation manufacturing: nearly nine times as productive as the Chinese industry.

China's industry has been growing, but **domestic sales, not exports, have been the primary driver**. Compared to aviation manufacturing industries in other countries, sales remain concentrated on the domestic market. Cumulative exports ran 17.3% of the cumulative output from 2005 to 2010, exports as a share of output has fluctuated between 13 and 21%. Significant parts of regional jets produced in China, including avionics and engine components, are Western in origin. In 2014, China exported $3 billion in aircraft and parts [3] vs the $57 billion exported by the United States in civilian aircraft and nearly as much in aircraft engines and parts. The export figures went up to $3.4 Billion in 2016 vs $22 Billion in imports (58% from the US)[27].

The leading sub-sector in the Chinese aviation industry is aircraft parts, both manufacture and repair. China's import market for aircraft parts and components exceeded $2.19 billion in 2016 (30% from the US). China's demand for aircraft parts can be attributed to a number of factors, including increasing capacity utilization rate, the ageing and expansion of China's aircraft fleet, and the domestic production and assembly of aircraft. The best immediate opportunity for foreign companies will be in supplying parts for China's commercial aircraft fleet, as this is the largest and best-established segment of China's aviation market and is currently dominated by western aircraft with western suppliers. China's domestic aircraft parts and assembly manufacturing sector is also growing. Around 200 small aircraft parts manufacturers and a number of regionally based major manufacturers concentrated in Shanghai, Chengdu, Xi'an, Nanchang, Harbin, Shenyang, and Shijiazhuang. Large aircraft and engine manufacturers have committed to expanding procurement in China over the long term, although highly technical and sophisticated parts will continue to be imported.

Sales and Revenue	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Output	$6847	$7475	$11482	$13377	$12728	$169043
% change over previous year	Not available	9.2%	53.5%	16.5%	-4.9%	26.0%
Export	$995	$1262	$2003	"2775	$1779	$2107
% change over previous year	26.8%	58.8%	38.5%	-35.9%	18.4%	26.8%
Export as a share of sales	14.5%	16.9%	17.4%	20.7%	14.0%	13.1%

Table 20. Sales and Revenue of China's Commercial Aviation Industry by Year. (Source: China Civil Aviation Industrial Statistical Yearbook 2007-2011)

Employees	2005	2006	2007	2008	2009	2010
Total employees	234390	230547	251390	246736	241609	254844
Engineers and technicians	36709	38166	52005	49250	48250	48383
Engineers and technicians as % of total employees	15.7&	16.65%	20.7%	20.9%	20.0%	21.4%
R&D personnel	22278	25616	23653	27233	26812	28050
R&D personnel as % of total employees	9.5%	11.1%	9.4%	11.0%	11.1%	11.0%

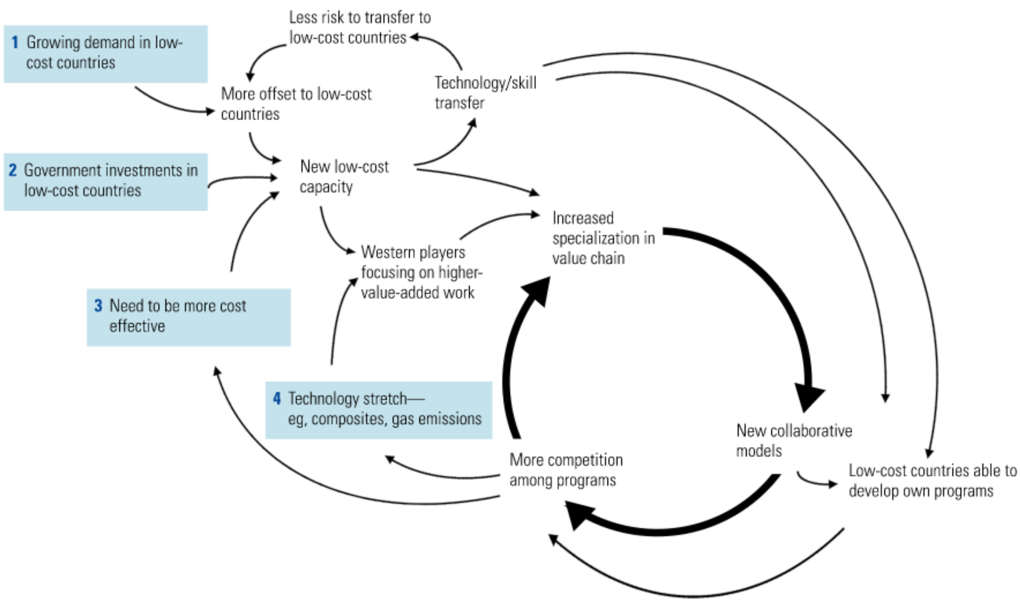
Table 21. Employment in China's Commercial Aviation Industry by Year. (Source: China Civil Aviation Industrial Statistical Yearbook 2007-2011)

The consolidation of the aviation industry in China is contributing to a more global, fragmented and competitive industry. New Boeing and Airbus aircraft involved in a high percentage supplier from all around the world. This creates complex management, coordination, and design integration challenges, but at the same time, these new models have helped them to a considerable reduction in cost and increasing sells in emerging countries. However, despite the global nature of the air transport industry, globalization in commercial aviation, design, development and production remains in its infancy.

The development of emergent strong commercial aviation manufacturing players, particularly China, but also other countries such as India or Russia, will give Western companies major short-term cost-reduction opportunities that they must capture. Lower labour costs in emerging countries, which are, on average, three to five times lower than in the developed ones, can provide major economic savings and advantages, even considering transportation, the coordination complexity and supply chain management, supply disruption risks, etc… The cost of manufacturing typical aircraft structures (such as body panels or fuselage sections) can still be roughly 20 to 25% lower in these emerging markets than in more developed ones. Lower labour costs make these economies also interesting for labour-intensive maintenance and repair services

China and other emergent economies have the potential for increased amounts of low-cost manufacturing and engineering capacity for the aerospace industry. China leaps forward in learning, gain economies of scale, taking its place as a low-cost manufacturing and engineering platform for the world. China could become the preferred location for the manufacturing of simple airframes, while other emergent economies might specialise, for example, in other areas (Russia on low-pressure modules of aircraft engines, and India on detailed engineering). These changes represent a major opportunity for Western players to improve their cost performance through global sourcing, manufacturing, and engineering.

A dynamic view of the emergent economies and their role in the aerospace industry suggests that they will accelerate changes in the value chain [28], as indicated in Figure 12.28. Growing demand in low-cost economies such as China will lead to more offset of production towards these countries, a continuous seduction on the risks involved as technology, and skills are being transferred. In parallel, higher governmental investment in the aerospace industry will help to increase and consolidate these low-cost high technology production capacities. If western manufacturing can take advantage of this low-cost production and could direct its core activity towards higher added value work increasing its specialization and value in the production chain. Further specialization in design, manufacturing, and assembly is likely among both current and emergent players in commercial aviation. Specialization should necessarily go, hand in hand, with more extensive collaboration, placing a premium on an organization's coordination and integration capabilities. New collaborative models between economies and will allow emerging countries to develop their own pragmas, which will increase competition. Completion will place additional pressure over cost efficiency and added value work and specialization.



.Figure 12.28. Chinese Civil Aviation Industry gross output value

12.2.4.2 Aviation research networks structures

The competitiveness of the aerospace industry depends on mastering cutting-edge technologies in a wide range of subjects. The design of a successful aircraft does not tolerate anything less than first-rate solutions in an extensive range of 11 technologies [29], which are illustrated in **Error! Reference source not found.**. Since the substandard mastery of only one of these technologies can cripple an aircraft design and doom its market prospects, it is imperative to remain at the forefront of all 11 technologies to avoid being caught off guard by a competitor. In addition, these technologies must be ready for integration into new competitive products at any time deemed necessary to maintain market leadership in a new development program.

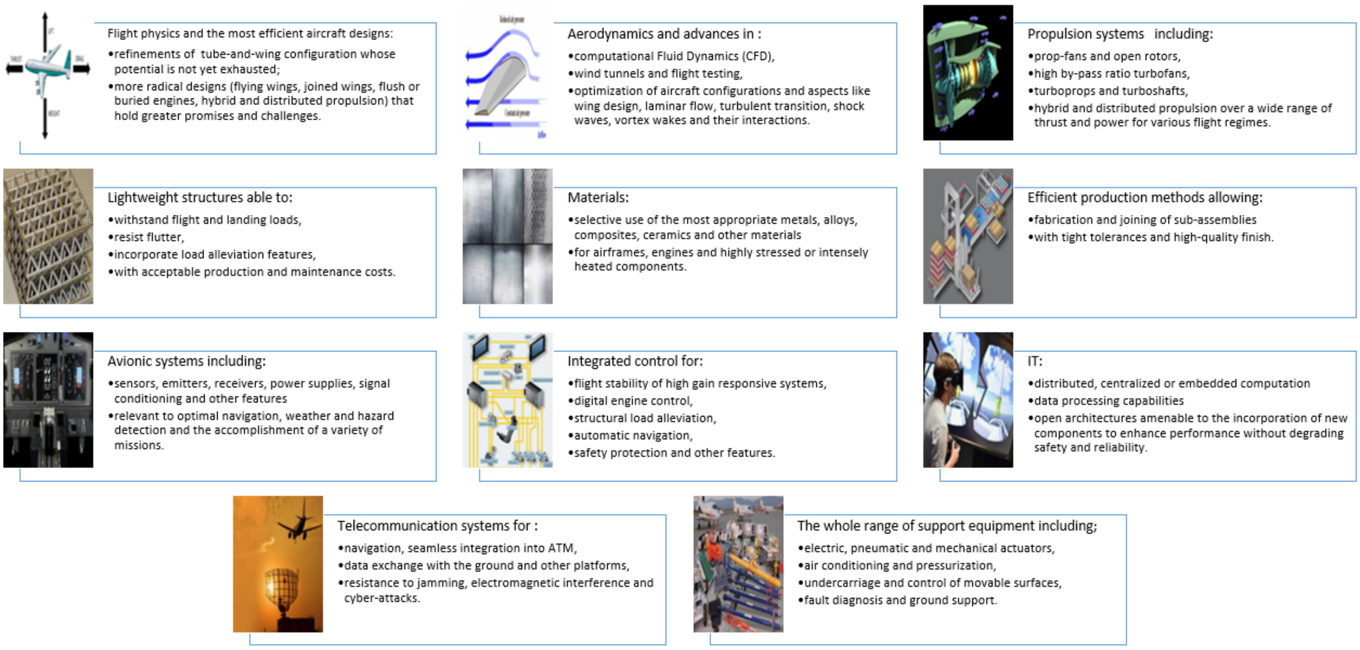


Figure 12.29. Key technological areas for the competitiveness of the aerospace industry.

The accomplishment of the goals envisaged for a future Chinese aviation implies impressive achievements across the full range of aeronautical products, particularly:

- Establishment of leading-edge technologies in all the sectors contributing to the design of aeronautical vehicles;
- Collaboration to integrate all these cutting-edge technologies into efficient aircraft production, certification, and service support programs.

In this section, we provide hindsight into two complementary issues:

- The analysis of the capacity of the Chinese aviation research network, in comparison with the western one, to master key technological areas and to innovate within them.
- The assessment of the aerospace collaboration structures and their ability to cooperate effectively and aggregate the knowledge and efforts that have gone into the innovation path.

These two factors are considered key for the sustainable development of aviation and are analysed in this chapter from the perspective of the technology network's structures. Aviation is a complex system involving highly interrelated technologies whose relations can be mapped as a network. The structure of this network, if mapped with precision, can help us to understand the properties and research of these technologies. Indicators of innovation in aviation, as in other sectors, are the patents in related subjects, collaborative projects, and publications. A technology network analysis is carried out in this chapter from patents, publications, and collaboration data using several databases and graphical analysis of proximity and interrelationships [30].

Two main databases have been used in this analysis. The first part of the study relied on the analysis of scientific and technical publications. Data on the publications were downloaded from the Web of Science (WoS) Database by using the "WC= ("Aerospace, Engineering")" query covering the 2008–2017 period (downloaded from WoS on 27 December 2017). A total of 57,982 publications under this category that were available from the Web of Science and produced in the last decade were analysed. All visuals in this study for publication analysis were prepared by using VOSviewer software (https://www.cwts.nl/, n.d.).

The second analysis focused on the evaluation of patents. In this analysis, the Derwent Innovations Index Database was used as a data source. In this database, patents are classified into 20 broad categories and three overall areas: Electrical and Electronic Sections (S–X), Engineering Sections (P–Q), and Chemical Sections (A–M). Categories are further split into classes, which are identified by a letter and two digits. For example, Automotive Electrics is designated as X22. The search term 'aviation' in the topic field of patents resulted in 23,508 patents. Since this study is configured as explanatory, filters were not applied to limit the data corpus at first. Data were retrieved from the database and then cleaned for further analysis. Some pre-specified thesauruses and fuzzy clustering algorithms were applied in this stage. The patent analysis was performed with VantagePoint software [31].

Assessment of the aerospace collaboration structures on the basis of the Web of Science database.

Hereafter we describe the international aviation scientific collaboration networks according to the nations and institutions involved, as well as according to aerospace subfields involved, to analyse the presence of Chinese institutions on them.

International Collaboration Networks

Figure 12.30 is presented to convey an understanding of the international aviation collaboration network. From the scientific field co-occurrence analysis, 6 main clusters are identified. The co-word bibliometric network studied is a weighted network. The edges indicate a relation between two nodes, as well as the strength of the relation. In **Error! Reference source not found.**, the main clusters of the international collaboration network are indicated with different colours, and the publication frequency is indicated by the size of the node. **Error! Reference source not found.** identifies countries with weighted direct citation links.

The highest publication frequency takes place in the USA, followed by China and the European Union. USA presents the top Weighted Degree (WD) value, WD = 3217, China accounts for a WD of 1287, and Germany, England, Italy, France, and the Netherlands complete the list of the 7 top countries with WDs higher than 1200. European countries dominate four of the 6 clusters; the two exceptions are led by Israel and the USA. Germany (WD= 1925), England (WD=1579), France (WD=1499), Italy (WD=1333), Netherlands (WD=1296), Spain (763), Belgium (WD=431) and Switzerland (WD=395) can be identified as the main actors in their clusters.

This structure of clusters highlights how the technological capabilities in aerospace engineering are spread or concentrated. Research capabilities and knowledge are homogeneously spread, with a clear geographical correlation, into four highly specialized clusters. However, national aerospace technological capabilities may not be easily collectivized. Therefore, aviation needs to pursue a dual policy of promoting excellence in the different aerospace subfields while also aggregating their information. On one side, research policy should support every cluster's continued excellence in different subfields. On the other side, research policy must facilitate the aggregation of the diverse experience and knowledge in each subfield into a shared platform for the aviation industry. It has to be considered that although national technological capabilities of aerospace engineering may not be collectivized, information and experience may differ in this regard. Therefore, innovation creation policy should reinforce the spread of knowledge while maintaining its mission orientation. Implementation of multi-objective innovation measures, both diffusion-oriented and mission-oriented, will be more suitable for maintaining excellence in aviation than single-objective policies.

Additionally, the figure does not only illustrate higher publication frequencies in both China (Weighted Degree-WD= 1287) and the USA (WD=3217), but also a high level of correlation between their research topics. On the other hand, European countries have very weak connections with the research carried out in China and other Asian economies. Research in the USA plays a pivotal role in the research infrastructure connecting the major players. The elevated number of publications in the USA and China, as well as the highly correlated topics between the two research networks, suggests the need for further analysis of the details of both research networks. Particularly, due to the weak connections between European clusters and Chinese publications, the specific analysis of China's research may provide the insight necessary to develop a competitive EU aerospace innovation policy.

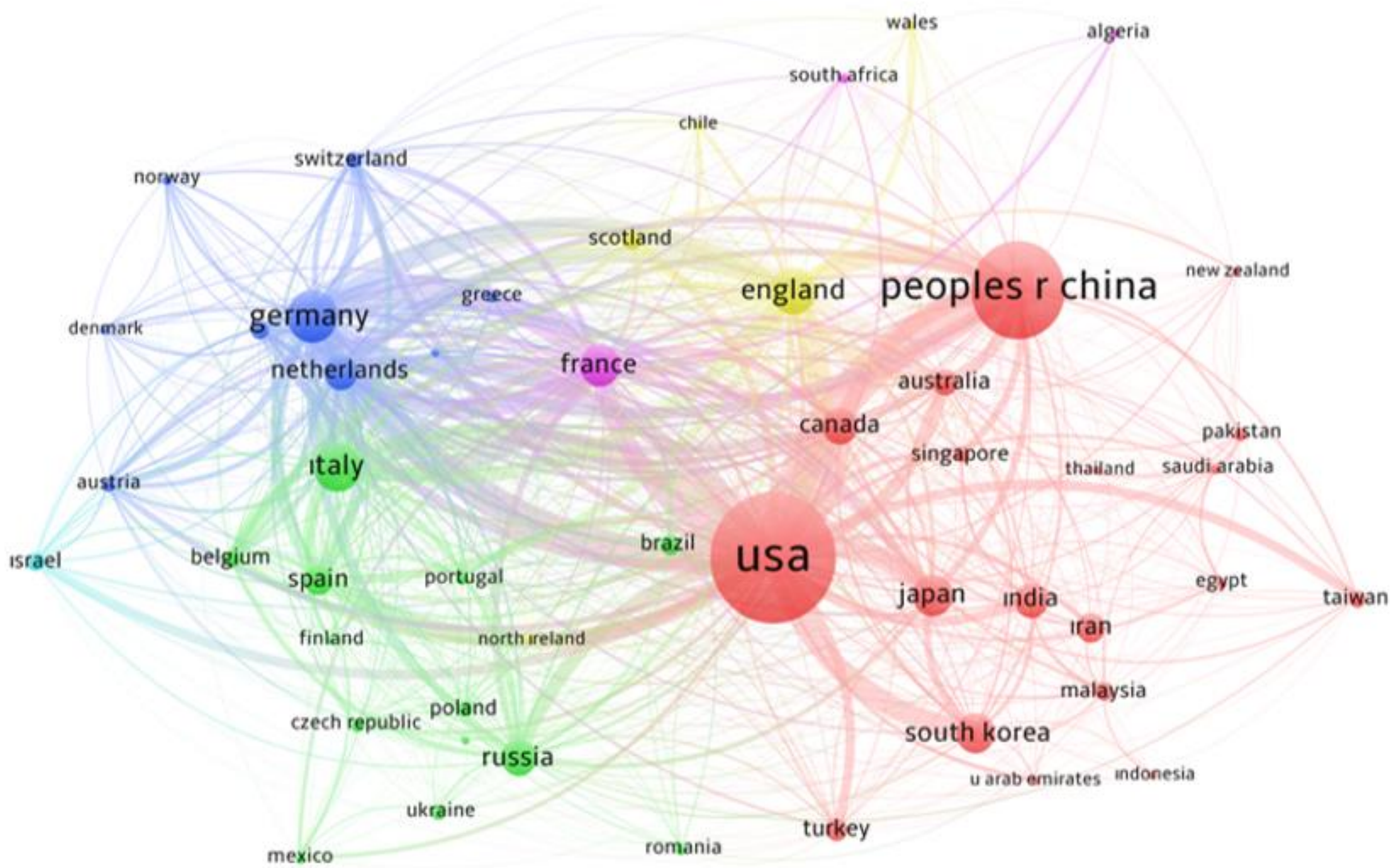


Figure 12.30. International Collaboration Networks with Document Frequency.

Collaboration Network of Institutions

A second visualization is prepared to illustrate the institutional collaboration network worldwide. There are many universities and research centres located as illustrated in **Error! Reference source not found.**. The European cluster can be identified as the blue group. The figure shows strong links between some Korean universities around the Korea Advanced Institute of Science and Technology that with a WD of 205 is acting as a research enhancer; and some strong links in several USA universities.

Those strong links evidence compact areas of collaboration and integration among these institutions. In particular, it can be observed that universities and research centres in the USA are organized into two distinct clusters. One of them is dominated by NASA (WD=826) and MIT (WD=196), and the other one is shared among NASA, some universities, and the United States Air Force (WT=179). Xiuxiu obtained similar results [32].

The main research directions of the two USA groups are the space station, target tracking, and monitoring of aircraft feedback. USA universities with a highest weighted degree are Caltech (WD=485), Georgia Institute of Technology (WD=217), University of Michigan (WD=217), Massachusetts Institute of Technology – MIT (WD= 196) and the University of Colorado (WD=184). Among the 10 top institutions, we can also find the Japan Aerospace Exploratory Agency (WD= 203), the Korea Advanced Institute of Science and Technology (WD=205) and the Beihang University

(WD=150). The 3 of them play a pivotal role in agglutinating and connecting research initiatives in their respective countries.

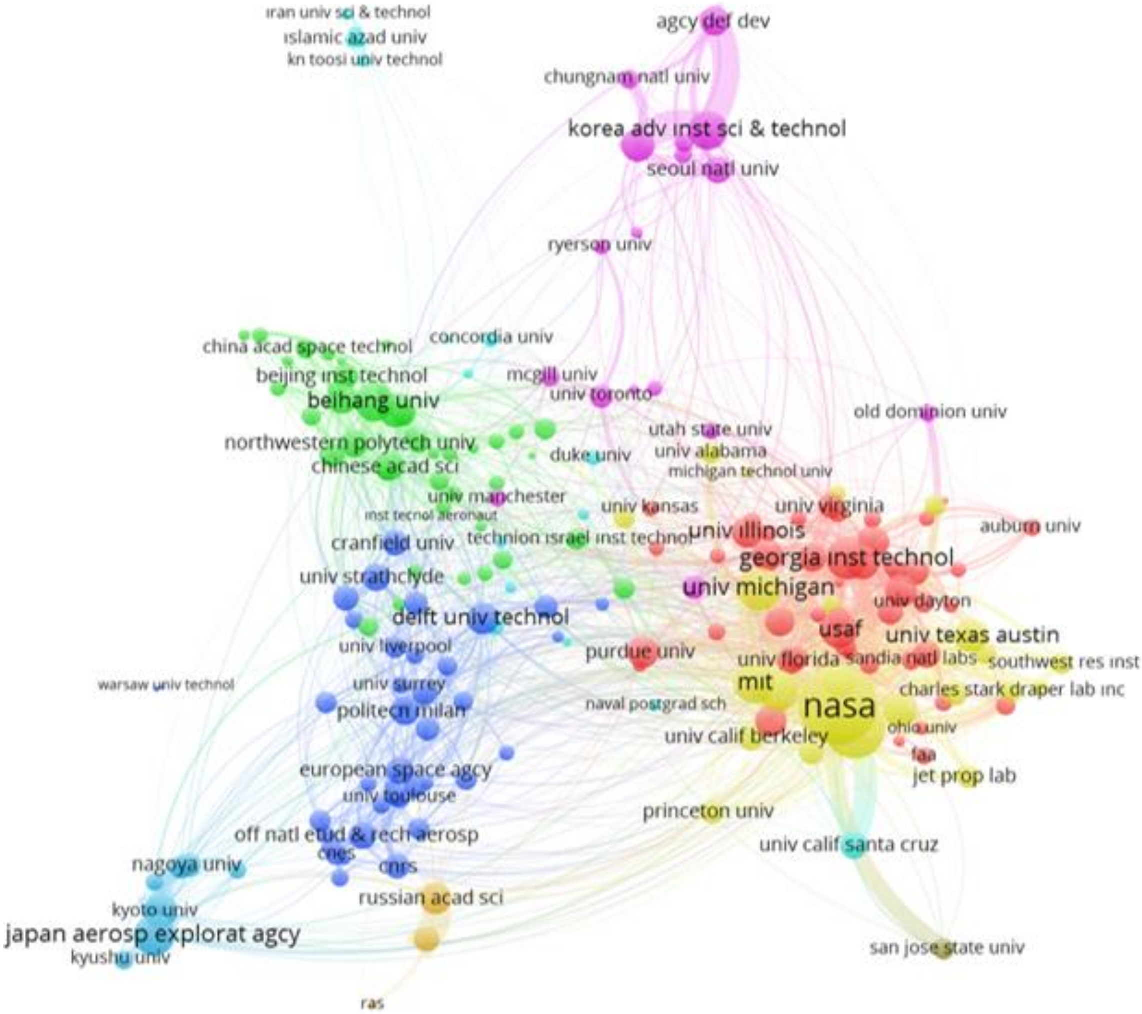


Figure 12.31. Institutional Collaboration Network.

Collaboration Networks in Aerospace Engineering Subfields

The last visual (**Error! Reference source not found.**) is prepared for demonstrating the research space of aerospace engineering by using the co-occurrences of different Web of Science categories. Naturally, aerospace engineering (WD=40419) is the central node of the network because it was the main Web of Science category selected. Additionally, five main clusters, in the figure with different colours, are identified that cover the following fields:

- Mechanical engineering (WD=10173), including biomedical engineering (WD=292), robotics (WD=46), and manufacturing (WD=886),
- Physics (WD=187), automation (WD=2020), telecommunications (WD=6798), electric-electronic and computer science (WD=13218);
- Materials science optics (WD=7937), nanoscience and remote sensing (WD=3409);
- Energy (WD=1644) and polymer science (WD=263);

- Acoustics (WD=734), thermodynamics (WD=1106), environmental studies (WD=54) and geology (WD=54).

The co-occurrence network graph in **Error! Reference source not found.** illustrates the connectivity among various research topics in the aerospace literature. The size of the nodes reflects the frequency of keywords: the higher the frequency of the keyword, the larger the size of the node. The size of the node also indicates also weighted degrees of the topic. The thickness of the line is proportional to the nearness of keyword connections; the closer the relationship between two nodes, the thicker the line.

Nodes without connections signify research fields lacking substantial cooperation with other research areas in the aerospace literature; they may be considered emerging or nascent topics that are sometimes in the margin of a research field, or they can be identified as areas in which mutual collaboration is lacking.

Mechanical engineering (WD=10713), telecommunications (WD=6798), electrical and electronics engineering (WD=13218), instrumentations (WD=5450), astronomy and astrophysics (WD=4028), optics (WD=7937), mechanics (WD=3864) had the highest frequency of co-occurrence in the literature with aerospace engineering, evidencing the areas were aerospace engineering publications are concentrated.

It is worth comparing the topics in Figure 12.32 with the 11 areas previously identified as key scientific disciplines involved in aircraft development. It can be observed that all of these areas are present in **Error! Reference source not found.** with a relatively high number of publications. However, these areas are not highly interconnected, evidenced by the lack of common research, and are thus losing potential synergies that could foster innovation. According to **Error! Reference source not found.**, this lack of common research is particularly notable between physics (WD=187), computer science (WD=174), and materials engineering (WD=520)—three fields among which collaboration is required to boost aviation innovation. To close this gap, it will be necessary to promote collaborative studies between these areas as part of the aerospace innovation funding policy.

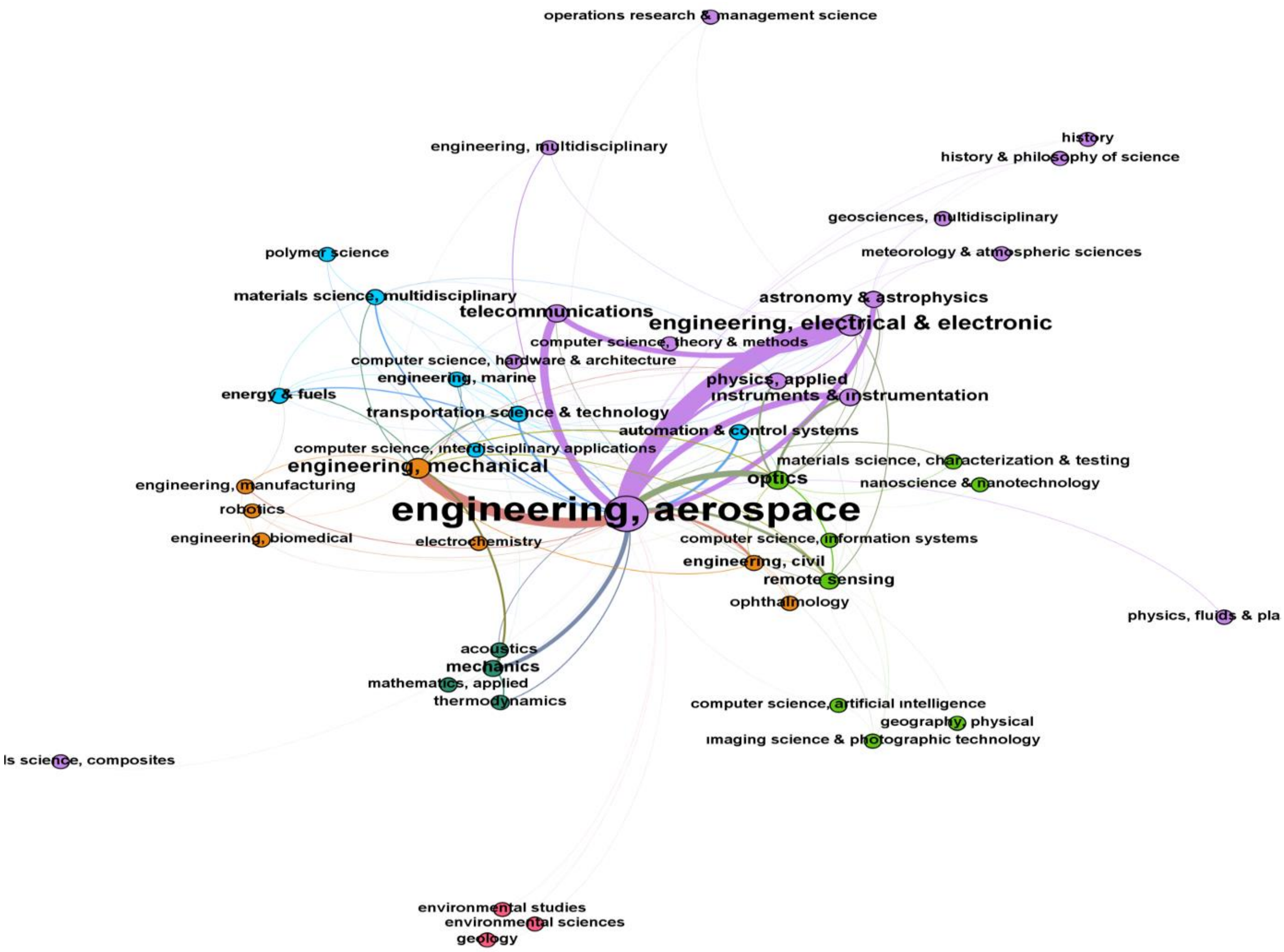


Figure 12.32. Collaboration Networks Based on Web of Science Categories

Trends of Patents on Aviation

Figure 12.33 presents the yearly evolution of the number of patents in aviation in the last 40 years. It can be observed that the number of patents has grown exponentially in the last decade. **Error! Reference source not found.** shows the breakdown of this evolution into the main Derwent categories. It can be observed that the greatest patent growth has taken place in the categories of operations and physics. Operations and physics are named macro-classes. Second in growth, named medium classes, are electricity, mechanical engineering, and chemistry. In contrast, the area of human factors has experienced very low growth, and the area of textiles has experienced practically no growth. Human factors and textiles are grouped in the micro-classes.

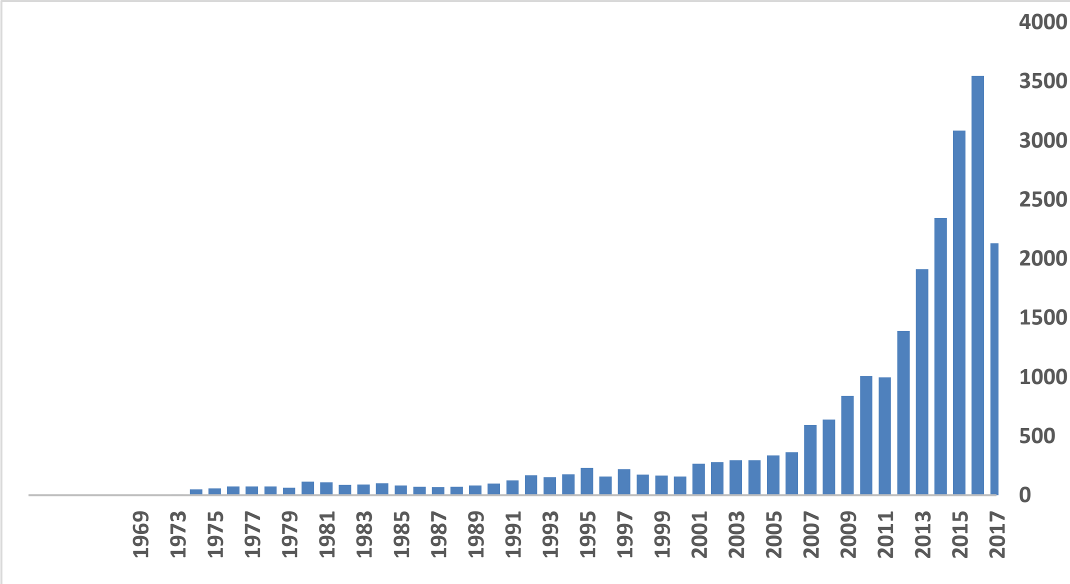


Figure 12.33. Number of patents in aviation per year.

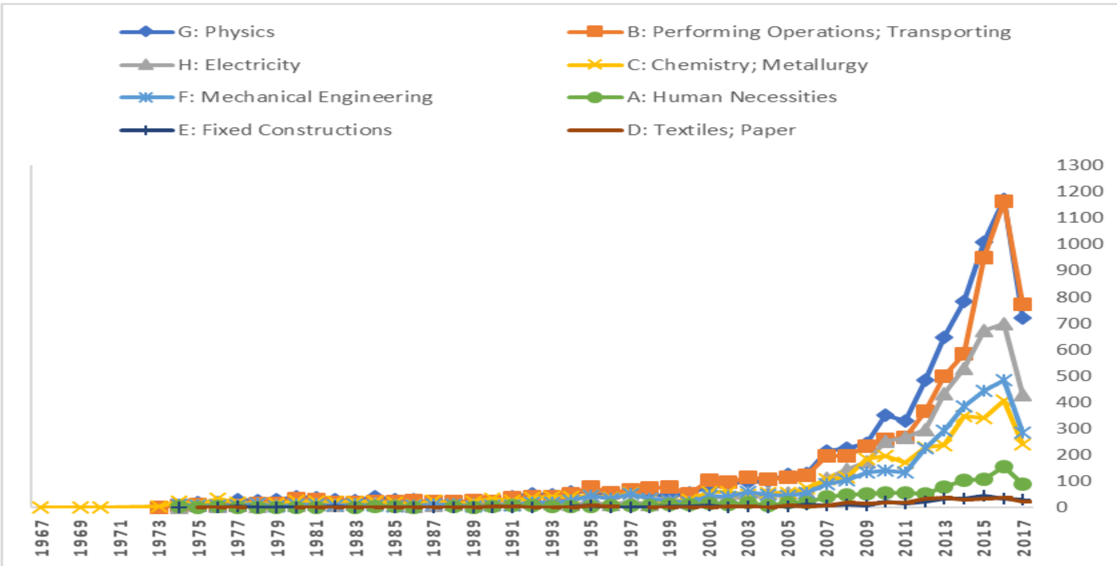


Figure 12.34. Chart of subclasses per year.

Geographical patent analysis

Error! Reference source not found. summarizes the accumulated number of patents per country. Figure 12.35 presents the annual evolution of patents for the top 10 countries, and **Error! Reference source not found.** shows the distribution of the patents according to class for these top 10 countries.

Basic Patent Country	Patent Number
China	11876
United States of America	3249
Russian Federation	2140
Soviet Union (USSR)	1393
World Intellectual Property Organization (WIPO)	1327
Korea (South)	1308
European Patent Office	637
Germany	369
France	305
Japan	254
United Kingdom	191
India	98
Canada	56
Brazil	37
Australia	28
Belgium	28
Taiwan	26
Romania	19
Spain	15
Poland	14

Table 12.22. The number of patents per country.

China is observed to be the country with the most patents in aviation, showing a strong dynamic in the field of patents. There is a sharp increase in the volume of patents filled in China: the number has quadrupled in the last five years. The data reflect how Chinese agents protect their intellectual property through patents, regardless of whether it was received through technology transfers or generated autonomously. Some authors have regarded this situation as replicating the strategy applied by the government and the Chinese industry in the railway sector; that is, the progressive development of barriers that are put in place to reduce the ability of non-Chinese agents to access the domestic market [40].

The high attrition rate should not be considered in isolation, as sometimes it is a consequence of governmental policies and effectively decreases when incentives are no longer applicable. Most authors recommend studying the patent lifecycle and its utility by periodically reviewing the number of patents discarded after a 5- or 10-year period [33], the number of international citations [34], or the citation lag [35].

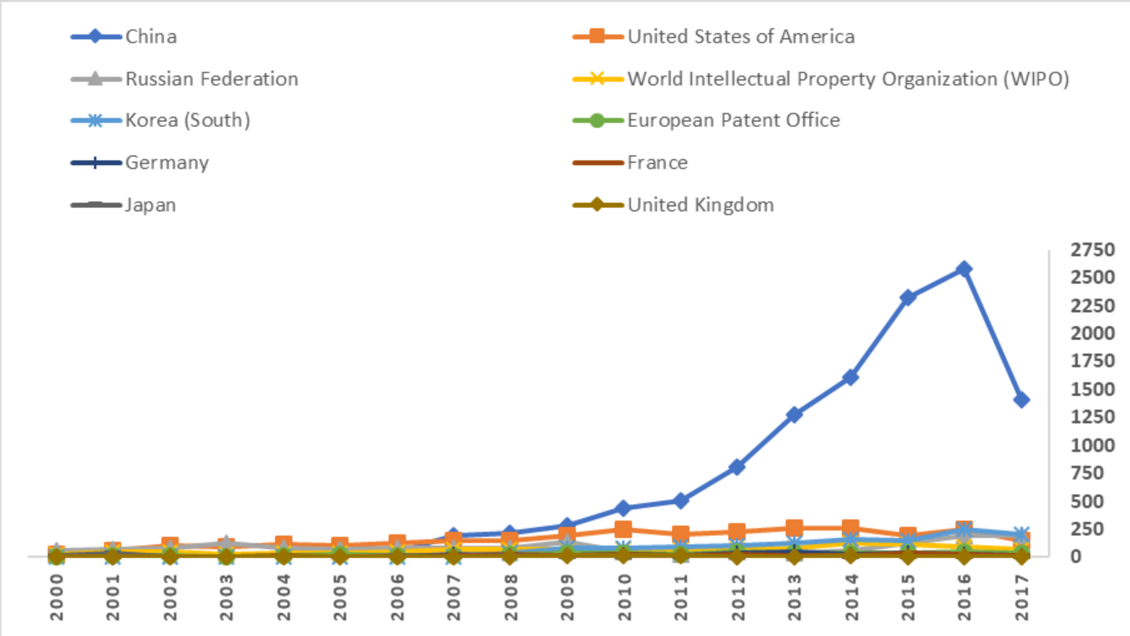


Figure 12.35. Evolution of the number of patents.

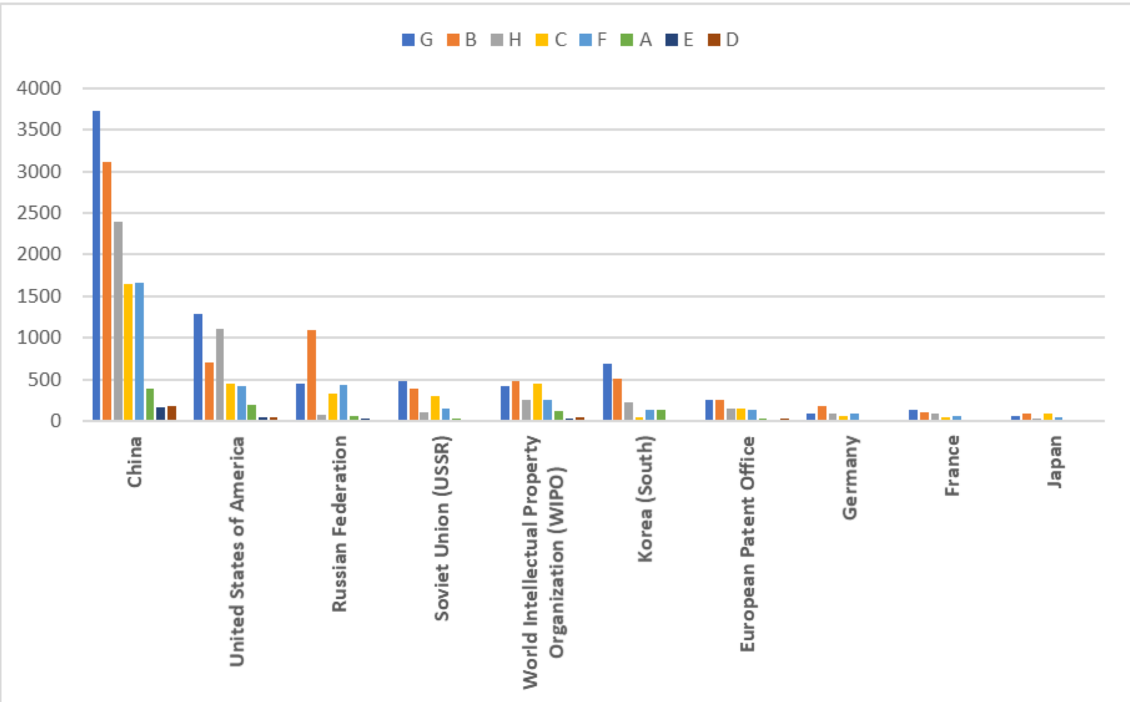


Figure 12.36. Aviation patents per country and class (A: Human necessities; B: Performing operations and Transporting; C: Chemistry and Metallurgy; D: Textiles and Paper; E: Fixed constructions; F: Mechanical Engineering, lighting, Heating, Weapons, and Blasting; G: Physics; H: Electricity).

The geographical analysis is complemented with the analysis of patent assignees. **Error! Reference source not found.** summarizes the top 20 firms by patent number. **Error! Reference source not found.** 12.37 illustrates the evolution of the annual number of patents for the 10 top firms, and **Error!**

Reference source not found. 12.38 presents the number of patents per holder according to subclasses.

Patent Assignees	Records
Stats Chippac Ltd	369
Honeywell Int Inc	233
Shenyang Liming Aero Engine Group Corp	222
General Electric Co	193
Univ Beijing Aeronautics & Astronautics	189
Univ Nanjing Aeronautics & Astronautics	165
Boeing Co	151
Harbin Inst Technology	145
State Grid Corp China	142
Rockwell Collins Inc	123
Univ Beihang	106
Avic Comml Aircraft Engine Co Ltd	103
Aviation Ind Corp China Shenyang Engine	99
Stats Chippac Pte Ltd	94
Univ Northwestern Polytechnical	90
Aviation Materials Res Inst	88
Univ China Civil Aviation	83
Thales	75
Avic Shenyang Engine Design Inst	71
United Technologies Corp	71

Table 12.23. Top Twenty Firms by the number of patents.

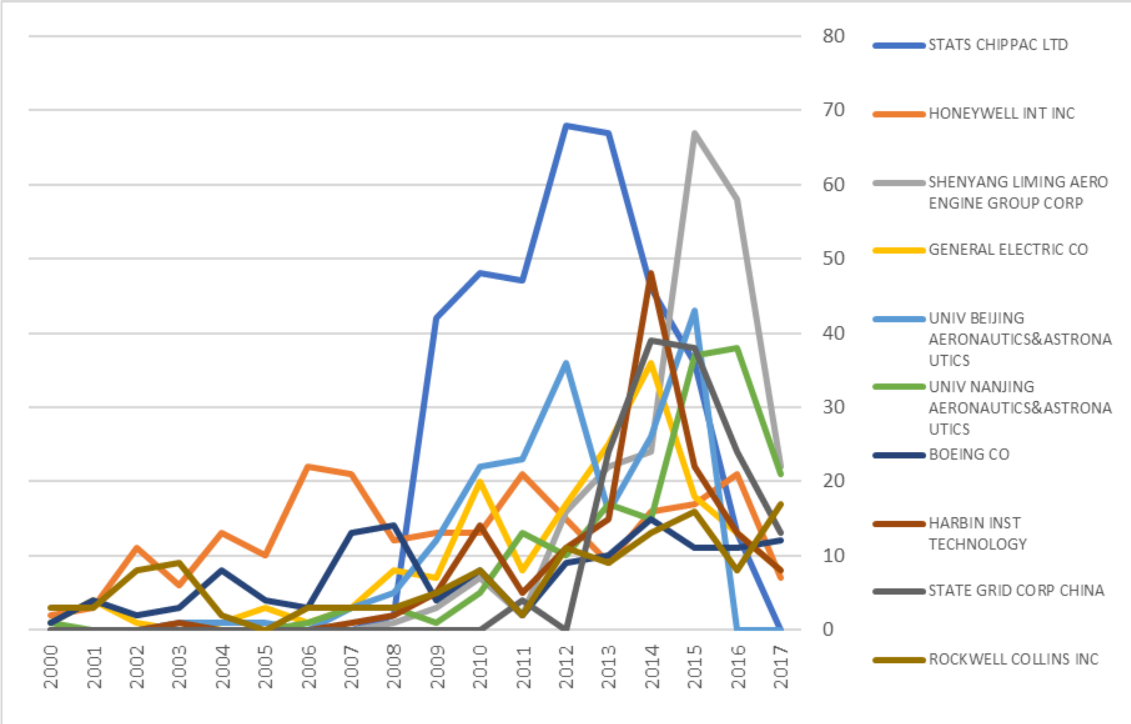


Figure 12.37. Top Ten Firms by the number of patents.

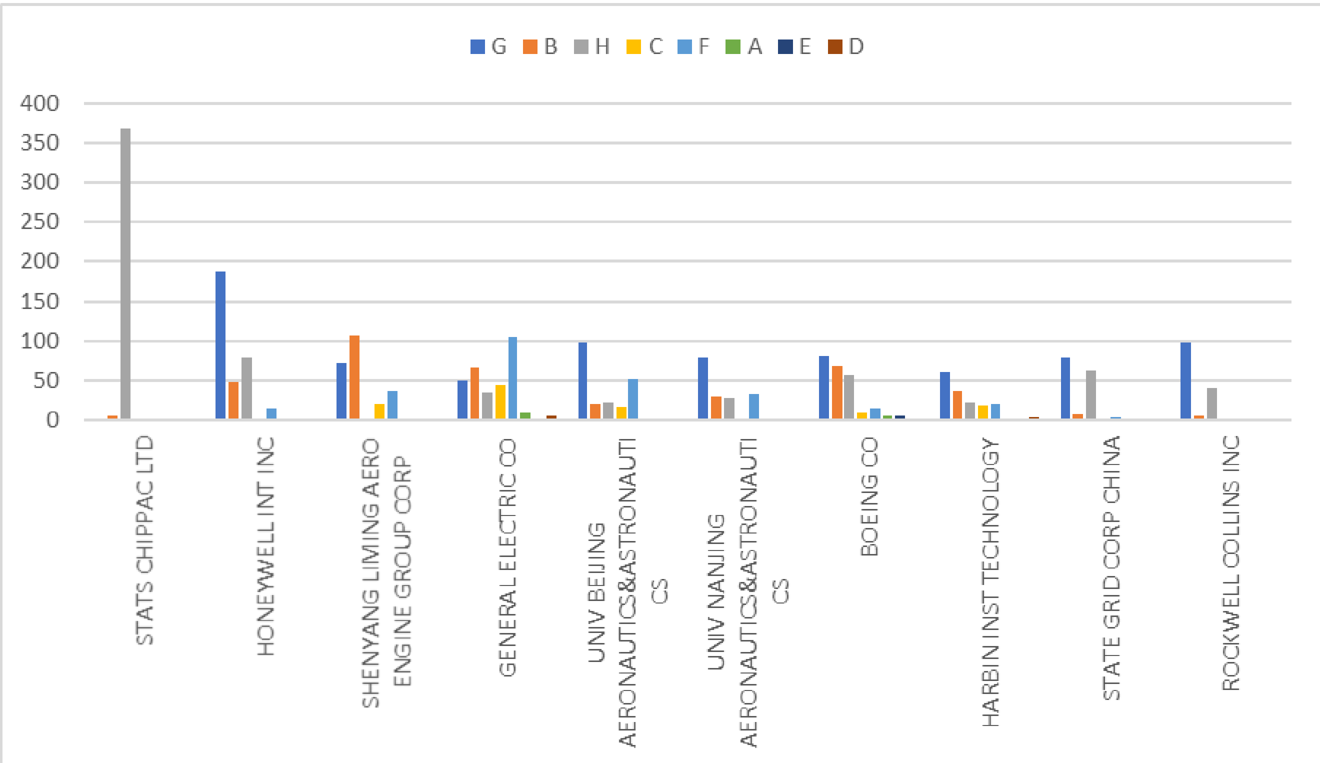


Figure 12.38. The number of patents per holder.

The results above show that although there was significant dominance by universities and research centres worldwide in the publication network, there are only a few universities among the top 20 firms by the number of patents, and all of them are Chinese universities. This highlights the lack of capacity of universities in Europe, as well as the USA, to translate basic research into products and industrial innovation. Future innovation and research policies should contribute to closing the existing research and innovation gap between academia and the aeronautical industry. University spin-offs may be integral to bridging this gap by playing different roles in intermediation, technology diversification, and technology renewal [36]. University spin-offs are start-up companies that are created by academics to exploit technologies and knowledge originating from the university. During the last two decades, spin-offs from universities have attracted increasing interest from research institutions and industry, mainly because these spin-offs have the capacity to bridge the gap between scientific and academic knowledge and their industrial application: "Universities need to reinvent themselves as microenvironments for innovation and entrepreneurship. A university that will not demonstrate its impact on the industry and the marketplace will become less relevant in the future" [37]. Today, Israel is the country with the most efficient policies for transferring innovation from universities and military tech units to industry and production. Policy programs are needed to stimulate the entrepreneurial activities of academics in aerospace [38].

The last conclusion, which is derived from the above analysis, is regarding the specific geographical differences between aerospace science and technology journals and patent information. Only one among the 20 top firms is European (Thales), and the remaining companies are American or Chinese. It is also remarkable that Airbus Industries is not among the top firms by the number of patents.

Patent structure analysis

In this section, the technological network derived from the patent technology space is examined. **Error! Reference source not found.** represents the percentages of patents for each class, and **Error! Reference source not found.** and **Error! Reference source not found.** present the percentages for each subclass in the categories of physics and operations.

As can be observed in **Error! Reference source not found.**, among the aviation patents, about 27% belong to the class of Physics, and 25% are in the class of Operations and Transporting. **Error! Reference source not found.** and **Error! Reference source not found.** shows the areas with higher concentrations of patents among the subclasses in Operations and Physics.

Error! Reference source not found. presents a network map of the patent topics relevant to aviation development. Five major clusters are observed in the figure with very limited interconnections. One cluster aggregates class around power generation topics, including electronics and materials involved in power systems. Another integrates instrumentation, digital computers, optics, printed circuits, and semiconductor materials and processes. The third one pivots around all types of materials used for aviation. The fourth includes electromechanical storage, power distribution, components, converters, and lighting. The last one includes organic compounds, lubricants, etc. Whereas a high level of cooperation and a mature stage is seen at the level of publication networks, the patent cooperation networks are relatively low and primary.

The network structure derived from publications presents a lower density exhibiting higher and looser contact, whereas the patent network is denser with less contact between the nodes and a closed structure. Worldwide universities are well represented in the publication networks, while the patent network is dominated by companies, apart from Chinese universities.

It is believed that cooperation should be aimed at the differences to encourage the integration of academic research and applied research to promote the development of the subject and the level of the aerospace industry.

Finally, we can expect a growing professional network of engineers and experts across state-owned and private sector companies. Over the coming years, industry best practices and more streamlined administrative processes could coalesce, and the growth in innovation and output, as a result, will be more exponential than linear.

First, we should anticipate a push from China's universities and corporations to produce advancements in engines and avionics, the main technological domains in which China lags most. Even Comac's C919 relies heavily on components and technology procured from foreign firms like General Electric.

Code	%	Definition
G	27.3	Physics
B	24.9	Performing Operations; transporting
H	16.2	Electricity
C	13.1	Chemistry; Metallurgy
F	12.2	Mechanical Engineering; lighting; Heating; Weapons; Blasting
A	3.7	Human Necessities
E	1.3	Fixed Constructions
D	1.3	Textiles; Paper

Table 12.24. Some patent codes.

Code	%	Definition
G01	12.7	Measuring; Testing
B64	9.3	Aircraft; Aviation; Cosmonautics
H01	6.2	Basic Electric Elements
G06	6.2	Computing; Calculating; Counting
H04	4.0	Electric Communication Technique
C08	3.1	Organic Macromolecular Compounds; Their Preparation or Chemical Working-Up; Compositions Based Thereon
C10	3.1	Petroleum, Gas or Coke Industries; Technical Gases Containing Carbon Monoxide; Fuels; Lubricants; Peat
F16	2.9	Engineering Elements or Units; General Measures For Producing And Maintaining Effective Functioning Of Machines Or Installations; Thermal Insulation In General
F02	2.9	Combustion Engines; Hot-Gas or Combustion-Product Engine Plants
H02	2.8	Generation, Conversion, Or Distribution of Electric Power
B23	2.6	Machine Tools; Metal-Working Not Otherwise Provided For
G05	2.5	Controlling; Regulating
G08	2.0	Signaling
G09	1.9	Educating; Cryptography; Display; Advertising; Seals
C22	1.7	Metallurgy; Ferrous or Non-Ferrous Alloys; Treatment Of Alloys Or Non-Ferrous Metals

Table 12.25. Some patent sub codes.

Code	%	Definition
B64C	4.1	Aeroplanes; Helicopters
B64D	3.7	Equipment for Fitting In Or To Aircraft; Flying Suits; Parachutes; Arrangements Or Mounting Of Power Plants Or Propulsion Transmissions
G06F	3.7	Electric Digital Data Processing
G01N	2.2	Investigating or Analysing Materials By Determining Their Chemical Or Physical Properties
G01C	1.9	Measuring Distances, Levels or Bearings; Surveying; Navigation; Gyroscopic Instruments; Photogrammetry Or Videogrammetry
G01M	1.8	Testing Static or Dynamic Balance Of Machines Or Structures; Testing Structures Or Apparatus Not Otherwise Provided For
C08L	1.7	Compositions of Macromolecular Compounds
H01L	1.7	Semiconductor Devices; Electric Solid-State Devices Not Otherwise Provided For
G01R	1.4	Measuring Electric Variables; Measuring Magnetic Variables
B32B	1.4	Layered Products, I.E. Products Built-Up of Strata Of Flat Or Non-Flat, E.G. Cellular Or Honeycomb, Form

Table 12.26. Some patent sub codes.

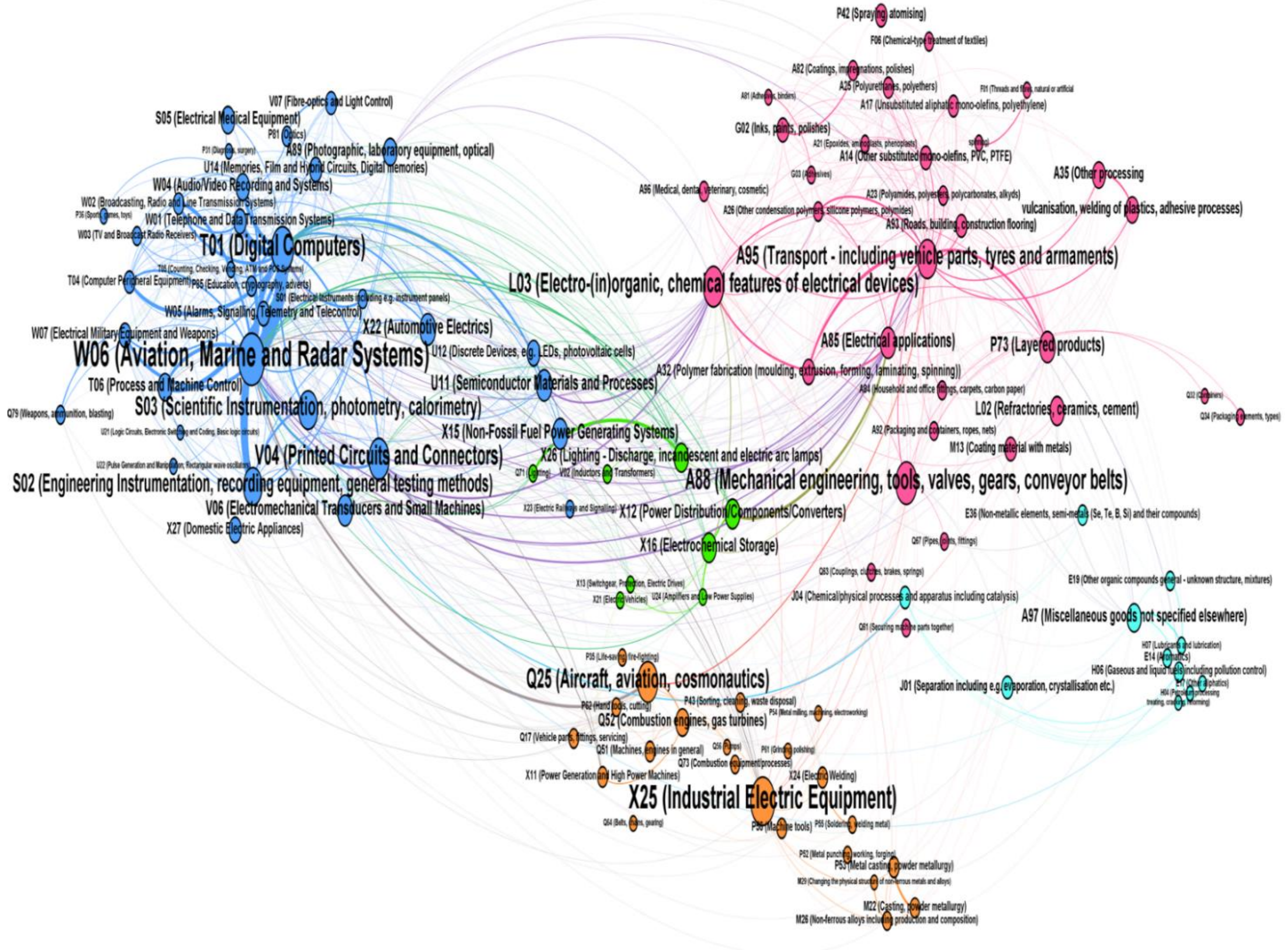


Figure 12.39. Patents in áreas relevant to aeronautics.

12.2.5 The COMAC consortium and aircraft programs

COMAC is an independent corporation responsible for the design, assembly, testing, and marketing of China's forthcoming indigenous commercial airliners. It was created from the former AVIC Commercial Aircraft Company in 2002. Current COMAC corporate structure is presented in Figure 12.40.

Motivations behind this strategic decision are multiple. On one side COMAC is an effort to create a commercial aviation manufacturer with a more commercial operation orientation, like those of Boeing and Airbus Group. It is also a step towards an easier way for foreign companies to provide components for COMAC's commercial aviation projects. Western, especially the U.S., restrictions on exports of technologies were expected to be looser if foreign companies were dealing with an exclusively commercial aircraft manufacturer rather than with AVIC or its subsidiaries. COMAC was also set up to address shortcomings in China's commercial aviation manufacturing industry that stemmed from AVIC's focus on military aircraft. Finally, the decision to set up COMAC was also driven in part by the perception that a new organization was needed to manage the program. This perception was driven in part by the success of the Chinese space program, which set up a new organization to spearhead the manned space program.

COMAC has a customer service centre and two research and design centres in Shanghai and Beijing. It is also a shareholder in Chengdu Airlines, a publishing house, and the Shanghai Aviation Industrial Company (SAIC), which is a holding company that controls businesses in non-core areas such as air freight, logistics, machine building, catering, and automotive components.[39].

The SAMC (formerly the Shanghai Aircraft Manufacturing Factory) is COMAC's assembly and manufacturing centre. It is responsible for the final assembly and systems integration of the ARJ-21 regional jet and the C919 narrow-bodied commercial jet projects.

SAMC established itself as China's leading builder of large commercial jets when it successfully developed China's first jet airliner, the Y-10, in the early 1980s. Between 1986 and 1994, it partnered with McDonnell Douglas to assemble the MD-80 series of narrow-body jets. Today, it is a subcontractor for Boeing and Airbus. SAMC's new assembly facility in Shanghai's Pudong New District was completed in 2009. By 2010, the facility reportedly had the capacity to assemble up to 30 ARJ-21s per year; the capacity was scheduled to expand to 50 by 2012. [40]

Figure 12.40. COMAC Corporate structure. (COMAC web page)

COMAC is currently working on four aircraft development programs at different levels of maturity: ARJ21, C919, C929 and C939. COMAC inherited, at its creation, the ARJ21 program and, in the early 2010s, kicked off three other development programs – C919, C929 and C939 – to enter different market segments. Main characteristics of the COMAC projects are summarised in Figure 12.41, note that no details are yet available for the C939.

Figure 12.41. The COMAC family. As of January 2019 [41]

- **ARJ21**

The development of the regional jet ARJ21 started in 2002. However, the project suffered numerous problems, among them wiring, cracks appearing in the wings, faulty doors and poor performance in rainy weather.

The project experienced significant delays compared to the initial plan: the first commercial flight took place in June 2016, six years later than planned, and only two ARJ21 aircraft had been delivered as of February 2017 (both to Chengdu Airlines, a company owned by COMAC). After all those delays, the project is focused now on quality issues and ramping up production.

Depending on the version, the ARJ21 has a maximum seating capacity of 105 and a maximum range of 3,700 km, which makes it a direct competitor to Embraer E175 and E190, as well as to Bombardier CRJ900 and CRJ1000. COMAC, Embraer and Bombardier use variants of the same GE CF34 engine.

- **C919.**

The development of the C919 is intended to compete with Airbus A320 and Boeing 737 in the short- to medium-haul segment, the segment that is expected to generate most aircraft deliveries over the coming two decades. It is a narrow-body, twin-engine aircraft, with a capacity between 158 and 174 seats and a maximum range of 5,500 km.

Launched in 2010, this program leverages the experience gained on ARJ21. The first official targets for its first deliveries was 2019, but it has been delayed to 2021. Despite significant delays compared to the initial timeline, the C919 performed its maiden flight on May 5th, 2017.

- **C929 and C939.**

COMAC targets to develop long-haul aircraft targeting commercial services after 2025. To that aim, COMAC recently initiated the development of two long-haul aircraft to further extend its product range: The C929 and the C939. Even well before the C919 enters service, China is taking on a much bigger project: the CR 929. This aircraft will be jointly developed by COMAC and Russia's United Aircraft Corporation (UAC) in a joint venture China-Russia Commercial Aircraft International Co (CRAIC).

The C929 will be a twin-aisle with 280 (between 250 and 300) seats and a range of 12,000 km (6,480 NM), well shorter than the competing 787-9 and A330-200/800. This wide-body, twin-engine aircraft will compete against the Airbus A350 and the Boeing 787. The airplane looked like a combination of the A330 and B787, in the model shown at the 2017 Paris Air Show. This aircraft is expected to satisfy the country extra wide-body lift. China forecasts a domestic market in the next 20 years for wide-bodies of 2100 vs Airbus' 1,100 and Boeing's 1,600. Part of this difference is justified by the increase in airports and the stringent airspace limitations. In the next 20 years, China is going to double its airports to 450. With military airspace restrictions and future growth with domestic air traffic, China might copy the Japanese model that uses wide bodies between major cities.

Its first flight is scheduled in 2023, with commercial service in 2025, six years from now. It's an ambitious plan, given the long dates from the ARJ21 and C919. Even Airbus and Boeing have yet to meet this kind of timeline for a new airplane in the last 20 years, and these companies have been building aircraft for decades. It is expected that the panel-like composite fuselage of this future model, similar to the Airbus A350, will be built in China. The composite wing will be built in Russia. Out-of-autoclave production will be used.

The other model, the C939 is still very undefined. With 400 seats, this long-range, wide-body aircraft is intended to compete against the Boeing 777 and 747 and the Airbus A350 and A380. No schedule has been published so far.

12.2.5.1 C919

COMAC began production on the C919 in December 2011, with the goal of challenging the duopoly of international commercial passenger-carrying jets controlled by Airbus and Boeing. The aircraft made its maiden flight in 2017 at Shanghai's Pudong International Airport and is scheduled to achieve its first delivery to airlines in 2021. COMAC is projecting demand for 2,300 C919s, which cost half as much as an A320 or 737, about $50 million.

Dimensions and features comparison

Error! Reference source not found. and **Error! Reference source not found.** 12.42 summarises and compares the main dimensions and performances of the A320neo, the B737MAX and the C919.

How the C919 compares with the Boeing 737 and Airbus A320

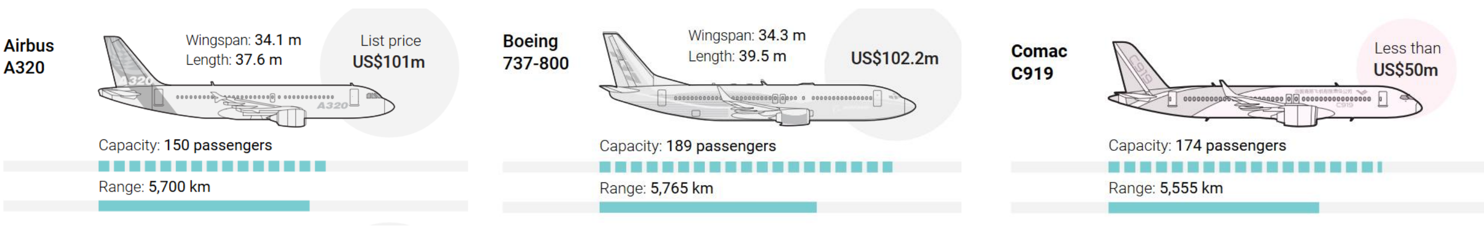


Figure 12.42. Dimensions comparison.

In its external shape, C919 resembles actual models. The aircraft nose looks like a Boeing 787; with curved flush cockpit windows and four large panes. The core of the aircraft, from the first door to tail, resembles an A320 although a bit longer with one more window before the over-wing exits. The tail cone is slightly longer than the A320 neo. The fuselage of the C919 is a bit longer than the one of A320. The shape of the main wing is very similar to the A320, although its wingtip is different, its area is slightly larger and the aspect ratio, lower.

All these resemblances with the A320 suggest that C919 designers have learned from the final assembly of the Airbus A320 in Tianjin during the last seven years, particularly from the solutions in the fuselage cross section and in the wing. The cross-section has the same dimensions as the A320 (within 1 cm), therefore C919 benefits from using the same container concept (LD3-45) and fuselage placed sub-systems. Because of these similarities, the number of sub-suppliers that could bid for work on the C919 grew a lot. Any updated solution for the A320 would fit in the C919 and retrofit and adaptation costs will be lower.

The wing employs the same high-lift trailing edge, and ingle slotted fowler flaps, using a flap track and a link to get both fowler motion and the desired flap angle. It has also the same layout of adjacent inner and outer flaps, combined with a single outboard high/low-speed aileron; although the flap tracks are made of titanium or steel with slim flap track fairings.

Wings are more tuning of existing models than a new design. Wings are conventional aluminium designs with composite wingtips, such as the older A320 design. The wing has a modern supercritical airfoil with low supersonic shock drag at the cruise Mach of 0.785 (A320 0.78 and 737 0.785), and tuned performances at higher cruise Mach. Wing fuel capacity is 400kg higher than the constrained one of the A320, thanks to the lower wing thickness of its no so modern profile.

Aircraft model	A320 neo	B737 Max 8	C919LEAP
EIS first variant	2015-12	2017-05	2018
OEM max range, NM	3700	41001	300s
Seating, 2 class1	150	178	158
Overall lengths, m	37.6	39.47	38.9
Wingspan, m	35.8	35.92	35.8
Effective wingspan, m	37.6	-	37.9
Wing effective aspect ratio	11.5	-	11.1
Wing area Airbus method, m2	123	127	129
Wing-loading MTOW, kg/m2	644	647	599
Airplane height, m	11.76	12.3	11.95
Fuselage width, m	3.95	3.76	3.96
Total wetted area, m2	786	-	804

Table 12.27. Main dimensions of A320 neo, B737 Max and C919 [42]

The original Operational Empty Weight (OEW) figure from COMAC was 42,100kg, although expert estimation provides a higher value about at least 46,500kg, which is higher than the A320neo and 737-8. Efficient engines like CFM LEAP or Pratt & Whitney’s GTF are heavy.

Fuselage and wings are based on classical aluminium design, rear bulkhead and horizontal and vertical tails made with Carbon Fibre Reinforced Plastic (CFRP).

Because the uncertainty of the exact cabin layout of the C919, it is difficult to estimate a fuel consumption per seat figure, calculations based on trip fuel consumption are more trustworthy, although there shall be a clear caveat around that figure as well. The fuel consumption model for the C919 assumes that COMAC can tune the Fly-By-Wire (FBW) control of the aircraft as well as Airbus, which has 30 years' experience of FBW on the A320. It also assumes that COMAC has made no mistakes in the aerodynamic design of the airframe, such as unwanted interference drag or transonic shocks.

With all these caveats, one can see that the higher effective span of the C919 wing claws back some of what is lost with a higher empty weight and larger wetted area. Dependant on actual seating arrangements and how well COMAC succeeds in tuning the aircraft in flight tests, it can come close to the fuel efficiency of the A320 neo but it will be hard to better the A320neo benchmark.

Another area that will be hard work for COMAC will be the integration of the complex systems on the C919. COMAC has created a full system iron bird for the purpose. This is now standard in the industry and it remains to be seen how well COMAC succeeds with the perhaps most challenging aspect of new airliner design. Airbus' A320 and Boeing's 737 are both over 99.5% in dispatch reliability, but it will take COMAC many years to even come close with C919.

Aircraft model	A320 neo	B737	C919LEAP
MTOW OEM kg	79000	82190	77300
MLW OEM Kg	67400	69308	66600
MZFW OEM kg	19300	65952	17500
OEW kg	45000	45070	46500
Max fuel l	23859	25816	24361
Max fuel US Gallon	6303	6820	6435
Max fuel kg	19157	20730	19560
Cruise Speed	0.780	0.790	0.785
Engine variant	LEAP -1A26	LEAP-1B	LEAP 1-C26
Mission range (NM)	1000	1000	1000
TOW mission kg	66003	-	68058
Payload mission kg	13608	16148	14334
Block fuel mission, kg	4900	5077	4996

Table 12.28. Weights, fuel data and preliminary efficiency of C919. [42].

The business group behind the C919

According to declarations by Zhou Guirong, the deputy chief designer of the C919, in 2017 the overall localization rate of C919 aircraft can reach over 50%, meaning more than half of its components are sourced from domestic enterprises and joint ventures between domestic and foreign companies. [43]

Companies under the Aviation Industry Corporation of China have been central to the manufacturing of the C919, producing the aircraft's head, body and central wing structure. Figure 12.43 illustrates the parts supplied by the Aviation Industry Corporation of China (AVIC) subsidiaries.

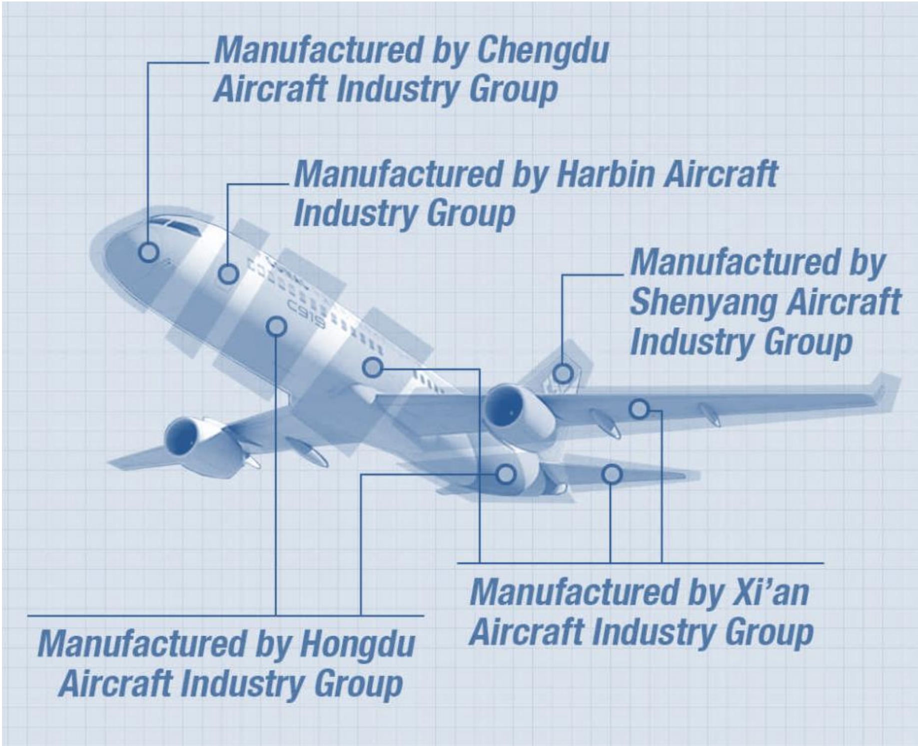


Figure 12.43. C919 parts supplied by Aviation Industry Corporation of China (AVIC) subsidiaries.

A total of 16 foreign suppliers have been involved in the C919 program including GE, Honeywell and CFM, Parker Aerospace and Liebherr, with joint ventures covering avionics, flight control, power, fuel and landing gear systems.

- **Honeywell** has provided the aircraft with its auxiliary power system technology, generating power in flight and starting the main engines before take-off. Pilots use the HonFei fly-by-wire flight control system and advanced Honeywell navigation technology to operate and navigate the aircraft. The Honeywell system for the C919 includes a complete auto flight system with automatic landing capability. Honeywell fly-by-wire flight control technology is used on many commercial aircraft, including COMAC's ARJ-21 regional jet, the Boeing 787 and the Embraer 170/190 family.

  COMAC and Honeywell have been working together since COMAC was founded in 2008, starting with the ARJ21 regional jet and continuing with the C919 program. Honeywell supplies the aircraft's fly-by-wire system through a joint venture with HonFei Flight Controls and supplies the braking system under a joint venture with Boyun Aviation Systems. Honeywell also signed a memorandum of understanding to form a joint venture with the Flight Automatic Control Research Institute (FACRI) for world-class electronics for the C919. Honeywell operates 10 different Aerospace facilities throughout China, including Aerospace maintenance and manufacturing facilities in Xiamen, Nanjing, Suzhou and Shanghai. The Asia-Pacific business is based in Shanghai. Additionally, Honeywell has opened a China Aerospace Academy that will help to train customer support and operations leaders to support the needs of the growing aerospace industry in China

- **Safran** supplies the entire C919 propulsion system, consisting of the LEAP-1C engine from CFM International [3] and the nacelle and O-Duct thrust reverser built by Nexcelle, a Safran Nacelles and Middle River Aircraft Systems (GE) joint venture, and supplied to CFM International. Safran Nacelles' O-Duct thrust reverser's designation comes from its O-shaped duct configuration when viewed from the front. The O-Duct is a single-piece unit produced with lightweight composite materials and replaces the two-piece "D" doors on traditional jet engine thrust reversers. When deployed, the O-Duct enhances the airflow path while also increasing thrust reverser efficiency. An electrical thrust reverser actuation system (ETRAS) is used to operate the O-Duct, replacing heavier hydraulics in other thrust reverser designs. The ETRAS' utilization on C919 follows Safran Nacelles' pioneering application of an electrical thrust reverser actuation system for the Airbus A380, which has been in airline service since 2007.

  Safran also supplies the C919's electrical wiring interconnection system (EWIS), via SAIFEI Aviation EWIS Manufacturing Co. Ltd. With Zodiac Aerospace[4] which supplies water & waste system, bulletproof cockpit door and evacuation slides.

  In total, 9 Safran companies contribute to the COMAC C919 program, which makes Safran a major partner on the COMAC C919. This collaboration started in 2009 when Safran become officially part of the program when COMAC selected the CFM International engine, LEAP-1C, as the sole Western powerplant for the C919 aircraft. The LEAP (Leading Edge Aviation Propulsion) family of engines is designed to power commercial aircraft requiring 20,000 to 33,000 pounds of thrust. The LEAP-1C is a new engine generation, part of the LEAP engine family, designed to be the successor of the CFM56 engines The LEAP-1C was the first engine of the family to be selected on an aircraft program, followed by the L.EAP-1A on the Airbus A320neo and the LEAP-1B on the Boeing 737 MAX.

- **Rockwell Collins** settle in 2014 a joint venture with CETC Avionics Company Limited (CETCA), Rockwell Collins CETC Avionics Company (RCCAC), to work in the COMAC 919. RCCAC, which is based in Chengdu, Sichuan, has been developing communication and navigation avionics solutions for the C919 and other aircraft programs in China. Specifically, the entity provided the C919 with audio, radio tuning, HF, VHF, GPS, DME, radio altimeter, VOR/ILS and an optional Inmarsat SATCOM solution.

[3] CFM56 and LEAP engines are products of CFM International. CFM International is a 50/50 joint venture between Safran Aircraft Engines and GE.

[4] Zodiac Aerospace joined Safran group since February 2018

Collins Aerospace also supplies avionics technologies to the C919, including its communication, navigation and integrated surveillance systems under joint ventures established with China Electronics Technology Avionics Company and AVIC.

- **Aviage Systems** is a 50/50 joint venture between **GE Aviation** and AVIC. Currently, it specializes in the supplies of the integrated modular avionics system to the C919. They are responsible for three avionics work packages - the core processing system, display system, on-board maintenance system, and the flight recording system - on the C919, that represent the next generation of avionics systems architecture in a multi-functionality, display-driven setup, taking on important tasks such as core data processing, signal transmission and signal function logic conversion. Through the avionics system, a pilot processes complicated data and connects and interacts with flight control systems to have full control of the plane and fulfil flight missions.

  The modular avionics system offered by the proposed AVIC-GE joint venture would form the backbone of the C919's networks and electronics and will host the airplane's avionics, maintenance and utility functions. The system replaces dozens of traditional, standalone computers fitted to aircraft flying today, resulting in weight savings, improved reliability and reduced operating cost.

- **Eaton** formed a Joint Venture with the Shanghai Aircraft Manufacturing Co. (SAMC), a subsidiary of COMAC, in July 2010. The joint venture is focused on the design, development, manufacture and support of hydraulic and fuel conveyance systems for the COMAC C919 single-aisle commercial aircraft program, COMAC ARJ21 regional jet program and other aircraft platforms in China and Asia-Pacific markets. The Eaton-SAMC joint venture (ESJV) was COMAC's first joint venture with a foreign company in China.

- **UTC** (United Technologies Corporation) Aerospace Systems' technology can be found throughout the C919. Key systems include electric power, emergency power, cockpit and thrust controllers, interior and exterior lighting, emergency passenger door actuation, fire protection, and ice detection and prevention.

- **Hamilton Sundstrand** has won a contract from China's Comac to provide the electric power generation and distribution systems for the 150- to 190-seat C919.

- **Leonardo** has signed an MoU with Kangde Investment Group of China to establish a joint venture, Kangde Marco Polo Aerostructures Jiangsu for the development, production and assembly of composite materials components for the CR929 wide-body aircraft. The carbon fibre fuselage sections for the new CR929 long-range airliner will be built in the new facilities in Zhangjiagang city, in the Chinese province of Jiangsu. Kangde Marco Polo Aerostructures Jiangsu - which will be responsible for the development, production and assembly of components for the CR929 airplane.

Error! Reference source not found. illustrates the main nationalities involved in the production of the C919, and **Error! Reference source not found.** shows the main companies involved in the different components of the aircraft.

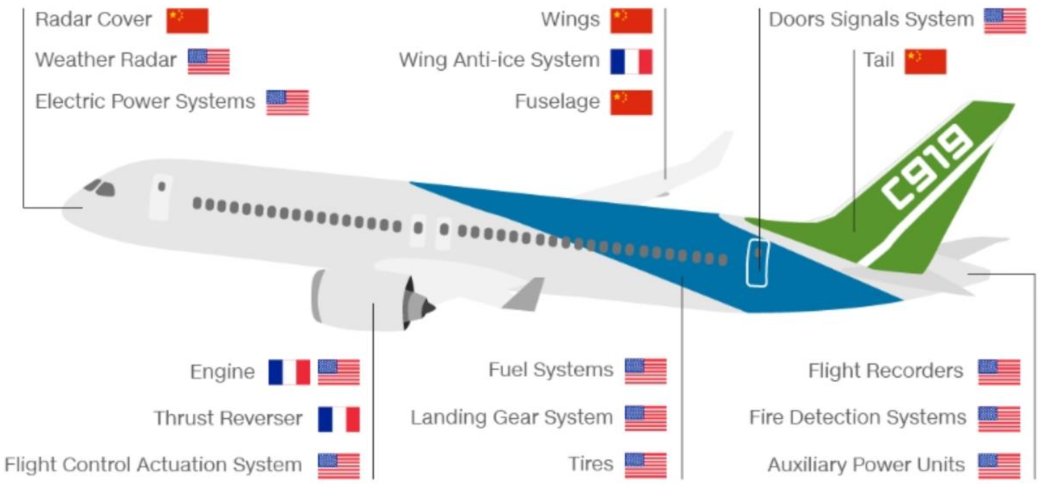


Figure 12.44. Main nationalities involved in the production of the C919.

Figure 12.45. Main companies involved in the production of the C919.

Suppliers comparison

In this section, we compare the suppliers' list of the three aircraft: The Airbus A320, Boeing B737, and COMAC C919. Suppliers are traced back to the company's country to see the representativeness of foreign and domestic players. Foreign/domestic nature of each company is correlated to the category of parts they provide (avionics/airframe/aircraft interiors ...).

As can be seen in Figure 12.46, the A320 presents the best balance of countries out of the 3 aircraft: 1/3 US, and approximately 12-14% each for France, Germany, and the U.K. The next countries fall rapidly below 2% (only Spain is above, at 3,4%).

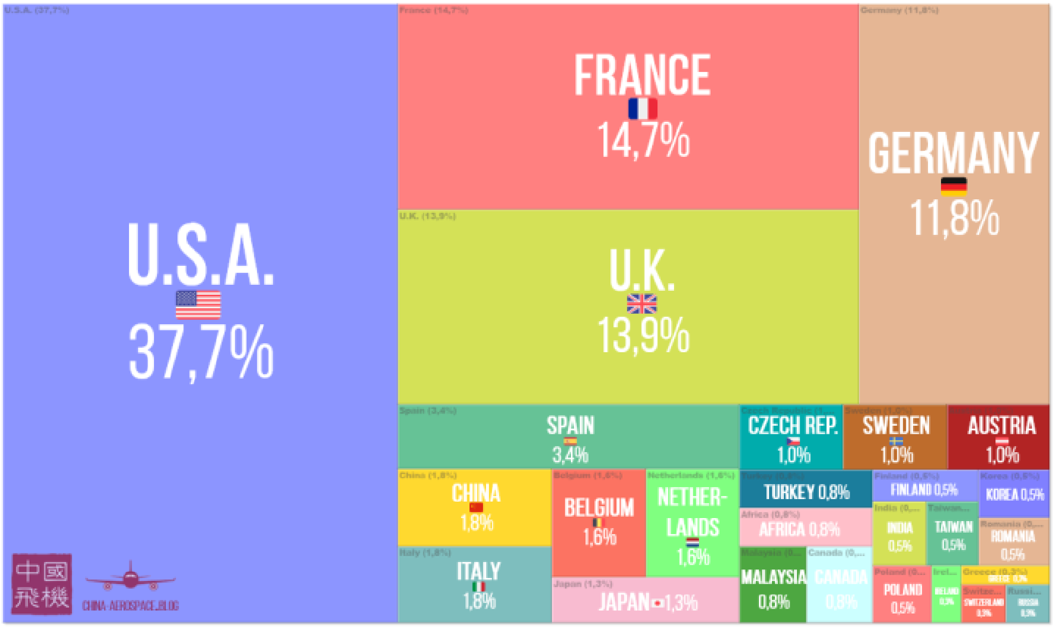


Figure 12.46. A320 suppliers. [44]

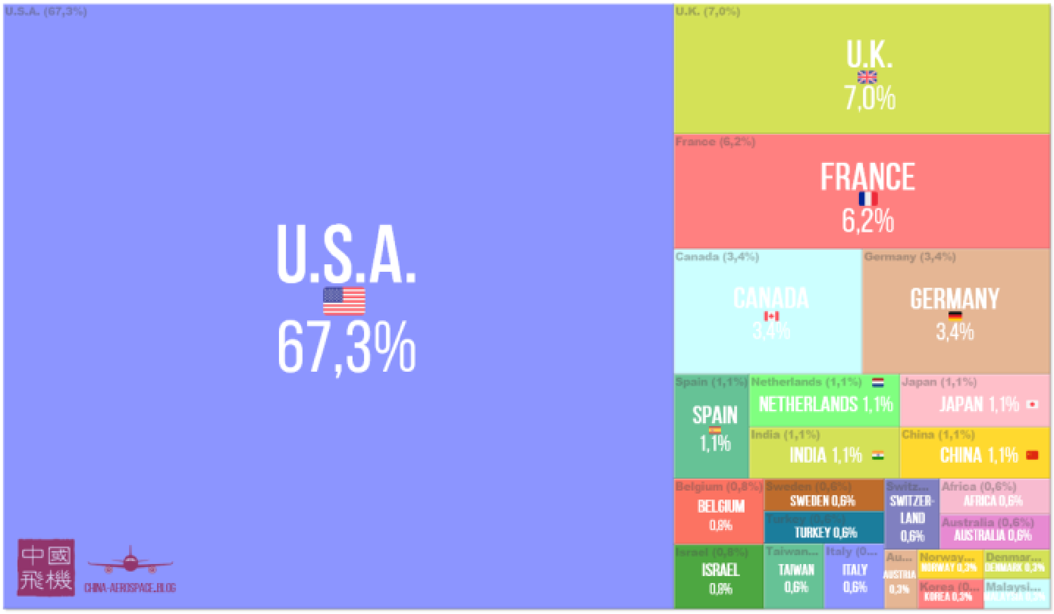


Figure 12.47. B737 suppliers. [44]

The B737 sees an overwhelming representation of US suppliers, snatching two-thirds of the aircraft's suppliers. We can also notice that the following order of countries after the US is the same: France, Germany, UK, thus accrediting the significance of the aerospace supply chain in these countries. Canada also stands out, being on par with Germany (3,4% each). All other countries are at 1% or lower.

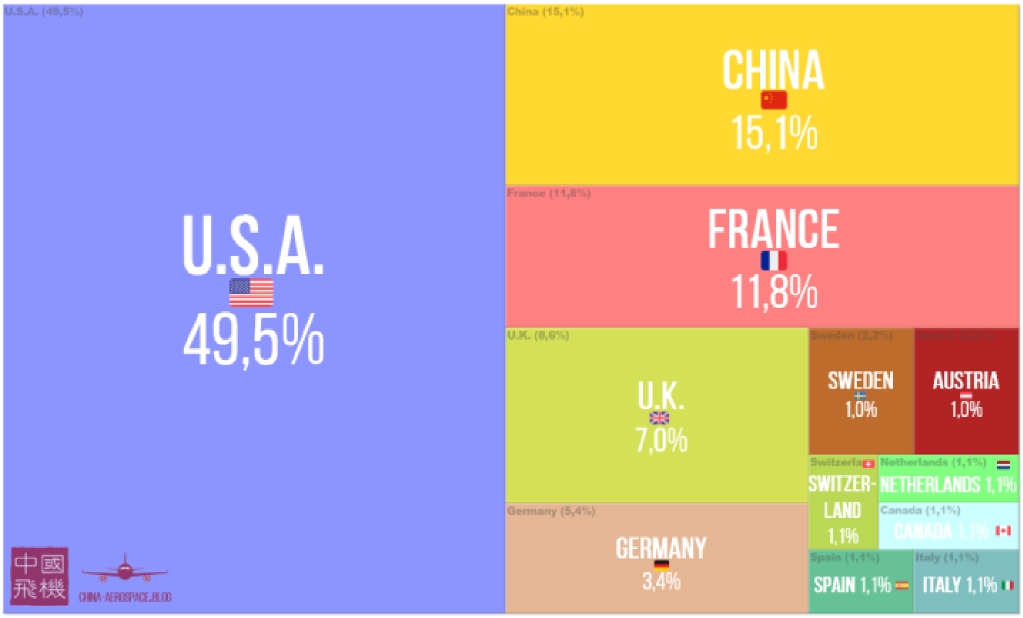


Figure 12.48. C919 suppliers. [44]

The C919 is somewhat in between the A320 and B737: strong US suppliers (approx. 50%), but with the importance of France/Germany/UK (adding up to 20%). The biggest difference lies however with the very striking presence of China, representing 15,1% and thus taking hold of the 2nd place as supplying country. This is also an expected result, as COMAC has explicitly pushed forward domestic suppliers or Sino-foreign joint-ventures (JVs)[45].

The industrial model of COMAC is comparable to Airbus and Boeing, focusing on the design and assembly of parts and systems procured from the global aeronautical supply chain.

AVIC is one of the main tier-1 suppliers selling aerostructures to COMAC, while all the others are typical Western aeronautical suppliers (e.g., GE, Safran, Honeywell, Rockwell Collins). Inhouse manufacturing is limited to very specific aerostructure components (e.g., empennage).

Another interesting point to focus on is the number of suppliers from the "domestic country". That would be the USA for the B737, China for the C919, and France/Germany/U.K./Spain for the A320, as Airbus can be considered as essentially a British-French-German-Spanish venture.

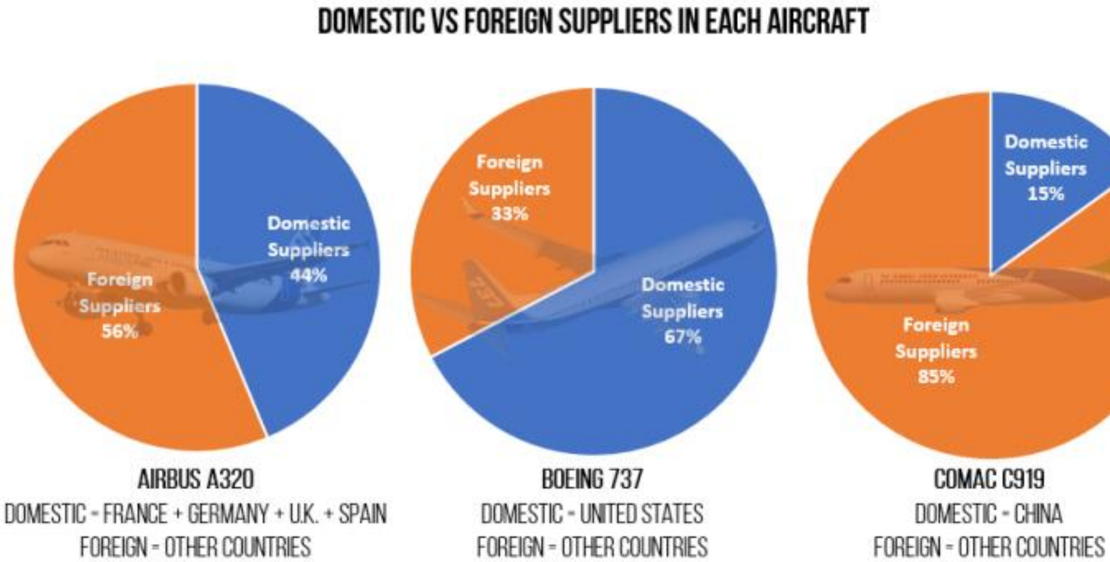


Figure 12.49. Foreign & Domestic players for each aircraft

All 3 aircraft see a strong representation of foreign suppliers in their supply chain (ranging from 33% to 85%). For each aircraft, there is a much stronger representation of domestic players: for the C919 (as mentioned before), but also for the B737 and A320, which were launched in the 1960s and 1980s, at a time where politics played a stronger role in the supply chain of aerospace programs. This may be less true today for Airbus and Boeing, which have strongly internationalized their supply chain since, as would probably illustrate a study of the more recent A350 and B787 supply chain.

Also, these pie charts combined with the previous block charts enforce the idea of US supremacy in aircraft manufacturing, as all non-US aircraft see US suppliers representing at least 1/3 of the supply chain, and consistently being the N°1 country in providing aircraft parts.

Orders

To date, COMAC boasts just over 1,000 commitments for the C919 from Chinese airlines and lessors. However, according to *Air Finance Journal* Fleet Tracker database firm orders number might be fewer than 400. In August 2018, FlightGlobal censes 305 orders plus 45 options and 658 letters of intent: 1008 commitments [46]. According to Fleet Tracker, the list is vastly over-dominated by leasing companies, just 55 of the 375 airplanes on firm order are from airlines. **Error! Reference source not found.** summarises the list of order known up to now, and the main assets are listed hereafter:

- November 2010: First 55 orders, plus additional 45 options from China Eastern Airlines, Air China, Hainan Airlines, China Southern Airlines, CDB Leasing Company, and GE Capital Aviation Services [39].
- October 2011: 45 C919s from Chinese ICBC Leasing[47].
- November 2014: Firm commitment for 30 C919s from China Merchants Bank's aircraft leasing division. This increased the total order up to 450 [48].

- June 2015: Letter of intent for 55 plus 7 additional C919 was placed by Ping An Leasing and Puren Group at 2015 Paris Air Show [49].
- November 2016: Orders for 20 C919s including 5 firms from Shanghai Pudong Development Bank Financial Leasing and for 36 C919s from CITIC Group Financial Leasing including 18 firms [50].
- December 2017: ICBC Leasing ordered 55 C919 increasing the order book to 785.[51].
- February 2018: Order for 200 from HNA Group in June 2018.[52]

Orders				
Customer **Airlines, **Leasing companies*	Firm orders	Options LOI/MOU	All	Date
Air China (Beijing) *	5	15	20	15 Nov 2010
China Eastern Airlines, Shanghai *	5	15	20	15 Nov 2010
China Southern Airlines, Guangzhou *	5	15	20	15 Nov 2010
GE Capital Aviation Services (GECAS) **	10	10	20	15 Nov 2010
Hainan Airlines, Haikou, under Grand China Air*	20	5	20	15 Nov 2010
ICBC Leasing, Beijing**			45	19 Oct 2011
Sichuan Airlines*			20	21 Oct 2011
BOCOMM Leasing, Shanghai **			30	23 Nov 2011
China Aircraft Leasing Company (CALC), Hong Kong**			20	9 Dec 2011
Bank of China – BOC Aviation**			20	14 Feb 2012
China Development Bank Leasing Company, Beijing**	10		10	29 Jun 2012
Agricultural Bank of China Financial Leasing**			45	2 Jul 2012
China Construction Bank Financial Leasing**	26	24	50	19 Sep 2012
Joy Air, Xi'an *			20	13 Nov 2012
Hebei Airlines, Shijiazhuang*			20	13 Nov 2012
GE Capital Aviation Services (GECAS) ***	13			13 Nov 2012
Industrial Bank Co. Financial Leasing, Fuzhou**			20	29 Oct 2013
China Merchants Bank Leasing **		30 (MOU)	30	12 Nov 2014
Hua Xia Bank Financial Leasing **		20 (LOI)	20	30 Jan 2015
Ping An Insurance Leasing, Shanghai**		50	50	17 Jun 2015
Puren Group**		7	7	17 Jun 2015
City Airways*		10 (MOU)	10	16 Sep 2015
CITIC Group Financial Leasing **	18	18	36	1 Nov 2016
Shanghai Pudong Development Bank Financial Leasing **	5	15	20	1 Nov 2016
China Everbright Group Financial Leasing Co**		30	30	13 Jun 2017
China Nuclear E&C Group**	20	20	40	19 Sep 2017
Huabao Leasing**	15	15	30	19 Sep 2017
AVIC International Leasing**	15	15	30	19 Sep 2017
Agricultural Bank of China (ABC) Financial Leasing**	20	10	30	19 Sep 2017
ICBC Leasing, Beijing**			55	5 Dec 2017
HNA Group**			200	2 Jun 2018
Total	**177**	**314**	**996**	

Table 12.29. C919 orders.

The standard practice among western manufacturers is to announce publicly only firm orders, backed up with a non-refundable deposit payment. COMAC accepts buyer's intent without deposits or fixed delivery dates for client airlines [53]. Those anticipated orders might just be described as "commitments" and not yet "firm orders" [54]. Therefore, uncertainty about the real value of the current order is high. [5] The number of orders may fall short of actual deliveries

China's Big 3 airlines—Air China, China Eastern and China Southern—each only ordered five. Financially troubled Hainan Airlines ordered 20. No currently operative airline outside China has placed an order. Although Ethiopian Airlines announced in May 2019, after the 737 accidents that they might consider COMAC C919 instead of Boeing 737 MAX 8. Ethiopian Airlines currently operates daily scheduled passenger and cargo flights from Addis Ababa to Guangzhou, Beijing, Chengdu, Hong Kong, and Shanghai; and they are working with the Chinese government to make Addis Ababa an aviation hub between China and Africa. [55]

Airlines in Southeast Asia may buy C919s because a lot of them do the four-hour regional flights and with bases geographically close to China, they could call on the manufacturer in case of mechanical problems. Southeast Asia is also rich in budget carriers, which might prefer COMAC's prices over those of its Western peers.

Analysts argue that the C919 with its "conservative approach" won't probably be a competitor for the much more efficient jets from Europe, Canada, Brazil, and Japan. But operators with cash problems looking to stretch their lifeline with a less aggressive efficiency increase could be interested in the COMAC C919 because of its lower promised price (half the price of its competitors A320 or B737). There is already a close precedent of this possibility. The A330neo, due to its higher discounts - lower sales prices, gave some operators a 5-6 years advantage over the most efficient B787 delivery delay. [6] For example in May 2019, Air Italy has decided to expand its fleet with Airbus A330s instead of Boeing 787s as was the original plan due to delays in 787 deliveries. [56]. According to Boeing's website, their current backlog for 787s overall is 624 aircraft out of the 1,441 that have been ordered. The 787-9 backlog currently sits at 389. [57] [7]

Western leasing companies prefer to see a significant airline base for new aircraft before committing to an order, although there have been exceptions. COMAC has one signature client outside China for the C919: Commercial aircraft and engine lessor and lender GE Capital Aviation Services (GECAS) signed a letter of intent in 2010 to buy 10 aircraft. Be noticed that CFM International, a 50-50 joint venture between GE and the French company Safran, had

[5] Said by Richard Aboulafia, vice president of analysis at Teal Group Corp, a US-based aerospace and defence market research firm. "Given the absence of firm order guidance from COMAC – a proper, verifiable order book – I don't take any of the order announcements seriously," he said.

[6] Although the price is listed higher for the –A330neo than the 787-9 Airbus will be more willing and able to offer deeper discounts than Boeing, in addition to a quicker delivery (at least until / the 787 backlogs going down made Boeing able to compete on delivery dates as well). Price is a major factor mostly because of lower fuel prices. The purchase price, lease price and insurance could all possibly be lower for the 330neo.

[7] The A330-800 EIS is expected to be in 2020. Since it appeared in Airbus catalogue in 2014, this variant of Airbus A330 only managed to secure 10 sales, out of which only 8 are a firm's orders. The A330-900 has 224 orders, including 100 from Air Asia X. In March 2018, Airbus lost its sole firm order at the time, placed by Hawaiian Airlines witched for ten Boeing 787-9 Dreamliners instead of six A330-800s. Airbus had to wait until July 2018 for a memorandum of understanding for two A330-800s from Uganda Airlines. In October 2018, Airbus received a firm order of 8 jets from Kuwait Airways. Both A330-800 and A330-900 are re-engined versions of the A330-300 and A330-200, using the new generation of Rolls Royce aircraft engine, the Trent 7000, which according to the plane manufacturer reduces fuel consumption by 25% compared to the previous generation.

already signed with COMAC as the Chinese firm's sole foreign propulsion system and engine supplier. GE officials could not be reached for comment.

For the sake of comparison, Status of B737 and As320 orders, deliveries and backlog are illustrated in the next figure. [58]

Deliveries	Airbus	A220-100	A220-300	A319ceo	A320ceo	A321ceo	A319neo	A320neo	A321neo	A320ceo	A320neo	TOTAL
		4	16	8	133	99	0	284	102	240	386	646
	Boeing	737:		-700	-700C	-800	-900ER	BBJ	MAX	737NG	737 MAX	TOTAL
				2	0	287	34	1	256	324	256	580
Gross Orders	Airbus	A220-100	A220-300	A319ceo	A320ceo	A321ceo	A319neo	A320neo	A321neo	A320ceo	A320neo	TOTAL
		0	135	5	19	2	22	393	136	26	551	712
	Boeing	737:		-700	-700C	-800	-900ER	BBJ	MAX	737NG	737 MAX	TOTAL
				0	0	13	0	0	747	13	747	760
Backlog	Airbus	A220-100	A220-300	A319ceo	A320ceo	A321ceo	A319neo	A320neo	A321neo	A320ceo	A320neo	TOTAL
		76	404	11	70	84	55	3,678	2,158	165	5,891	6,536
	Boeing	737:		-700	-700C	-800	-900ER	BBJ	MAX	737NG	737 MAX	TOTAL
				0	2	61	22	3	4,675	88	4,675	4,763

Figure 12.50. Boeing and Airbus 2018 orders, deliverables and backlog.

12.2.6 Chinese policies

This Chapter provides an overview of the main Chinese government policies regarding aircraft designing and manufacturing. Some of the strategies used in the past by the government to launch the aviation industry in China are presented.

12.2.6.1 China's government policies

Chinese government envisaged the designing and manufacturing of a commercial passenger jet as a symbol of the nation's technological progress and as a source of economic growth and technological spin-offs. Consequently, it has made creating a commercial aviation manufacturing industry a priority as is reflected in China's last few Five-Year Plans.

The strategic view of the Chinese government involves the following steps:

1) First engaging in domestic production and assembly using foreign designs,

2) Then developing its own designs with foreign assistance,

3) Culminating in the completely independent domestic development of a commercial aircraft without foreign assistance.[1]

According to the RAND Corporation study, the Chinese government has employed the following policy instruments to achieve that aim:

- Setting up **national champions**, and create, in 2008, COMAC, which mission is to produce commercially viable jet aircraft, a mission no previous Chinese state-owned company has had.

- Providing **subsidies and launch aids** for C919, like those listed in **Error! Reference source not found.** [59], [60].
- **Compelling state-owned airlines to purchase Chinese aircraft**, which by today are virtually the only customers for both the ARJ-21 and C919. The Chinese government is able to pressure China's airlines to order these aircraft through:
    - 1) approval of all purchases of aircraft by Chinese airlines;
    - 2) state-property of the three largest airlines;
    - 3) airlines financial support from the state, and loans from state-owned banks at lower-than-market interest rates, to finance their operations and expand their fleets
- **Targeting orders** to foreign manufacturers with assembly operations or suppliers in China. The government encourage foreign commercial aviation product manufacturers to purchase Chinese components and to set up joint ventures in China. This operation benefits both parts. For example, the opening of Airbus's assembly operation in 2005 coincided with a dramatic increase in sales of Airbus aircraft to Chinese Airlines. Since this assembly operation, Airbus has passed from a lower market share in China, to more or less split the Chinese market with Boeing. Additionally, as a consequence of these agreements, both Airbus and Boeing track purchases of components from Chinese companies have increased. More than half of all Airbus planes contain components manufactured in China. Chinese manufacturers are the sole source providers of a number of parts made of composite materials for the B787, including the rudder, the fin, and fairings. These purchases are seen as important for continued sales.
- **Stipulating that foreign suppliers enter into joint ventures** with Chinese partners. Joint ventures are designed to help Chinese firms acquire technologies, managerial know-how, and production experience. The foreign partner typically supplies production design and management expertise. Chinese partner provides the facility and labour and gains an opportunity to learn how to efficiently produce a line of products it did not previously have the capability to produce. Although this tool has worked well in the past, a drawback to manufacturing joint ventures can be that they are often effectively controlled by the foreign partner, which limits the Chinese partner's ability to steer the venture toward product areas of interest to the Chinese parent company. **R&D joint ventures are seen as better opportunities** for the Chinese partner to learn not just how to produce a specific line of products, but how to design and develop entirely new product lines. This might be the next step in this policy. Additionally, local production is a requirement for foreign suppliers to the C919 program in high technology areas such as advanced materials and flight control systems where Chinese technology is lagging [61]. In areas of less concern, the Chinese are content with traditional subcontracting or other work-share arrangements.
- **Acquisitions of foreign companies and foreign technologies.** The first acquisition of a large Western aircraft manufacturing company by a Chinese aerospace Company was in 2009 with the purchase of 91.25% of the Austrian company Future Advanced Composite Components. In March 2011, CAIGA became the first Chinese company to acquire a foreign aircraft manufacturer when it acquired 100% ownership of the Duluth, Minnesota-based Cirrus Aircraft Corporation.

- **Encouraging foreign countries to purchase Chinese aircraft through diplomatic persuasion and the provision of loans.** To date, this strategy to support COMAC has had only limited success. Laos has ordered two of COMAC's ARJ-21 (Table 12.30); Myanmar had options for two but appears to have cancelled the orders. However, industry observers believe that the prices that have been quoted to these countries have been steeply discounted and that financial terms are subsidized.

Source	Received subside	Form
State owned companies	19 billion renminbi ($2.8 billion)	Paid-up capital to begin development of the C919.
	6 billion renminbi	State-owned Assets Supervision and Administration Commission of the State Council (SASAC)
	5 billion renminbi	Shanghai Municipal Government's Guosheng Investments Group
	1 billion renminbi	Aluminium Corporation of China (Chinalco
	1 billion renminbi	Baosteel Group
	1 billion renminbi	Sinochem
AVIC's equity investment	5 billion renminbi	Transfer of assets: Commercial Aircraft Co., Shanghai Aircraft Manufacturing Factory, Shanghai branch of First Aircraft Institute, Intellectual property rights to the ARJ-21.
Loans from state-owned banks	Credit line of 30 billion renminbi ($4.4 billion)	China's Bank of Communications
Initial resources	$7 billion	Coupled with the equity investments
Guarantees on loans made to COMAC.	Investors such as the state-owned companies and the Shanghai Municipal Government	
Regional, provincial, and local governments	Financial and other support to joint ventures with and subsidiaries of AVIC and other manufacturers of aviation components and modules. Setting up industrial parks for aircraft manufacturing, Reserving plots for manufacturers, Financial assistance, Engaging in workforce training	

Table 12.30. Subsidies and launch aids for the C919.

12.2.6.2 Overview of Chinese Investments in the Western Aviation Industry.

In general, acquiring foreign competitors, as well as establishing Joint Ventures with leading-companies supplement the development of the national R&D program, and help to close the technological gap and catch up the global state-of-the-art. This strategy is also part of the Chinese approach for aviation, in particular, the first point. Acquisition of foreign companies has been articulated through Chinese FDI (Foreign Direct Investment) activity. In this section, China's FDI activity in aviation is tracked down and summed up in the main trends.

One of the first fact that call the attention is that, compared to other sectors where Chinese companies have been more aggressive, global aviation industry accounts for a relatively low number of Chinese acquisitions [62],[63], [64], [65]. All those acquisitions have been focused on smaller and less technology-significant companies. This low profile justifies the absence of concerns about Chinese foreign acquisitions in the international domain. Probably two main reasons explain this low profile: national security in the aerospace sector, and the interest of companies in increasing their market and decreasing risk.

Most aerospace companies directly supply to both civil and military clients, and in most of the countries, their acquisition is subject to national security criteria and barriers. For example, the US CFIUS (Committee on Foreign Investments) has blocked several operations in the aviation industry. Additionally, the wellbeing of the industry and the increasing number of aircraft translate in growth and need of investment capital on the entire supply chain to follow the ramp-up in production. Connecting with Chinese companies could increase the potential of western companies on the Chinese aviation manufacturing market, as it is the case of COMAC, that favour Western suppliers which explicitly designed and/or manufactured in China through a JV to supply the C919 [45].

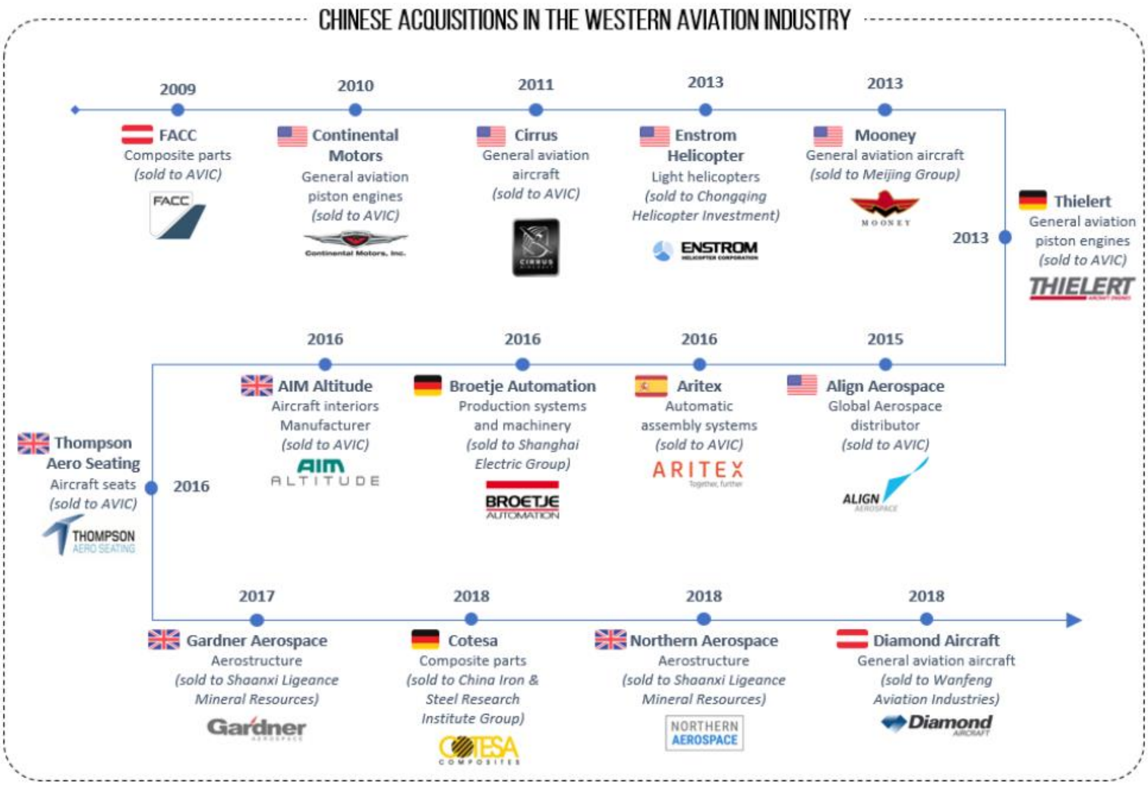


Figure 12.51. Timeline of the larger Chinese acquisitions of Western aviation companies (>1M turnover)

Error! Reference source not found. summarises in a timeline the larger Chinese acquisition of Western aviation companies. As of 2018, Chinese acquisitions have been restricted to small and medium-sized aviation companies, most of them bellow 100 million euros and with a total amount under 400 million euros. One of the earliest acquisitions, Austria-based FACC by AVIC's Xi'an Aircraft Corporation in 2009, also marked the first M&A operation implying a Western tier-one supplier to Boeing and Airbus.

Chinese acquisitions have mostly focused on general aviation (GA), especially in the early years, accounting for 7 in 15 operations. Particularly relevant are Cirrus and Diamond, two of the biggest GA manufacturers. Considering acquisitions excluded from **Error! Reference source not found.** due to their smaller size, this number rises to 17 out of 25. This is coherent with the Chinese government plans to develop general aviation in China [27][8] in the 12th and 13th Five-Year Plan [24]. Although there will be some lessons in terms of product support, international marketing or industrial efficiency to be learned through general aviation, the technologies involved are far from those required for commercial aircraft and even certification standards are different. The main benefits of the investments by Chinese firms to date would be on the business-process side, such as international marketing, achieving safety certifications, and product support.

More relevant for commercial aviation is the strong emphasis put on aerostructures, including composites. Acquisitions in this area were done by different companies: Shaanxi Ligeance Mineral Resources, Shanghai Electric Group, AVIC, and China Iron and Steel Research Group. Other than AVIC, the corporations were non-aerospace specialists. Acquisition of FACC by AVIC is strategic. Composite materials are one of the keys to reduce weight and increase the competitiveness of future aircraft. FACC has enabled AVIC to increase knowledge and production capability through the partnership with the AVIC domestic subsidiary Fesher Aviation Components, and also to put forward its composite material providers to directly supply FACC in the raw material. Additionally, because FACC makes winglets for the Airbus A350, AVIC can now enter the Western aerospace supply chain for leading-edge composite components.

Recently, COMAC took a further step in this direction by the MoU between Leonardo and Kangde Investment Group of Chinato to establish a joint venture, Kangde Marco Polo Aerostructures Jiangsu for the development, production and assembly of composite materials components for the CR929 wide-body aircraft. Leonardo is a strategic risk-sharing partner for Boeing producing the 14% share of the B787’s airframe: the horizontal stabilizer at its Foggia plant, both central fuselage sections at its innovative plant in Grottaglie through “one piece barrel” advanced technology, plus frames, shear-ties in Pomigliano D’Arco and metal alloy machined parts in Nola. It also produces all the ATR fuselages complete with empennages.

Ultimately, AVIC has created in 2018 a new entity, AVIC Cabin Systems, integrating acquired FACC, Thompson Aero Seats and AIM Altitude with domestic subsidiaries Jiatai and Fesher, bringing a new vertically integrated player in the field of aircraft interiors.

A more specific view of the European perspective shows that Chinese companies have begun to invest in the European commercial aviation industry since 2009, pursuing to access technology and know-how through acquisitions (Fischer Advanced Composite Components – FACC) and engine maker (Thielert Aircraft), and establishing offices to promote R&D cooperation and recruit local talent (COMAC’s office in France).

[8] This activity that is strongly underdeveloped in China due to its restricted airspace and lack of infrastructure (roughly 1500 GA aircraft in 2016, compared to over 200 000 in the USA)

Many of the acquired companies in Europe such as Aritex, FACC or Cotesa have decided to open manufacturing facilities in China and have hopped onboard Chinese indigenous aircraft programs after the acquisition [66], [67].

However, compared to other industries, total investment in the aviation sector remains residual compared with other technological sectors (about $340 million cumulative investment by the end of 2014, mostly in Austria, Germany, and France). Figure 12.52 comparatively show Chinese investment in European industries in 2018.

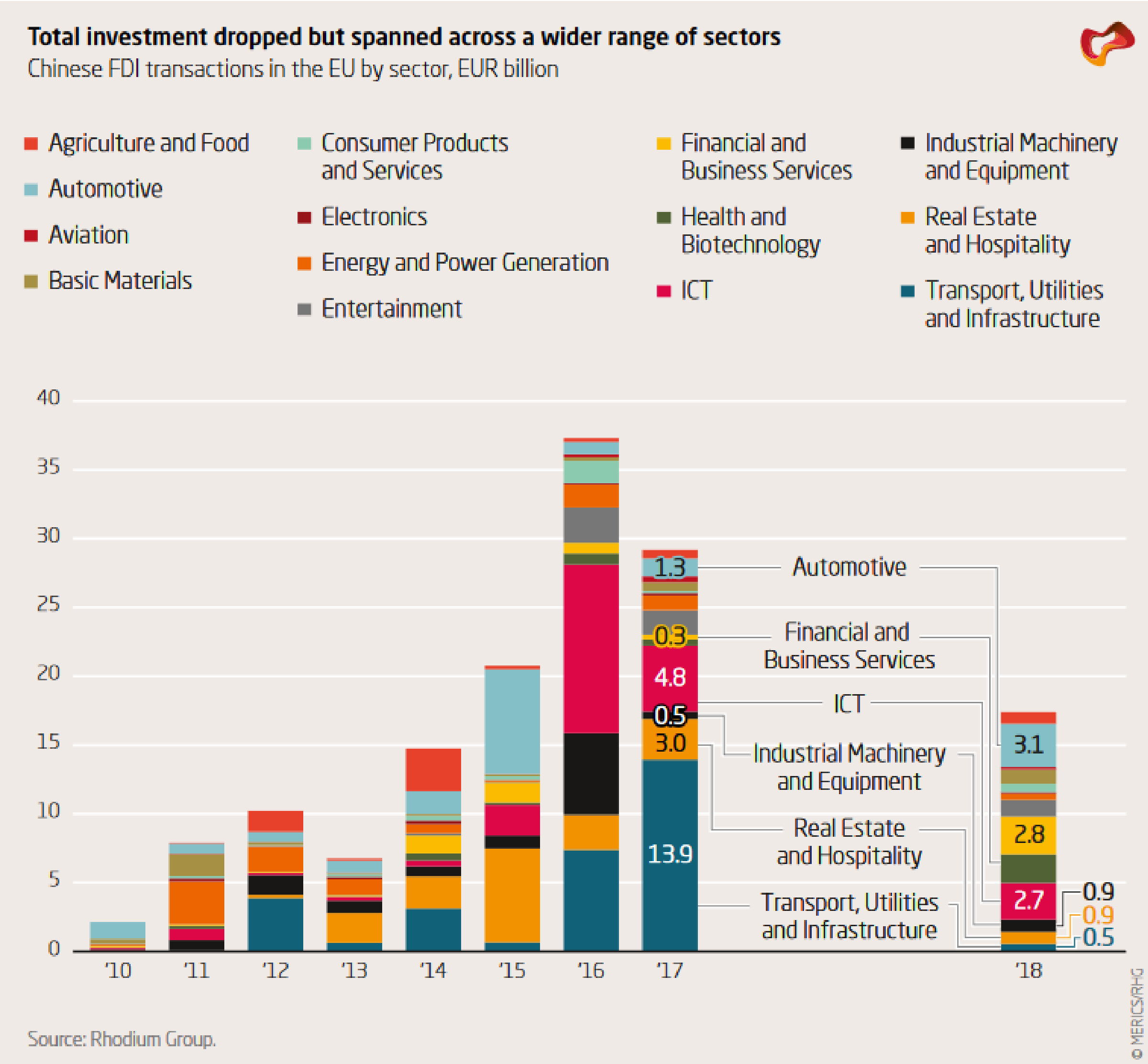


Figure 12.52 Chinese investments in European industry by sectors.

The future trajectory will depend on the feasibility of integrating foreign technology and mitigating existing national security concerns in EU countries over the applicability of aviation technology for defence purposes.

Looking at the US, the situation is quite similar. Chinese companies have also steadily increased investment in U.S. aviation since 2005 by acquiring, merging, or establishing joint ventures with more than a dozen U.S. aviation companies. During the last 10 years, despite US government foreign investment and export laws restrictions, it accounts an average of one to two investments in U.S. aviation per year, including 12 mergers and acquisitions, three joint ventures, and nine other agreements or failed deals. These investments are constrained by U.S. government foreign investment and export laws as well as classic business concerns about return on investment. The most relevant operation in the US is reflected in Figure 12.53.

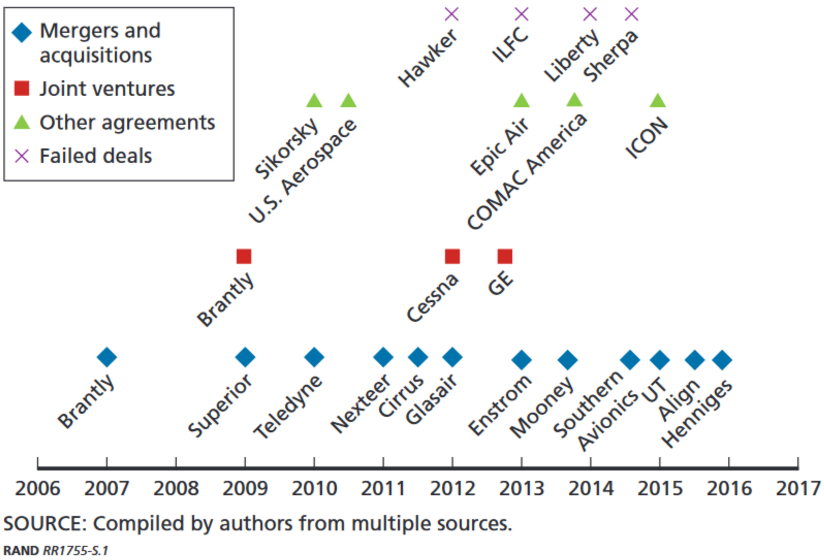


Figure 12.53. Timeline of Chinese Investments in U.S. Aviation

Majorly, Chinese investment in U.S. aviation over the past decade has primarily involved lower-technology GA manufacturers that do not affect U.S. competitiveness. Those GA companies that fall outside export controls and U.S. foreign-investment regulations as GA technologies are broadly available.

All these acquisitions are targeted at building up of expertise in GA, composites, and assemble and integration technologies. They constitute a serious push to integrate the global supply chain as well as securing technology for its aircraft programs. This international strategy is in line with the development of indigenous commercial aircraft, and the recent consolidation of the Chinese aerospace value chain (AECC, AVIC Cabin Systems).

Based on the feedback available in open-source literature and press releases, impact on employment in the US and Europe has mostly been positive, with increased investment and expansion of manufacturing capabilities otherwise not possible. Among the list of companies that acknowledge positive effects are: FACC, Continental Motors [68], Thielert [69], Thompson/AIM Altitude [70], Aritex, Cotesa, Gardner Aerospace/Northern Aerospace [71], [72].

12.2.7 Lessons learned from other industries development in China

Several authors have studied the effectiveness of Chinese government industrial developments policies in key industries during the last decades. The most relevant cases might be those discussed hereafter.

High-speed trains. China opened its first high-speed train line in 2007. Today it has the longest high-speed network in the world, and the plans are to expand even more the network, up to 25000Km by 2020. The first bid was launched in 2004 and awarded to 3 of the 4 contenders, Kawasaki Heavy Industries, Alstom and Bombardier. Companies were required to have a local Chinese partner to manufacture trains. In a few years, state-owned Chinese partners were able to manufacture their own trains and did not purchased the 200 trains foreseen in the contract. In a very short period of time, local companies absorbed the technology and were no longer dependent on foreign companies.

Wind-power generation. China became the world largest manufacturer of wind turbines in 2009, passing in less than 4 years of being just a player to become the major player in the industry. By 2012 almost all the units installed in China were manufactured locally. This powerful industry development responds to a series of measurements that include domestic subsidies, licensing agreements, acquisition of foreign companies, and joint ventures with foreign manufacturers.

Automobile manufacturing. China became the world's largest market for new cars sales in 2009. For exploiting this market, manufacturers have to set up assembly operations in China and a joint venture with a local partner. Other measurements to favour local industry include the restriction to purchase foreign vehicles by government agencies or subsidies for electric vehicles only for a model produced by Chinese companies. However, in this case, those measures have not yet been able to generate a strong automobile industry, and models manufactured by joint ventures still dominate the market against national pure products. Despite local partners were able to acquire the technology, Chinese consumers still prefer foreign brands because of their better reputation and prestige. All these have translated in an increase in the production of joint ventures but very low development of pure local brands.

The main lesson that can be derived from these 3 sectors is the relevance of the industry structure in the process. Those industries where the customer are state-owned companies (wind power generation) are very much sensible to Chinese government policies to drive purchases, as well as those industries where state owned companies have a monopoly (railway sector). In these cases, the Chinese government has been able to induce firms to buy products manufactured by Chinese companies, even when products are available from joint ventures with foreign manufacturers. The state-owned purchasers have not been concerned about disputes about ownership of the technologies underlying these products.

Where the decision to buy depends on the final consumers the situation is different. In the automotive industry, Chinese customers are free to choose the vehicle they prefer, and foreign brands manufactured by joint ventures dominate the market. Automotive brands have been able to maintain and control their intellectual property better than other industries and have made optimum use of their reputation for safety and reliability. They have also created a dealership network and have invested in marketing in china to back up their position in the market. They have also been able to compete in cost, by spreading R&D cost over their global operations and reducing the cost per vehicle of developing a new model.

The commercial aviation manufacturing industry falls somewhere between the previous cases. On one side, the Chinese government influences the choice of aircraft purchased by China's state-owned airlines. The CEOs of these airlines are selected by the government, that can pressure them to buy national products. However, Chinese airlines are subject to competition among them and with other companies, because they sell airplane tickets directly to consumers. There will be a conflict of interest between government desires to purchase aircraft manufactured by COMAC, and the need to ensure that their airlines operate safely and profitably.

Experts claim that because of its outdated design, the C919 will be more expensive to operate than next-generation Boeing and Airbus narrow-body aircraft. These differences in operating costs will directly affect the airlines' profitability. The extent up to which the CEOs of the three main state-owned Airlines will purchase aircraft that ensure the continued success of their operations, regardless of pressure to purchase Chinese products, will define different possible scenarios.

12.2.8 Policy options for foreign governments

The increase of joint ventures to support the C919 project together with Chinese policies to maintain aircraft and aircraft components in that large market are implying a slow shift in component manufacturing to China. This natural tendency could be distorted by Chinese industrial policies. Several authors have pointed out a set of measurements that both, United States and UE governments might consider reducing such distorting effects.

- Concerted effort to reduce the use of purchases of components from local manufacturers as a marketing tool in sales negotiations with CASC by Airbus and Boeing.
- Push Chinese government for more transparent and open tenders for purchases of new aircraft by Chinese state-owned airlines, to avoid situations like the last commitments by Chinese airlines to purchase the C919, not made after open tender solicitations for new aircraft in this category.
- Limiting the eligibility for EASA or FAA certification of products using illicitly obtained technologies. That will require to involve FAA and EASA in the process of ensuring that Chinese aircraft components submitted for certification do not incorporate intellectual property taken from other companies.
- Building a record of influence on investment decisions because of Chinese industrial policies that could support future bilateral discussions and WTO proceedings.
- Carefully monitor the evolution of the C919 and successive aircraft and intervene promptly with formal proceedings if WTO rules in this industry are violated.
- Continue to press the Chinese government in bilateral forums and at the WTO to give out industry-specific industrial policies.

However, all these measures will only mitigate some of the effects of China's industrial policies but will not be enough by themselves to create a level playing field in China for Western manufacturers. In the long-term health of the U.S. and European aviation industries will depend on continued technological innovation and the ability of the home countries to provide a competitive environment for manufacturing aviation products.

12.2.9 Factors impacting programme and delivery timescales

12.2.9.1 Development learning curve

The development cycle of future large passenger aircraft is a critical determinant of the future success of a commercial aircraft. The typical current development cycle spans several phases lasting 4 to 8 years. Typical phases in the development cycle are presented in **Error! Reference source not found.** [73]. Figure 12.54 illustrates the launch of entry into service timelines for different aircraft types [74].

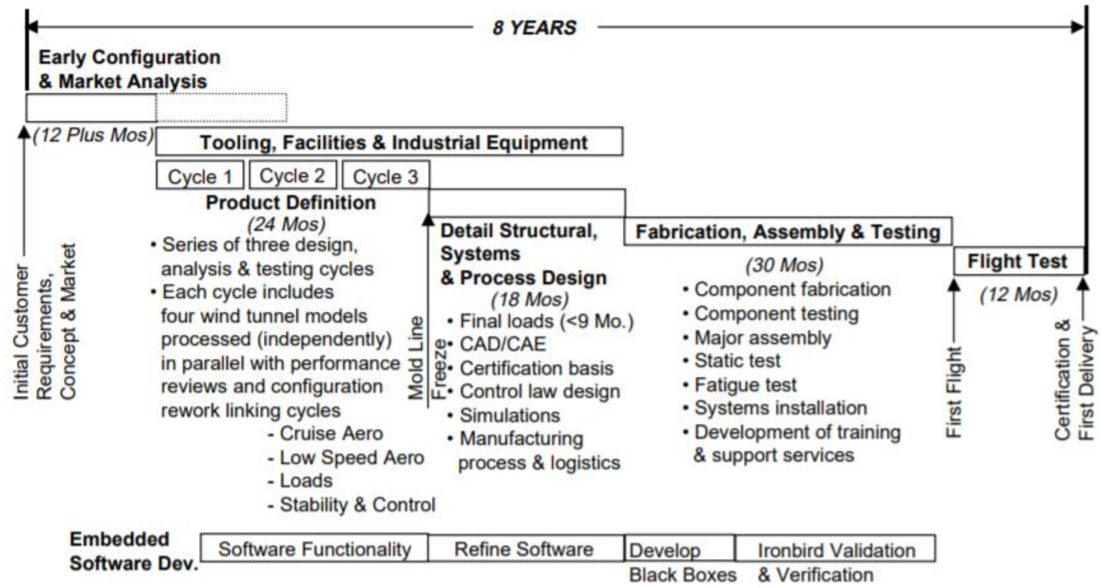


Figure 12.54. NASA Airframe Development Cycle.

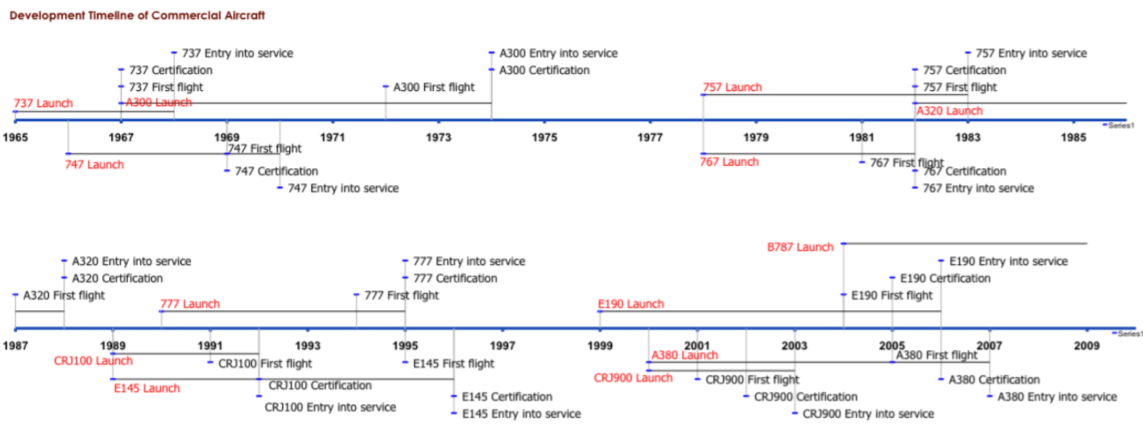


Figure 12.55. Launch to entry into service timelines for different aircraft types

Based on the information, **Error! Reference source not found.** presents a synthesised comparative of development years for COMAC, Airbus and Boeing aircraft. Figures for COMAC are based on firm information, beeing first maiden flight taken place in 2017, and an educated guess based on publicly available information for certification and EIS.

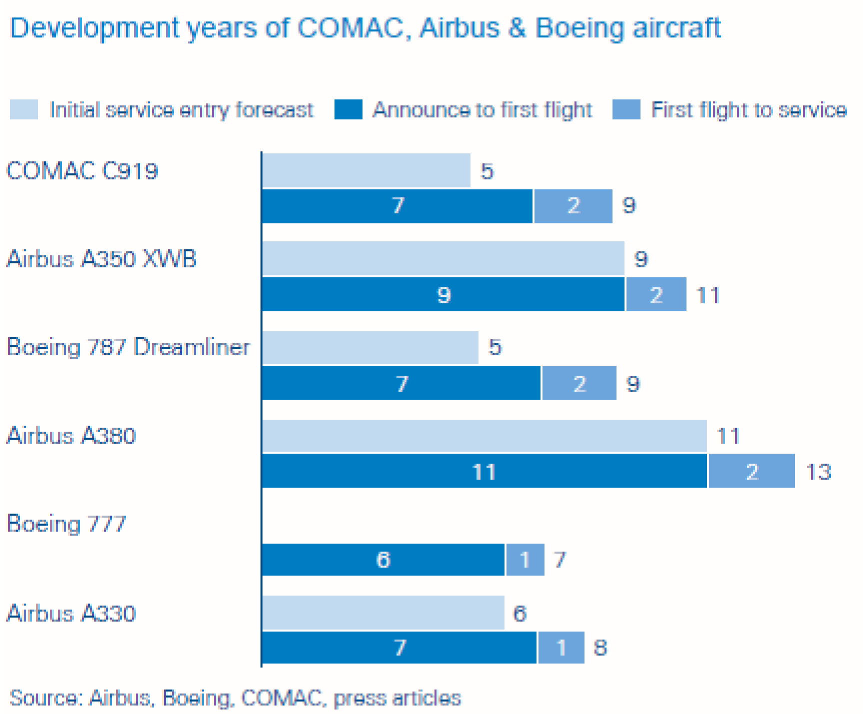


Figure 12.56. Comparative of development years for COMAC, Airbus and Boeing aircraft

Commercial Aircraft Corporation of China (COMAC) spent 11 years and at least US$9.5 billion to develop a plane that is comparable in size to an Airbus 320 or Boeing 737, although outside analysts place the budget at more than twice that amount.

Following its maiden flight in 2008, COMAC's ARJ21 regional jet was plagued by setbacks that delayed its mass-production certification by the Civil Aviation Administration of China for nine years. Similar aircraft made by Boeing and Bombardier typically see certification and commercial introduction in roughly two years, underscoring the challenges facing Chinese firms. With the right help, COMAC expects it might receive airworthiness certification for its C919 large commercial jet in 2021, only four years after its first flight. [75]

It will be very important for COMAC to maintain a constant or increasing rate of production over time in order to benefit from the decreased unit costs resulting from learning economies. Even small variations in production rates (especially in early years) can have dramatic effects on realized learning economies, and hence on net profits. At [73], NASA illustrates how variable costs are affected by changes in production rates with a simpler version of Benkard's model.

Additionally, reducing development times will be a key factor for the second generation of C919. Learning economies are one important benefit of cycle time reductions, reducing production costs and increasing profits. However, learning economies depreciate over time when they are unused. Getting to market earlier means that the company will have more opportunities to dominate a particular market segment before a competitor can react. If a company can lock in more customers, it has a better chance of both producing more units and smoothing the production run over the product's life cycle and thereby realize its learning economies. By getting to market faster, the forecast for the product and the expected profitability of the program are more likely to be realized. Airbus access to the single-aisle Chinese market is an example of this.

Firms will have an incentive to invest in existing technology when increasing returns to adoption are present. This can delay or prevent the introduction of new superior technology. When there are large learning curve effects on production costs (i.e., the incremental production costs decline with succeeding units of production), a firm has an incentive to produce more of an existing design, rather than introduce new technology that would cause higher costs associated with the beginning of the learning curve.

The increasing returns to adoption model may be particularly appropriate for the civil aircraft industry. Here a manufacturer is often faced with a choice of producing a derivative of an existing design versus a totally new aircraft. The implications of the increasing returns to adoption case are that firms may have economic incentives to forego superior technologies that may have potentially large long-run payoffs. As a result, firms may underinvest in R&D, even up to technology demonstration and validation. This does not apply to cases where companies receive development funds from the government. If the government wants the industry to apply these superior technologies, it may have to invest in their development, demonstration, and validation. This is especially the case for technologies that are significantly different than those embodied on existing products. The technology base for high-speed civil transport aircraft is one example of potentially superior technology in which the industry may not have adequate incentives to invest.

History suggests that dominant firms in the airframe industry will be reluctant to make technological leaps forward because they do not wish to compete with their existing and successful product lines and their incentives to undertake the considerable risks involved are less than those of companies with less of a stake in the existing aircraft market. This is known as the effect of the dominant firm. In other words, dominant firms become dominant by successfully making significant technological breakthroughs first. They remain dominant by winning any direct competition with other major manufacturers (e.g., the B-707 vs. DC-8, and the DC-3 vs. the B-247) and by successfully differentiating products (e.g., the B- 727 and the B-747). But they can lose their dominance by underinvesting in technological advances and the R&D necessary to support them.

12.2.9.2 Certification hurdles

The COMAC industry faces challenges to comply with the certification procedures required to allow the sale in the United States. The primary means COMAC has employed to reach certification is to incorporate only modules and components that have already been certified by the FAA and EASA; the components and modules used in the C919, in fact, incorporate the same technology as Boeing 737 and Airbus 320. However, the process is not as simple.

In 2018 COMAC industry failed to pass the Federal Aviation Administration (FAA) exams regarding the flight tests of the C919. Engineers began to reassess the design of the C919 flight deck to comply with Part 25.1302 of the Federal Aviation Regulations (FAR). Section 1302 is quite strict with respect to human factors and is necessary for FAA certification, but is not required by the Civil Aviation Administration of China (CAAC).

C919 continues to undergo further envelope expansion testing at its Shanghai facility and the team encounters repeated setbacks due to interruptions in design changes and a shortage of local experts.

COMAC plans to carry out 4,200 hours of flight tests. It has already produced 3 out of the 6 planned prototypes required for the certification. The third prototype took its maiden flight in December 2018. The 3 remaining prototypes are expected by the end of 2019. To accomplish the 4200 hours required will take long. An optimistic and ambitious estimation will be around 2 years. So far, the two prototypes have only flown a combined 150 hours. To reach the deadline for service by 2021, they will need to fly around 150 hours a month. Flying all six for an hour a day, 365 days a year would require two years of testing alone. This without considering other delays, for example as prototypes required modifications. In February 2019 China Daily announced that existing prototypes are laid up, undergoing modifications for as long as three months, pushing-back the timetable.

European certification is even more delayed, as COMAC started this process later. The first C919 that lodged an application with the European regulator took place in 2016.

These problems are a reflection of a major problem that affects China's aerospace industry and that analysts summarise as the **technical expertise achieved**. While foreign experts in China transfer knowledge of manufacturing and R+D, Research and Development capabilities, **communication problems**, **misinterpretation of FAA requirements** and **limited local skills** have significantly delayed the progress of the development of certainties for the FAA. The local expertise is taking a much longer time to navigate the various steps required by foreign aviation bodies to be approved for sale overseas. This can be related to language barriers as well as its test site, the very busy Shanghai Pudong International Airport.

COMAC engineering is going through a learning curve, which means it will take longer to achieve FAA certifications. Unlike Airbus or Boeing that can meet the process within a period of 18 months, the Chinese industry needs the optimum maturity to achieve international certifications. Foreign companies associated with COMAC can serve as effective vehicles for the transfer of knowledge, international companies recognize the need to carefully safeguard their intellectual property and technologies, but at the same time, COMAC needs to commit the necessary collaboration to meet its objectives.

COMAC aim was to have the first aircraft delivered by 2021. However, the most optimistic date for C919 getting its paperwork in order will be the start of 2022, although a more conservative approach, considering the previous numbers, would be a date closer to 2025.

By 2025, at current targeted production rates of around 60 a month for the A320neo and 737 Max, there will already be 10,000 competing Airbus and Boeing planes in the air by that time, and Boeing's planned new midsize aircraft could be nearing its first deliveries.

With maximum ranges about a third less than its competitors and the capacity to carry only about three-quarters of the weight of passengers and cargo, the C919 will be looking a generation out of date. Moreover, given it's largely made of parts from conventional suppliers such as Honeywell International Inc. and General Electric Co., it's going to be challenging for COMAC to find the cost savings necessary to undercut Boeing and Airbus outside China.

It is not expected that COMAC could overcome these drawbacks in the next 10 years, raising doubts about that they will be able to develop a local alternative to the CFM LEAP-1C engines C919 within a decade, or that they could reduce production cost to be competitive with incumbent manufacturer in less than two generations of the aircraft.

Obtaining aircraft certifications from the National Aviation Authorities in Europe and in the US might prove a challenging and long process for COMAC. For the time being, US authorities do not allow importing of Chinese-made aircraft, except for the Harbin Y-10. COMAC is slowly moving towards improving its overall technological capabilities, and progressing towards the certification, although repeated delays and dependence on foreign assistance will continue for some time. Certification is not expected before 2025, and the first generation of the aircraft might not be competitive in technology not in price with incumbent manufacturers. At some point, the successors to the C919 may pose a formidable threat to Boeing and Airbus, but this is not expected, according to the main analysist during the next decade. Obtaining certifications might slow COMAC export to Western countries, but this appears less of an issue in developing markets. According to Arthur D. Little intelligence, COMAC benefits from a large and growing domestic market and an addressable export market in many countries, which are already purchasing Chinese civil and military aircraft.

12.2.9.3 System integration skills

The lack of systems integration skills has been identified as one of the capabilities that the Chinese aviation industry still need to improve.

Following the stela of incumbent manufacturers, Boeing and Airbus, the Chinese industry is trying to use a "distributed airframe manufacturing process," whereby subcontractors are responsible for manufacturing major sections of the airframe. However, the Chinese assemble processes is still suffering a lack of communication and coordination, which is causing the manufacturers to be working on their own, and finished products having compatibility issues during final assembly.

Chinese industry is also still at initial stages in the learning curve regarding the integration of new designs into manufacturing. Traditionally, China's research and design institutes had been completely funded by the state through annual budgetary allocations. The institutes still receive partial support through annual budgetary outlays, but now depend on contracts for the remainder of their funding. Historically, after an institute completed the design, the designers reportedly simply handed over the blueprints and design data to the manufacturing enterprise without compensation. This state of affairs has changed. Aircraft design institutes now face greater financial incentives to develop designs in collaboration with manufacturers and better attuned to the needs of the final customer, but the separation of Research and design into separate institutes detached from manufacturers still makes the integration of R&D into the final products more difficult than it is in Western companies.

12.2.9.4 Engines industry

Other relevant concern about the capabilities required to develop national aeronautical industry is the know-how and evolution of the engine industry.

The industry has built Soviet designs on the license since the 1950s and only recently managed to present functional own designs, after many failures. The first jet engine that was produced under license was the Klimov VK-1 (for the Mig-17), a Russian copy of the Rolls-Royce Nene. China later built the Tumansky RD-9 jet engine under license for their locally produced Mig-19, the Shenyang J-6. The production was done by the same companies that produced the aircraft in their engine production departments. Gradually the Chinese aircraft industry started to try and make modifications to engines they built under license. It did not go well. Engine development and changes were much harder to do than making adaptations to aircraft. The locally adapted engines were not reliable, so the Chinese military continued to source engines from Russia/Ukraine for their aircraft projects. Engines were the Klimov RD33 (the MIG-29 engine) for the locally developed canard aircraft, J-10, which looks like a larger Lavi, and the J-17 Thunder; the Saturn AL-31 for license-built and locally developed copies of the Su-27 Flanker; and the Ivchenko-Progress/Motor Sich AL-25 (Yak-42 engine) for the Hongdu L-11 jet-trainer. The AL-25 is license-produced as the WS-11. The other engines are imported from Russia.

There were many attempts to develop and produce an indigenous engine. As there was no Chinese commercial aircraft development of any scale, the Chinese engine industry/state focused on getting self-sufficient on military engines. Most projects died out when no reliable engine came out after 20-30 years of effort. The first local program that finally managed to produce an engine which had acceptable reliability was the Shenyang Engines WS-10. The WS-10 project was started by the strongman after Mao Tse Tung's death, Deng Xiaoping, in 1986. The target was to replace the 30klbf Saturn AL-31 for the Chinese Flanker variants. The WS10 is a low bypass two-shaft engine in the 30klbf class. Its core is modelled after the CFM56 (from the GE F-101), which China could examine in 1986. It took until 2009 for the engine to get a thrust and reliability level that it could replace the AL-31 on the local Flanker variant J-11.

The problem was that turbine engines require massive investment in technology and production equipment. None of the engine companies had the critical mass to keep pace with the Western technology-driven companies or companies/agencies in Russia/Ukraine. The result has been an engine industry that has not been able to produce virtually any successful engine programs over the last four decades. China engaged Ukraine to come in and help them with engine technology in recent years. Western companies have been hesitant, given China's handling of intellectual propriety rights. Rolls-Royce licensed the Spey RB-168 as the local WS-9 (used for a local strike aircraft JH-7, looking like a large SEPECAT Jaguar) after China tried unsuccessfully to copy it. SAFRAN group's Turbomeca licensed turboshaft engines like the Ariel for helicopter applications.

Based on the WS-10 core, Shenyang Liming Aero-Engine Group developed a high bypass variant, the WS-20. The target application is the military heavy-lift transporter Y-20 (similar to a Boeing C-17), which presently is using low bypass Russian D-30 engines (the Tu-154 engine). This is the first high bypass engine development in China with an estimated By-Pass Ratio of around 5-6. Thrust is around 30klbf. With the original WS-10 core modelled after the CFM56, the high bypass variant now has data, which resembles the CFM56-5. The engine is presently on flight test on an IL-76. WS-20 is also the right size for a COMAC C919 application, but a full generation behind the CFM LEAP-1C engine, which was chosen for the aircraft. The engine has therefore not been accepted as an option.

Today, the Chinese engine industry is closely modelled after the Chinese aircraft industry, but contrary to the Chinese aircraft industry, it has had major problems in gaining the necessary know-how to start developing and producing its own designs. The technological cornerstone of commercial aircraft engines manufacturing is the know-how and tools needed to produce lightweight blades. Even with reverse engineering and access to the design, China has no access to the advanced machine tools" required to produce turbine blades. The US and other Western countries do not sell China the advanced machine tools, and the ones purchased from them are not precise enough to mass-produce the intricate blades needed for the engines. Additionally, aircraft turbofan engines required technology is guarded as proprietary knowledge by a handful of companies. Four US and European companies – CFM, Pratt & Whitney, Rolls Royce and GE – control close to 93% of the market share, according to Market Research Future. Regulators have very strict rules on what these engine companies can do with Chinese collaborators, especially in the US and UK.

In an attempt to surmount these limitations, on top of COMAC and AVIC, the Chinese government is investing in domestic aircraft engine manufacturers to complete their manufacturing capabilities. In its "Made in China 2025" industrial policy presented in 2015, the Chinese government identified aircraft engines as one of the 10 crucial manufacturing sectors of importance.

In order to steer the development of this sector, a new state-owned entity was created in 2016 with the objective of building a world-class jet engine. This new entity, called the Aero Engine Corp. of China (AECC), consolidates all existing Chinese engine manufacturers.

The corporation consists of 46 affiliate companies, including 22 engine companies, several institutes, 3 aeroengine-repairing factories and some other small companies, with the majority of the affiliate companies having been split from Aviation Industry Corporation of China. The main institutes are Beijing Institute of Aerial Materials, Shenyang Engine Design and Research Institute, China Gas Turbine Research Institute, China Aero Power Machine Research Institute, Guizhou Aero-Engine Research Institute, Chine Aero Power Control System Institute.

The main Companies are Harbin Dong'an Engine Manufacturing Company, Shenyang Limin Engine Manufacturing Company, Chengdu Engine Manufacturing Company, Xi'an Aero-

Engine Manufacturing Company, Liyang Engine Manufacturing Company, Shanghai Commercial Aero-Engine Manufacturing Company.

With its 46 subsidiaries and 96,000 employees, AECC is responsible for the R&D and manufacturing of aircraft engines and gas turbines. At launch, AECC was to be capitalised with $7.5bn with AVIC and COMAC both shareholders. This strategic move aims at strengthening the Chinese aviation industry by reducing its reliance on foreign suppliers. AECC plans to build engines that can replace foreign-made engines on the ARJ21 and the C919.

12.2.9.5 Avionics

Another important area where the Chinese industry is expected still to make significant progress is avionics. Avionics in the C919 program is key components supplied by western companies such as Collins Aerospace, GE Aviation and Honeywell Aerospace. The three of them have joint ventures and partnerships with Chinese companies supplying COMAC. Aviage Systems, for example, is a 50/50 joint venture between GE Aviation and AVIC. Currently, it specializes in the supplies of the integrated modular avionics system to the C919. Honeywell's Asia-Pacific aerospace division, the company has more than 12,000 employees in China right now[9] including 700 aerospace experts working across seven manufacturing plants and two joint ventures for the C919.

To accomplish this challenge these companies are working on what they qualify as the "next generation of avionics systems architecture in a multi-functionality, display-driven setup, taking on important tasks such as core data processing, signal transmission and signal function logic conversion". Collins Aerospace also supplies avionics technologies to the C919, including its communication, navigation and integrated surveillance systems under joint ventures established with China Electronics Technology Avionics Company and AVIC.

Western avionics suppliers envisaged a huge market in China. One of the drivers of this is China Southern. The airline plans to expand its domestic fleet from 786 to 1,000 cargo and passenger aircraft by 2020 and double that to 2,000 aircraft by 2035[10]. The carrier selected Thales to provide the avionics for a fleet of 80 combined Boeing 737 MAX and Airbus A320neo aircraft in November. Under that contract, Thales will equip those aircraft with flight management systems and satellite communications systems featuring access to Inmarsat satellite-based connectivity. The fleet will also be equipped with head-up display systems from Thales to meet the Civil Aviation Administration of China's (CAAC) 2025 mandate for Chinese carriers to have 100% of their domestic fleet equipped with head-up displays.

Collins Aerospace, which has had a presence in China aviation for more than 30 years, plans on continuing to expand in China through the design and launch of new products and technologies specifically designed to meet the needs of Chinese customers.[11] Collins supplies avionics and interior systems to Chinese airlines for their Boeing and Airbus platforms,

[9] According to Amit Kaul, head of the business and general aviation division of Honeywell.

[10] The carrier's chief executive confirmed during a press conference held at the World Routes conference in September 2018

[11] Grace Du, managing director for the avionics division of Collins Aerospace China.

provides business and regional avionics solutions to Chinese airframes for indigenous regional airplane and helicopter programs, and have increased significantly the number of new products in recent years. They supplied ProLine 4 avionics systems to the Avicopter AC312 as well as the latest displays and Pro Line Fusion 21 avionics for the new AC312E platform. Collins also served in the avionics system integrator role for these programs and has a position on Avicopter's AC352 with its Pro Line 21 radio equipment. Through a Chinese joint venture partnership, Collins is also producing full flight Boeing 737 simulators, completing its first simulator delivery to a local pilot training centre last year.

Chinese aircraft-builders are interested in Russian avionics – potentially due to their comparably lower cost and generally acceptable quality level. AVIC is in talks with Concern Radio-Electronic Technologies (CRET), a leading Russian designer and manufacturer of military spec radio-electronic, for the design and further supplies of avionics for a new heavy helicopter currently being jointly developed by Russia and China.

Experts see big prospects for the Chinese avionics market to continue growing into the future as the Government policies encourage the development of the aviation industry and collaboration with proven western suppliers. This companies also provide navigation solutions for other modes of transport, and they will additionally benefit from other Chinese strategies in other modes transport such as Belt & Road and Made in China 2025.

12.2.9.6 Composite materials

The amount of composite materials has become an important symbol of the advanced nature of the new generation of civil airplanes. It is also a key parameter to the main civil airplanes' manufacturer for the new round of international civil aviation market share. On the other hand, metal materials are still indispensable and will benefit from the application of 3D printing technology.

Today the most used composite material is in Boeing 787 with 50% utilization rate. Boeing 787 seriatim; followed by A400 (39%), A380 (23%), A340 600 (13%) and Boeing 777 (11%) [76].

The use of composite materials at C919 is discussed at [77]. At present, the C919 uses only 12% of the composite materials [78], of which all are imported, as domestic composite materials have still some problems [78]. For example, domestic composite material lack experience in civil aircraft, especially in large civil airplanes; production process control system is imperfect, cause a large material properties dispersion and low allowable value; domestic materials overall level of development lag behind; brand is numerous; credible data is too little and domestic composite materials lack of competitiveness in price.

When the C919 passenger plane was developed, the original plan was also to use a composite wing to reduce the weight of the aircraft structure and improve economic performance. However, after analysing the relevant units, it was considered that domestic composite materials technology processing capacity was still underpowered. So COMAC decided, as a first step, develop the C919 with metal wings and flat tail composite materials.

To be competitive with Boeing and Airbus in this area C919 needs to increases the % of composite materials in its structures, and need to improve its local production process. [79]

12.2.9.7 Customer countries

China has developed close relations with several developing world countries. In fact, some of the countries not eligible for EU or US assistance due to domestic issues find in China an alternative partner.

Pekin is also investing more than a Billion of Euros in emergent markets in Asia, Africa and South America with its new "silk route", reinforcing infrastructures and backing up commerce. Those markets can become new market niches for China.

Could China use these countries as customers preferring its airliners even if they are not the most efficient? How much market share could be obtained in this way, possibly combined with dumping at unbeatable prices?

Figure 12.57 illustrates the countries using Chinese airliners, combat aircraft, helicopters, transport or UAV produced in China. It includes countries in South America (Colombia, Venezuela, Guyana, Peru, Bolivia); Africa (Mali, Egypt, Sudan, Nigeria, Cameroon, Togo, Namibia, Zambia, Tanzania, Kenia, Congo, Sudan) and Asia (Iran, Yemen, Afghanistan, Pakistan, Mongolia, Myanmar, Singapore, Malaysia). All these countries could be possible clients for the C919 in this scenario. Sing of this expansion are some recent news:

- Africa World Airlines Ltd., partly owned by China's HNA Group Co. agreed in March 2019 to buy two COMAC ARJ21 regional jets.[80]. AWA has also set up an earlier agreement with HNA, by which the Chinese conglomerate plans to operate 100 ARJ21 in the future.
- In April 2019 the Airliner announced that Ethiopian Airlines was considering adding Chinese COMAC C919 to its fleet. The African carrier has formed a joint committee with the Chinese manufacturer to examine the suitability of the aircraft to the Ethiopian fleet. The airline is in talks with the Chinese government to transform Addis Ababa in an aviation technology hub in Africa. Ethiopian Airlines currently operates daily scheduled passenger and cargo flights from Addis Ababa to Guangzhou, Beijing, Chengdu, Hong Kong, and Shanghai. This news comes just after the announcement on April 5, by the Ethiopian CEO that its company would cancel an existing order for 25 Boeing 737 MAX 8 after one of its jets of the same type crashed in Addis Ababa during take-off. [81].
- Ghana, Africa World Airlines Ltd., partly owned by China's HNA Group Co. may agree in 2019 to by two Comac ARJ21 regional jets.
- Laos, Pakistan and Bangladesh are likely to purchase China's J-10 fighter jets. [82]
- In March 2019, Malaysia Prime minister announced that its country may buy China-made planes if hit by EU palm oil ban. [83].
- Venezuela, which imports 23% of its weapons from China. [84]
- Since 2014, Saudi Arabia, UAE, Jordan and Iraq have all bought military drones from China.
- China is now marketing its indigenous, armed unmanned aerial vehicles (UAVs) to potential buyers in Egypt and Nigeria.

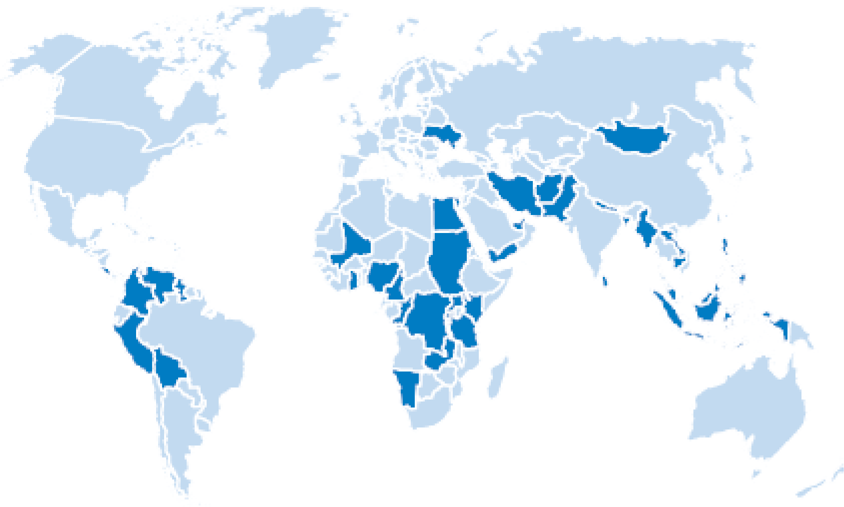


Figure 12.57. Chinese aeronautics exports market

12.2.9.8 China industrial capacity in other modes of transport

China has demonstrated its capacity to grow as a global leader in other industrial sectors. China became a global leader in the high-speed trains sector (also) thanks to technology transfers from top manufacturers.

Players starting in the 1990s, leading high-speed train manufacturers such as Siemens and Kawasaki were asked to partner with the local industry and operate technology transfers as a condition of commercializing their products in the Chinese market.

Figure 12.58 below compares the evolution of patenting activity in China between the railway and aerospace sectors, and highlights three relevant turning points in the development of the local high-speed train sector:

1. In 2005 a joint venture was established between Siemens and CNR for the transfer of high-speed train technology.
2. In 2009 a $5.7bn contract was awarded to CNR for the manufacturing of 100 trains for Beijing – Shanghai highspeed railway, $1bn was subcontracted to Siemens.
3. In 2015 CNR was competing with the major high-speed train manufacturers, including Siemens, on a global scale. Deutsche Bahn publicly stated that it was considering buying trains and spare parts from Chinese producers.

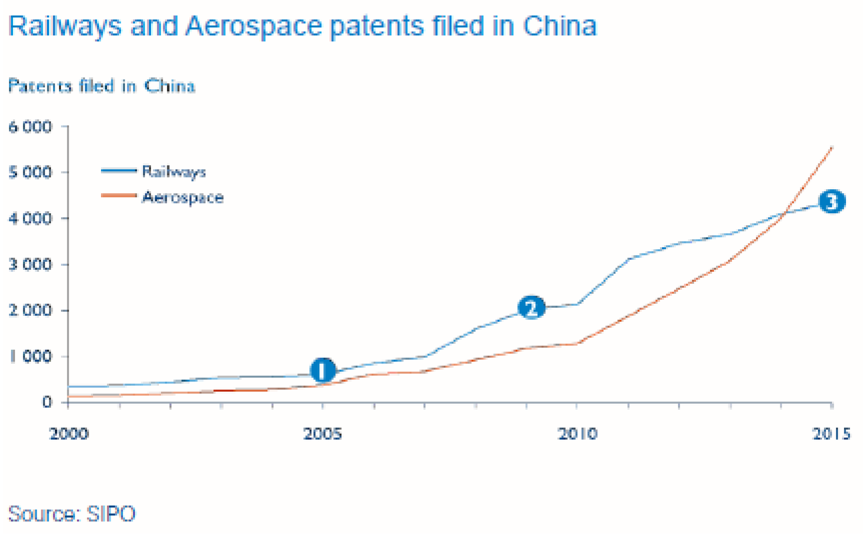


Figure 12.58. Evolution of patenting activity in China between the railway and aerospace sectors

As can be noted from the chart, Chinese players used patents to protect their intellectual property, either generated autonomously or received through technology transfers; this allowed them to create additional entry barriers to protect their domestic market.

In the aerospace sector, we notice a steep increase in the volume of patents filed in China, which grew more than four times over the last five years.

Based on our recent project experiences and discussions with industry leaders, we believe the Chinese government and aeronautical industry might be replicating the same approach adopted by the railway sector, progressively building barriers to reduce the ability of non-Chinese players to access the market.

12.2.9.9 Production Capacity Constraints

Scaling up production is the key priority for COMAC to address the growing demand in the Chinese market.

The Chinese regional jet ARJ21 is already on service and in production after being certified by the CAAC. The Chinese airlines' intention seems to be of using this aircraft for domestic routes, in substitution of the options of the two main Western regional jets manufacturers, Embraer and Bombardier. The aircraft has received a total of 302 orders by August 2018, most of which are from Chinese airlines, as well as 31 from other countries, such as the Republic of Congo or Laos. COMAC's industrial plans were to achieve a production rate of 20 aircraft a year by 2018, but they only managed to deliver 6 units up to date, which puts in doubt its capacities to satisfy a high-growing demand.

In order to capture the domestic demand, COMAC must scale the production and delivery of its ARJ21, as well as its C919 airplanes once they enter into service. The key question today is how long it will take for COMAC to fix the initial quality issues (e.g. on the ARJ21) and scale up the production to a few dozen aircraft delivered per month – a level comparable to A320 and 737 production lines.

In some ways, Airbus has helped the Chinese with their own learning curve in the production process with the opening of an assembly plant in China over 11 years ago. Boeing missed a trick here and have paid the price for it. 25% of Airbus' sales are in China; just 14% of Boeing's are. Airbus is winning in the East, at least in part thanks to their willingness to let China in on the secrets of their build. Boeing opened a plant for the 737 MAX in China, finally, in December 2018, but they were very late to the party.

To give a plausible answer to these questions, the evolution of A320 and B737 families past and future production rates, and in particular to the Airbus and Boeing final assembly lines in China will be analysed.

The rate increase for A320 and B737 families' production

The excellent selling records and prospects of the industry are convening manufacturers to increase its production rates. Traditionally, increases in production were done in a bunch of 5 units per month, but manufacturers are producing over this number in an attempt to satisfy demand.

Airbus maintains eight final assembly lines (FALs) at four locations worldwide that produce the company's full range of single-aisle and wide-body jetliners. Five of these are for the A320 Family[85].

- Toulouse, France (five FALs): two for the A320 Family; one each for the wide-body A330, A350 XWB and A380
- Hamburg, Germany (one FAL): all four production lines for the A320 Family
- Tianjin, China (one FAL): A320 Family. The UTainjin S. site delivered its first A320 Family aircraft in 2009.
- Mobile, United States (one FAL): A320 Family. The U.S. site delivered its first A320 Family aircraft in 2016.

Airbus reached a monthly production target of 60 aircraft mid-2019, as it continues to ramp up manufacture of the A320neo. Airbus also stated that a rate of 63 is "targeted" for the end of 2019. At the same time, Airbus saw potential commercial demand for 70 or 70-plus of the same aircraft in the longer term, but those decisions had not been taken yet. [86]

On the other side, Boeing at its Renton (USA) factory does all 737 final assemblies since 1970, although mayor parts and much of the sub-assembly work is outsourced beyond Boeing. To satisfy demand growth in the 737, production rates have been increased during the last years, as indicated in Table 12.31.

Year	Boeing 737 Family production rate Units /month		Airbus 320 family production rate Units/ month	
	Delivery rate	Target rate	Delivery rate	Target rate
2010		34 early 2012		
2011 June		42 in 2014		
2012 August	31.5 with 3 production lines	Start to analyse 60		

Year	Boeing 737 Family production rate Units /month		Airbus 320 family production rate Units/ month	
	Delivery rate	Target rate	Delivery rate	Target rate
Jan 2013	38			
Nov 2013 -		47 by 2017		
Feb 2014	42			
December 2015		52 at 2018		
Jan 2017		47 by the end of 2017 52 in 2018 57 in 2019		
April 2018 [87]	52	57 2019	55	60 mid-2019 63 end 2019
June 2018 [88][89]			Airbus open fourth assembly line in Germany (up to 10 units per month)	60 mid-2019 63 end 2019 70 2022
Mid 2019[90]			60	
End 2019				63
2020				70

Table 12.31. A320 and B737 families' production rate evolution

To complete this view **Error! Reference source not found.** and **Error! Reference source not found.** present the past and forecast delivery rate for the aircraft in both families according to Airline Monitor statistics. Although there could be a significant difference between production and delivery, the figures for A320 and 737 confirm the past tendency to increase production rate in a bunch of 5 units per month.

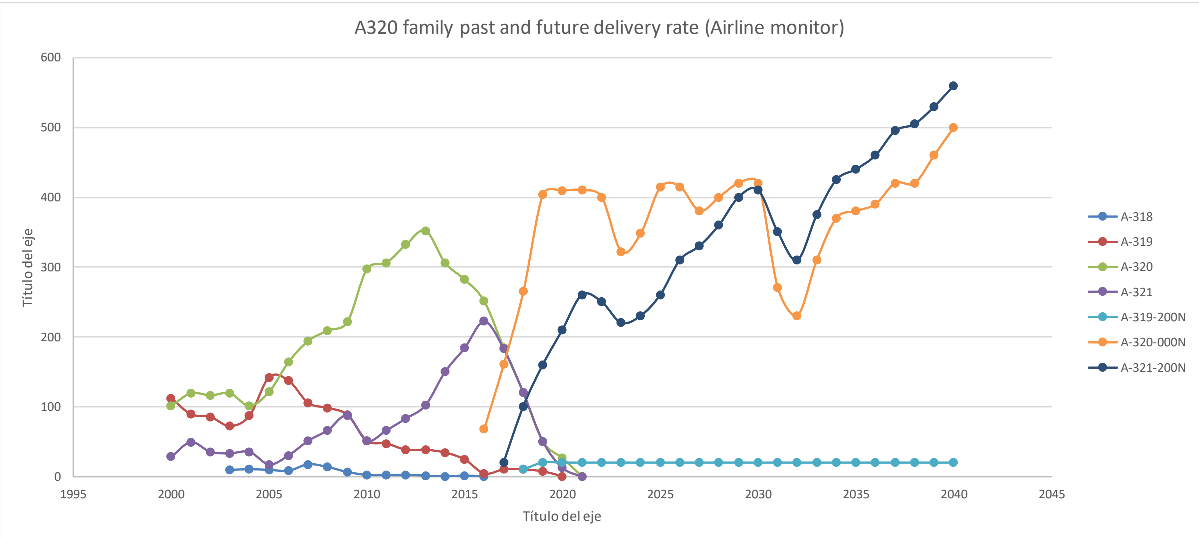


Figure 12.59. A320 family past and future delivery rates

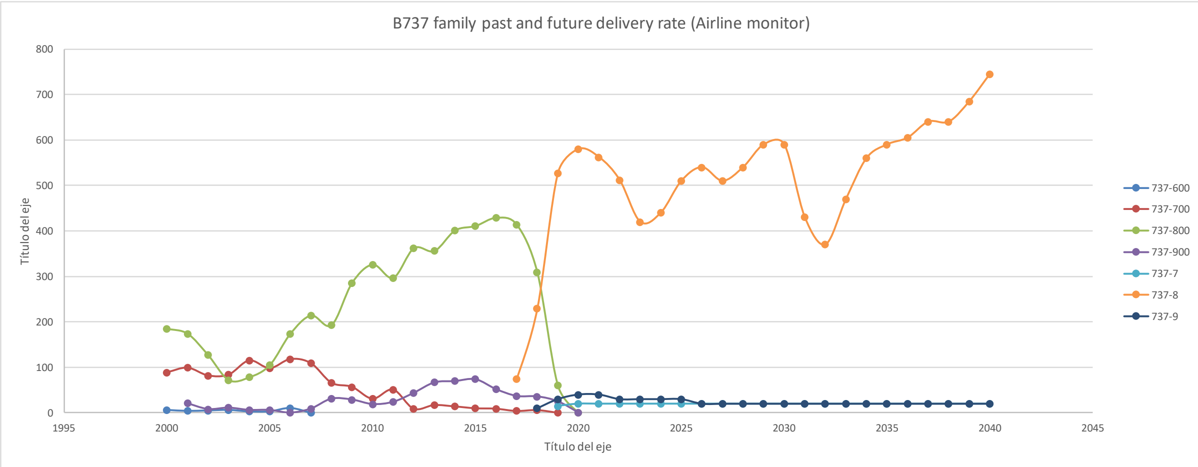


Figure 12.60. B737 family past and future delivery rates

The manufacturer decision of increasing production rate has impacts also in the suppliers' production. For example, while Airbus presses to increase the production rate of its best-selling aircraft family, its various suppliers are reluctant to extend that commitment. One of the critical vendors for the A320 family is Safran, which provides, in partnership with General Electric, the CFM LEAP engines that both the new A320neo and A321neo variants use. Safran publicly pushed back. Parts issues with the LEAP and delayed deliveries over an unprecedentedly short time give Safran pause on the prospect. It is to be noticed that the C919 will mount the same family of engines.

Pratt & Whitney hasn't publicly pushed back, but its problems with the GTF engine on the A320 are well known. PW also supplies different versions of the GTF for the A220, Embraer E2 jet, Mitsubishi MRJ and soon the Irkut MC-21. Its production is under stress having to produce spare engines to replace the A320 1500G engines that have given Airbus and airlines so much trouble since their introduction in 2016.

Airbus A320 and Boeing 737 production capacity in China

In 2008 Airbus inaugurated its Final Assembly Line at Tianjin, China, the first Final Assembly Line outside of Airbus' European home territory. It was created in a joint venture with the Tianjin Free Trade Zone and China Aviation Industry Corporation. The Tianjin A320 Family's Final Assembly Line now has more than 730 employees, and it is one of the four global locations for assembly of A320 Family jetliners, joining the other Airbus sites in Toulouse, France; Hamburg, Germany; and Mobile in the U.S. state of Alabama. Today it is the third-largest single-aisle assembly line for Airbus after Toulouse and Hamburg.

The first Tianjin-assembled A320 Family aircraft was delivered in 2009. Towards the end of 2018, the factory assembled an average of four-and-a-half A320 aircraft a month in Tianjin, and it delivered a total of 52 A320s in 2018. Early in 2019, produced five A320 aircraft a month, and by the end of 2019, it will produce six A320s a month, according to the company. By the end of 2018 over 380 jetliners from the best-selling A320 Family have been delivered from the site to both Chinese and international airline customers.[91]The production ramp-up follows an agreement between Airbus and China signed during French President Emmanuel Macron's state visit to China in January.

In 2017 the assemble line has been expanded to the widebody jetliner segment with Airbus' Completion and Delivery Centre for A330s. As with the A320 Final Assembly Line, the A330 completion and delivery centre was the first of its kind for Airbus outside Europe. The initial A330 was delivered from Tianjin in September 2017, with seven aircraft provided so far at the end of 2018 to customers. However, progress is slow. Plans were to reach two aircraft a month by early 2019. Market intelligence indicates the centre is struggling at rate 1/mo. [92].

To date, A330 and A320 Family aircraft have been provided from Tianjin to such carriers as Sichuan Airlines, Beijing Capital Airlines, Shenzhen Airlines, Loongair, China Eastern Airlines, China Southern Airlines, Air China and Air Asia.

From its side, Boeing opened in 2018 its first completion centres outside the US in Zhoushan, 140 kilometres southeast of Shanghai, for the 737 as a JV with COMAC. The airplanes are assembled in the US and flown to China unpainted and without interiors. Chinese workers at the new plant will put the finishing touches on US-built planes flown over from a Seattle-area factory, before delivering them to local customers. This completion centre will give COMAC valuable experience for its own programs. Boeing eventually plans to put the finishing touches on 100 of its 737 Max planes each year at the new completion centre, predicting a gradual step up, as workers are trained. Handing off light manufacturing to the new completion centre eventually will free up valuable capacity as Boeing charts 737 production increases well beyond the 57-month rate set for 2019.

However, despite the experience gained with the assembly of A320 and B737, the problems mentioned before highlighting the complexity of the task and the still incipient step of the Chinese learning production curve.

Expected production curve for the C919.

From this information, we may estimate a maximum production rate of 8 units per ensemble line, similar to those achieved by western manufacturers, when the assembly line is fully operational. Higher productivities, up to 10 units per month, are possible at state-of-the-art production lines, as the one Airbus deployed at Germany in 2008. This type of technology will not be available at the first C919 assembly line, although it might be at a second one either for C919 or for a new model.

However, attending to the Tianjin experience with both A320 and A330, the Chinese's industry still will take time to get to this optimum production rate. Tianjin line took 10 years to get to 4.6 units per month, 2 additional years more are expected for achieving 6 units per month, and there are no plans for further productivity increase. Initial problems with A330 confirms the learning curve has not significantly improved. Therefore, the same learning curve is extrapolated for the first C919 assembly line. The expected production curve is illustrated in Figure 12.61. This production rate will deliver 1260 C919 units in 20 years with only one production line, as indicated in Figure 12.62.

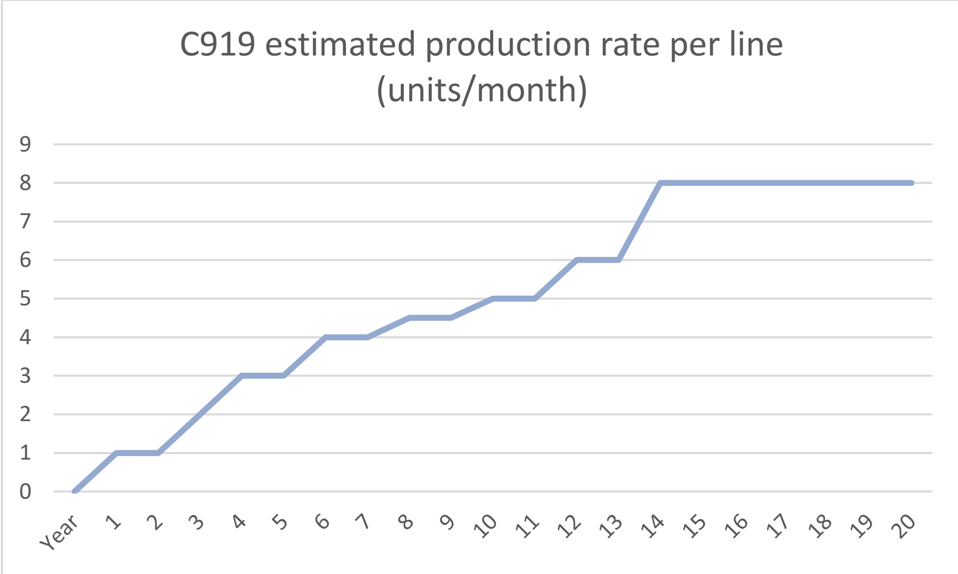


Figure 12.61. Expected production curve for the C919 (units /month)

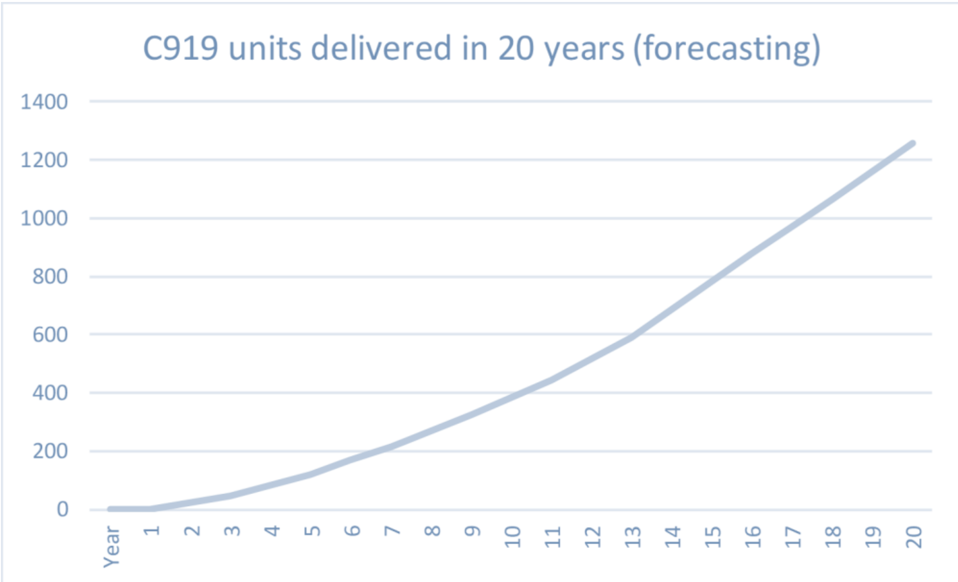


Figure 12.62. Forecasted C919 units delivered in 20 years

12.2.9.10 Skills shortage in the aviation market

Finding, developing and retaining a skilled workforce is a major challenge - not just to manufacturers but also to the supply chain and operators. This labour shortfall may be felt the soonest in Asia where the biggest portion of the fleet expansion is taking place. [93]

The aviation skills shortage in Asia could have a dramatic effect on the region's development and is also magnifying the global problem. Causes are:

- Rapid growth in demand: Airbus and Boeing predict the region will require 200,000 – 226,000 new pilots alone within 20 years, with only 65,000 currently registered. 238,000 technicians will be required to service new aircraft, representing 40% of total global need. China growth by its own will require 100,000 additional pilots and 106,000 new technicians.[94]

- Lack of resources for aviation training. Airbus recently opened the world's largest pilot training school in Singapore. The aircraft manufacturer hopes this centre will process up to 10,000 new pilots per year.
- Developed markets can no longer supplement the workforce. European and North American markets are facing a skills shortage of their own.
- Factors are stemming the flow of new pilots worldwide at present, including increasingly strenuous working conditions, the rising cost of training and retirees/staff leaving the industry

According to CAAC in 2017 [95]:

- The enrolment by universities and colleges directly under CAAC totalled 21 636, among which, 882 were postgraduate students, 18 573 undergraduates and junior college students, and 2 181 adult students.
- The number of registered students at universities and colleges directly under CAAC stood at 70 291, among which 2 743 were postgraduate students, 62 706 undergraduates and junior college students, 4 842 adult students.
- A total of 16 846 students graduated from universities and colleges directly under CAAC, among which, there were 822 postgraduates, 13 868 undergraduates and junior college students, and 2 156 adult students.
- CAAC inspected and accepted a total of 20 scientific and technological achievements and elected 28 for the awards for science and technology of CATA, certified 14 key labs and engineering and technology research centres in civil aviation.
- By the end of 2017, there were 55 765 licensed pilots in the industry, up by 5 261 from 2016

Type of License		Number	Year-on-year Increase
Aircraft	Private Pilot License	2 642	182
	Commercial Pilot License	27 349	2 105
	Airline Transport Pilot License	22 195	2 502
	Multi-crew Pilot License	147	43
Helicopter Pilot License		2 741	341
Other Aircraft Pilot License		805	97

Figure 12.63. Statistics of Civil Aviation Pilots of China in 2017

The report on skills shortages in the Chinese labour market by JP Morgan highlights gaps in supply and demand for highly skilled labour, and regional differences in the type of skills required. Two particular challenges are the shortage of employees with training and skills in internationalized management and strategic planning, and skill deficits encountered by enterprises that are seeking for industrial upgrading. These two challenges affect the aviation industry [96]. To close the skills gap, JP Morgan recommended:

- Reform Chinese educational, vocational training, and certification systems.
- Adjust macroeconomic policies.
- Reduce skill mismatches
- Provide more on-the-job training
- Better thought-out curricula – with the government and private companies joining forces to ensure a good match – are required at the service level.

Skills and workforce shortage is especially relevant in three areas: 1) pilots, 2) certified technicians for MRO maintenance, repair, and overhaul (MRO) industry and 3) engineers.

The situation, however, is also worrisome worldwide. The influential Aerospace Industries Association (AIA) warns that it is not the actions of foreign competitors what could knock the western leadership prevalence in aviation; the biggest threat comes internally as a result of skills shortages. Aviation risks to experience also what is called the talent paradox — when, despite high unemployment, employers still struggle to fill technical and skilled jobs, primarily down to applicants lacking technical or specialist skills.

There is a need for collaborative action, to achieve impact, with every stakeholder working together, including Government, associations and professional Institutions. The industry cannot do it on its own and neither schools can. The focus should not be just on technology, but also on how to retain skills, how to up-skill staff and how to ensure the future engineering capabilities from schools, universities and colleges. The future aviation industry will require professionals with skills at the cutting edge of technology, but also skills to innovate and exploit technology.

12.2.10 COMAC C919 cost analysis and program valuation

In this chapter, an aircraft program cost model is developed in order to estimate the pay-offs for the C919 program under different scenarios and varying both market and production conditions, such as the price or the estimated demand as well as other parameters of which values are uncertain, like the R&D cost of the program. This cost analysis model is explained extensively in the 'What if' Case Study 2: The Boeing NMA case and the reader is referred there for a clearer explanation. These payoffs could be used as the outcome of the games that will allow determining the best manufacturers' strategies to be applied under different scenarios proposed in the study.

It is important to note that there will be some uncertainty in the model's input parameters since companies' financial data are not public in order to protect competitive interests. This uncertainty is even bigger for the case of a Chinese governmental company. For that reason, the purpose of this study is to determine the rank ordering of manufacturers' strategy payoffs, the break-even price of the new aircraft and the estimated number of units that the company would need to sell for the program to be economically profitable.

12.2.10.1 C919 Net Present Value

One of the most effective ways to financially evaluate medium- and long-term decisions of aircraft manufacturers are using the Net Present Value of their investments. The Net Present Value is used as the objective function that manufacturers use to maximize their mark-ups. Considering the company f, the objective function of one of its products, i, is given by:

$$\pi_{fi} = \sum_{t=1}^{n} (\delta_t [p_{it} q_{it}(p) - c_{it} q_{it}(p) - I_{it}] - I_{i0}),$$

where δ_t is the discount rate at the period of time t, p_t is the price of the product at the period of time, I_{i0} the initial investment required (i.e. R&D and manufacturing costs), I_{it} are the fixed costs due to capacity, c_t is the cost of the product at the period of time t and q_t the quantity sold at the period t, which is the product of the manufacturer's market share and the total expected demand.

It is necessary to remark that other authors like Irwin *et. al* [97] calculate the payoff considering the uncertainties of the demand and jet fuel prices so that the Net Present Value is calculated as a statistical distribution with different probabilities for the multiple possible paths. Thus, the value used for the payoff function is the expected value of the NPV, $E[NPV]$, instead. For this case study, a simplified calculation form of the function was assumed, neglecting these uncertainties of the demand and jet fuel prices.

This objective function accounts for two characteristics of the aircraft industry: learning by doing in production and multi-product firms. First, the existence of learning by doing implies that the firm's choices today affect the costs of production in the future through accumulated experience. Firms likely consider these intertemporal linkages in their profit-maximizing decision. In particular, these dynamic considerations might make it profitable for a firm to price below marginal cost during the initial stages of production in order to quickly accumulate the experience and reduce the future cost of production. Nevertheless, this might not be the case of the Chinese manufacturer COMAC, since the big amount of subsidies received by the government might help the company to sell the aircraft below the marginal production cost for a longer time.

There are many input factors influencing the payoff as shown in the previous section of this chapter. The R&D investment, the cost of the first unit or the selling price are some of the variables that affect the most to the payoff function. These parameters are summarized in **Error! Reference source not found.** for the evaluation of the COMAC C919 program and it will be used later for the breakeven calculations.

Parameter	Reference Value
Learning curve slope	90%

Parameter	Reference Value
First Unit Cost [mill. US$]	520
Capacity Fixed Costs [mill. US$/month]	3
R&D Investment [mill. US$]	9500
Discount rate	8.0%
Expansion costs [mill. US$]	20
Demand [units]	1260
Price [mill. US$]	70

Table 12.32. NPV model input parameters

The Theoretical First Unit Cost was calculated as the stated in the methodology explained in the Case Study 2 [98] For the COMAC C919 the cost is estimated to be in 520 million of 2019 US$. Regarding the Learning Curve slope, typical values for the aerospace industry usually are around 85%, but a more conservative number of 90% has been assumed for this program due to the inexperience of the Chinese manufacturer in the industry.

Research and Development (R&D) costs were estimated to be 9,5 billions of US$ in 2011, although some analysts say it to be a 50% higher, (14,3 billion) [99]. Another key parameter for the valuation of the program is the selling price, which was firstly announced as 50 million of US$, although some analysis of actual COMAC's order book estimated a unit price of 68 million[100].

The demand is estimated using the production capacity constraints of section **Error! Reference source not found.**, which is 1260 aircraft for the next following 20 years. The rest of parameters' values (i.e. expansion costs and discount rate) are the same as the in the Case Study 2.

With all these assumptions, the NPV is:

$$NPV_{C919} = -46400 \text{ mill. US\$},$$

which shows that the program would not be profitable within the announced reference values. Additionally, if we take into account the increment of the R&D costs by 50% announced by some analysts the NPV would be even lower, resulting in higher losses for the company:

$$NPV_{C919} = -51100 \text{ mill. US\$}.$$

This is due to the low sold price assumed for the new aircraft, which summed up to the poor learning curve considered, result in losses for all the aircraft produced in the period. The cost analysis shows that first unit cost, as stated, is 520 million US$. Every aircraft produced after the first unit will be significantly lower in cost due to the experience gained in production processes. With a learning curve of a 90% slope, the reduction of cost in every aircraft produced is lower than for other expert companies such as Airbus or Boeing (whose learning curve is around 85% slope). The following graph shows the evolution of the production costs for all the aircraft produced in the considered period for both 85% and 90% slopes.

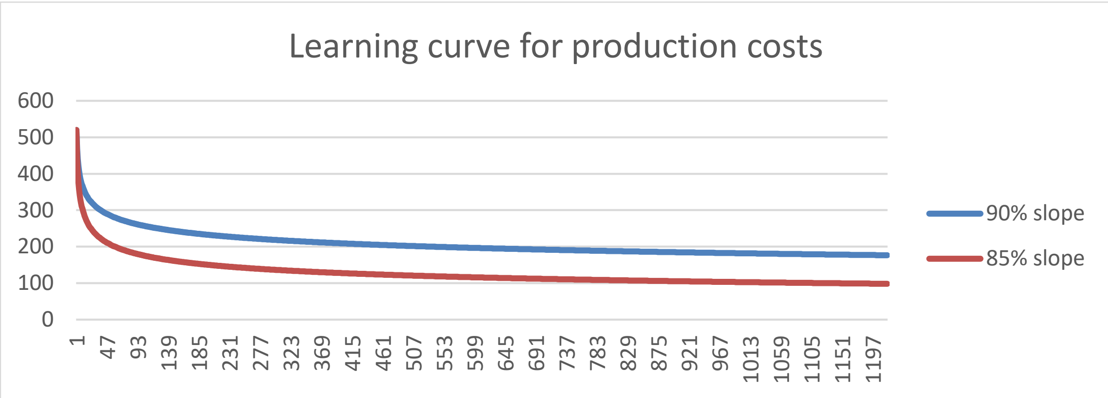


Figure 12.64. The C919 learning curve for production costs

As it can be seen, not even for an 85% slope learning curve the aircraft's production costs would reach its sold price. For a 90% slope, the aircraft production costs after the unit 1000 would still be over 200 million US$. Selling the aircraft at the announced price of 70 million is very unlikely to be profitable, as every unit would result in loses bigger than 100 million US$. These estimations question the economic viability of the program under the announced sold conditions, taking into account the low experience of the Chinese manufacturer in the industry.

With a learning curve of 90% and without varying the demand, the break-even of the program (this is when the NPV equals 0) occurs at a sold price of 143,15 million of US$, which is more than the double of the announced price.

12.2.11 SWOT Analysis

Taken all the arguments and figures discussed in previous sections, this chapter performs a SWOT analysis of the case of study.

Strengths:

1. Technology

   1.1. **Chinese suppliers have become increasingly proficient at process technologies.** Chinese companies have mastered the highly technical machining needed for gearboxes and other complicated metal components and are becoming more proficient at working with composites.

   1.2. **Supplier relationships and joint ventures have helped improve the technological capabilities of Chinese enterprises**.

Joint ventures create opportunities to learn how to efficiently manufacture new product lines and to acquire the know-how from repeatedly manufacturing the same component and to meet Western quality standards.
Foreign customers of Chinese components have forced Chinese suppliers to become more efficient, improve manufacturing technologies and quality control.
In manufacturing joint ventures, the foreign partner typically supplies the production design and management expertise, while the Chinese partner provides the facility and labour. As the Chinese partner gains experience, its engineering and management skills tend to improve.

1.3. **Acquisition of new product and process technologies and markets through the acquisition of foreign firms**. As noted above, AVIC, with the assistance of the Chinese government, has embarked on an ambitious program of developing China's general aviation (private aircraft) manufacturing capabilities through its subsidiary, CAIGA. Through CAIGA's acquisition of Cirrus, CAIGA has gained access to Cirrus's manufacturing technology and R&D capabilities for general aviation. CAIGA is also setting up an assembly plant for Cessna's Citation jet in Guangdong. CAIGA is intent on learning manufacturing technologies associated with assembling the Citation jet and bringing an increasing share of the assembly work to China. Cessna's interest in the joint venture is driven in part by the potential of AVIC to assist in inducing regulatory changes in China concerning the use of airspace and flight notification times that would make purchases of corporate jets more attractive in China.

2. Labour

2.1. Chinese **machinists and workers in composite materials are proficient**.

2.2. **Design and engineering talent rate very high**.

2.3. **Chinese universities and technical schools are turning out substantial numbers of well-trained technicians and engineers**.
The Chinese national and provincial governments are highly involved in improving the quality of Chinese engineering and technical schools, providing the necessary funding to create and support the aeronautical engineering and technical programs needed to teach these skills.

2.4. **Institutions of higher education have also improved the quality of their staff, recruiting expatriate** Chinese engineers and professors to return to China to teach in these institutions. State support in the form of higher salaries and attractive benefits packages have been important to provide these inducements to attract these individuals.

3. Finance

3.1. Despite the lack of a track record as a commercial aviation manufacturer, **COMAC has not experienced financing constraints.** Though purchasers reportedly have not made down payments on aircraft orders AVIC and COMAC have enjoyed substantial help from China's government in obtaining the financing and resources needed to enter the commercial aviation market. [12]

Through the use of appropriations from the state budget, equity investments from national and local governments and state-owned enterprises, loans from state-owned banks, retained earnings from non-aviation activities and other assistance provided by local communities, AVIC and COMAC have marshalled the resources needed to design, develop, and invest in new products and manufacturing facilities. In particular, like other state-owned enterprises in strategic industries, COMAC and AVIC have enjoyed preferential access to loans at below-market interest rates from state-owned banks.

3.2. **China's strategy of providing the necessary resources to create national champions** gives state-owned aviation manufacturers the luxury of sufficient time and resources to work through the complexities of developing and manufacturing a new aircraft. Financial support has been—and will be—essential to cover the extended periods of time and provide the resources needed to solve the developmental problems associated with a new aircraft.

4. Marketing

4.1. China has used its **diplomatic leverage** and state financing to induce a few airlines in developing countries in Southeast Asia to place orders for the ARJ-21. For example, Lao Air has ordered two.

4.2. The Chinese state is able to compel state-owned airlines to purchase aircraft favoured by the national government. By making purchases of Chinese-made components an important criterion for aircraft purchase decisions, the Chinese government has helped generate orders for components manufactured by Chinese companies.

Weaknesses

1. Technologies

1.1. **Joint ventures do not guarantee that the Chinese partner improves its capabilities**. The joint venture is often effectively controlled by the foreign partner, which limits the Chinese partner's ability to steer the venture toward product areas that are of interest to the Chinese partner.

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[12] The development by Airbus and Boeing of the A380 and the 787, respectively, ran several billion dollars each. As noted above, the initial available financing for the C919 exceeded $7 billion

1.2. **China has yet to master some key advanced technologies, such as engines and avionics.** For a number of key materials, Chinese aerospace raw material suppliers have not yet been able to produce materials of a quality that could be certified.

1.3. **Aircraft might become technologically obsolete because of the difficulties in certifying the plane**, and the resulting additional time needed to develop the plane.

1.4. **Local firms have been encouraged to focus on technological achievements over profits or potential financial losses.** For example, state-owned airlines in China now perform their own maintenance despite being often costlier than outsourcing.

2. Labour.

2.1. **Chinese project management skills are weaker than in manufacturing and engineering skills.** COMAC has been struggling with systems integration in the design of the C919. COMAC's design team is younger than 30 and lacks experience with integrating complex systems into an aircraft.

2.2. **The Hierarchical management style** of Chinese state-owned enterprises is also a problem, impeding the cross-communication and delegation of decision making necessary for moving complex projects forward in a timely, thoughtful manner.

2.3. **Substantial cost derived from deficiencies in corporate and project management imposes substantial costs** and the rising cost of skilled aviation manufacturing technicians and engineers.
Because of the high demand for these skills, labour turnover is often high. Foreign (and Chinese) manufacturers spend considerable effort to retain skilled Chinese labour, as training new staff is expensive.

3. Financial

3.1. **Financial support from the Chinese state is not unlimited**. For example, the ARJ-21 is not receiving similar levels of support as the C919.

4. Marketing

4.1. Setting up a **sales network and establishing the credibility** to induce buyers to purchase a new aircraft will take COMAC considerable time to develop.

4.2. COMAC **lacks a global logistics network for its new aircraft**. Despite the size of the internal Chinese market, Chinese aircraft will need to be able to operate outside the country. COMAC also hopes to sell more planes abroad. To do so, COMAC will need to invest in distribution, customer support, and training facilities, investments that Airbus and Boeing have already long since made.

4.3. **COMAC faces competition from used aircraft.** In most industries, entering a new market involves providing a product better than, or of equal quality with incumbent products at a lower price. In the case of aircraft, the C919 will be competing against used Boeing and Airbus aircraft as well as their newer models. In most industries, buyers would prefer a competitively priced new aircraft to a used product, but because of the global service networks of Boeing, Airbus, and their suppliers, used Boeing and Airbus aircraft are attractive to price-conscious buyers because they can be serviced so easily. Without an extensive service network, COMAC products will have difficulty in breaking into the global market.

4.4. **Reliability is an essential feature of an aircraft**. Because the C919 uses only internationally certified components from well-regarded firms, some concerns about reliability will be allayed. However, until the C919 establishes a track record for reliability, foreign buyers are likely to remain wary.

Opportunities:

1. Technologies

1.1. **Certification is not a permanent barrier** to entry for competitors. COMAC, for example, is learning how to get through the certification process with both the FAA and the Civil Aviation Administration of China. Once Chinese companies master this process, they will be better placed to develop into global suppliers.

1.2. **Concern about the theft of intellectual property**. Once Chinese competitors have mastered technologies, the companies fear they will lose some of their competitive advantages.

2. Labour

2.1. **Wages for production workers in the aviation manufacturing sector are still substantially higher in foreign countries than for similar Chinese workers.** To the extent that manufacturers in China approach productivity and quality levels in foreign plants, foreign manufacturers will face competitive cost pressures from cheaper Chinese labour.

3. Financial

3.1. **Incumbent aircraft manufacturers face financial pressures that COMAC and AVIC do not**. In the case of general aviation, these pressures have resulted in the sale of one manufacturer, Cirrus, to CAIGA and discussions with a Chinese investor to purchase another manufacturer, Hawker- Beechcraft, which went bankrupt.

4. Marketing
   4.1. **Incumbent worldwide service and distribution networks.** All the major manufacturers can guarantee delivery of key components to airlines at any major airport in the world in very short order. In most cases, key parts are already available at the airport. These distribution and support systems are a key sales argument because of the importance to aircraft owners of keeping their commercial aircraft flying.

Threads

1. Technologies

   1.2 **Certification is a market entry barrier**. Incumbent suppliers enjoy a strong competitive advantage because their materials and components have already been certified. To enter the market, Chinese companies have to first go through the certification process and then attempt to edge out foreign suppliers. New entrants have a hard time displacing incumbent on the basis of price because of the premium that purchasers place on quality.

   1.3 The **importance** of **proprietary technologies to commercial success**.

   1.4 **Continuous development of cutting-edge new technologies protects** the incumbent manufacturer from Chinese competitor, despite their proficiency at copying and often improving existing technologies.

2. Labour

   2.1. **Clusters have emerged all over the world to design and assemble aircraft.** These locations concentrate on well-trained labour forces with the skills and experience to manufacture and assemble aircraft with the requirements of precision and quality. Cluster favour the emergence of local suppliers to provide materials, parts, and support services required by aircraft manufacturers. This co-location of companies, suppliers, and workers provides a competitive edge to manufacturers in these centres, which is difficult for new entrants to overcome.

   2.2. **Incumbent manufacturers still had a cost, quality and technological competitive advantage in managing technological development and their production lines**. Long experience with integrating components into modules and designing modules to meet the needs of aircraft manufacturers also provides a competitive edge.

3. Financial
   3.1. **Boeing and Airbus Group and all of the Tier One commercial aviation component suppliers are large, financially sound companies.** They are able to arrange to finance for purchases of their aircraft from a wide variety of sources. In

addition to commercial lending, both companies are able to tap government-supported export financing institutions like the U.S. Export-Import Bank for loans.

4. Marketing

   4.1. **Restricting subsidies** available for trade financing among the United States, the EU member states, and other developed countries limit the ability of Boeing and Airbus to match financing packages that COMAC may be able to offer to potential clients in developing countries.

12.2.12 The case of the new entrant in aviation

The problem of the duopoly between Boeing and Airbus and the appearance of a new competitor in the single-aisle market has been studied from the point of view of competitor's strategies by some authors in the past.

Authors at [1] consider the situation of the manufacturers' duopoly in the single-aisle market and the possible strategies they could take when a new competitor intent to enter in the market by defining this problem as a strategic game model with three players.

Statistical or deterministic models about single-aisle market share are not available. Market share dynamics are difficult to model in part due to a number of confounding factors that difficult the determination of a statistical relationship between aircraft performance and market share. Notwithstanding, it is possible to synthesize some heuristics to estimate the market share between competing aircraft, based on a historical analysis of market share. This heuristics finding have been summarised by [1] in three gold rules:

- *15% Minimum Market Share:* The minimum market share for an aircraft that a manufacturer still finds profitable to produce was assumed to be 15%, based on the wide-body market segment historical analysis. Boeing's 777 controls ~85% of the market vs. Airbus's A340, while Airbus's A330 takes ~85% of the market vs. Boeing's 767.
- *50%/50% Split for Equivalent Aircraft:* Aircraft with equivalent performance is assumed to split the market, as the 737-800 and A320 do.
- *Switching Costs:* Switching costs prevent airlines from receiving a higher utility from aircraft that have a marginally (e.g. <5%) performance advantage. Therefore, incremental improvements generally do not result in market share increases as competitors generally match each other's incremental improvements, with some time lag.

In the study, they also considered that in the new entrant problem, incumbent manufacturers can decide between four generic strategies:

(1) *maintain* their existing product lines, with incremental improvements over time,
(2) *re-engine* their existing airframes, providing superior performance improvement,
(3) develop *new*, clean-sheet design aircraft that offer the greatest fuel burn improvements, or

(4) *exit* the market.

In a free market, the new entrant would only take market share if it produces an aircraft of superior performance to the incumbent's current product. The amount of market share would be dependent on the level of performance of the new entrant's aircraft. **Error! Reference source not found.** indicates the market share heuristics if the new entrant performance would be equivalent to the ones of the incumbent's new aircraft. It can be observed, that in that case, the new entrant would to leave standing incumbents' products with the minimum market share. Figure 12.66 summarises the market share in the case the new entrant would only be equivalent to the incumbents' re-engined aircraft in terms of performance. In this case, the new entrant would only be able to capture 50% of the market from two stagnant incumbents. Such logical games were used to estimate the remaining market shares in each cell representing the intersection of the players' strategies in the figures below.

New Entrant Performance = Incumbent New Aircraft performance		**Player B**		
		Maintain	Re-engine	New
Player A	Maintain	15%, 15%, 70%	15%, 25%, 70%	15%,43%,43%
	Re-engine	25%,15%,60%	25%,25%,50%	25%,38%,38%
	New	43%,15%,43%	38%,25%,38%	33%,33%,33%

Figure 12.65. Three player market share rules when the new entrant performance is equivalent to the new incumbent one.

New Entrant Performance = Incumbent RE-ENGINED Aircraft performance		**Player B**		
		Maintain	Re-engine	New
Player A	Maintain	25%,25%,50%	20%,40%,40%	15%,55%,30%
	Re-engine	40%,20%,40%	33%,33%,33%	25%,50%,25%
	New	55%,15%,30%	50%,25%,25%	40%,40%,20%

Figure 12.66. Three player market share rules when the new entrant performance is equivalent to the re-engined incumbent one.

In a generic situation, the new entrant can produce an aircraft that has lower, equal or superior performance to the ones the incumbent manufacturer has already in the market. In their study [1], only analysed the last two options, as in a free market a lower performance aircraft will not have any possibilities to break the entry barriers and made itself a place in the market. However, the analysis of the C919 need to consider this alternative as its main market, Chinese air transport system is highly regulated and manufacturers rely on government subsidies, two conditions that could guaranty C919 a quote of the local market even if it is less performance than its competitors.

It has to be noticed that these rules are applicable in a free market competition, where airlines utility is the main driver of the aircraft buying process. This might not be the case when analysing the Chinese internal market due to the high influence of the government in the airline purchasing decisions. But, it will be a reasonable hypothesis for the scenario in which China would be able to produce a competitive aircraft and certify it according to FAA and EASA rules, so it could compete worldwide with Airbus and Boeing products.

Additionally, it has also to be noticed that this analysis does not consider any manufacturer restriction to cope with the demand, that is, it assumed that the manufacturer will be able to produce all its demand on time. This might not be the case of the C919 according to the problems observed up to now in the final step of the integration chain.

12.2.13 Scenarios for impact analysis

All the previous analysis allows defining 5 different scenarios for the C919 impact of the single-aisle market.

Scenario 1. Scenario 1 is built upon the hypothesis of successful certification of the C919 by the Chinese' CAA in the short time horizon with an expected entry into service of the aircraft by 2021. The timeframe for this scenario is supported by the discussion in section 12.2.9.2. Comparatively, the contemporary Boeing and Airbus models, C919' technology will lag behind as explained in chapter 8, and its performance in terms of fuel efficiency and operational cost will be worse. This model will eventually not get certification from the FAA nor EASA and will only be sold in the internal Chinese market or on those countries where Chinse government economic and political influence might facility purchases. Additionally, based upon the problems with final integration, lack of knowledge and immaturity of the commercial operational network, production rates for this model will be low, not enough to satisfy even national demand, as explained in section 12.2.9.9. Airbus and Boeing will have an opportunity window to maximise their sells in the Chinese market and profit for the foreseen development of the Chinese air transport in the next 20 years. In this scenario, Airbus has a completive advantage over Boeing derived from their investments in the country during the last 10 years.

Because of this reason, this first version of C919 will be considered as a transitory model that will give COMAC the opportunity to consolidate the whole production and commercialization chain and gain enough experience, to initiate an upgrading process of a more advanced and competitive product that could be certified and sold worldwide. Expectations that Chinese industry can improve its learning curve and be able to develop such a product in a second version of the C919 are high.

This scenario can be split into two variants. In variant a) C919 is sold uniquely inside China. In option b) C919 is also sold in third countries under the political or economic influence of the Chinese government.

Scenario 2. In scenario 2, COMAC is able to obtain FAA and/or EASA certification for the C919. This will not happen soon enough to allow entry into service any time before 2025. Although the C919 would have been previously certified by the Chinese CAA, it will have to have mayor adaptations and modification to obtain western certification. A few units of CAA certified C919 might be produced before 2025, but not a significant and stable production. However, these first units will help COMAC to gain experience in the integration and final assembling favouring the production process from 2025.

Despite the fact of obtaining western certification, the technological level of this model will be the same as in scenario 1. Its lower performance will not make it attractive for big airliners who have to compete with the much more efficient jets from Europe, Canada, Brazil and Japan. However, it's expected low prices (half of the price of its contemporary Boeing and Airbus models) might bring to C919 into a niche between operators with cash problems or that do not want to wait for 737 and 320 delivery delays. As discussed in section 12.2.5.1 there are precedents of similar situations with the A330.

To take full advantage of this window of opportunity the Chinese industry should focus its effect in improving its production learning curve and expanding its production chain as quickly as possible without affecting reliability. Demand in this scenario might be significate, and if being able to satisfy it, C919 might make a negative impact on the selling prospects of Boeing and Airbus. The exploitation of this market opportunity might justify a slowdown in the upgraded and re-engined of new versions of C919.

Scenario 3. Scenario 3 considers a longer timeframe with COMAC producing a new upgraded version of C919 equivalent in terms of technologies and performance to its contemporary Boeing and Airbus models. It is not expected that this will take place in the medium term, not before 10 or 15 years after the EIS of the C919. By that time Boeing and Airbus will have probably also made evolve their current B737 and A320 models, or even consider a new clean-sheet design. This upgraded C919 will be able to compete in equal conditions with its counterparts, producing again a situation similar to that experienced in the industry by the '80s, with three manufacturers competing in the single-aisle market with equivalent capacities and designs.

This scenario is considered to be subject to free-market competition rules for market share allocation, being fuel efficiency, the main driver guiding airlines decisions. According to the argumentation in chapter 6, manufacturer evolution in this market is characterised by incremental improvements to maintain or gain market share. This scenario represents a classical example of the new entrant problem with 3 players. Incumbent manufacturers will have possibilities to either maintain its product line with only minor modification and minimal performance improvements; re-engineer them to improve its performances significantly or bet for a new clean-sheet design to improve even more its performances. Final market share will depend upon the COMAC technical capability and strategic decision to produce an aircraft that equals the performance of Airbus or Boeing reengineered version or the performances of Airbus/Boeing new clean designs. Game theory will offer a valuable tool and information to evaluate possible outcomes in this scenario.

This scenario is therefore split into two options:

- Scenario 3 a) where COMAC produced an aircraft with performance equivalent to those of Airbus or Boeing re-engineered models.
- Scenario 3 b) where COMAC produced an aircraft with performance equivalent to those of Airbus or Boeing new clean sheet designs.

<table>
<tr><th colspan="3">Short – medium term scenarios</th><th colspan="2">Long term scenarios</th></tr>
<tr><th>Scenario 1a</th><th>Scenario 1b</th><th>Scenario 2</th><th>Scenario 3a</th><th>Scenario 3b</th></tr>
<tr><td colspan="2">• C919 certified only by Chinese CAA
• No Western certification is granted
• Entry into service by 2021
• Conservative production curve
• C919 performances lag behind B737 and A320
• C919 final prices, including discounts and subsidies, will be half the price of B737 or A320</td><td>• C919 grants FAA and/or EASA certification
• Entry into service by 2025
• C919 performances lag behind B737 and A320
• C919 final prices, including discounts and subsidies, will be half the price of B737 or A320
• Conservative production learning curve</td><td colspan="2">• COMAC produce a new upgraded version of C919 equivalent in terms of technologies and performance to its contemporary Boeing and Airbus models.
• By that time Boeing and Airbus will have probably also made evolve their current 737 and ·20 models.
• This upgraded C919 will be able to compete in equality of conditions with its counterpart producing again a situation similar to that experience in the industry by the '80s. This scenario is considered to be subject to
• Free market competition rules for market share allocation
• Fuel efficiency main driver guiding airlines buying decisions.
• Classical example of the new entrant problem with 3 players.
• Incumbent manufacturers will either maintain its product line with only minor modification and minimal performance improvements; reengineer them to improve its performances significantly or bet for a new clean sheet design to improve even more its performances.</td></tr>
<tr><td>• C919 sold primarily in CHINA by governmental influence on the 4 bid Chinese Airlines</td><td>• C919 is additionally sold in countries where the Chinese government have political or economic influence</td><td>• C919 could be sold worldwide.
• Its lower price will favour its position in a market niche despite its lower performance
• C919 sold primarily in CHINA by governmental influence on the 4 bid Chinese Airlines
• C919 is additionally sold in countries where the Chinese government have political or economic influence.</td><td>• COMAC produced an aircraft with performance equivalent to those of Airbus or Boeing reengineered models</td><td>• COMAC produced an aircraft with performance equivalent to those of Airbus or Boeing new clean sheet design</td></tr>
</table>

Table 12.33. C919 impact scenarios.

12.2.14 Analysis of the short- and mid-term scenarios.

12.2.14.1 Scenario 1A

There are a few key items to considerer in the analysis of this scenario:

- The detailed characterisation of the single-aisle internal demand in China.
- The estimation of the possible market share that C919 would be able to capture inside China.
- The estimation of the likely production and delivery rate for the C919.
- The contrast between possible C919 demand and delivery capability.
- An assessment of how incumbent manufacturers might share the remaining Chinese market.

All these points are discussed hereafter.

Detailed characterisation of the single-aisle internal demand in China

The market forecasts analysed in the PARE "What if" study 2 [101] predicted air traffic to grow in the period of 2017-2037 with an expected yearly rate in the range [4.5% - 5.1%]. The most "optimistic" numbers are the ones from the Airline Monitor report, which expects the worldwide passenger turnover (RPK) to triplicate over the forecast period, with an average yearly growth of 5.1%. On the other hand, the most "pessimistic" ones belong to Airbus' report, as well as the Japanese JADC. In the middle of this range, there is Boeing's approach, which estimates a rate of 4.7% yearly growth, alongside the Russian UAC, with an estimation of 4.6% per year. As discussed in Chapter 6 China is on its way to becoming one of the world's largest aviation markets, and it is expected that will constitute nearly a 20% percent of the global traffic by 2037.

PARE's single-aisle forecast will be structured around Boeing's traffic prognosis values, using the results of the open dataset released by the company as a baseline for the calculations. For Boeing, traffic is expected to increase in China by 6.2% annually. To cope with that increase the fleet will growth by 4.5 % annually. Boeing Commercial Market Outlook for the period 2018-2037 foresees a total of 5730 new single-aisle deliveries from 2018 to 2037, what will increment Chinese single-aisle fleet from 2790 in 2017 to 6100 in 2037. In addition to this, we have developed a yearly intermediate scenario considering single-aisle aircraft retired and retained, as well as new deliveries. Yearly figures on expected aircraft retirement are derived for the Airliner Monitor database. Resulted distribution is presented in **Error! Reference source not found.** for each region of the world. In Figure 12.68, China figures are presented separated from those of the Asiatic market. Asia figures are presented aggregated for the whole continent and are also presented excluding the China contribution.

						Total traffic forecast per regions of the world																				
Region	SA 2017	SA 2037	Total 2017	Total 2037	TOTAL Growth rate	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
APR (ex China)	2480.0	6780.0	3810.0	9570.0	1.047	3810.0	3989.6	4177.6	4374.4	4580.6	4796.5	5022.5	5259.2	5507.1	5766.6	6038.4	6322.9	6620.9	6932.9	7259.7	7601.8	7960.0	8335.2	8728.0	9139.3	9570.0
China	2790.0	6100.0	3550.0	8630.0	1.045	3550.0	3711.2	3879.8	4056.0	4240.2	4432.8	4634.1	4844.5	5064.6	5294.6	5535.0	5786.4	6049.2	6323.9	6611.1	6911.4	7225.3	7553.4	7896.5	8255.1	8630.0
APR (inc China)	5270.0	12880.0	7360.0	18200.0	1.046	7360.0	7700.8	8057.4	8430.6	8821.0	9229.5	9656.9	10104.1	10572.0	11061.5	11573.8	12109.7	12670.5	13257.3	13871.2	14513.5	15185.6	15888.8	16624.6	17394.5	18200.0
North America	3970.0	6650.0	7210.0	10390.0	1.018	7210.0	7342.9	7478.3	7616.2	7756.6	7899.6	8045.2	8193.6	8344.6	8498.5	8655.2	8814.7	8977.3	9142.8	9311.3	9483.0	9657.8	9835.9	10017.2	10201.9	10390.0
Middle East	670.0	2030.0	1500.0	3890.0	1.049	1500.0	1573.2	1650.0	1730.5	1814.9	1903.5	1996.4	2093.8	2196.0	2303.2	2415.6	2533.5	2657.1	2786.8	2922.8	3065.4	3215.0	3371.9	3536.4	3709.0	3890.0
Europe	3450.0	6670.0	4900.0	8880.0	1.030	4900.0	5047.9	5200.2	5357.1	5518.7	5685.3	5856.8	6033.5	6215.6	6403.2	6596.4	6795.4	7000.5	7211.7	7429.3	7653.5	7884.4	8122.3	8367.4	8619.9	8880.0
Latin America	1240.0	3010.0	1560.0	3580.0	1.042	1560.0	1626.2	1695.1	1767.0	1841.9	1920.1	2001.5	2086.4	2174.8	2267.1	2363.2	2463.4	2567.9	2676.8	2790.3	2908.7	3032.0	3160.6	3294.6	3434.4	3580.0
Africa	370.0	1060.0	690.0	1630.0	1.044	690.0	720.3	751.9	785.0	819.4	855.4	893.0	932.2	973.2	1015.9	1060.5	1107.1	1155.7	1206.5	1259.5	1314.8	1372.5	1432.8	1495.7	1561.4	1630.0
CIS (inc Russia)	730.0	1250.0	1180.0	1970.0	1.026	1180.0	1210.6	1242.1	1274.3	1307.4	1341.3	1376.1	1411.8	1448.5	1486.1	1524.7	1564.2	1604.8	1646.5	1689.2	1733.1	1778.1	1824.2	1871.6	1920.2	1970.0
World	15700.0	33550.0	24400.0	48540.0	1.035	24400.0	25221.9	26075.0	26960.6	27880.0	28834.6	29825.9	30855.4	31924.7	33035.4	34189.3	35388.1	36633.8	37928.3	39273.6	40671.9	42125.5	43636.6	45207.6	46841.2	48540.0

Figure 12.67. Single-aisle traffic forecast per regions of the world

Year	Total World Fleet Boeing)	World Retirements (Airline Monitor)	SA Fleet	Factor Retiradas	SA Retirements	SA Retirements Acum	SA Deliveries	New Deliveries Acum	Retained	Replacement	Growth
2017	24400	873	15700	1.25		0		0	15700	0	0
2018	25222	556	16294	1.25	449	449	1043	1043	15251	449	594
2019	26075	621	16913	1.25	503	952	1122	2165	14748	952	1213
2020	26961	676	17556	1.25	550	1503	1194	3359	14197	1503	1856
2021	27880	729	18226	1.25	596	2098	1265	4624	13602	2098	2526
2022	28835	792	18922	1.25	650	2748	1346	5970	12952	2748	3222
2023	29826	314	19647	1.10	259	3007	983	6953	12693	3007	3947
2024	30855	380	20401	1.10	314	3321	1068	8022	12379	3321	4701
2025	31925	502	21186	1.10	416	3737	1201	9223	11963	3737	5486
2026	33035	642	22003	1.10	535	4272	1352	10575	11428	4272	6303
2027	34189	780	22854	1.10	652	4923	1502	12077	10777	4923	7154
2028	35388	882	23739	1.10	740	5663	1625	13702	10037	5663	8039
2029	36634	919	24661	1.10	773	6436	1695	15397	9264	6436	8961
2030	37928	905	25621	1.10	764	7200	1724	17121	8500	7200	9921
2031	39274	882	26620	1.10	747	7948	1747	18868	7752	7948	10920
2032	40672	891	27661	1	757	8705	1798	20666	6995	8705	11961
2033	42125	954	28745	1	814	9519	1898	22563	6181	9519	13045
2034	43637	1013	29873	1	867	10386	1996	24559	5314	10386	14173
2035	45208	1083	31049	1	930	11316	2106	26665	4384	11316	15349
2036	46841	1149	32274	1	990	12305	2214	28879	3395	12305	16574
2037	48540	1181	33550	1	1020	13325	2296	31175	2375	13325	17850

Figure 12.68. Yearly distribution of single-aisle aircraft retained, replaced and delivered world-wide

Figure 12.68 provides detailed information, year by year, of the distribution of single-aisle aircraft retained, replaced and delivered worldwide. The same information for China is presented numerical y graphical in **Error! Reference source not found.** and **Error! Reference source not found.** respectively.

	SA fleet in CHINA							
Year	**SA Fleet**	**SA Retirements**	**SA Retirements Acum**	**SA Deliveries**	**New Deliveries Acum**	**Retained**	**Replacement**	**Growth**
2017	2790	0	0	0	0	2790	0	0
2018	2901	80	80	191	191	2710	80	111
2019	3017	90	170	206	397	2620	170	227
2020	3137	98	268	219	615	2522	268	347
2021	3262	107	375	232	847	2415	375	472
2022	3393	116	491	247	1094	2299	491	603
2023	3528	46	538	182	1276	2252	538	738
2024	3669	56	594	197	1473	2196	594	879
2025	3815	75	669	221	1694	2121	669	1025
2026	3967	96	765	249	1943	2025	765	1177
2027	4125	118	883	276	2219	1907	883	1335
2028	4290	134	1017	298	2517	1773	1017	1500
2029	4461	140	1157	311	2828	1633	1157	1671
2030	4639	138	1295	316	3144	1495	1295	1849
2031	4824	135	1430	320	3464	1360	1430	2034
2032	5016	137	1568	330	3794	1222	1568	2226
2033	5217	148	1715	348	4142	1075	1715	2427
2034	5425	157	1873	365	4508	917	1873	2635
2035	5641	169	2042	385	4893	748	2042	2851
2036	5866	180	2222	405	5298	568	2222	3076
2037	6100	186	2407	419	5717	383	2407	3310

Figure 12.69. Evolution of single-aisle fleet in China.

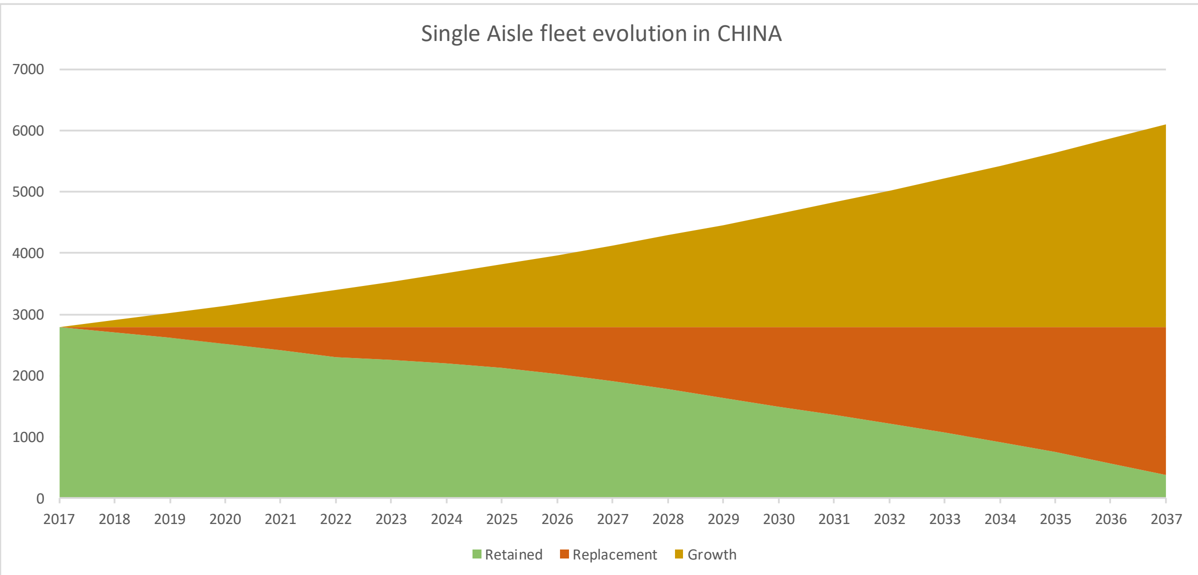

Figure 12.70. Graphical representation of the evolution of the single-aisle fleet in China.

Estimation of the possible market share that C919 would be able to capture inside China.

For the estimation of the actual internal Chinese market demand for the C919 the following factors have been considered:

- The airlines operating of the single-aisle market in China discussed and analysed in Chapter 5. The 4 big airlines of state property account for 75% of the SA aircraft currently operated in China.
- Influence of the Chinese government in the buying decisions of the big four to favour the acquisition of the C919 against its counterparts from Boeing and Airbus, as discussed in section 12.2.6.1.
- C919 current order book of 1000 units, which despite the doubts around, indicates a demand of 1/5 of the B737 orders, and close to 1/7 of the A320 ones [58]. However, uncertainties led to a more conservative figure around 400 orders. Of the 37 firm orders, only 55 are from companies, the rest are from leasing companies. China's Big 3 airlines—Air China, China Eastern and China Southern—have ordered five each. Hainan Airlines, despite its financial problems, ordered 20. No currently operative airline outside China has placed an order.
- The percentage of the total Airbus/Boeing demand that is due to Chinese fleet demand, roughly around 20%. 25% of Airbus' sales are in China; while only 14% of Boeing's sells are due to the Chinese market.

Figure 12.71 presents the possible accumulative demand for the C919 estimated as a percentage of the overall deliveries of the four big Chinese airlines. This % variates between a conservative 10% and a more optimistic 30%. It is to be noticed that no deliveries are considered before C919 certification and entry into service in 2012.

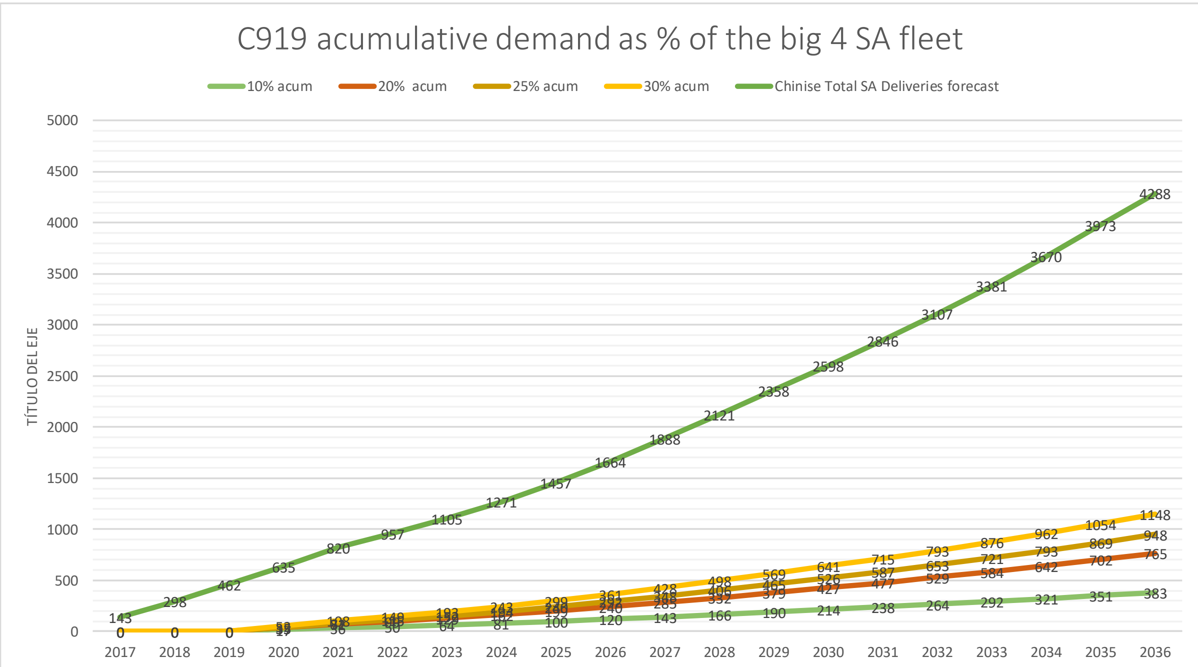

Figure 12.71. Accumulative C919 demand presented as a % of the 4 big deliveries.

A complement estimation can be done by attending to the market share in terms of orders. A conservative realistic approach of roughly 400 firm orders is considered for the C919. A320 and B737 orders for the Chinese market are estimated for the global backlog proportionally to the Airbus/Boeing total sells in China. The resulting Chinese market share will be 60% for the A320, 25% for the B737 and 14% for the C919. Yearly figures are presented in Figure 12.72. It can be observed that this approach is equivalent at considering that 20% of the 4 will SA deliveries will be covered with the C919.

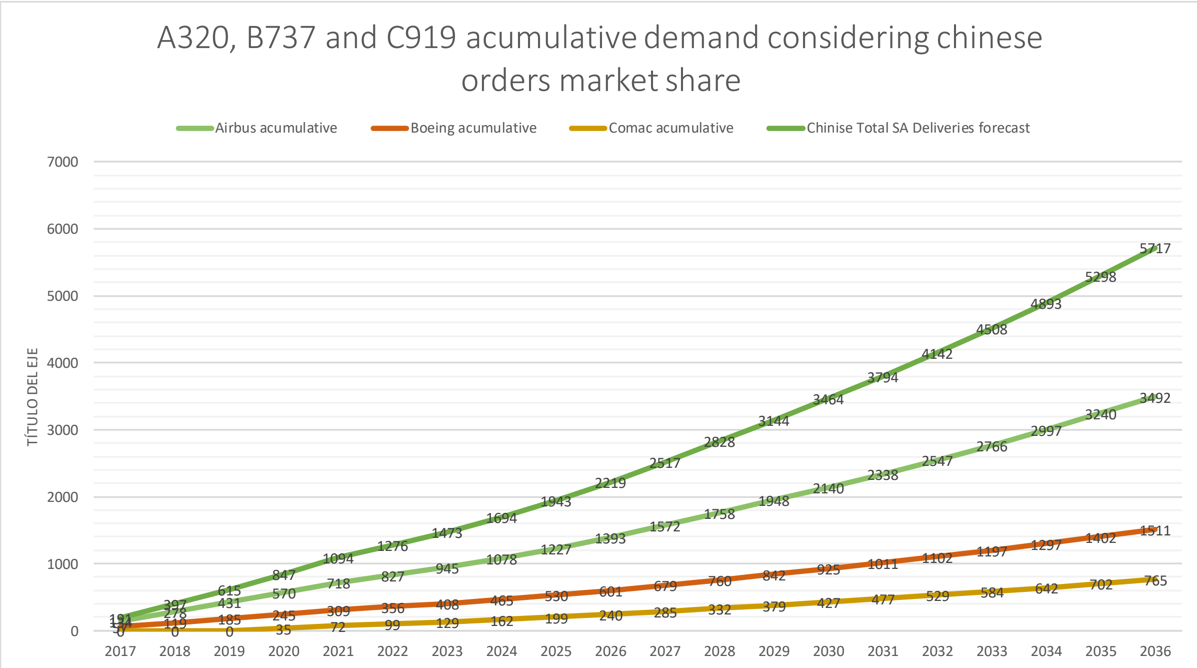

Figure 12.72. Accumulative demand for A320, B737 and C919 families according to orders share.

The contrast between possible C919 demand and delivery capability.

Production rates capabilities and constrains have been discussed in section 12.2.9.9 for the various production lines of Boeing and Airbus. Special consideration has been paid to the difficulties both manufacturers are experiencing in its final assembly lines in China. With all this information we may estimate a maximum production rate of 8 units per assemble line, similar to those achieved by western manufacturers when the assembly line is fully operational. However, attending to the Tianjin experience with both A320 and A330, the Chinese's industry still will take time to get to this optimum production rate. Tianjin line took 10 years to get to 4.6 units per month, 2 additional years more are expected for achieving 6 units per month, and there are no plans for further productivity increase. Initial problems with A330 confirms the learning curve has not significantly improved. Therefore, the same learning curve is extrapolated for the firsts C929 assembly line. The expected production curve is illustrated in **Error! Reference source not found.**. This production rate will deliver 1260 C919 units in 20 years with only one production line, as indicated in **Error! Reference source not found.**.

Based on these previous analyses, **Error! Reference source not found.** illustrates on one side the expected accumulative demand for each fleet (320, B737 and C919) based upon the previous hypothesis. Red line represents C919 accumulative demand as in **Error! Reference source not found.**. It considers that C919 will capture approximately 20% of the 4 big Chinese airlines single-aisle deliveries (4Big 20% SA). The yellow and brown lines represent de C919 accumulative deliveries for the hypothesis of 1 or 2 production lanes respectively. As can be seen, COMAC could satisfy the Big 4 20% SA demand with one single line. If COMAC were able to put in place two production lines, its delivery capability would be higher than Boeing's expected demand, but it will require that the 4 big would order 50% of its deliveries to COMAC.

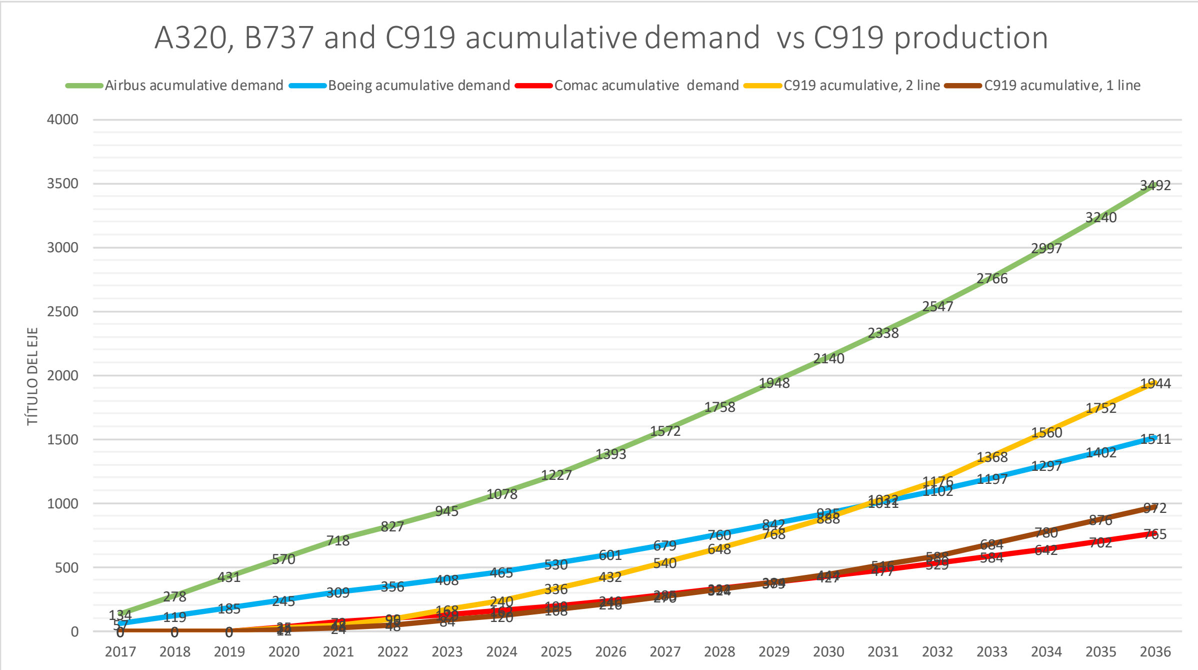

Figure 12.73. A320, B737 and C919 accumulative demand vs C919 accumulative production for 1 and 2 productions lanes

12.2.14.2 Scenario 1B

Scenario 1B is quite similar to the previous one. The only relevant difference is that we estimate a little additional demand for the C919 coming from third countries, that could relay in the Chinese model for political and/or economic influences, despite C919 not granted an FAA/EASA certification. This hypothesis has been discussed and evaluated in section 12.2.9.7.

This market would be small and somehow anecdotic. To estimate its magnitude the fleets of all airlines in the countries of influence indicated in **Error! Reference source not found.** have been analysed. 2019 actualized data from Planespotter (https://www.planespotters.net/airline/Hainan-Airlines-Group) have been used. A320 and B373 aircraft of each one of the airlines registered at each of these countries have been revised and the number of aircraft have been registered.

Error! Reference source not found. sums up the number of A320 and B737 that currently are operated by Airlines registered at third countries potential buyers for the C919. The total figure of 863 aircraft represents 18% on the single-aisles fleet in these regions. The possible political and economic influence of Chinese companies in these countries will hardly justify big orders from their airlines. Considering orders and exports of the Chinese aviation industry (as discussed in sections 12.2.5.1 "Orders" and 12.2.4.1) this hypothetical demand is estimated between 1 and 3% of the single aisle operating in those countries.

Total SA per region	Region	Potential countries C919 buyers	SA aircraft currently operated by airlines register at each C919 potential buyer country				
			Airbus A318	Airbus A319	Airbus A320	Airbus A321	Boeing 737
1,240	South America	Colombia	10	14	62	11	15
		Venezuela	10	15	62	11	51
		Peru	0	2	2	1	20
		Bolivia	0	0	0	0	24
370	Africa	Mali	0	0	0	0	1
		Egypt	0	3	24	1	43
		Nigeria	0	2	0	0	53
		Cameron	0	0	0	0	2
		Togo	0	0	0	0	6
		Namibia	0	0	0	0	0
		Kenya	0	0	0	0	14
		Congo	0	0	0	0	11
		Sudan	0	0	1	0	10
3,150	Asia and Middle East, excluding China	Iran	0	3	28	5	22
		Yemen	0	0	3		
		Afghanistan	0	0	0	0	7
		Pakistan	0	0	14	4	10
		Mongolia	0	0	0	0	8
		Malaysia	0	1	99	0	84
		Singapore	0	3	53	0	28
		Myanmar	0	3	0	0	3
		TOTAL	**20**	**50**	**348**	**33**	**412**

Table 12.34. The number of A320 and B737 operate by Airlines registered at third countries potential buyers for the C919.

The expected additional demand for the C919 is presented in **Error! Reference source not found.** based upon the analysis of the A320 and B737 fleet on the possible countries of influence, the additional demand will range between 22 and 65 additional aircraft. As expected, the figures are minimal and do not change significantly the results of the analysis in scenario 1A.

	SA deliveries 2018-2037	SA deliveries at C919 potential buyer countries 2018-2037	C919 demand as % of SA deliveries at potential countries 2018-2037		
			1%	2%	3%
Asia and Middle East excluding china	8,480	1526.4	15	31	46
Africa	890	160.2	2	3	5
South America	2,660	478.8	5	10	14
TOTAL	**12,030**	**2,165**	**22**	**43**	**65**

Table 12.35. Potential additional C919 demand from third countries.

12.2.14.3 Scenario 2

The main difference between scenario 2 and 1 is that COMAC would obtain FAA and/or EASA certification for the C919. Experts and analysts' best optimist estimation for FAA/EASA C919 certified aircraft entry into service would be 2025.

Despite western certification, the technological level of this model will be equivalent to the one in scenario 1. Its lower performance, particularly in terms of fuel efficiency and operating costs, will not make it attractive for big airlines who have to compete with the much more efficient A320 and B737. [102] analysis of fleet turnover concluded that airlines purchase decisions have historically not been affected by fuel prices when the selection of aircraft types available remains constant. However, the mean fuel burn of new aircraft orders is strongly affected by the introduction of new aircraft models with significantly lower fuel burn. Reduced operating cost savings is a major selling point of new aircraft programs, although the magnitude of operating cost savings is partially dependent on future fuel prices.

Another factor to be considered in this scenario is switching cost. In a normal case, switching costs prevent airlines from receiving a higher utility from aircraft that have a marginally (e.g. <5%) performance advantage. In this scenario, this effect will be even more accentuated as the C919 will not offer performance advantages over A320 and B737 families.

The main competitive advantage of C919 in this scenario will be its lower selling price, that might create and additional temporal demand from a niche of operators worldwide. This possibility has been discussed in section 12.2.5.1 "Orders. The low prices might compensate for the inferior performances enough to grant C919 a minimum market share in the single-aisle market.

Some authors have estimated in 15% the minimum market share for an aircraft that a manufacturer still finds profitable to produce, based on historical analysis. However, this historic analysis represents manufacturers that have already exploit a product line for a long period for time. The figure for minimum market share should be considerably reduced for the case of a new entrant manufacturer offering a product with inferior performances.

A scenario of low fuel prices will have a positive effect for C919 demand because fuel efficiency will not be as critical for airlines as it would be if fuel prices are high and their access to the market will be higher.

As discussed by [1] high fuel costs will provide incentives for airlines to improve fleet fuel efficiency, which would be harmful to the C919. Under the expectation of low fuel prices, incumbent manufacturers are not able to increase the sale price of a new aircraft, as fuel cost savings are negligible over the course of the aircraft's life. The incentive to develop a new aircraft is to gain market share from a competitor or to raise entrance barriers to protect against new entrants. Both incumbents, Airbus and Boeing, will be inclined to maintain their current aircraft, reaping large profits while splitting the market.

According to the previous arguments, internal Chinese demand will not be significantly different from the one in scenario 1, however, C919 demand from external countries might vary between 5% of the market for a high fuel price scenario and 10% for a low fuel price scenario.

Figure 12.74 presents C919 accumulative demand, considering C919 gets 5% and 10% respectively of the external SA market. It can be observed that the reaming demand to be shared between Boeing and Airbus is not significantly affected. By 2037, C919 will have obtained a demand less than the 9% of the global worldwide SA deliveries over the total period 2018-2037, this is 2657 out of 31175. However, in this case, the C919 selling might be enough to justify economically the investment in the C919 program.

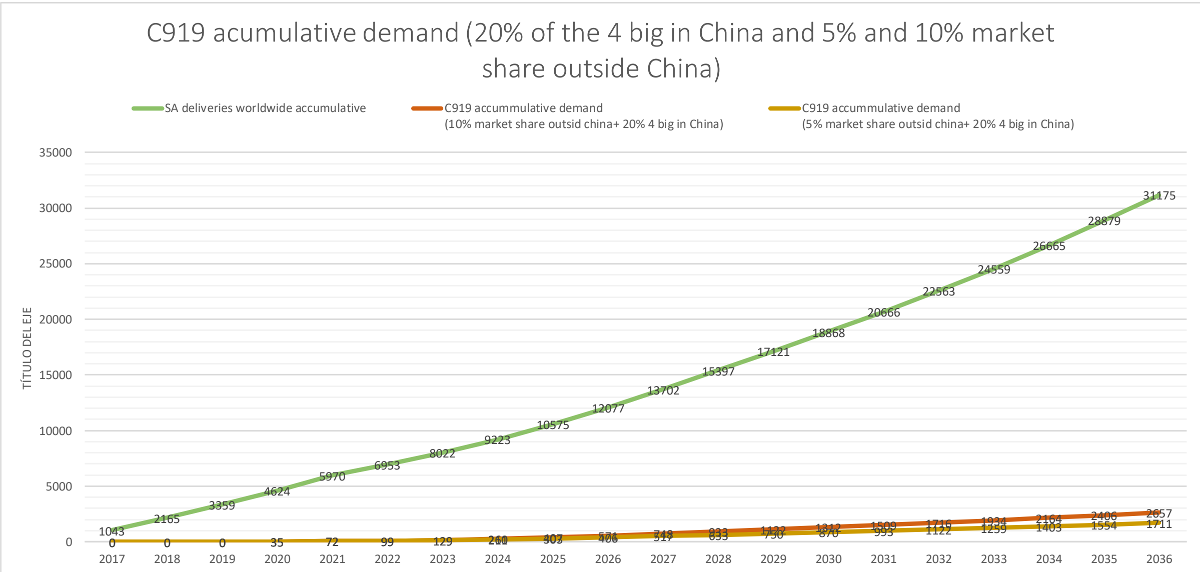

Figure 12.74. C919 accumulative demand considering 20% of the 4 big internal demand and between 5% and 10% of the market share outside china.

To take full advantage of this window of opportunity, the Chinese industry should focus its efforts on improving its production curve, expanding its production chain as quickly as possible without affecting reliability. Demand in this scenario might be significant, and if being able to satisfy it, C919 might make a negative impact on the selling prospects of Boeing and Airbus. The exploitation of this market opportunity might justify a slowdown in the upgraded and re-engined of new versions of C919.

12.2.15 Analysis of the long-term scenarios

To analyse the possible results of these scenarios we rely on game theory analysis and in particular on the findings of previous research work that have used this technique for strategic decision analysis in a three-player situation. We also reutilise in this analysis the aircraft development valuation model that was developed by UPM for the assessment of the What if study Nº 1 about the New Middle of the Market Aircraft. For the sake of simplifying this model could be consulted in detail in [103].

Game theory involves a set of concepts and tools to analyse decision making under specified rules in situations of competition, conflict, cooperation or interdependence. A strategic game reflects a situation where two or more participants are faced with choices of action. The choices of action may imply gains or losses for each participant, depending on what the others choose to do or not to do. Therefore, the final outcome of the game is not determined by the strategies or actions of a single participant, but instead, it is the result of the combination and interaction of the strategies applied by all the participants.

The game theoretic framework allows accounting for the presence of multiple competitors, all of whom make rational decisions in accordance with their own best interests. It is assumed that all players will act rationally and all of them know that other players make rational decisions. That is, the goal of each individual is to maximize their well-being. Therefore, he will make an optimal choice according to the beliefs he has about the decision making by other players. Each player will decide to choose one strategy or another according to the thought and knowledge each one has about the situation in which he is.

These assumptions enable the discovery of the Nash equilibrium of competing players' strategies. **The Nash equilibrium** is the **predicted strategy for each player that is the best response to the predicted strategy of all other players**. In a Nash equilibrium, firms are assumed to be capable of predicting correctly the behaviour of their competitors. Starting from the premise that players are rational, they will carry out rational decisions and each of them will have a unique rationale strategy. Nash's equilibrium identifies strategy profiles that are stable, so no player has any incentive to deviate from the established if the other players make the decisions expected of them. Therefore, the set of rational strategies of each player will form the Nash equilibrium.

A three-player game follows a logic of two simple movements. In the first movement the new player, COMAC, decides to initiate or not the production of a new advance and improved version of the C919. In the second movement, the incumbent manufactures, Boeing and Airbus, decide simultaneously their best response to the COMAC strategy. To cope with a competitive new COMAC aircraft the incumbent manufacturers can decide between three generic strategies:

(1) *maintain* their existing product lines, with incremental improvements over time,
(2) *re-engineer* their existing airframes, providing superior performance improvement,
(3) develop *new*, clean-sheet design aircraft that offer the greatest fuel burn improvements.

Boeing and Airbus will decide their optimal strategy given their perceived probability of COMAC producing a new competitive aircraft. If COMAC would expect a negative Net Present Value (NPV) given the Boeing and Airbus expected responses, it might decide not to go for a new aircraft and remain in the case studied in Scenario 2.

The structure of the game is illustrated in **Error! Reference source not found.** and the dynamic of the game is illustrated in **Error! Reference source not found.** a strategic decision tree.

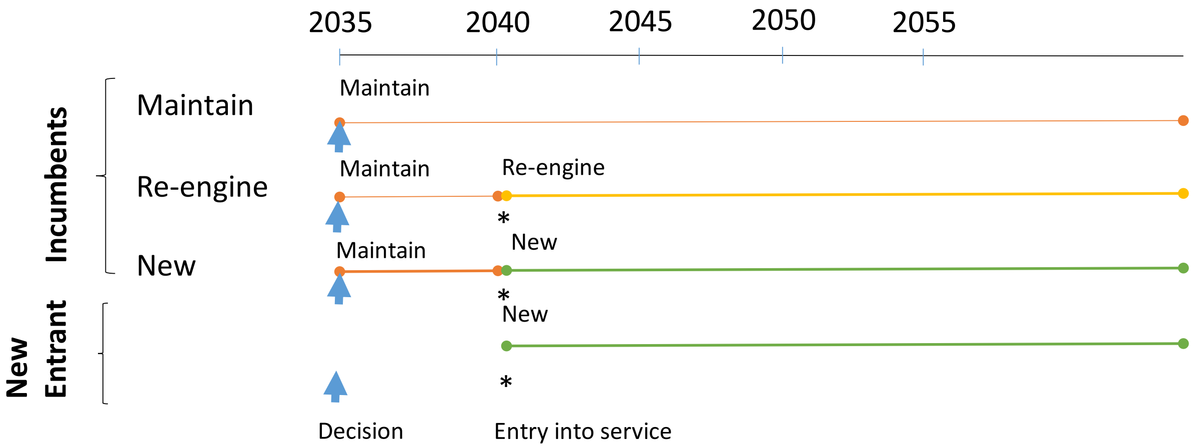

Figure 12.75. Structure of the three player's game.

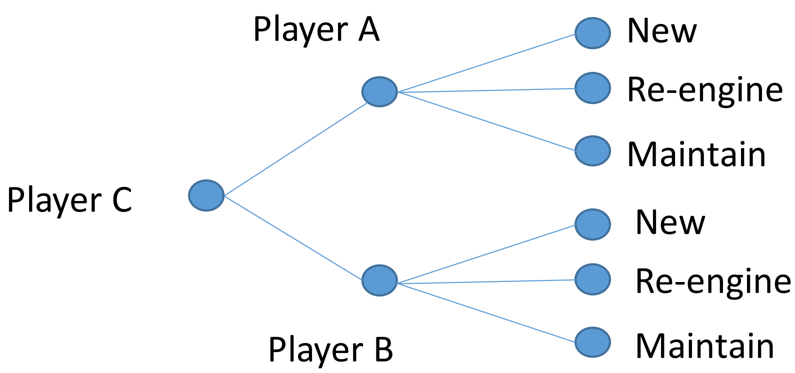

Figure 12.76. Strategic decision tree.

The hypothesis supporting the game analysis in this case is:

- The performance level of the new entrant. In a generic situation, the new entrant can produce an aircraft that has lower, equal or superior performance to the ones the incumbent manufacturer has already in the market. The case of lower performances has been studied in scenario 2, and scenario 3 focuses on the cases of equal or superior performances.
- Heuristics for market share based on a free market performance-driven competition. The new entrant would only take market share if it produces an aircraft of superior performance to the incumbent's current product. The amount of market share would be dependent on the level of performance of the new entrant's aircraft.
- This analysis does not consider any manufacturer restriction to cope with the demand, that is, it assumed that the manufacturer will be able to produce all its demand on time.
- Fuel prices keep rising. Therefore, the main driver for airlines buying decision will be fuel efficiency and savings in operational costs.

- Lifecycle fuel cost saving can be reflected in sales prices.
- Investment required for re-engined incumbents' models is not symmetric. Boeing will require greater investment to reengineer his 737 families.

12.2.15.1 Scenario 3A

The main difference between scenario 3A) and 3B) are the level of performance achieved by the new entrant. This has a direct impact on the calculation of payoffs, particularly in the market share.

It might happen that due to its inferior experience in design and production, COMAC new version will not be able to equal the incumbent's new clean-sheet designs performance and be only able to equal the performance of incumbents' re-engined aircraft.

Error! Reference source not found. summarises the market share in the case the new entrant would only be equivalent to the incumbent incumbents' re-engineered aircraft in terms of performance. In this case, the new entrant would only be able to capture 50% of the market from two stagnant incumbents.

New Entrant Performance = Incumbent RE-ENGINED Aircraft performance		Player B		
		Maintain	Re-engine	New
Player A	Maintain	25%,25%,50%	20%,40%,40%	15%,55%,30%
	Re-engine	40%,20%,40%	33%,33%,33%	25%,50%,25%
	New	55%,15%,30%	50%,25%,25%	40%,40%,20%

Figure 12.77. Three player market share rules when the new entrant performance is equivalent to the re-engineered incumbent one.

Based on the work by [1], this scenario presents an off-symmetric equilibrium, in the case Boeing develops a new clean sheet improved design to maintain 50% of the single-aisle market while Airbus and COMAC split the remaining 50% of the market with models slightly inferior in performance to the Boeing one. In this scenario, COMAC will only receive positive payoff if neither incumbent develops a new aircraft. These results indicate that if COMAC would seek to maximise profits could decide not to produce a new model if its only as good as the re-engined A320 and B737 families. In this situation incumbent manufactures will not be concerned with new COMAC single-aisle designs unless there is a high probability that the new models could match or exceed the performance of the incumbent new aircraft.

		Player B		
		Maintain	Re-engine	New
Player A	Maintain	24.6/24.6/11	20.8/27.4/3	17.1/28.8/-5
	Re-engine	29/20.8/3	23.7/22.2/-2	17.5/ 24.2/-8
	New	28.8/17.1/-5	24.2/16.0/-8	15.1/15.1/-11

Figure 12.78. Game analysis for three players when the new entrant performance is equivalent to the re-engineered incumbent one. Results from the study at [1].

12.2.15.2 Scenario 3B

Error! Reference source not found. indicates the market share heuristics if the new entrant performance would be equivalent to the ones of the incumbent's new aircraft. It can be observed, that in that case, the new entrant would have to leave standing incumbents' products with the minimum market share.

New Entrant Performance = Incumbent New Aircraft performance		Player B		
		Maintain	Re-engine	New
Player A	Maintain	15%, 15%, 70%	15%, 25%, 70%	15%,43%,43%
	Re-engine	25%,15%,60%	25%,25%,50%	25%,38%,38%
	New	43%,15%,43%	38%,25%,38%	33%,33%,33%

Figure 12.79. Three player market share rules when the new entrant performance is equivalent to the new incumbent one.

As the new COMAC aircraft has a superior performance to the incumbent's, those might expect to suffer a significant loss in sales. This problem has been previously analysed by [1]. **Error! Reference source not found.** illustrates the equilibrium situation. The results illustrate that equilibrium might be possible in which one incumbent chooses to maintain while the other decides to re-engineer. Although this equilibrium is sensitive to the input parameters in the aircraft program valuation model, the greater investment required by Boeing to re-engine results in an off symmetric equilibrium. The superior performance of the new COMAC's aircraft will be able to capture a significant market share while Airbus attempts to maintain market position by reengining A320 latest models. In this situation, Boeing's optimal strategy is to avoid investment and maintain its current aircraft. Once the competitors' new and re-engineered aircraft enter service in stage 2, Boeing suffers from a greatly reduced market share, but it will continue to make small profits due to its unit production cost advantage while harvesting its existing product line.

The new entrant has a positive expected net present value in each possible outcome, except if both of the incumbents develop a new aircraft. This result suggests that there may be rents available in the single-aisle market, providing an incentive for increased competition if new entrants are able to overcome the significant entry barriers to develop an aircraft that can compete with the incumbents' new aircraft option.

		Player B		
		Maintain	Re-engine	New
Player A	Maintain	17.1/17.1/29	17.1/16/20	17.1/17.3/5
	Re-engine	17.5/17.1/20	17.5/16/11	17.5/13/1
	New	17.3/17.1/5	13/16/1	9.5/9.5/-2.4

Figure 12.80. Game analysis for three players when the new entrant performance is equivalent to the new incumbent one.

The analysis has shown that a new entrant's aircraft with the same performance as the incumbents' new option would take significant market share unless the incumbents decide to move. A new entrant's aircraft that has the same performance as the incumbents' re-engined aircraft would capture less market share.

An additional assessment can be made to determine the appropriate time for such a decision. The manufactures that first decide to move and get involved in the design of a new aircraft will take the risk of developing a clean-sheet design based on the expectation of higher payoffs. If the other decide to wait it will take a less risky strategy. Game theory can also help to figure out which manufacturer is likely to mode first base upon the manufacturing assessment of the confidence on the new COMAC aircraft performance.

For this analysis it is assumed that the manufacturer that believes that COMAC will produce a new competitive aircraft will be the first to move, resulting in the other delaying the introduction of their new aircraft.

The analysis of this same case by [1] show that, if the new COMAC Aircraft is as good as the new Airbus or Boeing ones, the payoffs to move first or delay are very close, with payoffs that are sensitive to the assumptions of the aircraft program valuation model. However, if the new COMAC aircraft will only match the performances of the Airbus or Boeing re-engined aircraft, both manufacturers will have an incentive to develop a new clean-sheet design aircraft as soon as possible. An early decision by one incumbent manufacturer will reduce COMAC market share up to a point that might not have a positive NPV. This suggests that an early movement of the incumbent could prevent the COMAC impulse to evolve C919. The manufacturer that delays the decision will temporally lose market that can regain when producing the new aircraft. Morrison clarifies in its analysis that this game is very sensitive to the aircraft program valuation model and the market share hypothesis. So, these results should not be taken in absolute terms, but should be better considered as an illustration of how the credible threat of a new COMAC competitive aircraft will be contested with different strategies depending on two main factors: a) the incumbent manufacture risk tolerance and b) its assessment of the competition threat in a new COMAC 919 model.

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