



# DISRUPTIVE AVIATION TECHNOLOGY 2013-2022

Opportunities and threats facing the world's  
commercial aircraft manufacturers from new  
technologies and new competitors

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## **Introduction: All forecasts are wrong**

All forecasts are wrong. But such is the power of numbers that any respected organisation which regularly forecasts detailed numbers of units and values, defining the size of a particular market over a number of decades, quickly becomes a mantra for the entire industry. In civil aviation the forecast figures from manufacturers are particularly powerful, especially as they have a history of being broadly accurate. However, we are entering new decades of uncertainty, where unforeseen economic drivers and emerging technologies are starting to change some of the fundamental principles which have underpinned the industry for the last thirty years. Until recently, no-one predicted that it would be 2017 before air traffic movements in Europe reached the same level achieved in 2008, for example.

So this paper looks at the implications of some of these emerging economic and technical uncertainties on the civil aviation market – and in particular:

- There may not be enough money to buy new airliners
- For the first time taking the train might be faster than flying
- That integrating new manufacturing and computing technologies will be more complex than originally thought
- That slow regulation will impede the progress of automation
- And that new computer technology will open the door to competition.

When it comes to assessing new competition or the introduction of game-changing technologies it is easy to see why Airbus and Boeing can be forgiven a slight degree of complacency. After all, if you look at the production rates of Boeing and Airbus narrow-body aircraft (their cashcows) and wind that clock forward to 2020 even if the newcomers - such as Bombardier, Mitsubishi, Irkut and COMAC - build to their full production rates Boeing and Airbus will still account for 90% to 95% of the market.

According to Eddy Pieniazek of Pieniazek Aviation Consulting Ltd. “It could be that when COMAC enters the wide-body market, that’s when they will start to make bigger inroads. COMAC and the Russians have both said they are looking at the widebody space but we are probably looking at 2025 or beyond for those new aircraft to materialize.”

### **Fuel efficiency is the driver**

If fuel-efficiency is the prime driver in the market then Airbus and Boeing have done almost everything they can to ensure mastery over the current and future technologies which drive increasing fuel efficiency. The world needs more airliners but they must be 15-20% cheaper to operate than the types they replace. This means more fuel efficient engines, more electric systems, better aerodynamics, lighter airframes and interiors, more efficient routeings and lower maintenance costs.

The long term research requirements to meet these needs have been in place in the USA and Europe for decades and the technology roadmap is more or less settled for the next 15 years (see table two). And the companies and research organisations which will deliver these new fuel saving systems – especially engine manufacturers – are all integrated partners. In other words we broadly know what a new airliner of 2025 will look like, what sort of engines it will fly with, what kind of avionics it will have and what sort of technologies will form the basis of the aircraft's systems.

Most of the key drivers in the aviation market for the next ten years appear to be known and understood. Airline traffic globally will rise at an average annual rate of 4.6% between 2005 and 2025, according to the International Civil Aviation Organisation (ICAO). Downturns in one aviation market, such as Europe, are being offset by a demand for new services in other regions, such as the Far and Middle East. Measured on a world-wide base, air travel is growing strongly. According to the International Air Transport Association (IATA), passenger numbers were 5.3% higher in 2012 than in 2011 and will grow 5.4% this year over 2012, well above the ICAO average.

The well-known variables – such as national economic growth rates, the price of fuel and labour, the speed with which new technologies can be matured, the health of aircraft operators, accidents – are all identified. The less known variables – increased long-term competition from manufacturers in the BRIC community, access to finance, technology and company failures – can be, to some extent, ignored.

Increasing the fuel efficiency of airliners is the key driver for new aircraft sales, but apart from structures the key technologies which deliver these efficiencies – engines, avionics and flight control systems, engine management systems interiors, air conditioning, fuel, electrical systems – are all dominated by Western suppliers. So what threat, if any, do Chinese manufacturers offer the West, apart from delivering the first platform for any new fuel-efficient from Western engine suppliers? It is highly unlikely that China, Russia or India will be able to develop the kind of semi-disruptive technologies and concepts that Airbus introduced (twin-engined widebodies and fly-by-wire airliners) to break the US monopoly in the 1980s on aircraft sales, unless these countries decide to introduce supersonic airliner programmes.

So, a degree of complacency is perhaps understandable.

### **What forecasters can't predict**

But are there any as yet unidentified phenomena out there which could disrupt our current understanding of how the airliner manufacturing sector will evolve over the next ten to fifteen years? Are there any new technologies, materials or operating concepts, any political or economic drivers which will change our vision of the 2023 airliner from what we have today?

After all, technology advancement is driven as much by industry's response to political and economic drivers – including demands to protect the environment from greenhouse-gas forming

emissions and, luckily, the related challenge of the high cost of fuel – as by the advent of new technologies themselves.

The industry is conservative and rather sceptical of any “radical” new aviation concepts – such as supersonic airliners or personal jets. It introduces new technologies – fly-by-wire flight control systems, composite structures – very slowly and very carefully.

At the Technology Forum for Business, organized by the Aerospace and Defense Industries of Europe (ASD) in October 2012, Airbus’s Gareth Williams, Head of R&T Business Development, identified his company’s view of the priority areas for future research efforts. In the near term – the Airbus A30X short range aircraft – these included new engine concepts (with new architectures such as unducted fans to deliver a quantum leap in fuel burn efficiency), fuel cells (to reduce kerosene burn and allow for zero-emission electric taxiing), smart wings (with low drag surfaces), optimized maintenance (through extensive systems health monitoring), an innovative cockpit (to lower crew workload and exploit new ATM architectures) and the use of advanced airframe materials.

These are all key elements within the National Aeronautics and Space Administration’s (NASA)’s fundamental aeronautics research program and the European Commission’s Horizon 2020 research agenda, which covers the years 2014-2020. In the longer term both Airbus and Boeing are targeting research areas such as smart energy harvesting and storage systems, intelligent materials and manufacturing methods, new tail and ellipsoid-like fuselage designs and “blended hybrid” engines.

In the USA, \$17 billion of the government’s budget was spent in 2012 on aeronautics and space research. In Europe, 12% of revenues of aerospace sales—more than €7 billion a year—is spent on civil aeronautics research alone, according to “Flightpath 2050”, a report by the European High Level Group on Aviation Research.

These long term research programmes are being enhanced by more short and medium term research work by industries in European and north America to develop technology improvements to reduce fuel-burn, such as new engine types (very efficient open-rotor engines, for example), winglets, fuel cells, low-drag wings and “smart” cockpit systems which will allow the aircraft to automatically fly the most efficient routes.

There is little sign of any disruptive technologies becoming available to aircraft operators outside the current known technology improvement programmes. The COMAC C919 and Irkut MS-21 are more or less complementary designs to existing types and all use the same engines and systems suppliers used by Boeing and Airbus.

### **Disruptive technologies**

But waiting in the wings are lines of potentially disruptive, or radical, new technologies, political pressures and operating concepts which do threaten to overturn the comfortable assumptions of today.

Some of these appear so remote as to be negligible, but others are much more significant. Thus 3D printing, quantum computing, automated cockpits, improved battery and fuel cell performance, more accessible programming languages, economically-viable hypersonic engines, network-centric operations all offer an extraordinary competitive edge to manufacturers who mature these concepts first.

Some of these are clearly over-the -horizon technologies and need not concern busy aerospace executives in Toulouse and Seattle. But what makes these technologies different from the past is that, some of them at least, will not necessarily be pioneered in North America and Europe and therefore their first appearance in the aviation industry may not necessarily be on Boeing and Airbus aircraft.

And there is another factor of technology evolution that Western aerospace manufacturers need to take increasingly into account. In the future, aircraft efficiencies will depend increasingly on the software capabilities of the aircraft's operational management system and the integration of aircraft within a wider network-centric traffic environment, rather than the performance of individual aircraft systems. This opens the door to new entrants from outside the industry with particular skills in dealing with large amounts of data. And in this area US and European manufacturers may be at a slight disadvantage to new entrants. For although they have decades of experience in development new systems they also have accumulated vast networks of legacy systems – both on-board the aircraft and within the wider air traffic management community – which need to be supported, financed and evolved before any new “game-changing” technologies can be introduced. Thus many performance-based navigation (PBN) techniques which guarantee to minimise the flight time between origin and destination airport are being pioneered in the Far East where they can be introduced as “greenfield” technologies. In this context the superior fuel burn of one aircraft type over the other can be more or less irrelevant if the more efficient aircraft has to spend hours in the air flying circuitous routes while the more fuel-hungry aircraft has a direct line to fly.

Of course these issues are known and understood by Western manufacturers – which is why they have invested so much in new flight planning and PBN businesses. But with software engineering becoming increasingly decisive elements in the competition to sell aircraft it is only a matter of time before Boeing and Airbus will face competitors who have aircraft with similar engines, avionics and systems but slightly better operational management systems – internally and externally – and more flexible financing options.

## Challenge one: There may not be enough money

The trouble with all forecasts is that they rely on there being enough money available to fund research and development projects and for aircraft operators to buy new aircraft. That is a very optimistic assumption.

To fulfil the Flightpath 2050 goals more than \$250 billion of investment would be needed to fund all the long-term projects identified. Governments and aircraft operators are already struggling to fund near-term improvements in aircraft performance which are seen as vital to the future of air transport in Europe and North America. For example, the total estimated cost of the *development phase* (2008-2013) of the European Commission's Single European Sky ATM Research (SESAR) programme is €2.1 billion. The task force set up to examine SESAR deployment costs reported in May 2012 that SESAR *deployment* requires total investments exceeding €30 billion over a ten-year period up to 2020. At €22 billion, airborne equipage including airlines (€11.5 billion), business aviation (€3.4 billion), general aviation (€940 million) and air forces (€6.4 billion) represents more than two-thirds of the total investment. The balance (€8 billion) consists of investments in ground equipment (ANSPs, military ground systems and airports). The bill for the USA's equivalent programme, NextGen, is likely to be \$11 billion in deployment and research for the next few years.

It is not clear where this money will come from. This is a particular problem for Europe. So when stable and significant growth does return to the market there might not be the capacity within the ATM and airport system hubs to cater for air traffic growth. Current new aircraft purchases in Europe are being driven by the replacement market, rather than the growth market.

And will airlines be able to afford the aircraft they have ordered? This year will be the first year that aircraft operators will face a bill of more than \$100 billion (see table one), based on aircraft list prices, for aircraft deliveries and this bill is expected to rise by around 10% per annum for the next few years, as more widebody (and expensive) aircraft roll off the production lines of Toulouse and Seattle. This is almost certainly sustainable in the short term but in the longer term will be less so as access to funding for aircraft purchases will become more costly. The European Sovereign debt crisis, more expensive funding of export credit guarantee-backed loans as a result of the new OECD Aircraft Sector Understanding (ASU) agreement and other new financial lending regulations could eventually make aircraft finance a major issue, especially if there are unpredictable shocks to the global banking system in the Middle East and Far East.

**Table one: Airliner funding requirements**

2012	2013	2014	2015	2016	2017
\$95 bill	\$104 bill	\$116 bill	\$125 bill	\$128 bill	\$132 bill

*Source: Boeing Capital Corporation*

Asian banks are becoming increasingly important sources of finance. In January 2013, Royal Bank of Scotland (UK) sold its aircraft leasing business to Tokyo-based Sumitomo Mitsui Financial Group for \$7.3 billion. Chinese banks have also started to enter the aircraft finance market and their share of the overall sector is likely to rise rapidly over the next few years. Given the cyclical nature of the business this challenge is likely to be felt most keenly in the next upturn of the ordering cycle when the annual cost of acquiring new aircraft will be more than \$150 billion. At the very least, if a COMAC widebody did appear in the next decade it is likely to be backed by experienced and innovative funding packages.

## **Challenge two: For the first time taking the train might be faster**

Asian countries are likely to spend around \$172 billion between 2010 and 2020 on high speed rail projects, according to a recent survey by market analysts Frost & Sullivan but this is a long way behind the \$338 billion earmarked for high speed rail (HSR) developments in Europe, according to the company. In north and south America the investment figure is likely to be \$137 billion.

What is new is HSR is now starting to become an increasingly important competitor on longer routes and in markets which until now have been preserved for aviation. And with faster trains being developed competition is about to become even fiercer. At the end of December 2012 China opened the world's longest high-speed rail line, a 2,298-km (1,428-mile) link between Beijing and the southern city of Guangzhou. In January this year it was announced India's first high-speed rail would run between Ahmedabad and Mumbai. In the Middle East an HSR link is being planned to link the states of the United Arab Emirates in a 1,200km network as early as 2018, with a wider network to link all six Gulf Cooperation Council (GCC) member states also under consideration. Saudi Arabia is planning a line to carry 200mph (320kmh) trains between the holy cities of Mecca and Medina.

In a head-to-head fight, on an even competitive playing field, HSR train companies and airlines tend to be fairly evenly matched on distances of around 400 miles (640 km), with rail companies dominating shorter routes and airlines starting to pull ahead once distances go beyond 500 miles (800 km). Two-thirds of Japan's population, or almost 100 million people, live in a narrow, densely populated corridor along the south shore of Honshu Island between Tokyo and Fukuoka – an ideal demographic for HSR services. According to a recent paper from the Transportation Research Board of the National Academies, Washington, airlines and train companies fight a fierce, competitive but mutually profitable battle for business along this narrow corridor which for some sectors sees airlines gain the upper hand (Tokyo-Fukuoka) while in others (Tokyo-Osaka) rail is the clear winner. Distance is a factor but other competitive issues, such as the amount of frequencies offered, are also important.

But Japan is unique. The demographics favour HSR and the solution provided by airlines in the form of high-density Boeing 747s for short-haul operations are found nowhere else in the world.

The distance between Madrid (with a population of 5.7 million people) and Seville (population 750,000) is 335 miles (536km). Before the HSR link was established between the two cities at the start of the 1990s the mix of air/rail passengers was 67%/33% air to rail. After the HSR link that changed to 16%/84% in favour of rail and will rise to 13%/87% in favour of rail by 2020, according to market analyst Frost & Sullivan forecasts.

In Europe HSR links have been developed and expanded between key trading centres at a great cost to airline markets. As HSR services are established on key routes – London-Paris, London-Brussels, Barcelona–Madrid, Paris-Lyons – airlines have either pulled frequencies, reduced aircraft sizes or departed from the routes altogether.

By 2020 a new high-speed line will be built between Paris and Barcelona, cutting journey times on the 514 mile (827.03 km) route from eight hours to four hours 30 minutes. This will be just the start of a new interconnected France-Spain HSR jointly-operated network, managed on the same lines as the UK-France Eurostar HSR system. By 2020 most of Europe's major trading centres will be inter-connected via an HSR network.

It is not just in Europe where aviation has been losing out to rail. At the end of March 2011 all airline services between Nanjing and Wuhan in China were cancelled following the establishment of an HSR link between the two cities, offering a cheaper and competitively fast link on the 284 mile (457km) journey. The introduction in 2007 of the 209 mile (335 km) Taiwan High Speed Rail link between Taipei and Kaohsiung launched in January 2007 has reportedly cut domestic airline services by 50% in recent years.

According to a study by the Centre for Asia Pacific Aviation on the implications of HSR growth on aviation in China: "Some estimates put the loss in revenue for China's aviation industry from reduced traffic and price pressure at up to CNY10 billion (\$1.5 billion) in 2012, or 3-4% of the total. Civil Aviation Administration of China (CAAC) Director Li Jiayang stated some 50% of flights less than 500 km in length could become unprofitable as a result of competition from high-speed trains and around 20% of flights of between 800 and 1000 km could also run at a loss for the same reason. But sectors above 1500 km are not likely to be threatened, he added.... Guotai Junan Securities recently predicted that high-speed rail could capture between 1.3% and 5.3% of domestic airline passengers per year by 2014. First Capital separately forecast that airline revenues would decline by between 3% and 7.9% due to shrinking demand. China Minzu Securities, while downplaying the impact of high-speed railways on airlines, stated up to 9% of passengers could shift from air to rail transport by 2016."

In 2011 the European Regional Airlines Association (ERA) produced a study that showed annual government subsidies for rail in the 27 countries of the European Union are 125 times higher than State aid granted to air transport. However, it is not all one-way traffic. Economic and other issues have slowed down HSR plans in many countries. Even in fast-spending China, the government plans to build 70 airports between now and 2020, suggesting that the country is building its aviation services in parallel with, rather than instead of, its fast train system.

One of the effect of HSR competition on northern European routes between London, Paris, Amsterdam, Brussels and Frankfurt has been to open up slots at heavily congested airports, a phenomenon most airlines have welcomed as they been able to replace short-haul services with more profitable long-haul routes. In this scenario integrated air-rail HSR networks allow fast trains to become feeder services to an airport hub, encouraging network carriers to develop their global services using larger aircraft.

In global terms, the battle between the two transport modes is still in the early skirmish stage.

### Challenge three: Integrating new manufacturing technologies

New more fuel efficient engines are the chief technology driver for the introduction of more fuel efficient aircraft and this is one area where new competitors will struggle to gain a foothold. Current technology engine efficiency is improving at an average of 1% a year. The arrival of the Pratt & Whitney's PW1000G geared turbofan series of engines (see table two) and the CFM International Leap X engines will provide a 15%/16% immediate efficiency gain over legacy types of narrowbody aircraft, though this actual figure will have to be confirmed by operational experience. Major airliner designs will evolve with adaptations of the current models until later in the decade when new generations of Airbus and Boeing single-aisle aircraft, due to enter service around 2030, will probably fly with open-rotor engines. Rolls-Royce and General Electric have progressed their competing open-rotor technology demonstration programs to a stage where they both believe these engines will be able to deliver the necessary step-changes in economic performance while meeting stringent new performance and noise targets. Fuel efficiency gains of 25% over current turbofan engines have been suggested.

**Table two: Aircraft evolution**

Year	Aircraft	Engine
2014	Bombardier C series	PW1500G
2014	MRJ	PW1200G
2015	A320neo	PW1100-JM
2015	A320 neo	CFM Leap-X
2016	MC-21	PW1400G
2016	COMAC C919	CFM Leap X
2017	Boeing 737Max	CFM Leap X
2018	E-Jet second generation	PW100G
2020	<i>Boeing 777X</i>	-
2023	<i>Supersonic business jet</i>	-
2025	<i>COMAC widebody</i>	-
2030	<i>Airbus A320neo replacement</i>	<i>Unducted fan</i>
2030	<i>Boeing 737Max replacement</i>	<i>Unducted fan</i>

It will be extremely difficult for new entrants to enter this market, given the complexities and scale of the research required to produce competitive engines and the extensive infrastructure needed to support and repair aircraft in service.

Airframes are becoming lighter as the amount of composite and lighter aluminium alloy structures increases. On the A300 the aircraft's structure comprised 4% composites, with titanium comprising a further 4%, steel 12%, aluminium 77% and other materials 3%. The Airbus A310, which first flew in April 1982, included large numbers of composite materials in secondary structures – spoilers, airbrakes and rudder – and later versions featured composite primary structures. The A380 features just under 25% of composites in its structure. Just over 50% by weight of the Boeing 787's structure is built from lightweight composite materials (compared with only 12% of the Boeing 777).

While the average percentage of composite structures per airframe is constantly growing another important change to the way aircraft are manufactured will be the increasing prevalence of advanced manufacturing techniques. Composite capabilities are being swiftly acquired among manufacturers in the Far East, Middle East and Latin America, and although composite manufacturing processes are still being pioneered among suppliers in North America and Europe it is only a question of time before heavy investment in automated composite machine tooling in states such as Malaysia, Mexico and Dubai will severely erode the competitive advantage of European and US suppliers.

For Western manufacturers to retain their advantage they will have to continue to research the potential of advanced manufacturing processes such as 3D printing, the increased use of industrial robots and automation. Without this Europe and North America will not be able to deliver aircraft structures which are lighter, more durable and less costly to produce than competitors.

While the West still has a critical edge in the technology of advanced aerospace manufacturing it is an edge which is being eroded every year, especially in the USA. According to the European Association of the Machine Tool Industries (CECIMO) European demand for current machine tool consumption represents just 24% of the global demand for machine tools, against 66% for the Far East (with China accounting for 45% of the global market). The Americas represent just 11% of the market. Manufacturing is currently responsible for just 15.6% of European Union (EU) gross domestic product (GDP), though four-fifths of its exports.

The promise of 3D printing has been known for some time but only now are the initial applications for aerospace manufacturing becoming clear. The process can save up to 65% in manufacturing costs, according to some estimates, while reducing waste, lowering emissions levels and providing parts at a much faster rate than currently possible. There are current limitations on the scale and range of parts which can be manufactured using this process but many in the industry believe that eventually the wholesale adoption of 3D printing could see an end to

the costly stocking and tracking of parts, assemblies and small structures as aircraft operators simply manufacture new parts as required. The certification issues around such processes will need some work but eventually whole manufacturing plants could be given to 3D printers; Airbus plans to build complete airliners with 3D printers by 2050.

According to Bastian Schaefer, a cabin engineer with Airbus, the company has been working on future cabin concept cabin, from which has sprung the idea of building the entire frame on a 3D printer the size of a hangar. According to Airbus: "That probably sounds like a long shot, since the biggest 3D printers today are about the size of a dining table. But the Airbus design comes with a roadmap, from 3D-printing small components now, through to the plane as a whole around 2050."

There are some challenges to the concept and the slow way in which the concept is being developed across industry. According to the UK's Technology Strategy Board, part of the government's Department for Business, Innovation and Skills (BIS): "The reasons for slow adoption include high cost, inconsistent material properties, lack of applicable industry standards, unexpected pre-and post-processing requirements and the failure to exploit the new design freedoms offered."

But the 3D printing revolution is gathering pace. In October 2012 Airbus and South Africa's Council for Scientific and Industrial Research's (CSIR's) National Laser Centre (NLC) and South African aerospace manufacturer Aerosud signed an agreement to research the application of titanium powder-based additive manufacturing concepts for producing large and complex aerospace components. South Africa is one of the world's largest producers of mined titanium ore. As part of the agreement Aerosud is building a R37-million laser-based part forming machine, which it plans to be complete by the middle of this year.

In November 2012 GE Aviation announced it had acquired Morris Technologies and its sister company Rapid Quality Manufacturing of Cincinnati, which have been producing components for GE Aviation using additive manufacturing techniques for several years. The companies have made lightweight parts for remotely piloted air systems (RPASs) and components for the CFM International LEAP jet engine, being produced jointly by GE Aviation and Snecma (SAFRAN) of France.

Europe is now making strenuous efforts via the European Commission, national and regional governments to retain its competitive edge in this area. As part of the European Commission's plans to reverse the relative decline of manufacturing in the continent it has set out a series of strategies which it hopes to increase manufacturing's share of GDP to 20% by 2020. Some of these strategies will have an important role to play in boosting the continent's aerospace competitiveness levels over the coming decades.

Replacing heavy hydraulic systems with lighter electric technologies is a long-standing trend. The goal of aircraft designers around the world is the "all-electric aircraft", using small electric motors instead of today's heavy, maintenance-intensive, hydraulic, pneumatic and mechanical systems.

In terms of aircraft systems we are moving, slowly, from the “more electric aircraft” concept” to the “all-electric” concept. The consequences of all-electric systems run through the entire aircraft design. The engine produces thrust, pneumatic power, hydraulic power and electric power and is being redesigned and optimized to produce thrust and predominantly electric power – but the benefits will be that an all-electric system aircraft will not require quite so much power from the engine. It is not just in power systems where new electrical networks are bringing down aircraft weight. Replacing steel brakes with new generation carbon brakes, augmented with new electronic management systems, can improve braking performance and decrease aircraft weight.

In the Airbus A380, the use of electric systems – such as the electro hydrostatic actuator (EHA) - in the flight control architecture has meant a weight reduction of around 3,300lb (1,500kg) over conventional hydraulic networks. In general there is a move away from numerous, separately-specified system components to integrated networks relying on solid-state power controllers and smart contactors. In a distributed, or integrated, architecture the long runs of individual power wires are replaced with secondary power feeders linked to multiplexed databus lines. The integrated network eliminates components and wires; reduces weight, installation and testing times and increases reliability. According to some manufacturers' figures, by using distributed power systems, the number of electrical components can be cut by 35%; wire segments by 40%; weight can be reduced by 40%; installation time reduced by 60%; and reliability improved by 20%.

Replacing engine-powered environmental control systems (ECS) - which traditionally use air which is bled from the engine – with electrically powered air conditioning packs have saved considerable weight in the Boeing 787. According to Boeing: “The adjustable speed feature of electrical motors will allow further optimization of airplane energy usage by not requiring excessive energy from the supplied compressed air and later regulating it down through modulating valves resulting in energy loss.” Under the Clean Sky programme European manufacturers and research agencies will be trialing all electric air conditioning packs in 2015.

Further down the line auxiliary power units (APUs), which are 15% efficient according to industry figures in converting jet fuel to electricity will be replaced with fuel cells, which will be 60% efficient. According to Boeing researchers, Polymer Electrolyte Membrane (PEM) fuel cell technology potentially could eventually power small manned and unmanned air vehicles, while solid oxide fuel cells could be applied to secondary power-generating systems, such as auxiliary power units for large commercial aircraft.

Again, this is an area which US and European aerospace industries seem to have covered. The Fuel Cells and Hydrogen Joint Technology<sup>1</sup> initiative will see national governments, the European Union and industry partners plan for an investment of nearly €1 billion over six years in new fuel cell concepts. Although this research is aimed mainly at the automotive and stationary electricity storage markets it is highly likely there will be aerospace applications. Unless there is a radical breakthrough in battery technology - such as lithium-air or “spray-on” batteries, which cover the

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<sup>1</sup> See: [http://ec.europa.eu/research/fch/index\\_en.cfm?pg=objective](http://ec.europa.eu/research/fch/index_en.cfm?pg=objective)

entire surface of the aircraft – the introduction of more electrical systems could well be hampered by the complexities required of the management systems and the slow evolution of electrical storage devices.

But as the recent saga with the Boeing 787s lithium-ion batteries has shown, the key issue for manufacturers in implementing electric systems on board aircraft is managing energy management and consumption across all systems. US and European manufacturers are at the forefront of this research but progress is likely to be slower than forecast. At current rates of progress battery lithium-based battery technology is doubling in efficiency every seven years, according to some industry experts, but the collateral effects of more electric systems will only be fully understood after aircraft using these systems have been operating them for some years in very different operating environments.

While work on advanced battery technologies is well underway in Asia, the USA accounts for just 1% of the total global lithium ion battery production, according to the recently formed US National Alliance for Advanced Transportation Batteries (NAATBatt), which is worried that US industry is falling behind its global competitors in this area.

## **Challenge four: Slow regulation will impede the progress of automation**

By 2023 aircraft flying in North American and European airspace will be able to fly more direct paths between origin and destination airports. At the heart of both the Federal Aviation Administration's (FAA) NextGen and the EU's Single European Sky ATM Research (SESAR) programme is the concept of trajectory based operations (TBOs) where the aircraft's preferred trajectory is chosen by the aircraft operator on the basis of speed, cost or environmental performance and the aircraft then automatically flies the most efficient route available to the destination point, making constant changes to take advantage of prevailing weather and traffic conditions, with the air traffic management (ATM) and aircraft computers updating each other many times a minute via data-link to ensure the optimum route is being flown at all times and the overall network can be adapted to ensure safety and predictability of the entire system.

The benefits to introducing such a network-centric system are substantial. "Current validation exercises and flight trials have demonstrated several reductions in average time spent in holding up to 100%, reducing distance flown per flight by up to 6.34%, reducing the number of potential conflicts by 68% and reducing average fuel consumption per flight by 11.42%," according to a SESAR report *From Innovation to Solution* issued in February 2013.

The current fundamental challenge is to agree a common technical framework to support TBOs. This means building a robust detailed TBO information network shared between all participants - air traffic management agencies, aircraft operators, airports - through a system wide information management system (SWIM) where all the information relevant to four-dimensional (4D) TBOs are shared among authorized users. Work for requirements, protocols definition and security aspects of SWIM has started. But it is a complicated process. It is highly likely that the organisations responsible for developing, managing and operating SWIM will be spread among a range of air navigation service providers (ANSPs) and industry. Gaining the support of all aviation system participants - including airports and the military - will need to be planned and common targets for financing and implementation agreed. And with so many different sectors involved one of the biggest challenges is to ensure that, in safety terms, nothing falls between the cracks.

The two key enabling technologies which will allow for this future network-centric based ATM system is the data-link system which will allow for the free flow of massive amounts of digital data between the ground and the air and the related software protocols which will ensure the pilots and controllers have the exact amount of data - neither too much or too little - to make the right decisions at the right time, even when parts or all of the system are in degraded mode.

Unfortunately even in the most thought-through and rigorous automated systems unforeseen failures can happen and the system has to be made robust enough to cater for these. In a cockpit there almost a finite number of possible failures which can be planned but across a global networked system, where a small failure in one sector could have unknown consequences down the line, this is a far more complex issue. "These kind of systems are just too complicated to assess, simulate and validate for us to fully understand what failures will do across the system," according to Marc Baumgartner, SESAR/EASA coordinator for the International

Federation of Air Traffic Controllers' Associations (IFATCA). "The solution to a crisis will be much more radical than what we know in order to keep the system resilient. If we don't have any separated and independent mode of recovery and we have everything integrated there is only one solution – empty the skies. The system will be automated to such an extent that if the data-link or a transmissions breaks down the chances of this happening will be much less than before but if it does break down the solution will be much more radical, shutting down the system for four to five hours."

In other words the speed with which more automated operations can be introduced will probably be driven by the speed with which regulators can certify all parts of the global network to be safe – and this is likely to be many years after airlines, aircraft manufacturers and individual systems suppliers have put the new network centric platform into operation.

## **Challenge five: New computer technologies will open the door to competition**

There is a global race underway – to develop the first commercial and stable quantum computers for widespread industrial use. And as quantum-based computers become more stable and affordable they will eventually find their way on board aircraft, transforming the speed with which flight management systems can process data, the accuracy of inertial navigation systems, the adaptability of autonomous systems, the speed and precision of simulations, and the capability of aircraft systems to optimize the performance and efficiency of aircraft for all phases of flight.

The potential of quantum mechanics and quantum computers has been well understood for some time. But it is only now that the technology is starting deliver to deliver real results.

The first commercially available quantum computers went on the market in 2011 – and aerospace organisations have been some of the most important customers. Lockheed Martin was one of the first customers for Canada’s D-Wave One quantum computer, a 128-qubit machine, and the company recently upgraded to the 439 qubit D-Wave Two, reported to be 500,000 times faster than its predecessor. In March 2013 it was reported that in a test to solve a complex optimization problem, a D-Wave machine was 3,600 times faster than a high-end personal computer.

According to Market Research Media’s October 2012 “Quantum Computing Market Forecast 2015-2020” governments are currently the major driving force behind investments in quantum computing research and development work, with priority areas being quantum cryptography for secure communications; the development of new weapons and the ability to break into adversary communications; weather forecasting and civil sectors such as new medicine and renewable energy.

However, there are considerable technical hurdles to be overcome before these computers can be mass produced. “Future technological development exploiting quantum features will have to include some robust stabilizing mechanism to protect their fragile quantum states,” according to a paper prepared by European industry in 2011 to suggest new research areas for European Commission funding in this area. In Europe, much of the recent research effort has gone into control systems. “Extensions of traditional control concepts, developed for classical systems, such as optimality, feedback, stability, robustness, filtering and identifications to the quantum systems are becoming key issues,” according to the paper.

So it might be a decade or more before the first quantum computers find their way on board civil aircraft. But in the meantime the development not just of new computers but the emergence of more capable and accessible programming languages will open the door to new entrants from outside the aerospace heartlands of north America and Europe.

Developing competitive software-based aircraft management systems is one area in which Chinese industry might be able to achieve a competitive edge over the next ten to fifteen years,

especially if, as seems possible, the current fragmented and complex software programming languages are replaced by more accessible new generations. According to Researchmoz.us the turnover of the Chinese software industry reached RMB2.5 trillion in 2012, presenting a year-on-year rise of 32.7% and the Ministry of Industry and Information Technology's Five-Year Plan on the Development of Software and Information Technology Service Industry is on target to grow the industry to more than RMB 4 trillion a year by 2015, with an annual growth rate of more than 25%.

In itself this would have only a small relevance to the civil aerospace sector but given that new generations of aircraft will be developed not just as flying platforms but entire transport systems and that China is many ways pioneering performance navigation techniques as it has little legacy infrastructure to replace, China's 2025 widebody might not just be a competitive platform with those in the West it could also be cheaper to fly, maintain and train on.

## About the author

Philip Butterworth-Hayes is founder and editorial director of PMI Media Limited and consultant and writer on global aviation affairs with a particular interest in the aircraft manufacturing market. He began his aviation career in 1984 with the management of an air cargo disaster relief operation between Europe and Sudan. He had previously worked as a lecturer and journalist in North Africa. For more than 25 years Philip has specialised in delivering highly complex technical and industrial aerospace information. He has authored a wide number of globally successful reports and studies based on future markets and analysis of current aerospace trends. These include *The Market for ATC Equipment* (Jane's Information Group) 1997, 1998, 2001; *The Market for Civil Aircraft Maintenance and Services* (Jane's Information Group) 1997; *The Market for Civil Aircraft* (Jane's Information Group) 1998; *The Very Light Jet Market* (PMi Media Ltd) 2006, 2007, 2008; and *The growth of aircraft manufacturing in low-wage economies 2005-2009* (PMi Media Ltd) 2010.

His aviation background includes posts as the director of communications and strategy at the Civil Aviation Navigation Organization (CANSO) in Amsterdam (2006-2007), the Manager of Jane's Air Transport Division and lead consultant for Jane's Information Group on civil aviation consultancy studies (1987-1992), founding editor of *Jane's Aircraft Component Manufacturers*, *Jane's World Airlines* and *Jane's Airport Review*, a former editor of *Interavia Aerospace Review*, *Airports International*, *Jane's Defence Industries*, *Jane's Military Aircraft* and several unmanned air system publications. He has been an aviation consultant to BBC Television and Time-Life books.

In 2007 he left CANSO to concentrate on developing aerospace consultancy and market report company PMI Media Limited. Over the next two years he developed the *Aviation Supply Chain Intelligence* database, to map global trends in aerospace manufacturing.

He also currently writes on aviation manufacturing for *The Wall Street Journal* aerospace supplements and he is the European correspondent for *Aerospace America*, the journal of the American Institute for Aeronautics and Astronautics. In 2010, his company PMI Media Limited published *Global Enabler – the story of the Airbus Military A330 MRTT*.

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## Aviation Supply Chain Intelligence (AvSCI)

Much of the background data to this report has been compiled from *Aviation Supply Chain Intelligence*, a database of suppliers and contract details for every fixed wing and rotary aircraft in production today. For more information please visit [www.AVSCI.info](http://www.AVSCI.info).