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From design to supply chain, from production to sales, from start-up to certification

Digitalization and Cost Reduction in Aerospace Industry

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Dedicate

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless

and grant him), who taught us the purpose of life,

My homeland, the warmest womb;

My great parents, who never stop giving of themselves in countless ways,

My beloved brothers and sisters;

To all my family, the symbol of love and giving,

My friends who encourage and support me,
To Nesrine, Djihane, and my K

I dedicate this research.

Khaoula Mazari

Dedicate

I dedicate my modest work to:

The man of my life, my eternal example, my moral support and source of joy and happiness, the one who always sacrificed to see me succeed, may god keep you in his vast paradise, you

my father.

To the light of my days, the source of my efforts, the flame of my heart, my life and my happiness,

my mother whom I adore.

To the people I have loved to be in this day, to my very dear brother Haythem, my dear sisters Rahma and Amel.

I dedicate this work to my binomial Khaoula and all the MAZARI family, to all those who contributed from near or far to make this project possible, just I thank you.

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Digitalisation and Cost Reduction

Abstract

ملخص الدراسة

الثورة الصناعية الرابعة" هي التسمية التي أطلقها المنتدى الاقتصادي العالمي في دافوس، سويسرا، في عام 2016م، ''
على الحلقة الأخيرة من سلسلة الثورات الصناعية، التي هي قيد الانطلاق حاليا

.
تنطلق الثورة الصناعية الرابعة من الإنجازات الكبيرة التي حققتها الثورة الثالثة، خاصة شبكة الإنترنت وطاقة المعالجة الهائلة، والقدرة على تخزين المعلومات، والإمكانات غير المحدودة للوصول إلى المعرفة. فهذه الإنجازات (Processing) تفتح اليوم الأبواب أمام احتمالات لامحدودة من خلال الاختراقات الكبيرة لتكنولوجيات ناشئة في مجال الذكاء الاصطناعي، والروبوتات، وإنترنت الأشياء، والمركبات ذاتية القيادة، والطباعة ثلاثية الأبعاد، وتكنولوجيا النانو، والتكنولوجيا الحيوية، وعلم المواد، والحوسبة الكمومية، وسلسلة الكتل (Blockchain)، وغيرها.

الرقمية تحول العالم. عندما تصبح التقنيات المتقدمة أرخص وتكتسب المزيد من الانكشاف ، يتم اختراق مناطق جديدة يتداخل فيها العالمان الرقمي والفيزيائي ويتمازجان معاً. تحتضن الشركات هذه التقنيات الناشئة ليس فقط لرقمنة عملياتها ، ولكن أيضًا للمشاركة في النظام الإيكولوجي للأعمال المرن والمشترك باستمرار.

الروبوتات A&D من أوائل من تبنوا التقنيات الرقمية. يستخدم لاعبو (A&D) كانت صناعة الفضاء والدفاع والأتمتة في خطوط التجميع الخاصة بهم منذ العقدين أو الثلاثة عقود الماضية. ومع ذلك ، فإن تطور التقنيات الرقمية الجديدة واعتمادها لم يكن أبداً بوتيرة أسرع من تلك التي يؤدي فيها النظام الرقمي إلى تعطيل النظام البيئي A&D اليوم.

الشركات لديها تركيز كبير على استخدام تقنيات التصنيع المتقدمة لخفض التكاليف وتحسين الإنتاجية. إن الكم الهائل من البيانات التي تم التقاطها من خلال أجهزة الاستشعار والتقنيات التحليلية المتقدمة قد فتحت وجهة نظر حول الأفكار حول العمليات وأداء المنتج والعملاء الذين لم يتم استكشافهم من قبل.

تحت ضغط مستمر لزيادة الربحية وتحسين الكفاءة التشغيلية. تعمل في عالم غير مؤكد ، فإنها A&D شركات مستوى جديدًا من الترابط ، والذي يتحدى المؤسسات رقميا تحتاج إلى التكيف باستمرار مع اضطرابات العمل. يجلب للتفكير بشكل مختلف حول المخاطر والمرونة مع تبني الفرص من خلال دفع الابتكار.

Abstract:

This thesis explores the impact of Digitalization on aerospace industry. The intent of our paper is to study the current state of Digitalization regarding the big development now, how aerospace industry is accepting Digitalization and it offers and to what extent Digitalization provides an appropriate answer to market challenges.

Through the use of a qualitative research, we have tested hypothesis about Digitalisation applications to the industry. We have realized 3 internships interviews with aeronautics engineerings.

Our study has identified 4 Digitalization applications to the industry: (1) Design, (2) Manufacturing, (3) development of new services, and (4) airport digitalization. Moreover, in order to improve digitalization in real world, we made a small application about it, application we are seeing it each day in our life, called drones.

Digitalisation and Cost Reduction

Abstract

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I. Introduction :

Following Schumpeter (1934) who defined innovation is "a new combination of production factors", we refer to digital innovation as (1) a new combination of production factors that introduce discontinuity to product, technology, organizing principle, market, or set of behaviours and (2) made possible by digital technologies. This definition emphasize discontinuity, by noting that only those combinations that have never been tried before can be classified as innovation. A necessary but insufficient condition for such innovation is digitization, i.e., the encoding of analog information into digital formats.

The rapid miniaturization of computer and communication hardware, combined with their ever-increasing processing power, storage capacity, communication bandwidth and more effective power management have made it possible to increasingly and pervasively digitize previously non-digital artifacts (Kurzweil 2006). According to Hagel et al (2009), a microprocessor that cost over $222 in 1992 cost only $0.27 in 2008. Similarly, one gigabyte of storage that cost $569 in 1992 cost only $0.13 in 2008; and the cost of communication with the bandwidth of 1 gigabit per second dropped 10 times from $1,197 to $130 from 1999 to 2008 (3). These smaller, yet increasingly potent digital components are becoming a part of previously non-digital products such as book, cars, furniture and buildings, radically altering the price-performance ration and opening up new innovation opportunities for both incumbents and new entrants alike.

Digitization adds new capabilities to non-digital artifacts by making them programmable, addressable, sensible, communicable, memorable, traceable, and associable (Yoo 2010). When digitization leads to a reconfiguration of underlying socio-technical relationship between produces and users, we call it digitalization. And, when digitalization reshapes the underlying value propositions, we refer to it digital innovation. An example of digitization is when the telecom industry installed digital switching in the 1970's, which did not change the socio-technical context of the production and consumption of the product. To the contrary, today's disruptive transformations in telecommunication, mobile media, broadcasting, and publications caused by iPhone and Google's Android are examples of digitalization.

And we'll see in the next part the difference between Digitization, Digitalization and Digital transformation

Digitization: Transitioning from analog to digital:

This is where it all began. Years ago, and sometimes still today, business processes were analog. If you had a device in need of repair, you would call the manufacturer who would fill out a work order form explaining your issue. A service technician would be assigned the task of making a field visit to assess, and hopefully repair the issue. All customer files, product manuals, repair handbooks were hard copies. This meant that the service technician would arrive with a stack of paper that might include anything from the customer's name and address to the product's history and a listing of replacement parts to a date book listing the day's appointments. Digitization is the process of making all of this information available and accessible in a digital format.

Digitalization: Making digitized information work for you:

Once analog data has been digitized, there is enormous potential for applications that facilitate standard work practices. Field service providers can implement field service management (FSM) software like Core systems to make smart use of digitized information. For example, centralized data about customers including contact information and product history help service technicians stay informed about their customers' previous issues and what types of problems they might encounter. This means they come prepared with an arsenal of current and background knowledge to assist in a smooth field service operation. In addition, information collected from different service technicians about the same or similar products can be compiled to create checklists for resolving recurring issues. This kind of knowledge sharing can also extend to product manuals, and video tutorials that are available on any mobile device. All these types of tools ensure that technicians in the field have access to as much information as possible to guarantee a first-time-fix.

Fig2. Digitization, Digitalization and Digital transformation

Digital transformation: Taking advantage of digitalization to create completely new business concepts

Thanks to digitization and digitalization, data is easily accessible for use across various platforms, devices, interfaces. Digital transformation is the process of devising new business applications that integrate all this digitized data and digitalized applications. These are the biggest game changers when it comes to digital transformation:

- Artificially intelligent: Using artificial intelligence, field services can be optimized to ensure the quickest service is performed by the most qualified technician. By quickly calculating a customer's location and the location of available field service technicians at any given time, and cross-referencing this information with the technicians' skill sets and expertise, AI powered FSM software can dispatch the best man or woman for the job in real-time.

- Augmented reality tools: Though AI applications ensure that the technician most suited for a task is assigned, no one can know everything. That is why combining augmented reality tools with a database of video tutorials, manuals, and even offsite experts is changing the way field service technicians tackle complex issues, and redefining the field service sector.
- Predictive maintenance: Thanks to sensors programmed to measure specifications like temperature, wear and tear, and a slew of other indicators, machines are now able to transmit warning signals well in advance of breakdowns and malfunctions. This makes it possible to schedule repairs at convenient low productivity times, and to avoid costly downtimes.

II. Chapter1 : Digitalization in Aerospace :

1- Aerospace industry: turning point ahead?

Among industry leaders there is hardly any doubt that the industry will be impacted by digitalization in the mid-term. More than two thirds see this already happening, or arising within just 2 years. Hardly any of the respondents – a mere 2% – would deny that there will be a profound effect within the next 5 years. However, 51% of the industry leaders questioned see the impact of digitization on bottom line efficiency only. 18% expect an impact on top-line in terms of new business models and/or new products or services, while 31% see an impact on both top- and bottom-line. From our perspective we'd say "only" half of them have disruption on their mind. This is surprising. A large share of industrial leaders seems to underestimate the risks that digitization poses for their value chains. Our experience from other industries suggests that digitization affects customer needs, i.e. solutions become possible that were unheard of before.

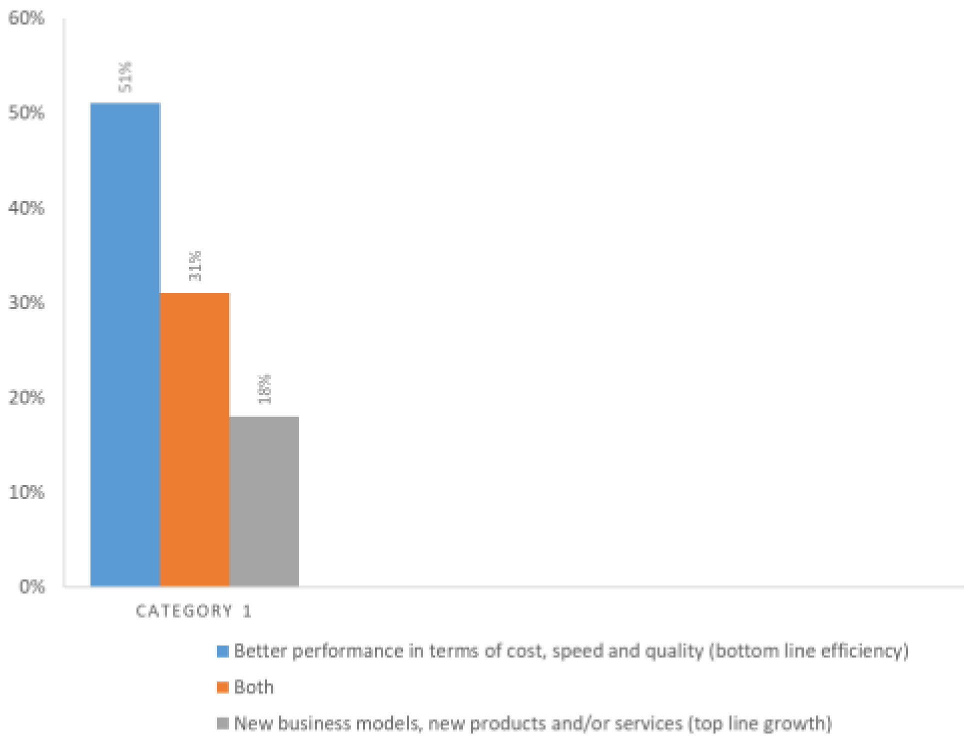


Fig3. Aerospace leader's thoughts in how digitization will impact the Aerospace industry (4)

2- In Aerospace, what is digitalization all about? CHANGING THE GAME FROM SCRATCH

Digitalization means rethinking business models from a customer perspective and deploying technology consistently. Yet it is also far more than just technological change: Digitization must be understood on a much more fundamental level. Getting it implemented is all about trial and error and – most of all – trying again and again and again until it works?

- SMART DATA/BIG DATA it's about knowing your customers inside out by capturing, processing and analysing data from internal and external sources, harnessing the power of data to improve forecasts and decision capabilities.
- AUTOMATION it's about automating internal business processes and standardizing interfaces to business partners. But it's also about combining conventional technologies with artificial intelligence to create autonomous, self-organizing systems.
- DIGITAL CUSTOMER INTERFACE it's about occupying and controlling key positions and pivotal points of customer access, creating total transparency and delivering new services.
- DIGITAL CONNECTIVITY it's about leveraging high-bandwidth fixed and mobile telecommunications to interconnect the entire value chain, synchronize supply chains and thus shorten production lead times and innovation cycles.
- CULTURE CHANGE it's about thinking in terms of minimum viable products (MVPs) and spiral development instead of "getting it perfect first time". The technical or commercial failure of a concept or product is no longer seen as a negative, but as part of an inevitable and valuable learning journey. If you fail, fail fast and cheap. Do it better next time?

3- Will digitization heavily impact the Aerospace Industry?

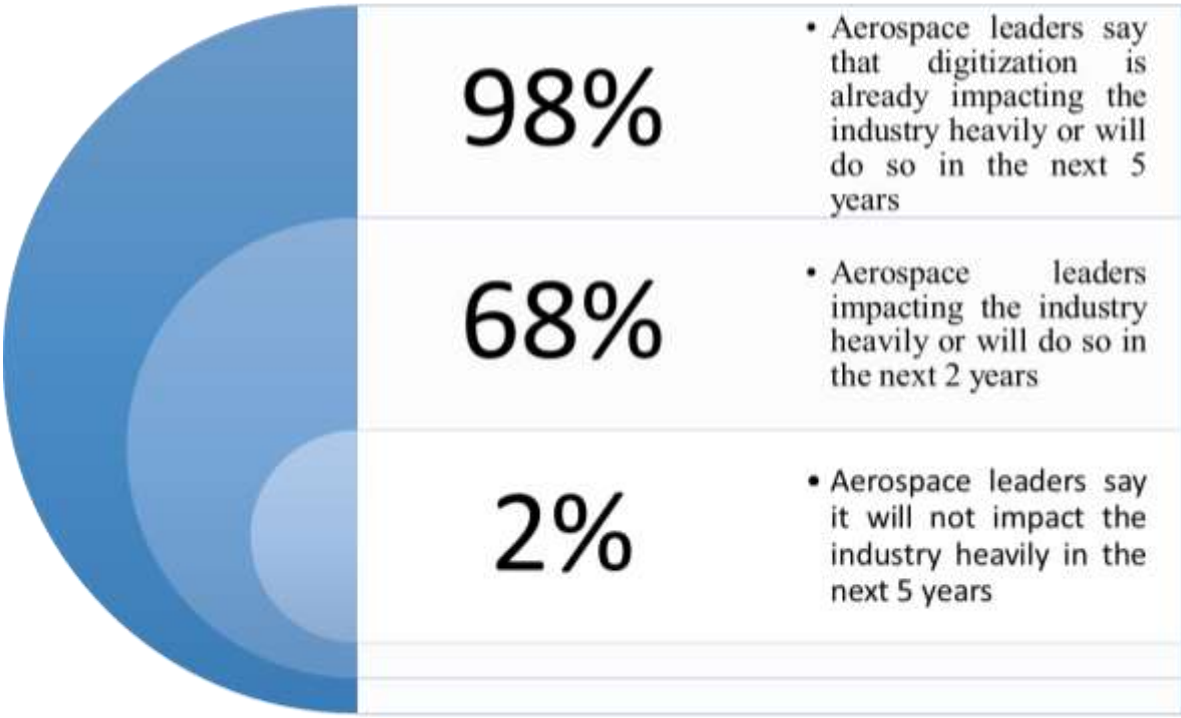


Fig4. Will digitization heavily impact the Aerospace Industry? (5)

4- How digitization will impact the Aerospace industry?

As pointed out, digitalization is already impacting business environments and the corporate way of working. Neglecting digitalization could create a risk of losing the game in the highly competitive markets. Digitalization can impact a company's entire operation environment and internal functioning. Digitalization can also bring new business opportunities, change the roles of operators in a value chain, and end existing business. For example, digitalization may remove traditional intermediates in the supply chain and create new intermediates. This can be due to, for example, direct access to consumers and the increased use of mobile devices. Thus, the impact of digitalization, and the goals of digitalization for an organization, can be identified from three different viewpoints:

1. Internal efficiency; i.e., improved way of working via digital means and re-planning internal processes;
2. External opportunities, i.e., new business opportunities in existing business domain (new services, new customers etc.);
3. Disruptive change; digitalization causes changes business roles completely.

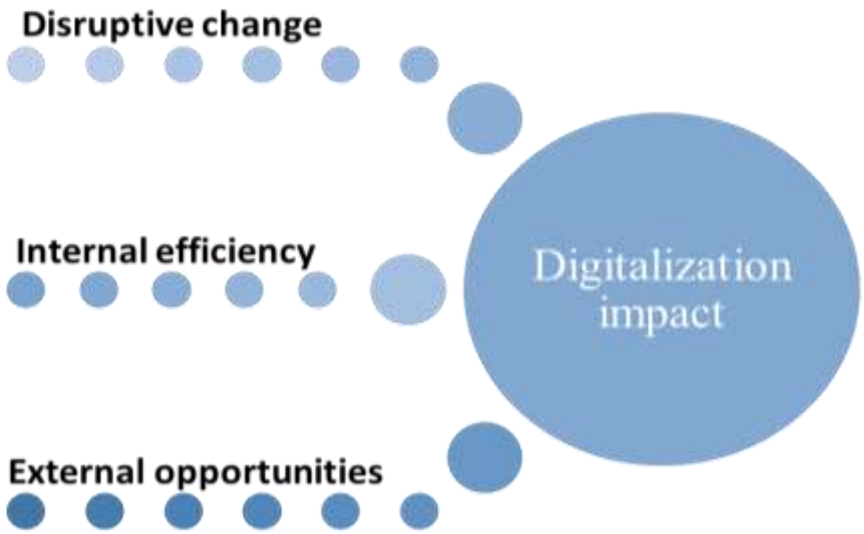


Fig5. Digitalization impact

The potential benefits of digitalization for internal efficiency include improved business process efficiency, quality, and consistency via eliminating manual steps and gaining better accuracy. Digitalization can also enable a better real time view on operation and results, by integrating structured and unstructured data, providing better views on organization data, and integrating data from other sources. Furthermore, digitalization can lead to better work satisfaction for employees through automation of routine work, thus freeing time to develop new skills. Digitalization also improves compliance via standardization of records and improves recovery via easier backups and distribution of storage. External opportunities include improved response time and client service, as well as possibilities for new ways of doing business. New digital technologies can create opportunities for new services or advanced offerings to customers. Disruptive changes involve changes in the operating environment of the company caused by digitalization; for example, a company's current business may become obsolete in the changed situation (e.g., manual scanning of invoices replaced by electronic invoice). On the other hand, digitalization can create completely new business, such as inclusion of an e-invoice operator, for example.

5- The Aeronautical industry is ready for the digital revolution?

The aeronautical industry is facing multiple challenges, with close to 6 billion annual passengers expected by 2030, up from 3.7 billion today, the aeronautical industry is at a crossroads. From limiting its environmental impact and energy costs, increased safety requirements, and the entrance of new competitors into the market who are redefining the established business models, such as low costs company and aircraft leasing companies. Responding to these new challenges will involve a greater use of digital technologies, which are now sufficient maturity for industrial use.

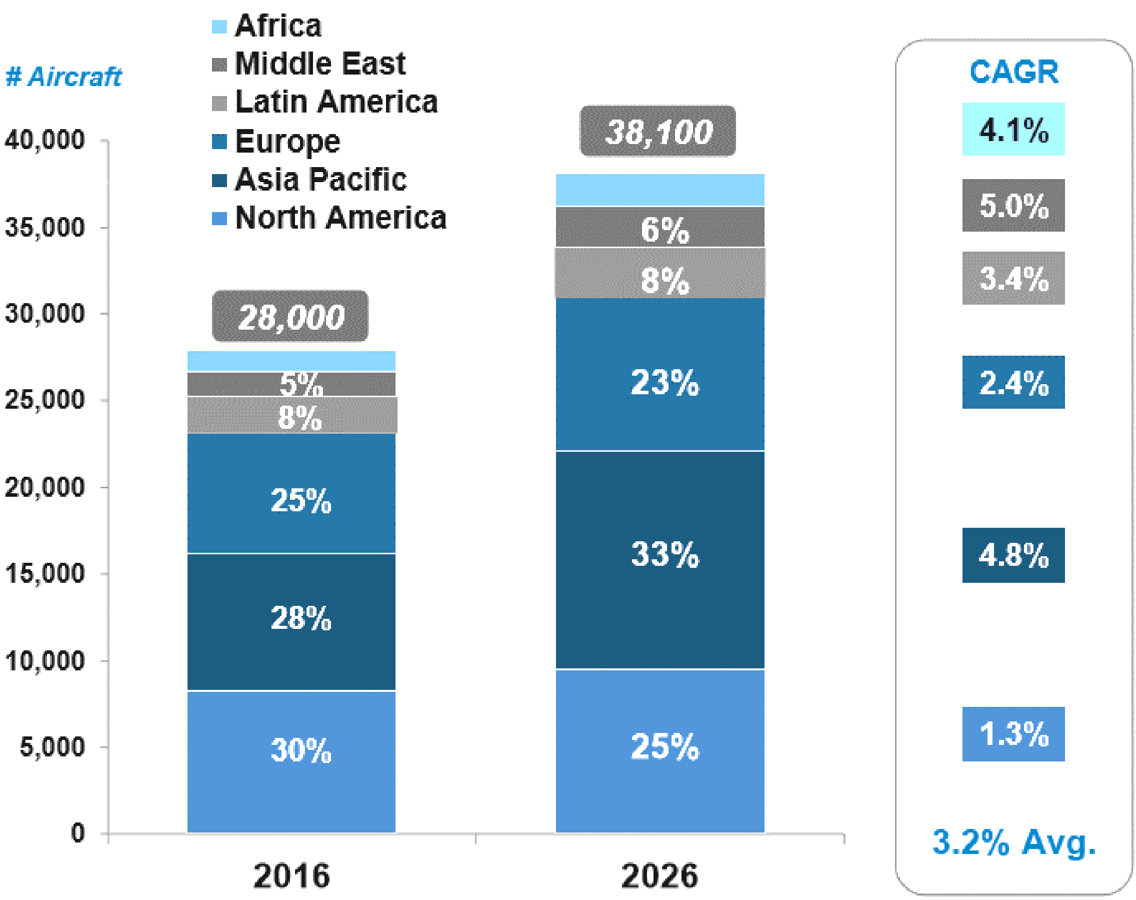


Fig6. 10 Year Global Air Transport Fleet Growth

6- Why it is important to reduce cost in aeronautics?

The aerospace industry today is a buyer driven market, where reducing product cost and delivery cycle time are critical for aerospace and their key suppliers to remain competitive. However, these companies produce highly complex products that require long development cycles and are manufactured in low volumes.

Aerospace companies continue to face (and address) challenges in managing product costs over a very long lifecycle of their aircrafts. It is very clear that these companies have to embrace a more concurrent approach to their operational processes and constantly review product costs to identify opportunities for cost reduction.

Since most of the aerospace OEMs source a large percentage of their component from suppliers (commonly 50-70%), this area requires special focus. It is important for OEMs to understand the costs involved in production of a part or a component sourced from an external supplier, as it will enable effective price negotiations with suppliers and also help assess the capability of potential suppliers. Understanding of component costing and measurement systems are aligned with the lean philosophy, and complements value stream organization by driving continuous improvement and supporting pull and flow production.

Companies worldwide should aim to identify the major cost drivers of components they design, manufacture and procure, much earlier in the product development cycle. With cost assessments early in the product development process, one can eliminate significant costs prior to production and get quantifiable savings in material, tooling, labor, and overhead, by evaluating alternative designs, processes and sources.

Current costing techniques vary throughout the aerospace industry and include the use of both proprietary and non-proprietary methods. Most companies still retain a traditional cost estimating department that uses experienced individuals backed by large proprietary databases. However, lack of adequate cost information can lead to poor decision making, time consuming redesigns, and high component costs. Zero based costing has been around for quite some time, but the availability of digital engineering models and specialized costing software have significantly enhanced the effectiveness of should costing and analysis.

A well-managed should costing and analysis initiative is clearly a critical activity for the aerospace companies, and sets the stage for consistent cost management, that leads to increase in profitability and stakeholder returns.

- What is Should Costing?

Should costing is a process, whereby one can determine the cost of the part or product, based on the raw materials used, manufacturing costs and overhead production costs. This can be achieved by analysing the engineering models to understand the raw material required, defining the manufacturing processes required to deliver the required form features, and calculating the total costs through the use of rate data related to material costs and processing costs. The ultimate goal of any should cost analysis initiative is to provide enough information to enable (depending on the stage) designers to modify raw material or form feature requirements, or enable suppliers to modify manufacturing processes with a view to reduce costs. Should costing, thus, provides a framework that enables a systematic focus on opportunities to reduce costs right from the conceptualization stage through the production life of the product?

- Scope of Should Costing in Aerospace

Aerospace manufacturing has achieved significant productivity improvements over the years, through development of new processes and by performing multiple operations on a single machine. Kaizen (continuous improvement) activities are also widely used in the aerospace industry to increase quality, and throughput, and reduce work-in-progress and setup times.

Proliferation of should costing in product development lifecycle can help aerospace companies accurately estimate the costs associated with developing and producing components and products, and take timely decisions throughout the product development lifecycle. During design stage, it keeps the design engineers aware of movements in product cost and enables them to select most economical designs for manufacturing, improve material utilization, reduce number of features and relax tolerance during new product development. It also helps designers analyse the design and make timely trade-off decisions with respect to cost and functionality.

When the product reaches industrialization, should cost models help to keep sourcing cost low. Cost models empower the purchasing team with knowledge of manufacturing processes, machines used, etc. which helps them effectively negotiate with suppliers. The costing model also provides a basis to seek out the right supplier, by comparing between the actual procurement or manufacturing cost and the cost model; and reconcile differences.

Although various cost estimation software are available in market to perform cost modelling, the core of good should costing solution lies in deep understanding of aerospace manufacturing processes to keep component costs low. While designing a component, companies need to keep production costs as low as possible and at the same time maintain quality. Knowledge and selection of best materials and manufacturing processes is essential to develop accurate should cost models.

Should cost estimates in aerospace industry are based on the mathematical calculation of feed, speed, RPM, IPR, IPM and other inputs such as historical data of process, best practices, raw material rates, work centre rates, special process specifications. Our experience in working the aerospace majors for global should costing operations, shows that the should costing team has to have good knowledge of machining factors such as nature of cut, work material, cutting fluid application and capacity of machine tools, particularly for specialized materials like titanium and Inconel, to develop accurate cost models.

Ability to leverage software engineering skills to set up intuitive knowledgebase of data related to machine tools, feed, speeds and MRR, and automate region cost specific templates also plays an important role in accuracy of cost models for global sourcing. It helps improve the product quality and reduce costs by eliminating or minimizing trial and error iterations involved in cost modelling process.

7- What is the aircraft life cycle cost?

In the next chapters we will see how digitalization impacted the whole aerospace industry by details, getting inspired from the aircraft life cycle, from design to supply chain, from production to operation and from start-up to certification. Which technology we are able to use in each cycle? And how it will reduce costs?

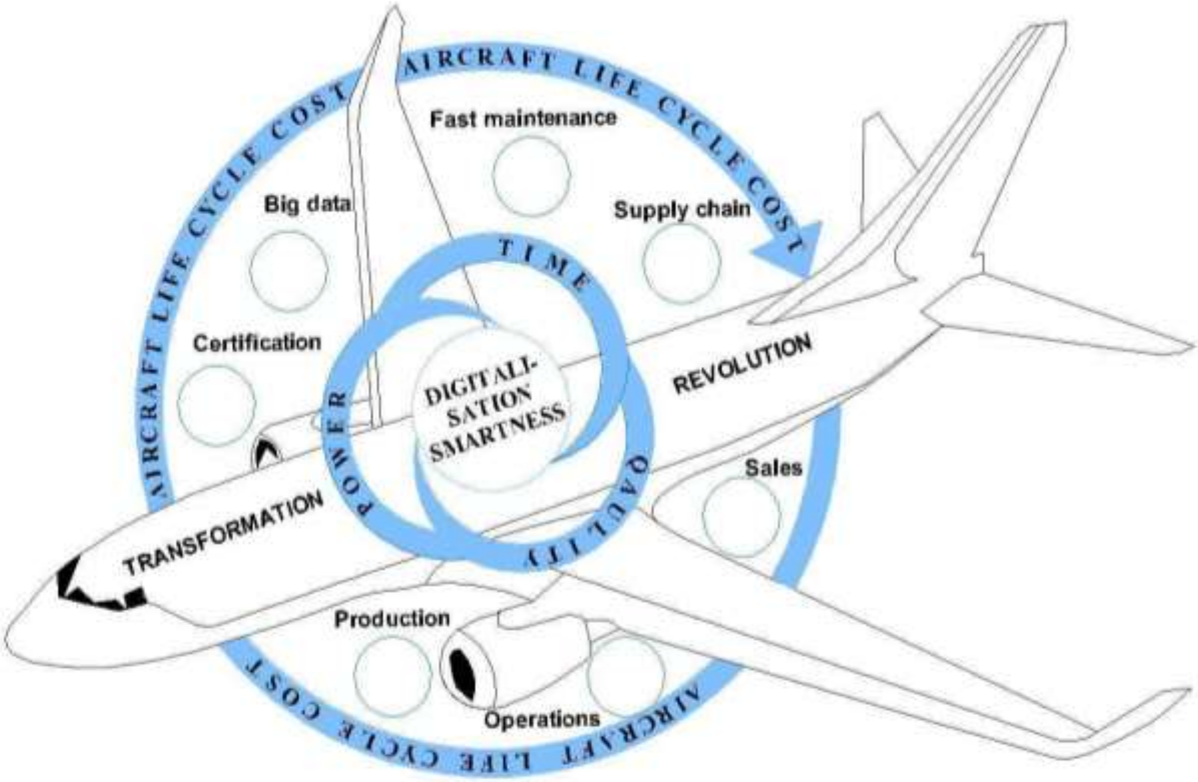


Fig7. Aircraft life cycle cost

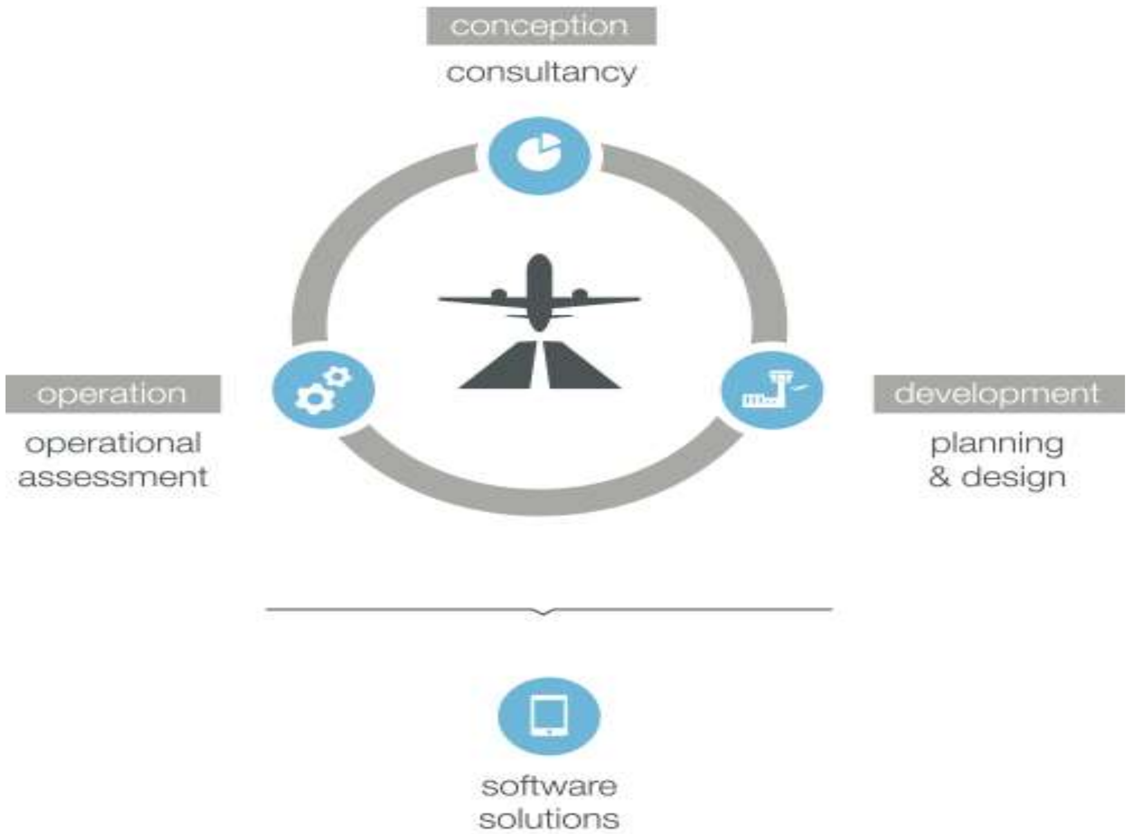


Fig8. Cycle solutions

Chapter 1

Digitalization in aerospace industry

Did you ever dream to take an aircraft like Concorde by the price of an ATR?

Ⅲ. Chapter2 : Aerospace Construction Digitalization :

1- Supply chain:

A supply chain is at the heart of any aerospace organization's success. Effective and efficient supply chains enable Aerospace organizations to meet their strategic and financial goals. The Aerospace supply chain is a complex ecosystem of different tiers of suppliers; original equipment manufacturers (OEMs); maintenance, repair and overhaul (MRO) providers; and customers including airliners and armed forces. With customers from across the globe, the supply chains of major Aerospace players are also very much global and diversified in nature. Not only do companies need to deal with suppliers and customers across different geographies, they also need to deal with an entire ecosystem of data, created by the digital disruption in the industry. Using supply chain data effectively and protecting it against cybercrimes are imperative for successful Aerospace players.

- Supply chain history:

A recent trend is, that aircraft original equipment manufacturers (OEMs) such as Boeing, Airbus, Embraer and for instance Dassault, are developing from "production" orientated companies towards "integrators". Suppliers were already involved mainly with built to print activities, leaving most of the risk with the OEM. Today, the suppliers are involved with the co-development of entire functions of the aircraft such as wings, fuselage, and stabilizers, which causes value to shift from the aerospace OEM towards the supply chain. An interesting example of supply chain involvement is the co-development and co-production of the Boeing B787, where suppliers are heavily involved with the design and production of parts and subassemblies. Boeing focuses on the core activities, such as concept design, certification, testing, services, marketing, global supply chain management and integration.

In fact, "supply chain" thinking destines from car producer Toyota, which introduced the supply chain "Avant la lettre" by involving suppliers with the co-development and co-production of cars in the 1960s. MIT researched this TPS "Toyota Production System" and named it; "lean manufacturing" in the 1990s. However, the focus of this research was still on the production system, the supply chain plays an important role in this lean manufacturing concept.

It seems lean manufacturing and supply chain, are interwoven and both are now adopted by the aerospace industry. This chapter highlights the principles of lean manufacturing in combination with supply chain management and open innovation in the aerospace industry and synergise these into value-leverage thinking, in which co-development and coproduction are the main value drivers. Two examples are presented; Euro copter and Boeing B787, to illustrate this new perspective on lean manufacturing and supply chain.

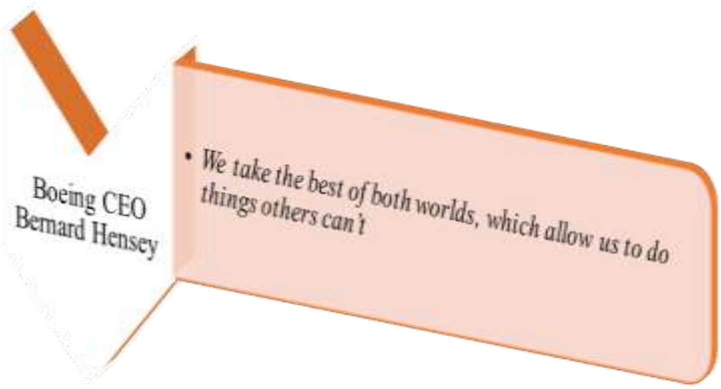
- 'Supply chain' or a 'complex network'?

Whereas a chain suggests a serial entity, the reality of the aerospace industry is an increasingly complex network of relationships. With the structure of modern aerospace industry moving away from traditional vertical programmes to highly distributed, multinational and multi-stage operations (including production and the rapidly expanding aftermarket Maintenance, Repair and Overhaul (MRO), there inevitably comes greater challenges. But with tier 1 and tier 2 suppliers taking on more responsibility and Original Equipment Manufacturers (OEMs) having less visibility and control over the supply chain than ever, how can the difficulties and the intricacies of the aerospace supply chain be adequately managed?

One possible solution may be stakeholders' improved collaboration, which can be facilitated through the usage of automated technologies such as Product Lifecycle Management (PLM).

- Facing up to realities

In recent times, both Boeing and Airbus have been victims of their supply chains' complexity. The delivery of Boeing's 787 has famously been hit by numerous delays, the majority of these as a result of failures in the supply chain. Likewise, the arrival of Airbus' A380 – the world's biggest commercial aircraft to date – has been clouded by a series of problems, shunting back its delivery schedule dramatically. Once again, the flaw in the A380 program lay within the production process, in what Christian Streiff, Airbus CEO and President called the 'one weak link in the chain', namely the airplane's electronic harnesses (6). Both examples go to show the challenge of managing complex programmes in the Aerospace and Defence industry, with immense difficulties inherent in aircraft production, as well as the need for OEM's active top-down supply chain management to ensure timely and cost-effective output.



Boeing's problems with the 787 in particular highlight the need for OEMs and increasingly top tier 1 and 2 suppliers to manage risk across the supply chain. Initially assigning its subcontractors to do more assembly themselves and deliver completed subsystems, Boeing intended to perform the final assembly of these component parts. However, some subcontractors encountered difficulty completing the extra work, because they could not procure the required parts; perform the subassembly on schedule, or both. As a result, Boeing was hit with serious delays. With hundreds of thousands of components coming together from hundreds of multinational suppliers all for one single aircraft, the prevention of late delivery will be a central concern for supply chain managers.

- The supply chain of the future is far more:

- **Instrumented:** Information that was previously created by people will increasingly be machine-generated — flowing out of sensors, RFID tags, meters, actuators, GPS and more. Inventory will count itself. Containers will detect their contents. Pallets will report in if they end up in the wrong place.

- **Interconnected:** The entire supply chain will be connected — not just customers, suppliers and IT systems in general, but also parts, products and other smart objects used to monitor the supply chain. Extensive connectivity will enable worldwide networks of supply chains to plan and make decisions together.
- **Intelligent:** These supply chain decisions will also be much smarter. Advanced analytics and modelling will help decision makers evaluate alternatives against an incredibly complex and dynamic set of risks and constraints. And smarter systems will even make some decisions automatically — increasing responsiveness and limiting the need for human intervention.

Building this kind of supply chain is a strategic undertaking; it implies a different role and set of responsibilities for supply chain executives. These executives must become strategic thinkers, collaborators and orchestrators who optimize complex networks of global capabilities. In their increasingly significant positions, Chief Supply Chain Officers have the mandate — and now the enablers — to create a Smarter Supply Chain of the Future.

- Cost Containment:

Supply chains can't keep pace with cost volatility

Supply chain executives rank cost containment as their number one responsibility to the business — far ahead of enterprise growth and product/ service innovation. This intense focus on controlling costs is also quite evident in their activities and programs; two out of the top three types of initiatives are aimed at improving efficiency (see Figure 2). These are also the areas where executives have realized the most past success.

However, what used to be a methodical, continuous improvement process has turned frenetic. Shocks to integral costs — rapid wage inflation in previously low-cost labor markets, spikes in commodity prices, or even sudden credit freezes — are becoming more common.

Supply chain executives find themselves reacting to whatever the cost issue of the day happens to be. Escalating fuel prices, for example, send executives scrambling to revaluate distribution strategies, engage third-party logistics providers more extensively or even share loads with competitors. When fuel prices fall, distribution and transportation methods become laxer as companies emphasize service over cost — reverting back to smaller, more frequent shipments and faster modes.

Shifts in costs and other operational fundamentals are happening so quickly that conventional supply chain strategies and design techniques can't keep up. New designs are outdated before executives can implement them.

Fig9. Cost control and efficiency programs significantly outnumber growth initiatives Percentage who report these activities and programs as very important or critically important. [7]

- Top supply chains are collaborating more to improve visibility:

More than half of all supply chain executives have implemented practices aimed at improving visibility, such as continuous replenishment and inventory management with customers. But less than 20 percent are pursuing these practices extensively.

In contrast, leaders of top supply chains are much more focused on improving visibility (see Figure 5). Twice as many report extensive implementations of collaborative planning with suppliers and vendor- managed inventory (VMI). And more than 60 percent of the top supply chains have implemented all the practices discussed in our interviews.

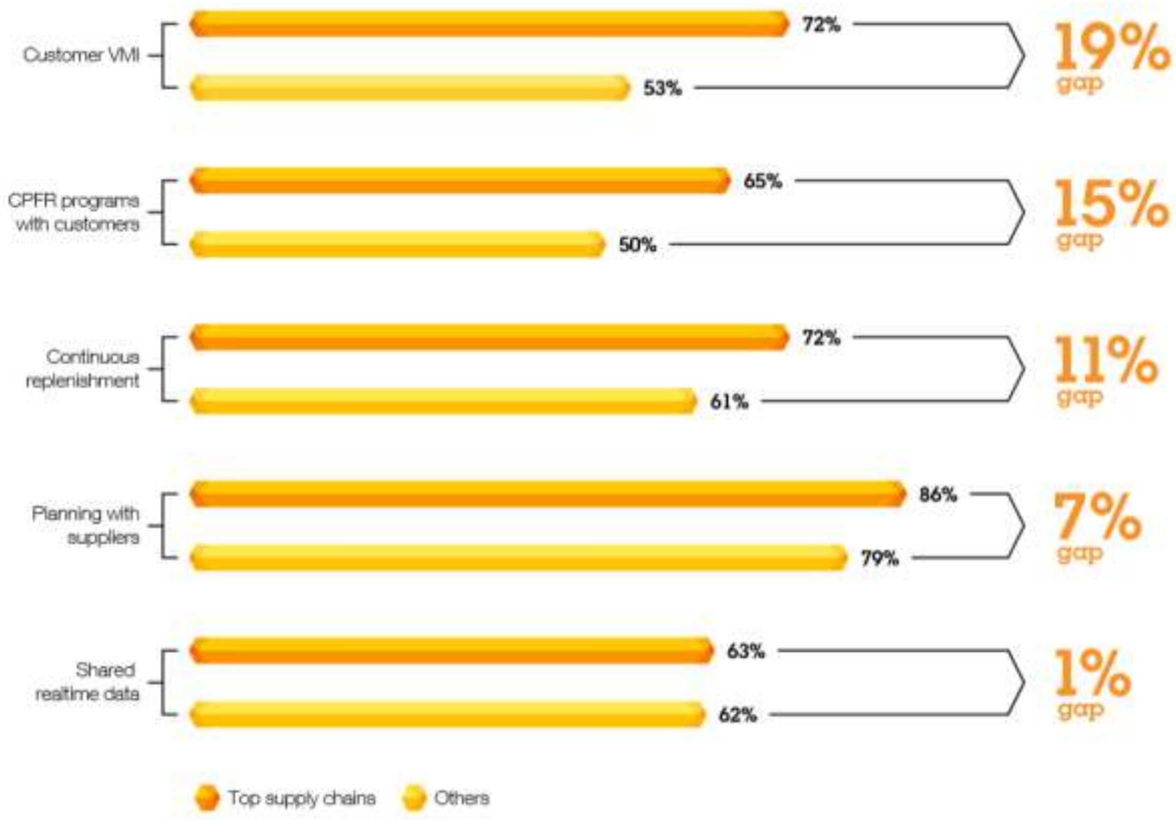


Fig10. Top supply chains’ largest leads are in the areas of customer collaboration Percentage who have implemented these practices. (8)

- **Top supply chains lead in risk management:**

  More than two-thirds of supply chain executives have programs in place to monitor compliance. But top supply chains are taking risk management a step further - incorporating it into their plans and using IT to monitor and act on disruptive events

Greg McKenna, Supply Chain Manager, Venture Production plc

- *Risk management is a fundamental building block of any supply chain strateg*

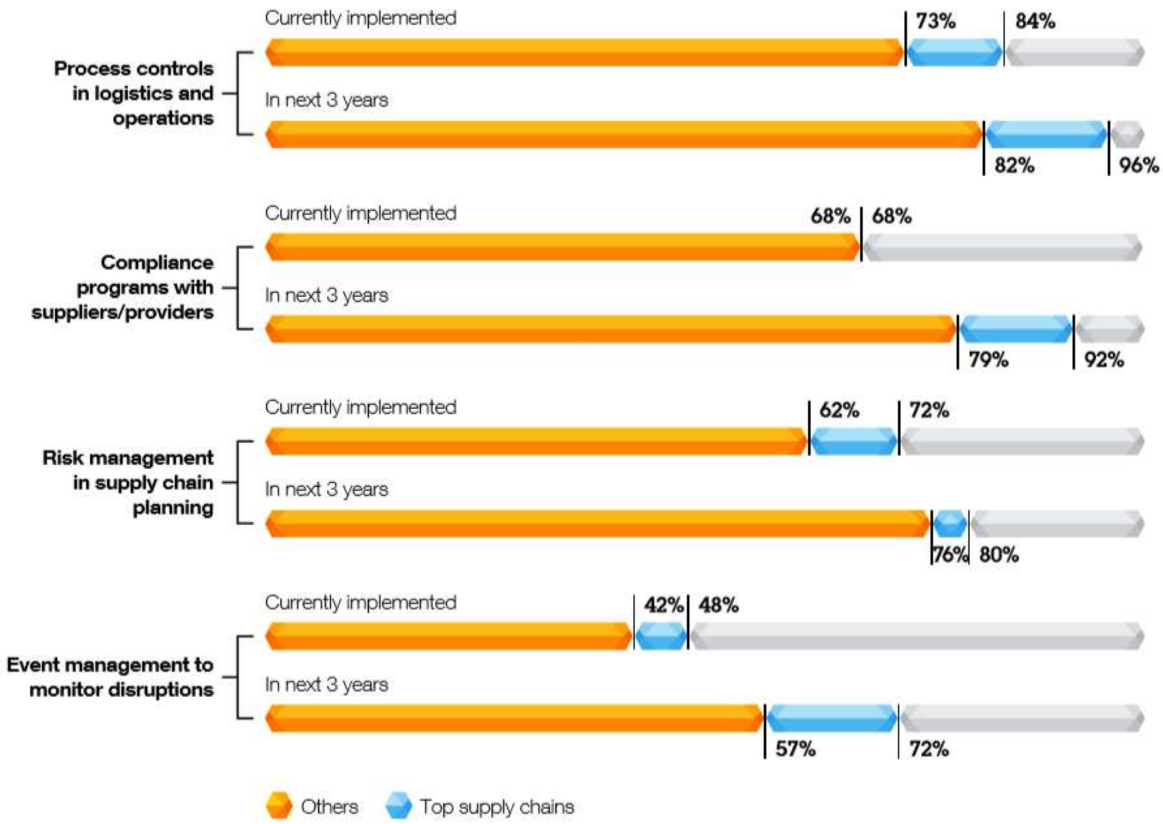


Figure 11. In all areas of risk management, leading supply chains are pulling away from the pack Gap between top supply chains and the rest of our sample in terms of current and planned implementations [9]

- **Smarter cost containment:**

INSTRUMENTED Sensor-based solutions to reduce inventory costs with increased visibility

- Production and distribution process detectors to monitor and control energy usage and waste
- Physical transportation, distribution and facility asset management, controlled and monitored with smart devices for efficiency and utilization

Interconnected Agile, on demand network of suppliers, contract manufacturers, service providers and other (financial and regulatory) constituents

- Outsourcing non-differentiating functions to share risks across the global network
- Variable cost structures that fluctuate with market demand
- Shared decision making with partners at source (local, regional, global strategies)
- Integrated, networked asset utilization and management

Intelligent Network and distribution strategy analysis and modeling with event simulations

- Scenario-based operational analysis
- Simulation models and analyzers to evaluate flexibility factors —
- service levels, costs, time, quality — with inventory synchronization
- Sustainability models to analyze and monitor usage impact (carbon, energy, water, waste)
- Integrated demand and supply management with advanced decision support

CASE STUDY

At Airbus, it's clear skies and high visibility10 Airbus is one of the world's largest commercial aircraft manufacturers, producing over half of all new airliners with more than 100 seats. With its suppliers becoming more geographically dispersed, Airbus found it increasingly difficult to track parts, components and other assets as they moved from suppliers' warehouses to one of its 18 manufacturing sites.

To improve overall visibility, the company created a smart sensing solution capable of detecting when inbound shipments deviate from their intended path. As parts move from suppliers' warehoused inventory to the assembly line, they travel in smart containers fitted with RFID tags holding vital information. At each important juncture, readers interrogate these tags. If shipments arrive at the wrong place or do not contain the right parts, the system alerts employees to fix the problem early before it disrupts production.

The Airbus solution, the largest of its kind in manufacturing, has significantly reduced the incidence and severity of parts delivery errors — and the costs associated with correcting them. Knowing precisely where parts are in the supply chain has allowed Airbus to reduce the number of containers by 8 percent and avoid significant carrying costs, and has also increased the overall efficiency of its parts flow. With its highly instrumented supply chain, Airbus is well-positioned to meet known — and unanticipated — cost and competitive challenges[10].

- Why build a smarter supply chain now?

Why are we so convinced that supply chains are about to become much smarter? After all, the underlying technologies that enable this sort of intelligence have been around for some time. Why such a dramatic change now — especially with so much uncertainty ahead?

Actually, that's precisely the point. Globalization and growing supply chain interdependence have introduced a heightened level of volatility and vulnerability that is unlikely to subside. Uncertainty has become the norm. This new environment demands a different kind of supply chain — a much smarter one.

With such a clear mandate for change, supply chain executives owe it to their organizations to revaluate current strategies and initiatives. Which investments are simply making processes faster or more efficient? And which go a step further — making the supply chain decidedly more intelligent and resilient in times of unprecedented instability and risk?

Often, when massive shifts are predicted, "change or perish" pronouncements pile up. But we do not see things in such a harsh light; the future we see is much brighter. Here's why: Executives have at their disposal the necessary ingredients to make their supply chains substantially smarter. But perhaps more important — from our interviews with 400 of them worldwide — we also know executives are determined to make their supply chains strategic enablers. They understand how critical their function is to their companies' success, and they relish the opportunity to create change that matters.

Thoughts and opinions on the smart supply chain concept and the business possibilities enabled by this kind of imbedded intelligence are evolving quickly. We look forward to discussing the Smarter Supply Chain of the Future with you in more detail — and working with you as you build it.

2- Aircraft Design:

Design to cost is just another hurdle that can be conquered with an integrated prioritized approach

- WHAT IS DESIGN?

Aircraft design is a separate discipline of aeronautical engineering different from the analytical disciplines such as aerodynamics, structures, controls, and propulsion. An aircraft designer needs to be well versed in these and many other specialties, but will actually spend little time performing such analysis in all but the smallest companies. Instead, the designer's time is spent doing something called "design," creating the geometric description of a thing to be built.

To the uninitiated, "design" looks a lot like "drafting" (or in the modern world, "computer-aided drafting"). The designer's product is a drawing, and the designer spends the day hunched over a drafting table or computer terminal. However, the designer's real work is mostly mental.

If the designer is talented, there is a lot more than meets the eye on the drawing. A good aircraft design seems to miraculously glide through subsequent evaluations by specialists without major changes being required. Somehow, the landing gear fits, the fuel tanks are near the centre of gravity, the structural members are simple and lightweight, the overall arrangement provides good aerodynamics, the engines install in a simple and clean fashion, and a host of similar detail seems to fall into place.

This is no accident, but rather the product of a lot of knowledge and hard work by the designer.

Other key players participate in the design process. Design is not just the actual layout, but also the analytical processes used to determine what should be designed and how the design should be modified to better meet the requirements. In a small company, this may be done by the same individuals who do the layout design. In the larger companies, aircraft analysis is done by the sizing and performance specialists with the assistance of experts in aerodynamics, weights, propulsion, stability, and other technical specialties.

- Advanced Design

The essential transportation properties of a new aircraft type, its overall system concept, design data and detailed geometry are defined by the company's advanced design (AD) office which is responsible for the generation of aircraft concept proposals including the technical, technological, competitive and commercial aspects. Focussing on new product development, the AD team is active in the overall concept development and in defining its technical and operational properties. AD is a vital and essential part of product development and has a substantial influence on the company's competitiveness and effectiveness. Dependent on the internal organization, most of the AD tasks can be categorized into the following activities.

- Future projects. The prime task of a future projects team is carrying out pre-conceptual studies, conceptual design and proof of concept for a new ('clean sheet') design and making proposals for novel configurations. This complex activity has a highly multidisciplinary character which requires that individuals from functional groups such as flight physics, structures/materials and systems integration are involved in the AD process. The team must accomplish the projected task subject to boundary conditions such as top-level requirements, certification rules, technical capabilities and economic environment of the company, customer operational aspects and other considerations.
- Tool development. Software tools for aircraft sizing, performance analysis, weight and cost predictionandoptimizationtechniquesareofvitalimportanceforasuccessfuldesigneffort. Reflecting the expertise of the company, these tools are in general not available on the commercial market. The capability to investigate a wide variety of vehicles and alternative conceptsrequiresthedesigntoolstobecontinuouslyimprovedbymakingthemmorereliable and versatile and by incorporating and expanding design data bases. Advanced designers will also be active immerging new results from the (applied) research field with available methods and procedures. Chapter 11 illustrates how a design tool can be developed.
- Enabling technologies. Most of the company's R & D activities aim at applications with one of its (future) production programmes. AD identifies the required key technologies in accordancewiththecompany'stechnologyobjectivesandgivesguidanceinthedevelopmen t of new technologies enabling competitive products. Included activities are assessment of operational research and market analysis, and available manufacturing capabilities.

- Competition evaluation. The technical, technological and economic situation of the company's products is judged versus competing products and developments. This requires year-round exploration and modelling of competing airplanes under consideration by the same potential customers and creation of a well-organized competition database.

In addition to these focussed activities, AD is responsible for highly constrained temporary tasks. These may entail, for instance, interaction with the company 'sales department and with (potential) customers, external suppliers and partners. The engine selection process requires that regular contacts are made with engine manufacturers. During the validation and detailed design phases of an ongoing project, AD specifies and coordinates the peripheral activities carried out externally such as wind tunnel, structural and system testing. Another activity is developing proposals for upgrade programmes and future derivatives or modifications of the company's existing product line.

Factors driving the design of airliners are relevant to some extent for business aircraft design as well:

- Propulsion: Turbofans of the next generation of civil aircraft are expected to have an ultra-high by pass ratio and geared turbo fans. Amor radical concept is open rotor engine technology in the form of contra-rotating prop fan so run ducted fans. Integration into the air frame of these new engine concepts may require an innovative overall airplane concept. Turboprops for high speeds will drive multi-bladed crescent-shaped propellers.
- Airplane configurations: Evolutionary development of airliners may result in different concepts emphasizing low-cost transportation, improved cabin comfort, reduced atmospheric contamination and external noise. Radical concepts such as integrated configurations, nonplanar wings, all-wing aircraft and propulsion by hydrogen fuelled engines require major investments in research and development.
- High-speed aerodynamics. Small airliners and business aircraft with a small wing leading edge sweep may achieve areas of natural laminar flow (NLF). Laminar flow control (LFC) by suction of the boundary layer through a porous skin is a potentially powerful fuel saver. Winglets and sheared tips reduce induced drag by up to 15%.
- Low-speed aerodynamics. Airplanes with stringent airfield performances require advanced high-lift devices. Options are variable camber, full-span flaps and powered lift by means of externally blown flaps or engines blowing over the wing. Reduction of aerodynamic flap/slatnoiseandmanipulationoftrailingvorticescanhaveafavourableeffectonairtraffic management (ATM) and environmental compatibility.
- Flight control systems: Flight envelope protection and stability augmentation are accommodated by a flight control computer and active controls. Manoeuvre and gust load alleviation are considered additional provisions for saving structural weight and improving comfort. Direct lift control and/or thrust vectoring can be considered for unusual configurations to improve their controllability.
- Airborne systems. Except for very light aircraft, fly-by-wire has become the standard for airliners and business jets – fibre optics may be considered in the future. More-electric

aircraft enable environmental and automatic icing control without making use of engine bleed air and simplify the auxiliary power unit.

- Materialsandmanufacturing.Compositesarebecomingincreasinglydominantwithapplications of fibre-reinforced plastics in primary and secondary structures. Fibre metal laminates are applied in fatigue-sensitive areas and secondary structures. Aluminium-lithium alloys replace the traditional 5000 series, leading to about 10% weight reduction.
- Structuralconcepts.Affordablecompositefuselagesarebecominganoptionformanyairliners and business jets. Lightning protection is required for all exposed composite structures. Aero-elastic tailoring is applied to avoid divergence or flutter and may be considered to enable a forward swept or very high aspect ratio wing. A morphing wing structure adapts the shape of high-lift devices off-design flight conditions.

- New directions for a more digital take on Industrial Design

It is evident that digital technologies are influencing the way that design project work and practical studio work are taught. As an example, 3D computer modelling, which began as a documentation tool for designers, used traditionally at end of design processes once a concept had been developed and resolved, is now coming out of darkened labs and into practical studios to be used in conjunction with other studio tools, allowing designs to be developed iteratively between screen and reality. However, if this specific practice is considered in relation to the propositions made in this paper, it is a divergence to current practice to adapt to digital technologies, albeit a significant change of practice, rather than an example of a radical redirection based on opportunities identified through a study of advances in digital technologies. To prompt new thinking for Industrial Design in relation to opportunities that might be provided by advances in digital technologies requires a disciplined initial research approach to exploring A specific field that could have relevance for a discipline prior to having a problem to solve.

- It's so expensive:

The whole air transport industry has been hit by the increasing of oil prices after 2004. Particularly with the rapid increase of oil prices in 2008*[1]. Considering airlines operating performance, fuel costs constitute a large portion of an airlines operating expenses*[2]. This is an enough reason, if not find a solution and limit oil use definitely, at list reduce it consumption.

For Free

NASA already posed in it plans the replacing of petroleum fueled aircraft system with lightweight electric systems, this transformation maybe it will cost in the beginning but the win after years will be unbelievable, for environment and costs, 'free electricity', free is enough to express it all, is it possible? Actually Nikola Tesla started working at it in 1899 and he proved it wireless transmission[*3] *, this technology depends on wireless transmission of electricity, with a transmitter and a receiver to be all clear, all is at frequency and vibration (may the aircraft will be lightest, faster, and more profitable to companies), this technology also can allow the structure of the aircraft to store electrical power, it's a permission to artificial intelligence and can replace fueled in aircraft propulsion system with light weight electric technology system, say goodbye to all the high costs of fuel.*

- **Software design:**

As the design influences between 70 and 85% of the total life cycle cost from the cost of developing only, producing, using and retiring a product, designers are in a position to substantially reduce it. There is therefore a need to develop methodologies to estimate the cost implications at the early design stage.

Companies can optimize their design and manufacturing of composite parts, they can use design software's to learn how to utilize materials more efficiently and effectively, and make more informed decisions concerning trade-offs between cost and functionality, also companies working within the supply chain can save money and speed up the manufacturing process.

A software like CATIA*[4] went a long way in digitization, by showing you the life of the aircraft, especially with-it different versions, like CATIA 3D MASTER that enables users to simulate the build variation to check if the product meets the dimensional product requirements. This allows customers to potentially loosen tolerances, which can reduce the cost of manufacturing by up to 90%, it's one from technology benefits.

- **2D and 3D design:** Although 2D drawings have been the norm in the product development process, they pose a number of challenges. Multiple 2D drawings are often required when producing a single 3D part, so changes to one drawing impacts the remaining drawings. This can cause costly delays in the product development process. That newt that 2D

Figure 12. 3D Technology

drawing are not a universal language and can cause communication issues that leads to mistakes.

- **Virtual reality, VR:** VR is one of the most promising technology investments for gaining a competitive advantage during the complete product engineering process by providing a collaborative and interactive product experience. VR software designed to make it quick and easy for engineers and designers to view, investigate and annotate their design as well. Using virtual reality at the company's allows to develop new methods of cost savings by taking the digital manufacturing idea into the virtual reality realm.

Figure 13. How it is VR

Major aerospace companies such as **Airbus, AVIC, Boeing, Bombardier, Lockheed Martin, Rheinmetall** and their suppliers, like **Safran Nacelles**, use a design-oriented software and hardware package from German virtual reality specialists ICIDO, that it's capable of rendering an exact 3D virtual copy of each piece of the aircraft, allowing for dynamic manipulation and visualization of products and parts from all angles.
VR allowed the companies to increase quality, reduce physical stress and determines the exact installation of a component like that costs will be lower, fewer injuries, higher quality and a faster time to market.

- Modifications:

- **Winglets:** According to industry, since first introduced to fleets, NASA-developed winglets have saved airlines approximately 4 billion gallons of jet fuel[12]. And in testing by Boeing and NASA, Blended Winglets have been shown to reduce drag by as much as 5.5%, as opposed to improvements of 3.5% to 4.5% from conventional winglets[13].
- **Avionics:** During the 1970s and 1980s, NASA created and tested the concept of an advanced cockpit configuration that replaced those dials and gauges with flat panel digital displays. The digital displays presented information more efficiently and provided the flight crew with a more integrated, easily understood picture of the vehicle situation. Glass cockpits are in use everywhere today on commercial, military and general aviation aircraft. As an example, without avionics upgrade the C-130H is becoming obsolete, the modifications in C-130H allowed it to be more rapid, low cost, low risk, fuel efficiency by reducing basic weight (A fleet of 4 aircraft could save $1.7M in Fuel over 10 years[14], also improve missions by: Digital

Moving Map, Electronic Flight Bag and Datalink Integration. In the next table comparison before and after upgrade so we can conclude that an avionics upgrade can save $4.9M per aircraft over 10 years[15].

Mean Time Between Failure (MTBF)	Before Upgrade	After Upgrade	**Reliability Improvement**
Communication Radios	108 hrs	1911 hrs	1,769%
Flight Menagement System (FMS)	102 hrs	1847 hrs	1,811%
Primary Flight Instruments	134 hrs	1463 hrs	1,092%
Navigation Radios	73 hrs	1170 hrs	1,603%
Automatic Flight Control System	96 hrs	3219 hrs	3,353%
Annual Cost to Sustain1	**$516k**	**$32k**	

Figure 14. The help of upgrading in aircrafts by hours

CASE STUDY

The Algerian Army has upgrade all C-130H, in URAT/UTAR (The Unit of Transport Aircrafts renovation) remarked the changes after upgrading avionics systems: the level of workforces has been raised up, the availability of aircrafts too, reduced aircraft downtime and provided optimal operational level, it supposed to save strong currency 60% of aircraft maintenance costs, and after having some problems in the lack of labors that's start to disappearing, also communication with 'Lockheed Martin' became easier and Test bands are more available. The reduction in parts and improved design means lower operating costs and higher reliability. So imagine if avionics systems can be upgraded more, virtual reality can make this more real, where you enter the cockpit and you see in front of you only what you need, Boeing already started working at this in the Dreamliner 787.

- How to minimize costs?

1. The first way to reduce costs is by optimising existing software licenses. To do this, companies need a clear overview of all services and applications currently installed, and in use across the organisation.
   This creates a software portfolio that can be compared against existing contracts and licenses to identify unnecessary costs, or whether additional licenses are required. If additional licenses are required, companies should take the opportunity to assess the use cases for the software to avoid any unnecessary investment.

2. Evaluating how software is used as well as an overview of the software in use, understanding if the need for a particular piece of software is essential; CIOs must understand who is using which software and how it aligns with their needs and role.
   This is important because employees change roles or leave a company – leading to situations where the applications are no longer required, but the maintenance and payment for that technology still continues. Does an organisation need 1,000 Microsoft Office licenses, if only 500 people use it?
   By having a firm handle on the specific technology needs of an organisation, organisations can make more targeted procurement decisions. That way, everyone always has the tools to do his or her job effectively, procured at the lowest cost possible.

3. Consolidating software: Effective SAM and consolidation software can have a dramatic effect on the number and type of required licenses. It's not unusual for companies to have several applications performing similar functions – it's common, for example, for businesses to have multiple instances of similar business productivity tools, all performing much the same function.
   This not only places an unnecessary workload on those tasked with managing software, but also wastes money. The consolidation of applications can very quickly lead to savings, without sacrificing functionality.

4. Controlling the cloud: Besides increasing operational flexibility, achieving lower costs is often a motivating factor behind embracing cloud computing. However, the cloud complicates SAM for CIOs as there are no longer a fixed number of users, workloads or devices.
   As a result, one way to control software in the cloud is through a cloud 'dashboard' which provides visibility into what applications are being used and how.
   This is important, as where software may have previously sat on a single owned server, it may now reside on virtual machines spread across multiple locations, which affects licensing considerations.
   For example, many End User Licensing Agreements prohibit the use of software in a cloud environment, which could render an organisation non-compliant and in need of additional licenses.

3- Manufacturing:

The aviation manufacturing is an important segment of the industry. This sector is expected to experience growth, driven by the rising volume of aircrafts to the next decades. Aviation industry is characterized by demand and its dynamic and competitive environment. The key to successfully compete in this rival scenario is to continuously strive towards higher levels of productivity, which is particularly essential for companies producing in high-wage countries.

Aviation industry has quickly improved in terms of technological development and its related manufacturing processes. Thus, it has sought better solutions during the development phase concerning manufacturing processes. The challenge is to find a better-quality final product, minimization of cycle times, manpower labor, and production wastes to aid the company's competitiveness in the global market.

Thus, aircraft market requires aircraft manufacturers to drive innovation and development innovative manufacturing processes in order to get competitive.

Faced to these trends, the Industry 4.0 concepts have been looked for improving the whole process in order to increase the productivity of companies. Briefly, in essence, Industry 4.0 is able to offer productivity gains based on collective term for technologies and concepts of value chain organization.

Within the Industry 4.0 context, Robots, Internet of Things (IoT), Augmented Reality (AR), Additive Manufacturing (AM), Radio Frequency Identification (RFID), Composite Materials, Cybersecurity, Cloud and the Big Data are some components of fundamental concepts of that.

On this way, the contribution of this part is to present an overview of Industry 4.0 concepts inside the aviation fabrication processes and its potential gains, benefits and advantages.

- **Aviation industry:**

Aircraft manufacturing is one of the most important branches of manufacturing of durable goods due to its high added-value. Also, this sector contributes to the development of new technologies that requires high-skilled professionals.

According to Barbosa, aircraft industry looks for potential suppliers of technologies, but these investments should be made with extreme care. This issue is relevant due to the development cost of new products is extremely high in this kind of business. So, errors must be avoided when investments are done in aircrafts fabrication.

Although the number of new transport aircraft has increased over the past decade, production and deliveries have trended steadily. As seen in Figure… below, this trend will continue in the coming decade.

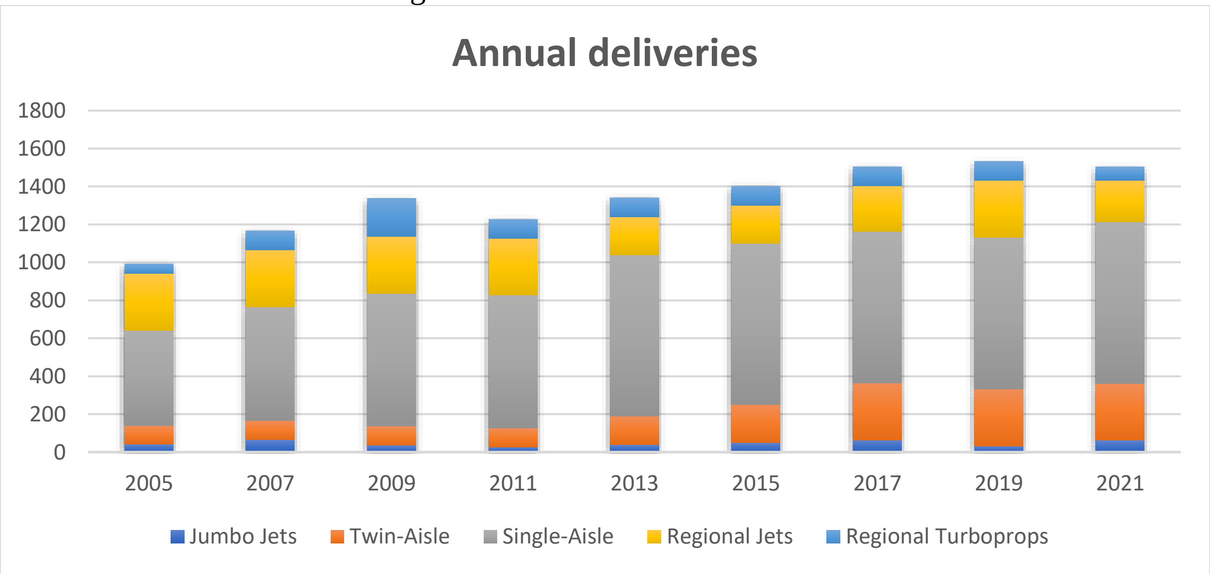


Figure 15. Historic and forecasted commercial aircraft unit

As presented in the **Figure15**, aircraft manufacturers are expected to deliver more than 16,000 aircrafts from 2012 to 2021.

In order to attend the increase of production demands, aircraft manufacturers are looking for improving their processes in order to increase the productivity. Thus, Industry 4.0 concepts have been input in aviation manufacturing environment to innovate and make the business more competitive.

- Industry 4.0

According to Lasi et al, industry is the part of an economy that produces goods which are highly mechanized and automatized. Since the beginning of industrialization, technological steps have changed the paradigm which today is named "industrial revolutions" as explained below:

1st: Focus on mechanization;
2nd: Intensive use of electrical energy;
3rd: widespread digitalization (Figure16**).**

Toward to future expectation, the term "Industry 4.0" was established as the "4th industrial revolution.

Industry 4.0 links the real-life factory with virtual reality and it will play an increasingly important role in global manufacturing.

The main concept of Industry 4.0 is to connect by IT systems, sensors, machines and parts along the value chain. These connected systems can interact with one another using standard internet protocols and analyze data to predict failure, configure themselves, and adapt to changes. It will provide conditions to connect and analyze data across machines, enabling faster, more flexible, and more efficient processes to produce higher-quality products at reduced costs.

This helps the increase of manufacturing productivity, reduction of wastes, growth in innovation and changes in the people's profile, contributing to the competitiveness of companies and areas.

Based on the increase and advance of digitalization within the factories, the conjunction of internet and oriented technologies in the area of "smart" machines and sensors, another new and essential industrial revolution named Industry 4.0 has been born.

The focus of future production contains modular and intelligent manufacturing systems and characterizes scenarios in which the products manage their own manufacturing process.

The Figure 16 shows the industrial evolution along the years and the 4th industrial revolution.

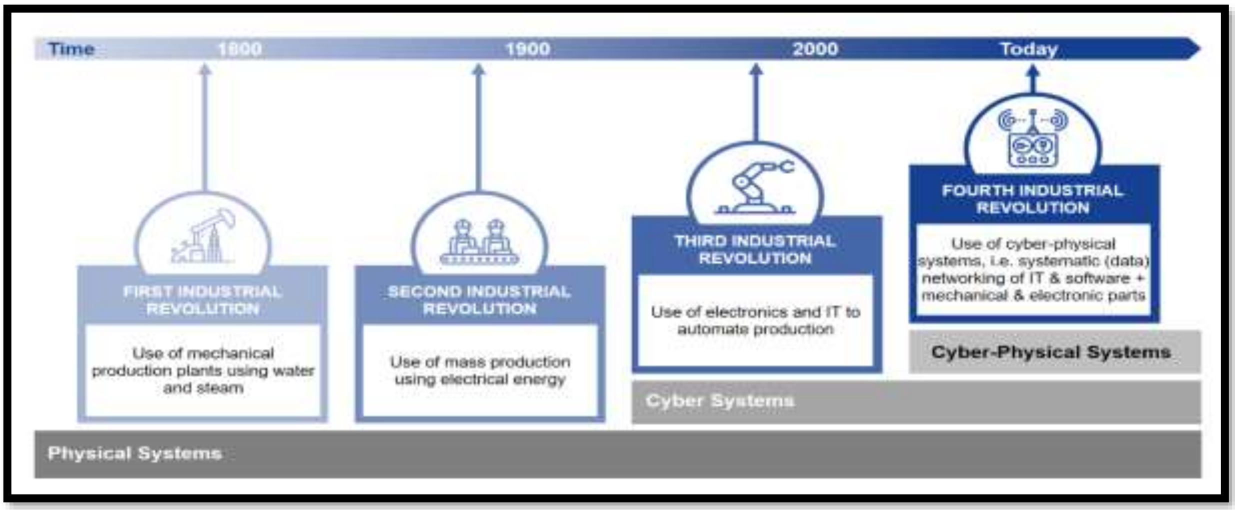


Figure 16. The fourth industrial revolution (Industry 4.0)

This figure above shows the nine technology trends that are the building blocks of Industry 4.0 and explores their potential technical and economic benefits for manufacturers and production equipment suppliers.
Thus, this paper has been focused on technologies that have been researched and applied on manufacturing of aviation industry.

- **Robotics**

There will be an increase of robot's installation around the world. According to IFR (International Federation of Robots), between 2015-2018, it is estimated a supply of new industrial robots that will represent 1.3 million dollars (Figure ….).

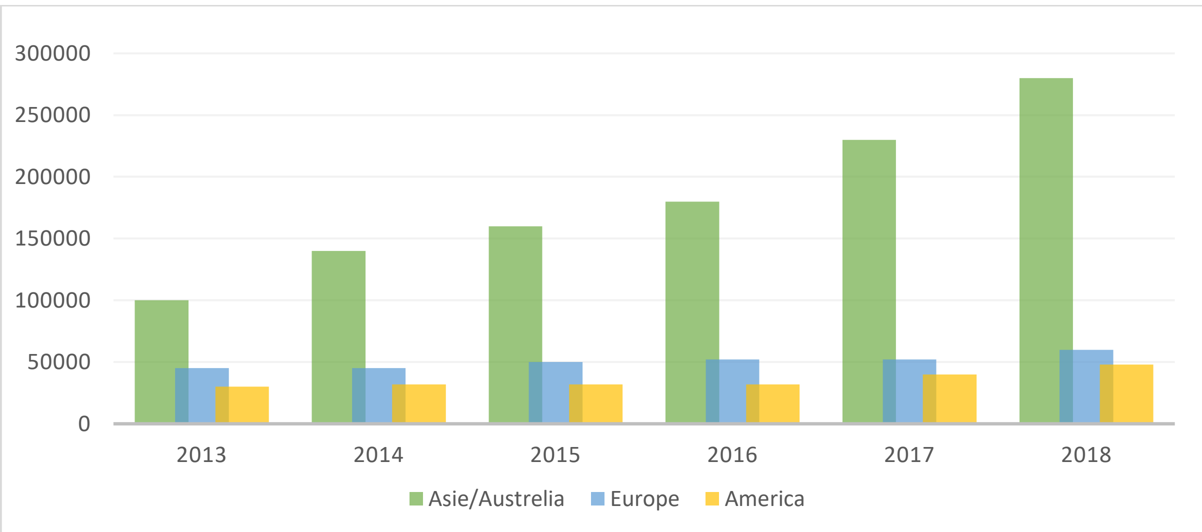


Figure 17. Annual supply of industrial Robots (IFR world robotics 2015)

Robots improve the productivity favoring the savings on production and eliminating problems of lack of qualified manpower.
Robots improve the quality of work by taking over dangerous, tedious and dirty jobs that are not possible or safe for humans to perform.

The high performance, low investment cost and most of all the adaptability of robots makes them the perfect choice for an efficient and easy automation solution. On this way, special software developed for robotics helps to improve the repeatability and the accuracy of robots' positioning. This feature contributes to meet the requirements of manufacturing aviation.
Due to be known as very conservative, the aerospace industry usually uses successful assembly methods that have already been proven to work in the past. But, in the past couple of years, the general attitude, in terms of assembly tasks, has really observed in the aerospace industry. Aircraft manufacturers tend to use robotics on some manufacturing applications to perform tasks that require precision and rigidity on big parts.

Aerospace and defense companies depend on precise and consistent machining and assembly to make safe and reliable products. Never tiring, never wavering, a robot follows the path it was taught without fail. Every piece is produced at the same rate, and each one is identical. Once labor-intensive tasks are increasingly performed by robotic manufacturing technology, the variability of human workers is eliminated while capacity increases, and costs fall.

In aerospace and defense manufacturing, there's constant pressure to reduce costs, while at the same time, adopting new processes and technologies. Where aluminum was once ubiquitous, today carbon fiber panels are assembled, bonded and inspected increasingly by robots.
Robotic technology lowers costs and improves quality while adapting quickly to changes in product design and production schedule.

- **Aerospace and Defense Robotics Applications**

Arc Welding - A robotic arc welder holds and moves the torch at the exact angle and speed needed for a quality weld and does it the same way every time. The last weld made is the same as the first, so quality and safety are built in.

Assembly - Robots, sometimes mounted on a transport unit, lay carbon fibers that eventually become wings. They apply beads of adhesive and sealant uniformly and consistently, and they rivet panels to metal spars. At the component level, robots can assemble faster and more accurately than humans, especially when aided by force-sensing and vision systems. Pumps, motors, seats and even electrical harnesses are all candidates for robotic assembly.

Machine Trending - Aerospace machining processes, usually performed on CNC machines, often have long cycle times. Having robots load and unload allows the system to run unattended, maximizing output from high-value assets. By mounting a robot on a transport unit, one arm can even tend several machine tools.

Material Removal - Aerospace manufacturers around the world have taken to robotic drilling. Assembling an aircraft takes thousands of rivets to hold the panels in place, and each rivet needs hole drilling and deburring. Today, robotic drilling systems swarm over airframes, ensuring every hole is in exactly the right location and burr-free.

PAINTING - Paint robots are commonplace in the automotive industry, but in aerospace manufacturing, they're used for depainting. Periodically, every aircraft must undergo a thorough structural inspection, and doing that means removing the paint. It's a job demanding great consistency in an unpleasant atmosphere, and one that's ideal for a robot. Whether blasting abrasive media or using laser ablation, robotic depainting ensures the job is done thoroughly and human workers are kept safe.

PART INSPECTION - There are no second chances at 36,000 feet, so every aerospace component and assembly is inspected thoroughly to ensure safety. Ultrasonic and visual inspection methods are the most widely used. Plus, sensors and cameras ensure nothing is being overlooked. It's even possible to add 3-D scanning technology to a robot so it can make dimensional checks.

- **Ensuring Smooth Integration**

Robots today are easier to program and deploy than ever before, but every industry is different, and integration always brings new challenges. For example, in aerospace manufacturing, the precision demanded by some applications requires secondary encoders on the robots. That's why it's so important to work with an experienced integration partner.
With over 35 years' experience and more than 4,500 installations throughout North America, Acieta has the knowledge and skills needed to integrate robots successfully.
Investments with robots on aircraft manufacturing can be beneficial when the payback is feasible.

It follows few of the robotic applications in aerospace manufacturing.
Drilling Fastening Inspection Painting Fiber Placement Sealing Manipulation **(**Figure …) illustrates some robot applications regarding the aviation industry.

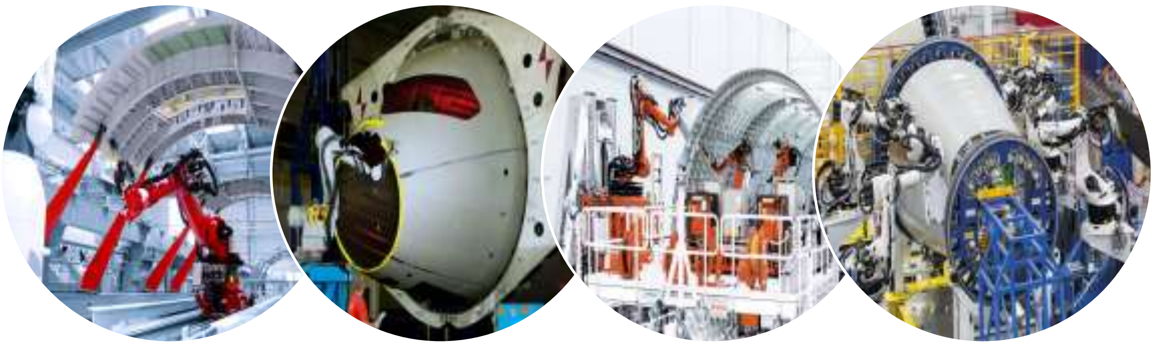


Figure 18: ROBOTS application in aviation industry

On the Industry 4.0 way, another good application is collaborative robots. The main advantage of this kind of robot is the collaboration between human-robot in work together.
These intelligent robots begun automating new areas with their sensitive capabilities to detect work piece positioning tolerances, work with non-rigid parts, open doors on machines,

recognize component types and perform an infinite number of other tasks. The range of possible applications in the factory of the future is virtually infinite. These robots currently work in industry proves the collaboration between humans and robots works (as seen in **Figure …**), even in the harsh environment of day-to-day production.

Figure 19: Collaborative robot machines in aviation

Where fences are no longer required between robots and humans, the way is paved for entirely new and highly productive approaches to industrial manufacturing. Its built-in sensor system allows the seamless integration and division of tasks between human and machine, with considerable advantages in terms of manufacturing efficiency and flexibility.

- **The Benefits of Automation**

Reduce Production Cost - A quick return on investment (ROI) outweighs the initial setup costs. All of the following automation advantages reduce production cost.

Decrease in Part Cycle Time - A lean manufacturing line is crucial for increasing efficiency. Robotics can work longer and faster which increases production rate.

Improved Quality and Reliability - Automation is precise and repeatable. It ensures the product is manufactured with the same specifications and process every time. Repairs are few and far between.

Better Floor Space Utilization - By decreasing a footprint of a work area by automating parts of your production line, you can utilize the floor space for other operations and make the process flow more efficient.

Reduce Waste - Robots are so accurate that the amount of raw material used can be reduced, decreasing costs on waste.

Saves Local Jobs - Instead of moving your company to a location with lower labor costs, incorporate automation in a few key areas. This will increase your product through-put and increase your profit so you can keep your company in the current location.

Stay Competitive - Reduction in schedule and cost attracts customers. Automation helps provide the highest throughput with least amount of spending.

***EXP*:**

The robotic cell that will be integrated into Boeing’s manufacturing process is using 3 KUKA robots to achieve fastener installation. The robot located on the outside of the fuselage is drilling holes for fasteners while the two robots inside the fuselage are installing the fasteners. The external and internal robots are aligned during the operation to have a greater accuracy in the process. As you have probably notice in the picture, the robots are fitted on mobile platforms that allow them to cover the total surface area of the fuselage.

EXP

The **Airbus** flagship – the **A380** – moves seemingly effortlessly through the air. To get the giant aircraft this close to the sky during construction on the ground, flexible and powerful, heavy-duty mobile platforms are used. Thanks to its Mecanum wheels, a KUKA omniMove is able to transport aircraft components weighing up to 90 tonnes around the production hangar in Hamburg with millimeter precision in confined spaces.

This wheel design ensures unrestricted maneuverability. In the building in which the A380 is manufactured, Airbus has been operating two of these mobile transport platforms for a year now in order to achieve the desired manufacturing cycle of the fuselage sections as they move along the production line. The platforms can be coupled together for transporting large parts.

- ## IoT – Internet of Things

Today, only some of a manufacturer's sensors and machines are networked and make use of embedded computing. They are typically organized in a vertical automation pyramid in which sensors and field devices with limited intelligence and automation controllers feed into an overarching manufacturing-process control system. But with the Industrial Internet of Things, more devices—sometimes including even unfinished products—will be enriched with embedded computing and connected using standard technologies. This allows field devices to communicate and interact both with one another and with more centralized controllers, as necessary. It also decentralizes analytics and decision making, enabling real-time responses.

Bosch Rexroth, a drive-and-control-system vendor, outfitted a production facility for valves with a semi-automated, decentralized production process. Products are identified by radio frequency identification codes, and workstations "know" which manufacturing steps must be performed for each product and can adapt to perform the specific operation.

The IoT concept can be defined as the use of internet technologies. It covers the wireless connection, micro-electromechanical systems, software and Apps. This approach has helped the linkage between Operational Technology (OT) and Information Technology (IT), allowing unstructured machine-generated data to be analyzed for monitoring that will orient improvements on production systems.

Every "thing" will soon be networked. Even today, almost every electronic device is able to communicate with the Internet. Digitization is triggering rapid developments in any area and digitally networked processes in Industry 4.0 will make it possible to manufacture products at a low cost in a manner that is more flexible, energy-efficient, resource-saving and customized.

For Manufacturers, IoT Means the 'Internet of Tools' I believe that the IoT will have two main areas of impact on the current manufacturing landscape.

The first concerns the organizational structure that is required to produce truly integrated IoT solutions. I.e. Machine camp + Internet camp will be required to work together.

The second area where the IoT will have a significant impact on manufacturers is in the area of manufacturing technologies, i.e. connected manufacturing equipment, connected logistic chains, cyber-physical systems, and big-data-based analytics of production processes will help improve the way the physical parts of a connected IoT solution are produced.

3D models: Airbus uses 3D data to emit laser projections over aircraft bodies in order to guide assembly line workers.

Airbus; is applying the Internet of Things technology not only to its products, but also to the tools its employees use in the manufacturing process.

Hence, an Airbus employee on the factory floor who can use a tablet or smart glasses to scan an airplane's metal skin can determine what size bolt is needed in a given hole, and the rotation force necessary to install it. That information can be spontaneously sent to a robotic tool, which completes the task. The smart factory (internally called 'Factory of the Future') aims to streamline many thousands of steps in the assembly of an airplane – it involves up to 400,000 bolts and screws alone, using 1,100 different tools. The main interest is that with those tools being connected, the process is much quicker and it is even more reliable than if the bolts were being tightened manually.

The integration of IoT into the aeronautics industry will provide considerable benefits as new services enable optimization of airline operations and asset management. The new services target the main point of the industry, from maintenance and fuel cost to optimization of traffic.

The development of preventive maintenance services will help reduce aircraft downtime and increase the safety of the industry.
Aircraft on ground (AOG) time is a critical cost factor for the airline industry. It can cause major disruption and damage an airline's reputation.
Large numbers of sensors are now deployed in the aircraft. They monitor in real time critical performance parameters and thanks to the IoT, the data can be transmitted in near real time.
It helps ground staff to analyze the data rapidly, detect any issue and quickly take corrective action. Overall it reduces both the time and the cost of maintenance.

$1,250,000 each day

Cost of a grounded A380

- **Value shift away from manufacturing**

For the aerospace manufacturing industry value is shifting as a result of the flexibility and efficiency gains offered by smart factory technologies.
Developments in the smart factory are leading to gains in production costs as defects are eliminated and automation reduces the human-resource intensity of production tasks.
Value is thus shifting toward research and development and design tasks, on the one hand, and to after-sales services on the other. These shifts are impacting players, enabling the development of smaller scale units focusing on design and engineering of products on the one hand, and the emergence of platforms and ecosystems on the other hand.

- New roles on data exchanges

The Industry 4.0 trend relies to a significant extent on the increasing integration of IoT data and IT systems between the actors of the value chain. This opens up a position for actors focusing on data exchange and analysis platforms.
The aeronautics industry relies already on a complex network of suppliers focusing on specific technologies. But the development of the IoT and Industry 4.0 is requiring stronger integration of their IT infrastructure.
Data exchange and interoperability between manufacturing systems is one of the key challenges and a new position in the value chain open for those providing it. The control they achieve on data access can in turn enable them to provide key optimization services for the industry.

- Products as a Service business model

The development of connected products is enabling the transformation of the business model into a service offering.
Key parts of the airplane are no longer owned by the airlines but rather rented as a Service. The first step in the movement toward servitization is often to try to bundle additional services with existing products. Producers can thus count on recurring revenues, while the consumer only pays for its actual usage of the product.
Rolls Royce motors8 "power by the hour" business model and "Total Care" service are well representative of a transition toward "product as a service" offering with service revenues four times superior to original product cost.
The data gathered from the motors has enabled Rolls Royce to take engagement9 on fuel consumption reduction with airlines, generating new service revenue opportunities.

These reductions can create a significant economic sector. According to GE11, each reduction of 1% in fuel consumption by Airlines would amount to an economy of 30 billion USD over 15 years. This also implies additional evolutions in the business relationships. It increases the role of customer relationship, shifts a one off CAPEX investment into OPEX costs and enables continuous improvements and support. This also implies additional evolutions in the business relationships. It increases the role of customer relationship, shifts a one off CAPEX investment into OPEX costs and enables continuous improvements and support.

Dubai aviation district looks to attract aircraft manufacturers: According to “Tahnoon Saif, the vice president of aviation at Dubai” by “2020 to 2025 this is when our original equipment manufacturer [OEM] initiative is going to start.” IoT will benefit airlines to cut costs across many areas of operations and processes, including maintenance.

- Digital manufacturing

• Digital Manufacturing Explained

Simply put, digital manufacturing is the application of digital technologies to manufacturing. It is all about having the right information, at the right place, at the right time.

Digital Manufacturing in Aerospace and Defense

Some areas of the aerospace-and-defense (A&D) industry are deploying digital tools to integrate their enormously complex supply networks. A modern jet turbine engine has hundreds of individual parts, for example, some made in-house and others sourced from dozens of vendors. Through digital manufacturing, cloud computing-based tools allow suppliers to collaborate efficiently. This greatly reduces the labor required to manage design changes and minimizes risk across the supply network. Boeing is a good example of an organization realizing the benefits of digital manufacturing. The A&D giant developed its 777 and 787 airframes using all-virtual design. This cut time to market by more than 50 percent.

• Simulation

In the engineering phase, 3-D simulations of products, materials, and production processes are already used, but in the future, simulations will be used more extensively in plant operations as well. These simulations will leverage real-time data to mirror the physical world in a virtual model, which can include machines, products, and humans. This allows operators to test and optimize the machine settings for the next product in line in the virtual world before the physical changeover, thereby driving down machine setup times and increasing quality.

For example, Siemens and a German machine-tool vendor developed a virtual machine that can simulate the machining of parts using data from the physical machine. This lowers the setup time for the actual machining process by as much as 80 percent.

Increasingly, simulations have been used in industrial operations, from the engineering phase, products’ modelling and definitions of materials and production processes. Simulations compare on real time data the physical world with a virtual model, which includes machines, products and people. This allows operators to test and optimize the machine settings for the next product on production in a virtual environment before changing to the physical condition, thus reducing the down time of machine setup and increasing the quality of the products.

It consists in a virtual integration on production shop floor, including equipment, products, planning, data and efficiency of operation. Digital manufacturing is also used to detect fails and interruptions of the production in order to reduce downtime, based on a virtual machine that can simulate the whole process.

Figure 20 : Digital manufacturing simulation.

- ## Augmented Reality (AR)

✓ Introduction

Augmented Reality (AR) is the augmentation of the real world with digitally generated sensory inputs like visual or sound. When applied to visual, as it was done for the current work, digital objects are registered spatially and rendered within the physical world often using a display device like a tablet or cell phone. Numerous advancements in technology have further enhanced the feasibility of using AR. AR can be applied for several purposes in different areas.

✓ Cases of augmented reality in aerospace industries

The advantages and benefits of AR have been widely applied by important aircraft manufacturers in global market. This section shows some related work beyond typical usage of AR on a synoptic analysis.

Boeing CASE

Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems. A top U.S. exporter, the company supports airlines and U.S. and allied government customers in 150 countries and has a long tradition of aerospace leadership and innovation. With corporate offices in Chicago, Boeing employs more than 165,000 people across the United States and in more than 65 countries.

One of AR studies developed at Boeing was in partnership with Iowa State University described in the work "Fusing Self-Reported and Sensor Data from Mixed-Reality Training" in order to evaluate three different methods of presenting work instructions. According to Richardson et al, the three methods were referred to as Desktop MBI, Tablet MBI and Tablet AR. The first mode is designed to mimic the instructions using Model-Based Instructions (MBI) on a stationary display located in a corner of one work cell and not visible from the work area. The Tablet MBI used the same instructions based on the exact model as the MBI desktop, but showed them to the trainee on a tablet PC mounted on a mobile arm. The Tablet MBI mode utilized the exact same Model-Based Instructions as the Desktop MBI, but showed them to the trainee on a tablet PC mounted on a mobile arm device. The third was the Tablet AR mode using the same tablet as used in the Tablet MBI mode, but presented the work instructions to the trainee using Augmented Reality. The Tablet AR mode used a custom Augmented Reality application and user interface built by Boeing Research and Technology. The interface and AR elements were selected through collaboration with Iowa State University. The screen of the Tablet AR mode was observed and recorded throughout using the same screen mirroring software noted for the Desktop MBI and Tablet MBI modes. Data of 46 participants were validated in that study, where 80% of these participants were between 18 and 20 years of age, 18% had between 23 and 30 years of age, and 2% were between 30 and 44 years of age. All participants were students and 78% of them majoring in engineering. There was an uneven gender split, 78% of participants were male and 22% female. When comparing the traditional model based instructions with augmented reality instructions, there were different areas of interest, these are first time quality (lowest errors), fastest time and worker efficiency. Each of these areas shows how the approach of fusing system data with human subject data can further enrich training outcomes and measures. Results covered in the previous section suggest that the use of augmented reality as a work instruction delivery method can increase first time quality and reduce time on task. The data also indicate that the use of AR also led to a greater emphasis on each task by the participants. It was found that those using Desktop MBI and Tablet MBI spent a large amount of time traveling and confirming information, looking at the screen. Finally, it was found that specific tasks can benefit more strongly from the use of Augmented Reality.

Airbus CASE

Airbus is an aircraft manufacturer with facilities mainly in France, Germany, Spain and the United Kingdom and others, with a global diversity highlighted by the multi-cultural workforce of more than 58,000. The company's manufacturing operations around the world set industry benchmarks in both quality and efficiency standards.

Airbus develops its product family in response to market needs and in close consultation with airlines and operators, suppliers and aviation authorities. This approach ensures the company's products to remain competitive through continuous upgrades. The company produces and markets the world's largest passenger airliner, the A380. Designed for the 21st century aviation industry, its unique size allows airlines to maximize their revenue potential through an optimized, segmented cabin, boosting their contribution to profit by up to 65 per cent per flight. Seating capacity ranges from 544 passengers up to 853 depending on the selected configuration.

Another industrial AR solution that is already in use comes from Airbus. With the master for a new aircraft production process developed entirely with digital tools, Airbus collaborated to create the MiRA (Mixed Reality Application) in 2009. This app increases productivity in production lines by using AR to scan parts and detect errors. On the A380, MiRA, which today consists of a tablet PC and a specifically developed sensor pack and software, has reduced the time needed to check tens of thousands of brackets in the fuselage from 300 hours to an astonishing 60 hours. Furthermore, late discoveries of damaged, wrongly positioned or missing brackets have been reduced by 40%.

Figure 21. MIRA solution by TESTIA

In the more commercial aerospace world, Airbus is using a technology known as MiRA, or Mixed Reality Application, where engineers installing equipment inside aircraft fuselages use a tablet computer and a sensor pack, which tracks their position and relates it to a Realistic Human Ergonomics Analysis (RHEA) tool, a full-scale 3D digital model of the aircraft they are working on. This enables them to call up an image of a bracket installation in the area where they are working to ensure that they have fixed it correctly. Geolocation devices attached to the aircraft interact with the sensor pack to allow them to view their work location from any angle. The RHEA is updated as each component is installed. This technique has helped reduce the time to inspect the 80,000 brackets inside an A380 fuselage, which hold systems such as hydraulics pipes, from three weeks to three days.

✓ **Conclusion**

Augmented Reality when applied to aerospace manufacturing processes offers a faster production, higher quality and reliability for the production processes, as well as increasing the company's competitiveness.

• Additive manufacturing (AM)

✓ **Introduction**

Since the Wright brothers first launched their wood and canvas glider in the early 1900s, technology has improved dramatically, making international travel and space exploration a reality. Additive manufacturing, better known as 3D printing, is playing a major role in this revolution by reducing weight, strengthening materials and streamlining design in the aerospace industry.

The Aerospace and Defense (A&D) industry is a great example of utilization Additive Manufacturing (AM) (commonly referred to as 3D Printing) with a clear value proposition and the ability to create parts that are stronger and lighter than parts made using traditional manufacturing.

The A&D industry was a very early adopter of 3D printing and still continues to contribute heavily to its development. Some aerospace companies began using this technology as early as 1989 and over the next couple of decades, the adoption of 3D printing increased substantially. In 2015, the Aerospace & Defense industries contributed approximately 16% of 3D Printing's $4.9+ billion global revenues.

- ✓ **3D Printing in Aerospace**

The aerospace industry includes a range of commercial, industrial and military applications, and is comprised of departments that design, manufacture, operate and maintain the aircraft or spacecraft. Among the first advocates of 3D printing, the airline industry is a driving force in the evolution of this technology for both manufacturing end-use parts and prototyping. Airlines depend on 3D printing to alleviate supply chain constraints, limit warehouse space and reduce wasted materials from traditional manufacturing processes. Rapidly producing aircraft parts on demand saves enormous amounts of space, time and money.

In fact, minimizing weight is the number one way that aerospace manufacturing companies save money because weight affects an aircraft's payload, fuel consumption, emissions, speed and even safety. Unlike traditional manufacturing processes, such as CNC where material is removed to create a part, Stratasys FDM (Fused Deposition Modeling) 3D printers create parts from the base up, layer-by-layer, allowing complex geometries and streamlined designs with less overall components. This all translates to reduced weight in the air. Since you are adding material rather than removing material, this process also drastically reduces waste during manufacturing. Air ducts, wall panels, seat frameworks and even engine components have all benefited from reduced weight enabled by 3D printing.

Figure 22. Parts in the aircraft by 3D printer

✓ 3D Printing for Commercial Aircrafts – Airbus

According to Apex, one of the aviation industry's top leaders, Airbus, now has a record number of 3D printed parts on their new A350 XWB aircraft, with 1,000+ parts. Partnering with Stratasys helped them produce these parts quickly and efficiently using high-performance FDM materials like ULTEM 9085.
This production-grade thermoplastic is a strong and FST (flame smoke and toxicity) compliant material with excellent strength-to-weight ratio, certified to Airbus's specifications.

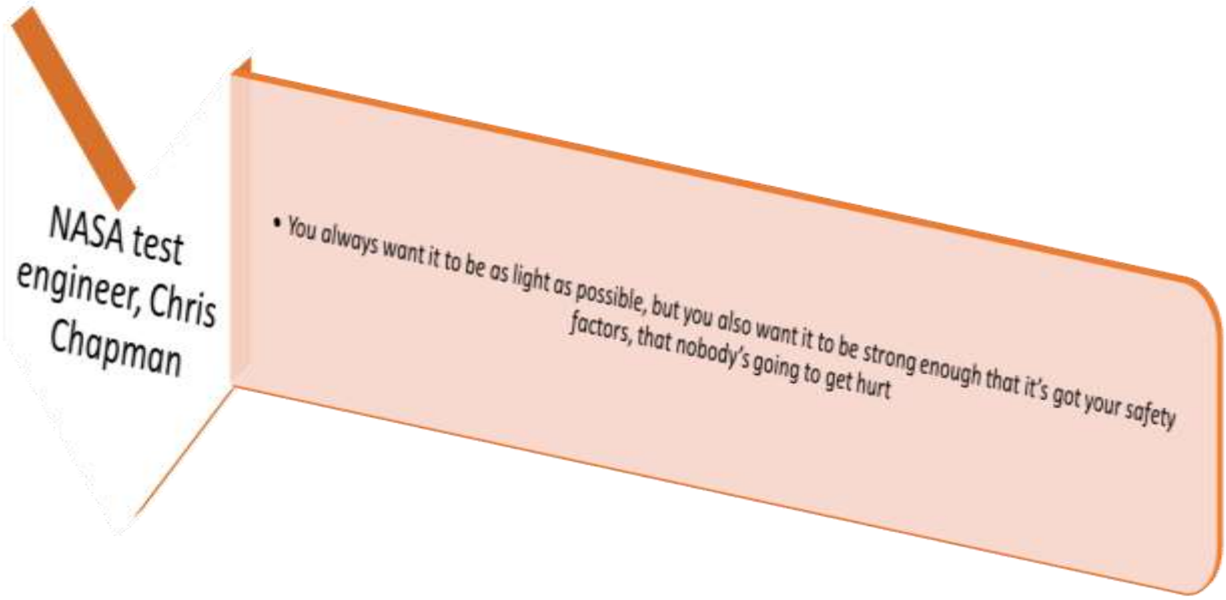
Figure 23. Airbus had 1,000 parts 3D printed. (Source: BBC Airbus Technology)

✓ 3D printing for Industrial Space crafts – NASA

Similarly, an article by Robert Dehue also explains that NASA is using a Stratasys 3D printer to develop and test a space rover. The rover is about the size of a Hummer with a pressurized cabin to support life on Mars and currently contains over 70 FDM 3D printed parts. The 3D printed parts on NASA's rover include flame-retardant vents and housings, camera mounts, pod doors, a large part that functions as a front bumper and many other customized fixtures.

FDM printing offers complex parts with quick turnaround time, which has helped the RATS team build customized housings for complex electronic assemblies that are needed to accomplish their goals. With an estimate of $10,000 per pound of material sent to space, it is no wonder why NASA leaned toward 3D printing.

Figure 24. SPACE CRAFT printed



In addition to the rover, Stratasys 3D printing also helps solve complex problems on the International Space Station (ISS). For example, the University of Alabama Birmingham (UAB) Center for Biophysical Sciences & Engineering (CBSE) develops low temperature freezers down to -256 degrees Fahrenheit to facilitate the transportation and processing of experiments to the ISS in accordance with NASA. When CBSE needed a new way to construct an interior liner for their freezer that was space and weight conscious, they turned to Stratasys 3D printing and the highly durable material, ULTEM 9085.

✓ 3D Printing Materials for aerospace applications

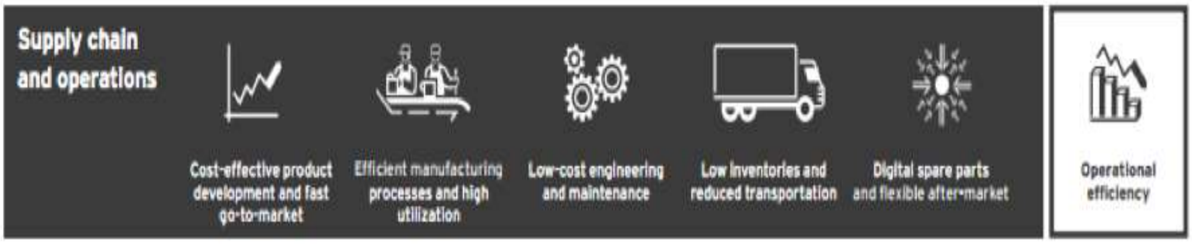
The table below summarizes the recommended materials for applications specific to the aerospace industry:

Application	Example part	Requirements	Recommended Process	Recommended Material
Engine compartment	Tarmac nozzle bezel	Heat resistant functional parts	SLS	Glass-filled Nylon
Cabin accessories	Console control part	Customized functional knobs	SLA	Standard Resin
Air ducts	Air flow ducting	Flexible ducts and bellow directors	SLS	Nylon 12
Full size panels	Seat backs & entry doors	Large parts with smooth surface finish	SLA	Standard Resin
Casted metal parts	Brackets and door handles	Metal parts casted using 3D printed patterns	SLA & Material Jetting	Castable Resin or Wax
Metal components	Suspension wishbone & GE Jet Engine	Consolidated, lightweight, functional metal parts	DMLS/SLM	Titanium or Aluminum
Bezels	Dashboard interface	End use custom screen bezels	Material Jetting	Digital ABS
Lights	Headlight prototypes	Fully transparent, high-detail models	Material Jetting & SLA	Transparent Resin

Figure 25. 3D Printing Materials for aerospace applications

✓ Impact on costs, product performance and inventory management

3DP benefits are found along the entire supply chain (*exhibit 1*). First, it increases efficiency in raw materials usage. Since 3DP builds products by addition instead of subtraction, it produces less waste thus lowering costs. Additionally, 3DP reduces tooling costs and shortens task times. A 3D-printer can produce different parts regardless of design and complexity. Under traditional manufacturing, diverse molds and tools are required depending on product characteristics, increasing tooling costs and set up times.



The number of components per product is also dramatically reduced. A General Electric (GE) fuel nozzle consisted of 20 different components. With 3DP, that nozzle is manufactured in one piece, reducing assembly times and costs, but most importantly, enhancing product performance. Reducing components per product improves durability and optimizes weight without compromising reliability. For airlines, higher durability translates into lower maintenance costs and weight reduction into lower fuel consumption and carbon emissions. According to GE, its 3DP nozzle has a 5 times longer lifetime and yearly fuel savings of $1.6M per airline.

3DP also brings improvements in inventory management. Regulations force manufacturers to provide spare parts for long periods after aircraft sales. Airbus stocks a wide variety of spare parts for each aircraft type. The A300/310 aircraft -no longer in production-, requires spares until 2050. Currently, Airbus has 3.5 million spares in stock consuming gigantic storage space and working capital. 3DP, as a "virtual warehouse", can quickly produce spares on demand, aggressively reducing inventory costs and delivery times (*exhibit 2*). According to Ernst&Young, aerospace companies will become the 3DP earliest adapters for spare part management

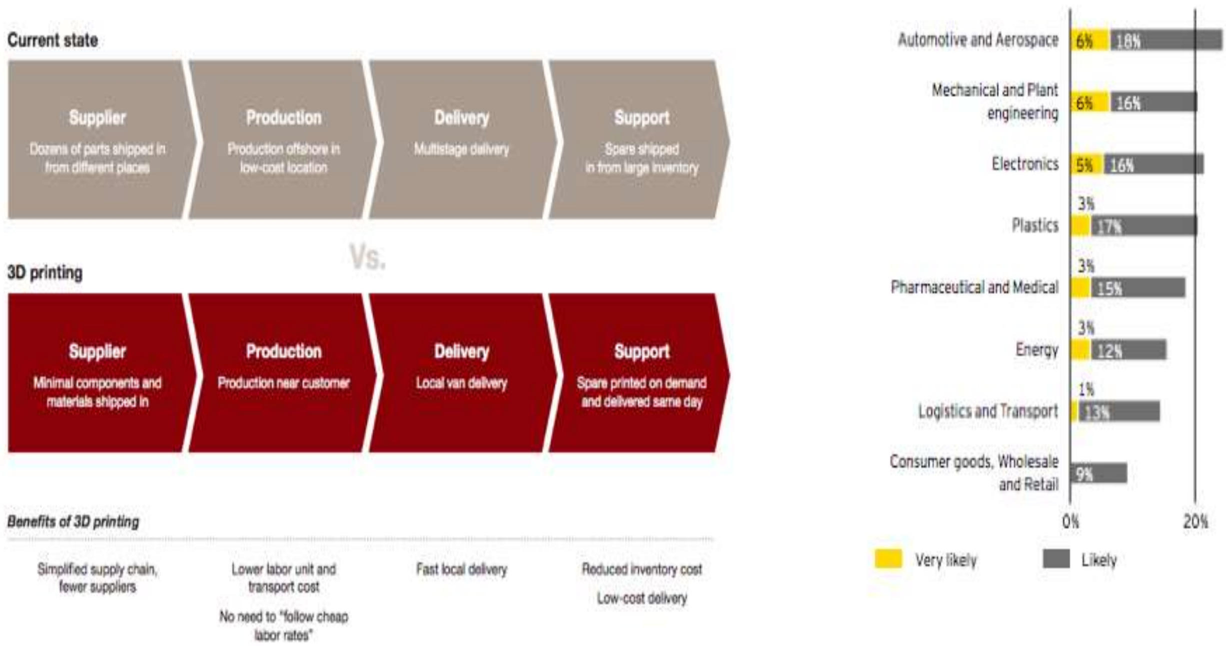


Figure 26. Benefits of 3D printing

✓ The Future of 3D Printing in Aerospace

NASA and Airbus are just a few examples of how major organizations are turning to 3D printing to solve complex engineering problems and create specialized parts. But what is next on the horizon for 3D printing in aerospace?

As metal 3D printing advances, we predict vital components of both domestic aircrafts and spaceships will adopt additive manufacturing methods using custom alloys and high-end lightweight thermoplastics. Companies like Boeing are already investing in metal 3D printing companies, like Desktop Metal with the hopes of utilizing these new technologies for research and development as well as end-use-parts for aircraft. With expanding capabilities, 3D printing will be an even more practical solution for aerospace manufacturing.

As if 3D printing on the ground isn't high tech enough, additive technologies are also being tested in space. NASA even foresees future spacecrafts coming equipped with 3D printers, so scientists can send astronauts digital CADD files to be printed. The ability to create unforeseen tools on a space mission is game changing.

• RFID

The name "Radio Frequency IDentification" implies the transponders and reading devices in RFID systems communicate with one another via radio. The RFID systems use a variety of carrier frequencies, depending on the application.

✓ How does RFID work?

RFID technology, or Radio Frequency Identification, uses radio waves or magnetic fields to identify nearby objects. It uses two components:

The RFID tag consists of an RFID antenna and a RFID chip, it comes in various shapes and sizes and has special technical features. The chip stores the information and sends it to a nearby reader via its antenna.

The fixed or mobile reader can remotely gather the chip's information using radio frequencies emitted by the latter. In some cases, the reader can also write in the tag's memory.

Figure 27: RFID tag

Tags can use three types of frequencies: low, high and ultra-high frequency.

The higher the frequency, the greater the distance the tag can be read – up to 10 meters for Ultra High Frequencies (UHF).
Likewise, UHF tags are more sensitive to surrounding metals and liquids than low frequency tags, as a result of how energy is reflected or absorbed. If this is the case, choose a metal-compatible tag, often thicker and heavier than a standard tag.

Intelligent RFID (Radio Frequency IDentification) tags could soon function as minicomputers that guide products on their paths through factories, stores or countries. RFID tags could be attached to many different things. Jeans, pharmaceutical products, and even cars, for example, are equipped with a tag so they can be identified beyond doubt during shipping. The principle is simple: if an object with an RFID tag, otherwise known as a transponder, passes a matching reader, the tag is activated and reveals the information stored in its memory. A manufacturer can thus know exactly when a product left its factory, a middleman can track it as it continues on its course and when the product arrives at its destination, the organization that processes it can confirm its status as “received”.
In Industry 4.0 context, new applications for these tags in the field are being developed to assist collaboration between computational elements and physical entities.
With the RFID technology, aircraft manufacturers are able to use this trend on their processes. For example, workstations and eventually work pieces themselves could be equipped with RFID tags holding all the data relevant to production of an item as the item itself are carried through a plant. RFID scanners read the data and issue corresponding commands to robots and its systems.
An interesting application is to control of the tools in the manufacturing environment that is not an easy task due to recurring loans and drives of them during the work shifts. Coupled to this, same tools are shared or specific use and may be of different sizes, with likely potential chances to be lost or forgotten in unwanted places.
Based on that, an application has been developed to be used on aircraft shop floor for providing management of those. A management system allows to view the status of each tool, and thereby, monitor the usage time per user and application, allowing optimize the allocation of use of more expensive tools and less availability. It can save money when a production ratio increases and demands of tools up.

- ✓ **RFID improves aircraft production and maintenance**

Boeing is a leading airframe manufacturer in both the commercial and defense sectors, with several projects employing RFID technology. RFID-based tracking and tracing of aircraft parts, during both the production and maintenance phases of the lifecycle, brings significant value to all stakeholders within the aviation ecosystem. The common thread for all of these stakeholders is an improvement in quality, productivity and maintainability over an aircraft's lifecycle, spanning several years. The use of RFID enables automated data collection, verification and validation, resulting in improved accuracy and reduced flow time. The reduction in maintenance costs to airlines due to the implementation of RFID will be enhanced with a new service offering initiated by Boeing's RFID integrated solutions division. Learn how the stakeholders are working together to maximize the benefits offered by the technology.
Speaker: *Rebecca Shore, Solution Architect, RFID Integrated Solutions, Information Services, Boeing Commercial Aviation Services*

- ✓ RFID takes airbus to new heights of efficiency

Airbus, a winner of the RFID Journal Award for best implementation, has been pioneering best practices in the adoption of RFID by deploying the technology as "business radar" across all aspects of its business, including supply chain logistics, transportation, manufacturing and aircraft in-flight operations. This approach, which leverages a passive and active RFID reader infrastructure for multiple applications operating on a common software platform, has yielded significant cost savings as well as improvements in operational efficiencies. During the past three years, the company has significantly expanded these capabilities to new areas of operations across its value chain. Hear how Airbus is benefiting from these systems, as well as its latest plans for the next few years.
Speaker: *Carlo K. Nizam, Head of Value Chain Visibility and RFID, Airbus*

- ✓ **Choosing the right RFID tool-tracking systems to save time and money**

In many industries—including automotive, aerospace, oil and gas exploration and production, and farming—a fully automated RFID tool-tracking system can eliminate human errors, freeing up workers to perform their primary jobs without worrying about the tools needed to do so. In this session, learn how to choose which technology will work best in your particular operating environment.
Speaker: *Maurizio Turri, Lab Manager, RFID Research Center, University of Arkansas*

- **Composite materials**

Composite is material consisting of two or more materials, which have different physical and chemical properties, combined together in a proper content and fashion to produce a new material property that are different from the properties of those individual materials.
Why composite in aerospace industry?
The main aim of the aerospace/aircraft industries is to reduce weight keeping the same or more strength than the regular metals have and help to reduce costs. These criteria leads to use composite.

- ✓ **Advantages of composite material over metals**

Light weight, High heat resistance, High strength to weight ratio, Low density, Corrosion
resistance, High stiffness, Fatigue resistance

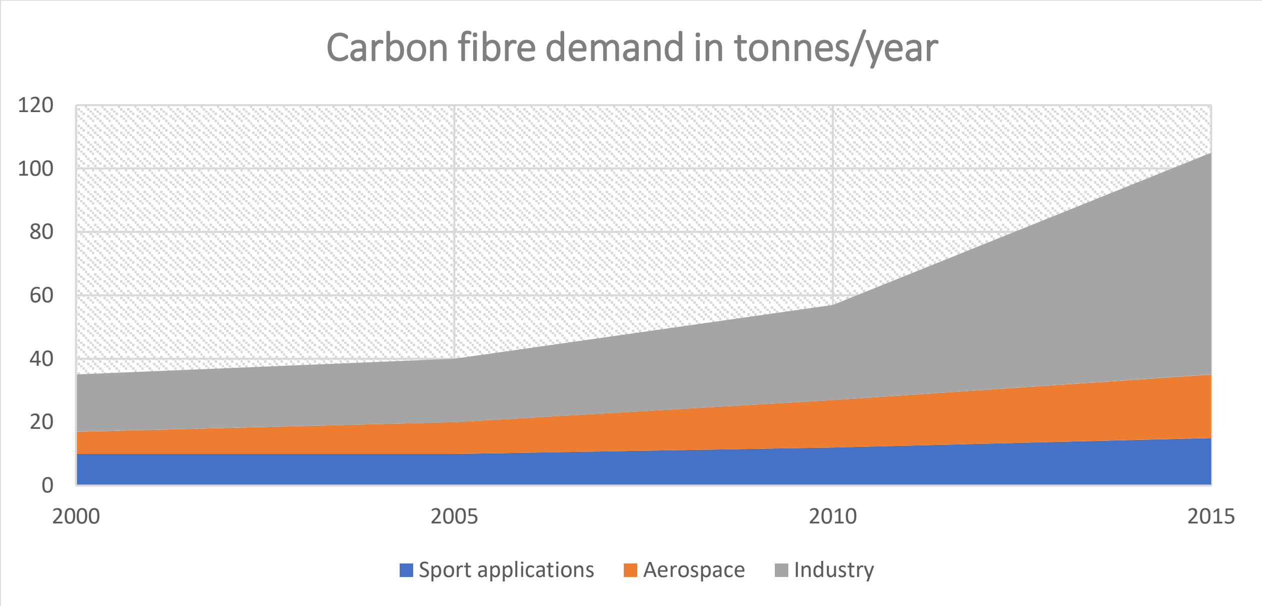


Figure 28: Graphical representation of use of composite materials over the

Types of composites used

- Fiber glass
- CFRP
- QFRP
- GFRP
- GLARE

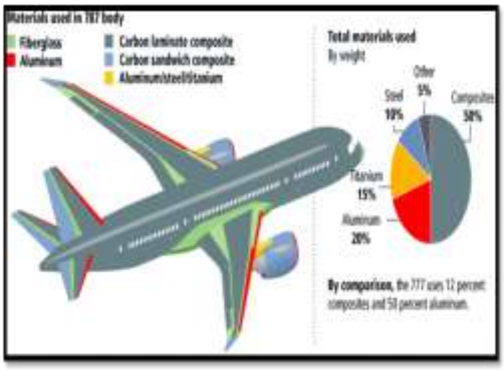
Application of composite in Aerospace

- Fuselage (Bulkhead)
- Wing flaps
- Rudder
- Elevators
- Radome
- Spoilers
- Floor beams and panels
- Helicopter main and tail rotor blades
- **Space vehicles**: Satellites, Missiles, Rockets etc.

Boeing 777 composite structure

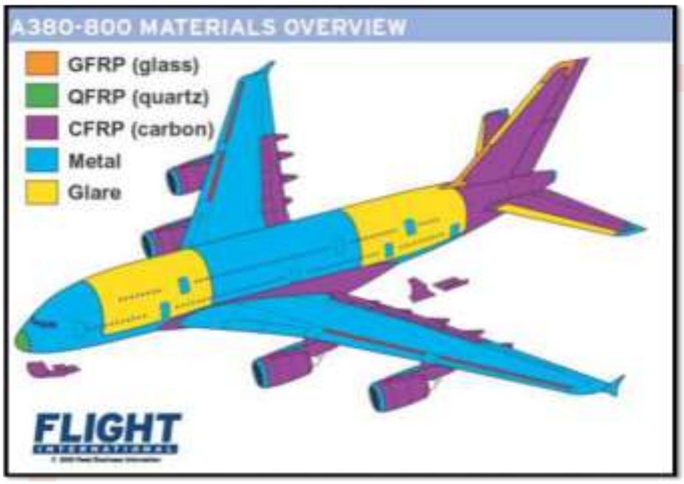
- **Components that uses composite structure are:**
- Horizontal Stabilizer
- Vertical Fin
- Radom
- Wing fairings
- Passenger floor beams
- Wing Box
- Engine Cowlings
- Engine fairings
- Reduction in weight is over 5800 pounds.

Boeing 777 composite structure



Boeing 787 "Dreamliner" composite structure

¬ Components that uses composite structure are:
Almost full fuselage
Upper and lower wing skin
Radom
Wing flaps, elevators, ailerons
Vertical Fin and Horizontal Stabilizer
¬ Use of composite is 80% by volume and 50% by weight.



A380-800 Materials overview

Airbus A380 composite structure

¬ Components that uses composite structure are:

-Horizontal Stabilizer

-Vertical Fin

-Radom

-Wing Fairings

-Wing Box

-Belly Fairings

-Engine Cowlings

-Engine fairings

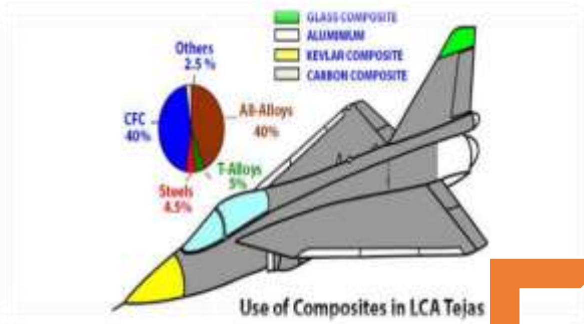
¬ Wing box, made of CFRP, has reduced weight up to one and a half tones.

B-2 Bomber composite structure

*B-2 Bomber is mostly made of carbon/epoxy materials.

*The reduction in weight was about 40000 to 50000 pounds.

*Design material was specially designed to absorb radar waves.



_LCA stands for Light Combat Aircraft which is basically use of composite materials in its structure.

Components which are made of composite material are:

*Nose

*Wing upper surface and leading edge

*Exit Nozzle

_Weight is reduced by 21%

Figure 29: LCA Tejas (HAL) composite structure

✓ Conclusion

Since the invention of composite materials, aerospace industry has shown significant use of it in building different parts first to almost most of the structural parts and use of it is rapidly growing.

The main aspect we need to keep in mind that strength and stiffness are major considerations for aircrafts whereas stiffness and low coefficient of thermal expansion are major considerations for space applications.

- ## Horizontal and Vertical System Integration

Most of today's IT systems are not fully integrated. Companies, suppliers, and customers are rarely closely linked. Nor are departments such as engineering, production, and service. Functions from the enterprise to the shop floor level are not fully integrated. Even engineering itself-from products to plants to automation—lacks complete integration. But with Industry 4.0, companies, departments, functions, and capabilities will become much more cohesive, as cross-company, universal data-integration networks evolve and enable truly automated value chains.

For instance, Dassault Systems and Boost Aero Space launched a collaboration plat form for the European aerospace and defense industry. The platform, Air Design, serves as a common workspace for design and manufacturing collaboration and is available as a service on a private cloud. It manages the complex task of exchanging product and production data among multiple partners.

A&D players adopt vertical integration to gain control over critical processes in the supply chain. Vertical integration helps companies in reducing their operating costs by eliminating supplier margin. It also provides them with the agility to swiftly respond to changes in product specifications as well as market demand, reducing the effective cost and time impact of the changes.

A leading commercial aircraft manufacturer adopted the strategy by establishing a new avionics and electronics unit to in source key technology and reduce costs. The company also aims to pursue more vertical integration of its aircraft manufacturing business by stepping up its capabilities in advanced materials, propulsion systems and actuators.

- ## Cybersecurity

Many companies still rely on management and production systems that are unconnected or closed. With the increased connectivity and use of standard communications protocols that come with Industry 4.0, the need to protect critical industrial systems and manufacturing lines from cybersecurity threats increases dramatically. As a result, secure, reliable communications as well as sophisticated identity and access management of machines and users are essential.

During the past year, several industrial-equipment vendors have joined forces with cybersecurity companies through partnerships or acquisitions.

With Airbus, flights with confidence. Cyber security is as important as the protection of people traveling by plane. Advanced cyber security services have been developed by experts for the aerospace industry.

✓ Comprehensive Solutions

Boeing provides a comprehensive suite of interactive solutions in Cybersecurity. The company's offerings include critical infrastructure protection network surveillance and data analytics, information security, mission assurance, and information operations capabilities. Boeing also provides a comprehensive suite of interactive solutions that help its customers better manage their data. Some of Boeing's Information Management systems work in limited- and no-connectivity environments. Boeing's solutions are trusted with the U.S. Department of Defense and intelligence communities.

Cyber-Range-in-a-Box

Cyber-Range-in-a-Box, or CRIAB, is a compact system used to support the development, test, and experimentation of cyber tools and techniques, as well as to train cybersecurity personnel. CRIAB allows modeling and simulation of complex missions and advanced threats for creation of security solutions.

CRIAB is Boeing's hardware and software solution to efficient network emulation, virtualization, and integration for training, platform validation, rehearsals and evaluations. CRIAB Range Management Services enable centralized and enterprise accessible range management, control, and use. Boeing offers Cyber Test and Evaluation Services for customers' training, workshop, and exercise needs, integrating CRIAB with the specific systems and scenarios of each customer.

Cyber Defense.

Boeing Advanced Malware Assessment Services leverage a proven process and multiple technologies, integrated into one portable solution for detecting advanced malware. This integrated suite of technologies provides real-time situational awareness of all network traffic, based on the behavior of entities operating across a network. Using passive network monitoring, the Boeing solution rapidly identifies network threats without disruption to network operations or performance. Boeing Advanced Malware Assessment Services discover and analyze the most advanced threats to a network by profiling threat actors and rapidly identifying compromised areas.

• The Cloud

Cloud computing is a model that allows ubiquitous access to resources shared computing (networks, servers, storage, applications and services).
Cloud computing makes it possible to outsource the management of the IT infrastructure and to reduce costs. In the context of Industry 4.0, cloud computing facilitates sharing of data between sites or systems. Even data and features related to production, monitoring and control of processes can be deployed in the cloud. Among the resources involved, which lead to the virtualization of infrastructure: Infrastructure as a Service (IaaS), Software as a Service (SaaS), Platform as a Service (PaaS), the data centers.
Cloud computing is a technology where massive resources are accumulated in large data centres and interconnected to provide consistent, inexpensive and secure services via Internet to huge set of users. Resources include applications, network, compute or host, storage and database.

✓ There are mainly four types of clouds

Public cloud - Here cloud services are available to public. The cloud is usually owned by an organization providing services.

Private cloud - Here cloud is operated by an organization and is managed by the owner or by a third party.

Community cloud - Here different organizations having similar mission, security requirements and policies collaborate to form a cloud which is either managed by one of the organizations in community or by a third party.

Hybrid cloud - It is a combination of any of the above-mentioned clouds.

The shift to cloud computing is part of the plane maker's long-term ambition to grow its commercial and military-services business to about $50 billion in annual revenue by 2025, according to a senior company executive, a massive expansion from its estimated $15 billion today.

Boeing's shift to cloud computing also reflects the increasing role of internet connectivity aboard commercial aircraft. Once self-contained islands of information and computing, airplanes are becoming nodes on a global network, with pilots and airline staff adapting their operations in real time as conditions change.

Over the long term, Boeing envisions a suite of applications that could improve aircraft efficiency in real time, cutting fuel consumption by around 10%. That saving is substantial when compared to the investment in an all-new jet that brings 20% savings.

Boeing had already begun rolling out the cloud-based software with its Amsterdam-based subsidiary AerData and will complete its transition more broadly over the next 12 to 24 months, said Mr. Crowley.

Boeing acquired AerData, which manages airplane and lessor maintenance records, in 2014. The move to the cloud increases the ubiquity and portability of records, often a key determinant of the continued value of a commercial jetliner and the ease of remarketing an aircraft for lease to its next operator.

This entry explores the possible use of cloud computing within various aviation systems. An aviation services cloud infrastructure is proposed in order to provide Cloud Computing (CC) to the aviation end user. Such short-term applications of CC are reviewed as for real-time flight data and cockpit data storage and analysis. A long-term application of CC for an artificial intelligence based robotic autonomous aircraft is reviewed. CC technology has the potential to greatly benefit aviation missions due to scalability, customizability, and outreach. There is a myriad of possible applications also within the aerospace defence community in terms of long-range intelligence gathering and data processing in much less time than the current technology requires and at a significantly lower cost by pooling various infrastructures computing power.

Boeing adopted Microsoft Azure for many commercial aviation analysis applications. Transferring these applications to the cloud is both tactical and strategic, "explained Gendreau". Tactically, we wanted to speed up the data acquisition and analysis process and send it back to customers as actionable results. This allows us to evolve more easily and adds reliability and performance. In terms of strategy, we wanted to work with a technology leader to help us realize our broader vision of digital aviation.

- Aerospace Bets on Big Data

✓ What is Data?

The quantities, characters, or symbols on which operations are performed by a computer, which may be stored and transmitted in the form of electrical signals and recorded on magnetic, optical, or mechanical recording media.

✓ What is Big Data?

Big Data is also data but with a huge size. Big Data is a term used to describe a collection of data that is huge in size and yet growing exponentially with time. In short such data is so large and complex that none of the traditional data management tools are able to store it or process it efficiently.

Big Data is getting bigger and so are its wide-ranging benfits. From IBM's Watson analyzing Big Data to help shoppers identify the trendiest holiday gifts to Boeing predicting part failures in airplanes.

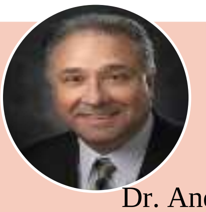
The aerospace industry is capitalizing on the enormous amount of data, transmitted via sensors embedded on airplanes, by using it to improve business processes. Sensors are generating so much data that airlines often face the challenge of interpreting it all.

"Big Data by itself doesn't produce any value," says Andrew S. Bicos, PhD, director, platform performance and systems engineering and chief engineer, aeromechanics at Boeing Research & Technology, the Boeing Company. "The value really comes from being able to look at the data through algorithms, machine learning, and data mining that help you pull out the information and then analyze the results and transform that data into right decisions," he adds.

ASME.org spoke with Dr. Bicos at ASME's Industry Advisory Board Fall 2015 meeting, where Board members discussed the wide-ranging impact and opportunities that the nexus of manufacturing, design, and Big Data presents to the field of engineering. His responses below highlight the impact of Big Data on the aerospace industry and how it will influence the future of flying.

✓ What data points are important for the aerospace industry?

Bicos: "It really depends on the point of the lifecycle of the product and what data you are looking for. In production, the quality of the parts can be monitored; Where the parts are in the supply chain, where they are in assembly line position, and what's the degree of completeness versus the planned one? These data points can help make decisions in the process of putting a product together. In flight, it could be things like the fuel consumption rate, stress levels, temperature, and power usage. By monitoring those things we can make sure everything is working as it should and if we detect any anomalous behavior, then we can use that to predict what might happen. For example, if the part needs to be replaced when it lands, the system can send a message and we can have the part waiting and replaced, thereby minimizing the turnaround time. On our customer side, we can use Big Data to help them optimize maintenance programs, pilot and crew scheduling to improve their overall operational efficiency. This all ties back into design, as we can use the information of the existing fleet to help design the next generation of airplanes more efficiently and be more cost-effective as well."



Dr. Andrew S. Bicos. Image: Boeing

<u>How is your team using Big Data to improve the design, construction, and operation of an aircraft?</u>

Bicos: Using the correct analytics can help us design more efficient airplanesas well as to operate and maintain them more efficiently. For example, if you have a plane in flight, Big Data can allow you to fly it more efficiently by adjusting the fuel consumption rates for the particular flying conditions that it's going through. You can also adjust the flight path to maximize efficiency as well as reduce turbulence. Typically there are thousands of flight parameters that are being recorded and transmitted during the flight. This data can be used to diagnose potential issues before they occur. If there are issues with any of the systems or structure, you can collate that data with flight operations and do prognostic/predictive analysis to take the appropriate action before it happens.

✓ How Rolls-Royce uses Big Data in practice?

Paul Stein, the company's chief scientific officer, says: "We have huge clusters of high-power computing which are used in the design process. We generate tens of terabytes of data on each simulation of one of our jet engines." That design data is then manipulated and visualised to essentially work out whether the design is good or bad, and where improvements

might be needed. Eventually, Rolls-Royce hopes to be able to visualize their products in operation in all the potential extremes of behavior in which they get used.
In addition, the company's manufacturing systems are increasingly becoming networked and communicating with each other in a move towards an Internet of Things (IoT) industrial environment. As Stein says, the innovation lies in "the automated measurement schemes and the way we monitor our quality control of the components we make."

In this way, Big Data analytics helps Rolls-Royce improve the design process, decrease product development time and improve the quality and performance of their products – while reducing costs at the same time. The company has also been able to further streamline production processes by eliminating faults during the design process.

Chapter 2

Aerospace Construction Digitalization

In this chapter we'll see how can small tools make big changes

IV. Chapter3 : Airlines Compagnies :

1- Airline Flight Costs:

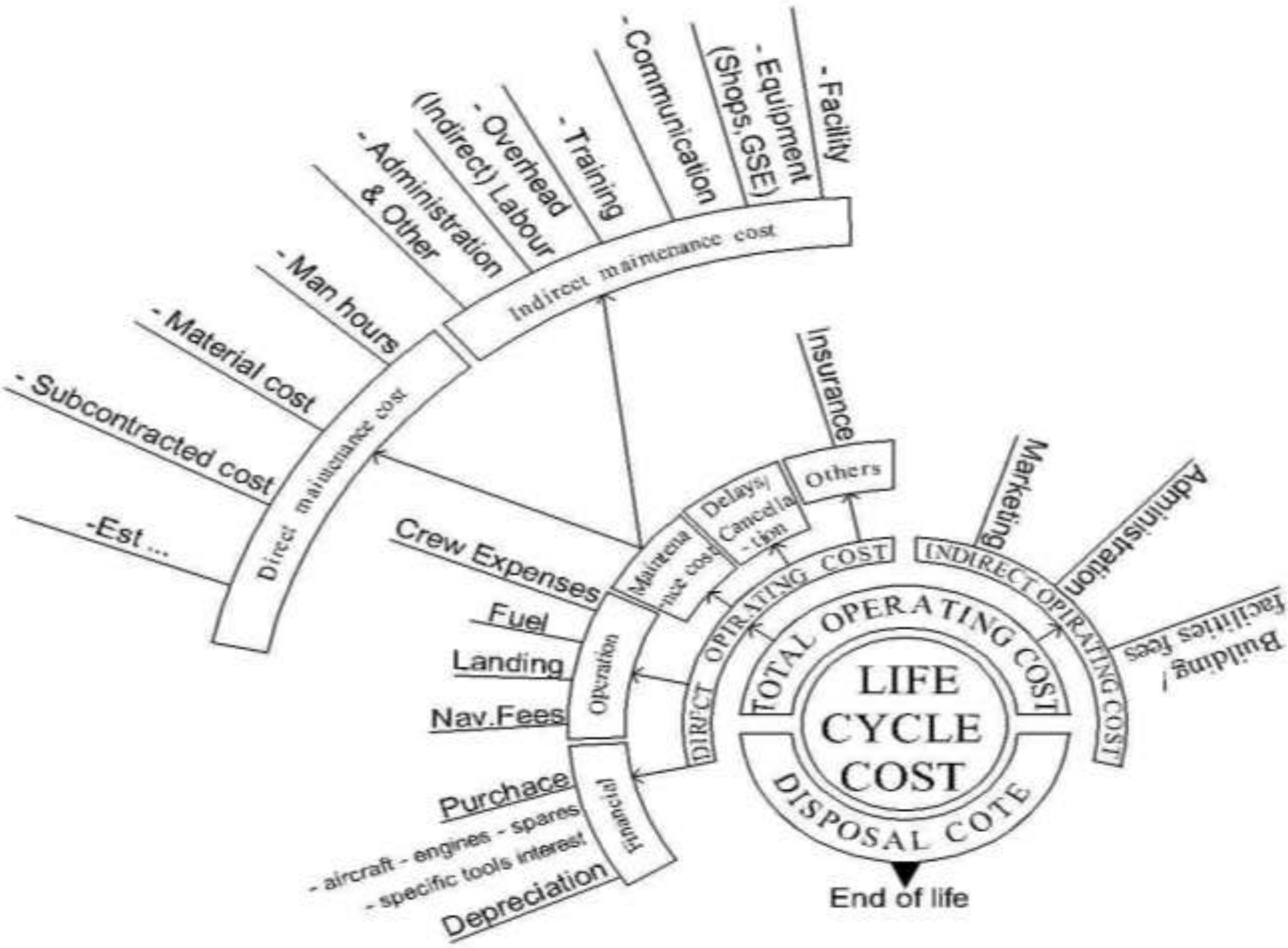


Figure 30: Flight Cost

The previous diagram shows every single cost in an airline company to take an aircraft to the sky, it all effects at it. When companies win more in all the sides, they can make it easier and cheaper at the traveler, so how to reduce all the costs in an airline company? Without over thinking, the technological transformation.

Digitization means changing the ways airliners interact with customers, partners, and suppliers, and dramatically rethinking their internal practices, behaviors, and processes to accomplish this. And digitization isn’t just about revamping IT and marketing. The demands of digitization will ultimately force companies to transform virtually every aspect of their business.

- HOW DIGITIZATION WILL AFFECT AT AIRLINES COSTS?

Digitization can affect directly and indirectly at company costs, directly can be by some modifications in the aircraft to minimize the weight which meaning reducing in fuel consummation, or even minimize the load of the aircraft by simple things like flying smart*[1] without papers*[2]…etc. And indirectly by letting everything go fast, time, the big effect, reducing means more revenues less errors, less losses and less costs, because time is money. Also improving the quality, to not be from the bests is a lost.

- Digital transformation, steps to it:

1- **STORE***:* Ensuring that all your content is managed and maintained centrally in a scalable, accessible platform is critical to maximizing its value. Being able to access stored content from different locations and devices enables collaboration throughout organizations, allowing workers to be more productive. And with everything in the same place, it is easier to keep control of your intellectual property and products, streamlining rights management and making day-to-day working much more efficient.

2- **DISCOVER:** A study by IDC showed that "an enterprise with 1000 knowledge workers wastes $48,000 per week due to an inability to locate and retrieve information". By ensuring assets can be found, filtered and manipulated, and by enabling context-based discovery and suggestions, you will be able to work more efficiently and better serve both your internal production team and end-consumers. This enables cost-effective working by allowing users to find what they need, when they need it, as well as eliminating the costs of repeat-purchasing, losing or misplacing assets.

3- **COLLABORATE:** Automating product preparation where possible frees your users to spend time on the specialist tasks that really matter. By providing intuitive tools for collaborative working, built into publishing workflows and integrated with familiar tools such as Microsoft Word and Adobe InDesign, you can ensure that your team is as agile as your content.

4- **GRANULARIZE:** This means using structured-content (typically XML or HTML) as early as possible in the production process. Once product has been separated from format and broken down into granular, reusable chunks, it is easier to store, find scale and manage.

2- Flight Operations

For flight operations area there are still a lot of processes based on paper, so replacement of paper-based workflows with digital workflows on the ground and in addition also in the digitizing of workflows in the cockpit

Airlines are entering a period of significant disruption as rising costs and competition force airlines to identify new revenue streams and change the way they interact with their customers.

Air travel demand is expected to double by 2037. Accommodating that growth safely and efficiently while meeting rising passenger expectations for a more personalized experience, depends on our ability to better integrate data and embrace digital transformation in our industry

By embracing new and emerging technologies – from big data to artificial intelligence and robotization – leading airlines can differentiate their brand, create competitive advantages and drive new value and intelligence throughout the customer journey.

But to become a truly digital airline, you must first enhance your infrastructure capabilities to enable new technologies and analytics to be performed, embrace agile working methods to deploy and implement key growth strategies, and deliver a more personalised experience across all touchpoints to deliver commercial benefits.
Digital enables a new level of data-driven collaboration across all airline functions collectively—connected people, processes, technology and culture to deliver a more seamless customer experience.

Aviation software development providers fully cater to airports and other operators in the aviation industry with custom flight operations software to managing personnel, fuel, flight planning and the planes themselves, reservation and ticketing systems, and MRO (Maintenance, Repair and Overhaul) software solutions.
flight operations software development solutions include scheduling and dispatching management and events monitoring for small to enterprise-level businesses.

FLIGHT SCHEDULING AND FLIGHT OPERATIONS MANAGEMENT	FLIGHT OPERATING SYSTEM DEVELOPMENT	GROUND HANDLING SOFTWARE SOLUTIONS
•Custom Reporting Modules •Invoice Management •Flight Planning Modules •Minimum Equipment Lists •Slot Management	•EFB App Development •Document Management Solutions •FCOM Development •Custom Document Creation •ATI Messaging	•Crew Management Modules •History Tracking Solutions •Custom Rules-Based Queries •Dispatch Modules Programming •Flight Logging Software Solutions

- Flight operating system developpement

Experts provide flight operating system software development services, such as Electronic Flight Bag (EFB) apps. they also design document management solutions for centralized storage of general operations manuals, Flight Crew Operating Manuals (FCOM), Quick Reference Handbooks (QRH), and custom document creation. they facilitate data link and operational messaging for sending and receiving Air Transport Industry (ATI) messages, including MVT (Movement), LDM (Load), and Euro control.

• Electronic Flight Bag (EFB)

EFB is an electronic information management device that helps flight crews perform flight management tasks more easily and efficiently with less paper, it is the general purpose computing platform intended to reduce or replace paper based reference material often found in the pilots carry on flight bag including the aircraft operating manual, flight crew operating manual and navigational charts including moving map for air and ground operations.

In addition, the Electronic Flight Bag can hosts purpose built software applications to automate other functions normally conducted by hand, such us performance takeoff calculations.

The EFB gets its name from the traditional pilots flight bag which is typically a heavy up to 40 pounds 18 kilograms or more documents bags at pilots carry to the cockpit the EFB is the replacement of those documents in a digital format.

EFB weights are typically 1 to 5 pounds (0.5 to 2.2 Kg) about the same as laptop computer, and the fraction of the weight and volume of the paper publications there are numerous benefits for usin an EFB but specific benefits very depending on the size of the operation type of the applications used the exiting continent management and distribution system, the type of applications deployed some common benefits include weight savings by replacing the traditional Flight Bags, reducing costs and increase the efficiency by reducing or eliminating paper processes, there are also claims of increased safety and reduced pilot workload according to the FAA advisory circular AC number 120 76 C.

EFB is an electronic display system intended primarily for cockpit flight deck or cabin use there are also militarized variant with secure data storage right vision goggle compatible lighting environmental hardening and military specific applications and data, EFB devices can display a variety of aviation data or perform basic calculations including performance data and fuel calculations; in the past some of these functions were traditionally accomplished using paper references or were based on data provided to the flight crew by an airlines flight dispatch crew

For large and turbine aircraft far 91.50-3 requires the presence of navigational charts on the airplane if an operator is sole source of navigational chart information is contained in EFB the operator must demonstrate will continue to operate throughout a decompression event and thereafter regardless of altitude, the only way is by using a solid state disk drive or a standard rotating mass drive in the sealed enclosure, the EFB market is estimated at 2.28 billion dollars in 2015 and is expected to register a cage of 13.41 % to reach 4.27 billion dollars by 2020.

- **Digital Process Optimization**

An Electronic Flight Bag replaces paper-based documents, but it is just more than document dematerialization; it is a matter of cutting away layers, doing better and faster, reducing overall costs.

- **Full-featured Electronic Flight Bag app**

EBriefing with flight plan & NOTAMS, document reader for different document types, eForms for the rapid collection of information, full text search and compliance reports.

- **Synchronization Processes**

Lean processes provide single actions to keep users up to date with all assigned content like Weather charts, forms or manuals in in their latest version.

- **On Premises or from the Cloud**

Logipad enables small, medium-sized and even large airlines a safe and secure EFB solution. We advise you, which model best, fits your existing infrastructure.

- **Role-based Management**

Roles help to ensure the provision of all relevant data to different user groups or departments e.g. flight operation, maintenance, cabin crew. The backend system ensures that users only receive relevant content.

- **Matches Requirements**

Our data processes are standardized and meets the requirements set out by the FAA and the EASA in the AC120-76B and NPA 2012-02 (former TGL-36) documentation.

- **Relationship between EFB Systems and Operational Information Flow**

With the usage of EFB systems, operators can access information about flight operations more quickly and easily. In EFB systems, the information required by users is presented in a much better format in an electronic environment. Information is stored in the electronic environment by minimizing the error rate caused by human factors and enhancing the reliability and authenticity of the information presented to the user. The use of EFBs in flight operations provides more accurate information for operational control of the user. By using EFB, it is possible to provide more information to relevant users for administrative control purposes when necessary.

- **Relationship between the Usage of EFB Systems and Cost Saving**

Businesses saving data updating process with the services and facilities/convenience provided by EFB systems, reaches faster turnaround structure. Having the ability to make more flights by saving operational time allows airline operators to run and handle more flights with the same resources. This provides long-term cost savings to businesses.

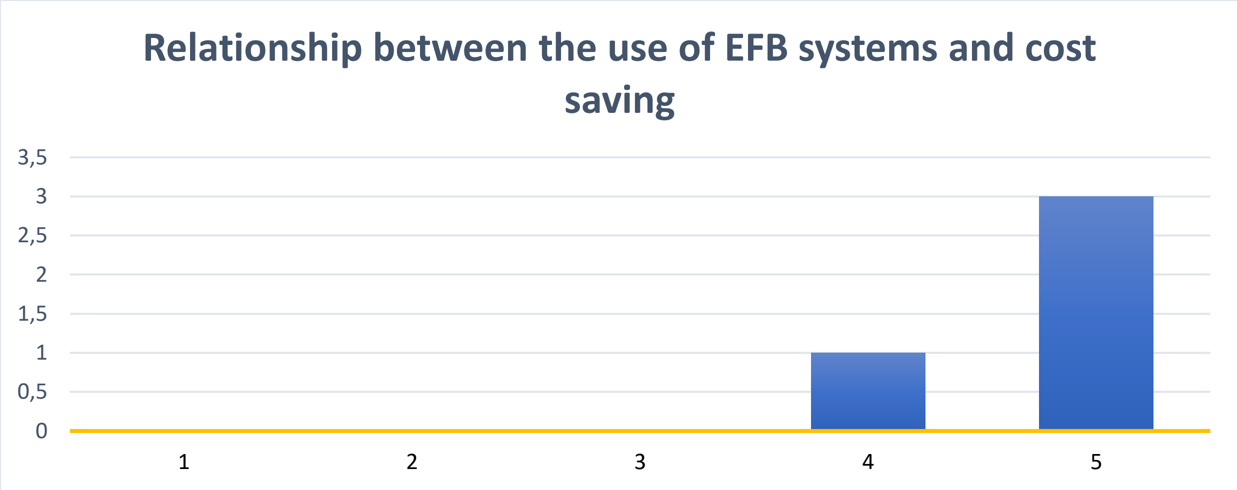


Figure 31: Relationship between the use of EFB systems and cost saving

In the future, with the developing technology, it can be foreseen to add voice command feature and three-dimensional chart display services to electronic flight bags, in order to enable live connection with air traffic units. EFB combinations with other technologies such as Google Glass instead of tablets are among the alternative technologies related to the usage of this application.

- How Will Air Traffic Management Change in The Future?

The digital age of aviation will revolutionize flight. Our skies are busier than ever. And with commercial air traffic set to double in the next 15 years, they will only get busier. In the near future, there will be 25,000 manned flights in the air at any given time that will soon be joined by an entirely new type of aviation: unmanned, autonomous aircraft. Airbus recognizes the need for unifying and harmonizing systems to ensure there will be interoperability across regions.

Around the world today, aircraft are being guided around the skies by air traffic controllers. Each controller is responsible for a sector, keeping aircraft safe by talking directly with pilots using radio communications. Estimates show that the growth of commercial air traffic is already exceeding the capacity of a human-centered system — and that is only for human-piloted flights. The expected growth of unmanned and self-piloted operations will increase traffic by several orders of magnitude.

To handle this dramatic growth, air traffic management must shift to a more scalable model: a digital system that can monitor and manage this increased activity. That system is what we call Unmanned Traffic Management, or UTM. The UTM team at Airbus has spent months executing research and tests to determine our recommendations on the best approach for a future UTM.

UTM is not a single, central system that mandates one way of operating for everything. Instead, it is a framework. It is a networked collection of services that join together and understand each other, based on common rules.

UTM is built to enable future applications. The challenge is designing a system that can remain relevant as technology progresses and market needs mature without knowing what that future will look like. For example, look at this ecosystem where all different type of aircraft serves communities through new missions and flight profiles such as self-piloted media drones, blood delivery, emergency services, and passenger delivery.

Rather than relying on centralized control, UTM frameworks around the world use the principle of distributed authority. This opens up the system to more service providers, who can adapt as the market evolves and needs change. Decentralization privatizes the cost of serving and adapting to market needs, while government regulators remain key for ensuring that safety, access, and equity are maintained.

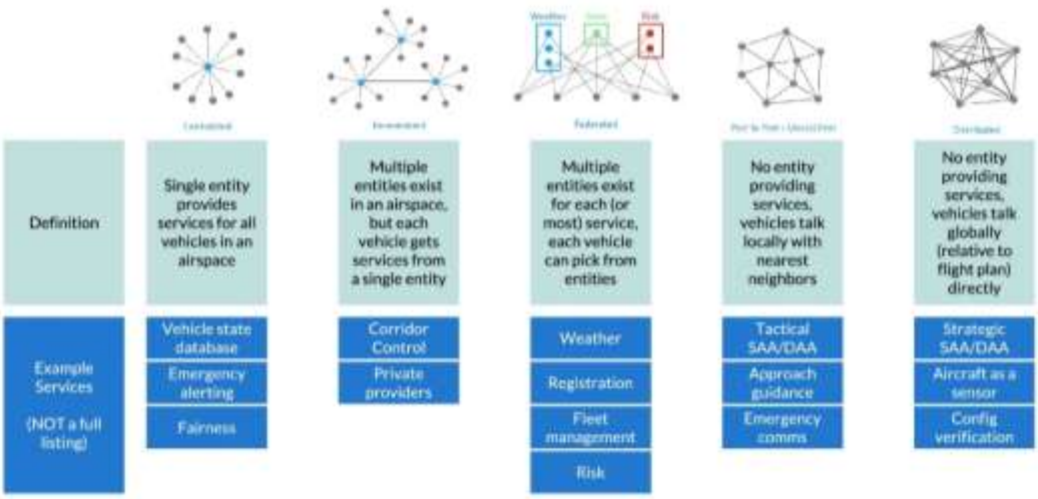


Figure 32: How Will Air Traffic Management Change

In practice, this means aircraft are no longer forced to talk only to a single entity, such as an assigned air traffic controller. Instead, aircraft can communicate freely with their service suppliers of choice, who are held to relevant safety, security, and performance standards by the authorities and coordinate with the rest of the network to make efficient decisions based on specific flight objectives.

Human air traffic controllers, meanwhile, will become airspace managers, focused on oversight, safety, and security.

UTM allows the same foundation to serve different needs in different geographies at different times. Regulators can adapt requirements to match their local needs, and operators can select the providers they need to complete their missions. Providers can create, update and deploy their own services quickly. One operator can choose to build, certify and supply its own services, while another may find the same services in a marketplace. Providers will be responsible for coordinating with each other.For unmanned applications to thrive, many stakeholders must come together to advance their respective domains. Advances can be accomplished in phases, with each phase dependent on the previous ones. As UTM shows positive results, there may be technology sharing or increased integration with traditional ATM.

- TRAINING AND RESOURCING:

E-learning is the solution to be out of paper control in training, and from its benefits: Cost-saving and time saving benefits: Statistics show that e-learning has saved businesses 50% of costs related to training when compared to traditional training which depends on a live instructor. It has also helped to decrease time spent in learning by 60%. Just imagine what businesses could do with all that extra money and time, also it increases the productivity, Employee retention, A competitive edge, Faster learning

- SIMULATOR SERVICES:

The available findings show that simulators are cost-effective for initial flight and maintenance training in institutions: they train as well as does actual equipment and cost less to procure and use. This finding applies also to computer-based instruction as compared to conventional classroom training. For example: A cost of an actual flight hour of F-16 is 5000$ but a cost of a simulated flight hour to the same aircraft is only 500$, the same for Army Missile Systems simulations have translated into cost savings and avoidance for weapons system development programs, the application of HWIL*[2] and DIS*[3] Simulation in MLRS-TGSM weapon can provide 45% reduction in flight which means $6M. Simulation is different services, there are: Simulator package, simulated hardware like Simulated Multi-Mode Navigation Receiver (simMMR), Simulator Management and Training Center Services

- FUEL OPTIMIZATION:

For any fuel optimization application, the goal is to save money by analyzing the amount of fuel in a tank at any given point along a route, the price of fuel along the route and the best places to purchase fuel based on these parameters. This can sometimes mean purchasing a minimum amount of fuel at one stop in order to have enough fuel available to make it to a better stop further along the route*[4]. Example: Fuel Dashboard, a customizable dashboard and reporting solution, allows a company to control how to view and analyze the information so it's tailored for operation, with more

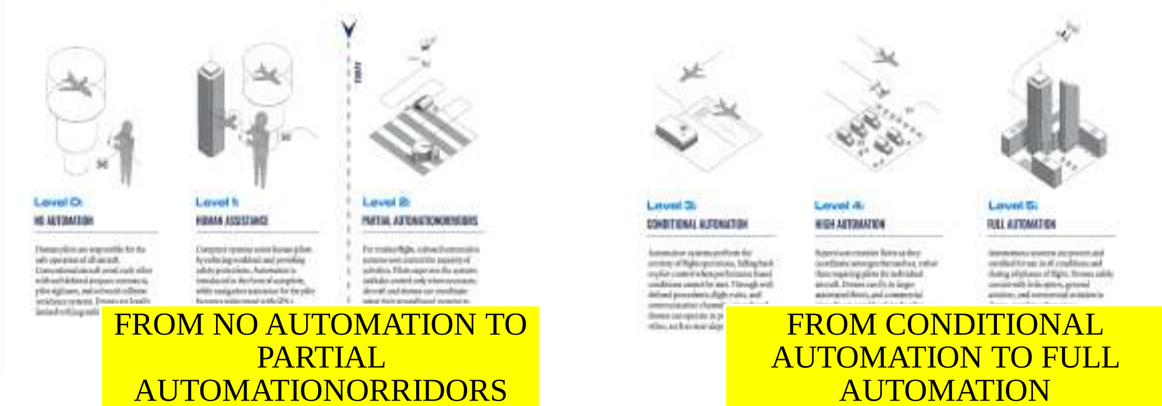


Figure 33: From none to full automation

precisely, it can modify the process and improve fuel efficiency, allowing quick decisions, and enables the company to predict fuel saving possibilities for proposed operational changes

- FLIGHT OPTIMIZATION:

- **Electronic charting**: A complete paper navigation replacement solution, a paper charting require more personnel to manage and maintain paper files, accesses and organize countless documents that's why an electronic charting means less man power, time and physical storage space are needed, for example Jeppesen's Flite Deck Pro application that delivers current navigational data to a tablet device using the smallest data footprint available in the industry.
- **Electronic Flight Bag:** An EFB based Performance calculation module completely eliminates the need for paper. A considerable amount of the data is already preloaded into the TODC module's interface from the preflight report and flight planning module as well as the load sheet. The pilot is only required to input the missing variables and a quick (avg. 2 seconds) calculation is made giving all the necessary information about the thrust and flap settings. Furthermore, in case of sudden changes in runway, cargo or meteo conditions the pilot is able to quickly recalculate the correct performance settings without wasting time fumbling with paper, also it's a lower cost solution than aircraft hardware and essential for reducing training costs.
- **Flight Planning:** While flight plan calculations are necessary for safety and regulatory compliance, they also provide airlines with an opportunity for cost optimization by enabling them to determine the optimal route, altitudes, speeds, and amount of fuel to load on an airplane, an optimized flight application like Jet Planner must into account the correct physics (i.e., airplane performance and weather) and also route restrictions from ATC and all relevant regulatory restrictions*[5].
- **Inflight Optimization Services:** Receive real-time wind, weather and traffic data based on current conditions and uplinked directly to the aircraft. Optimize step-climbs, cruise altitudes, descents and early transitions to save time and fuel. Inflight Optimization Services provide real-time information to airlines and their flight crews. This allows for adjustments to be made on route to optimize for current weather information and air traffic conditions.
- **Easier compliance:** For many companies an audit is a very onerous procedure, requiring considerable investment in time and effort by its specialists. This time costs money. When an airline is audited it is much easier to be able to present digital files illustrating how the company is keeping track of its documentation, crews hours, maintenance program, etc.

- AIRSPACE OPTIMIZATION:

Air route network optimization, one of the essential parts of the airspace planning, is an effective way to optimize airspace resources like The Next Generation Air Transportation System (NextGen) is a program designed by the FAA to enhance and modernize the air traffic control system. Elements of NextGen will be implemented in stages across the United States between 2012 and 2025. NextGen proposes to transform the air traffic control system from a ground-based system of navigation and surveillance to a satellite-based system and transition from voice communication to data communication. Satellite-based technology (often called global positioning technology – GPS) will be used to shorten routes, save time and fuel, reduce traffic delays, increase capacity, and permit air traffic controllers to monitor and manage aircraft with greater safety margins.

3- Maintenance and Engineering:

- MAINTENANCE, REPAIR AND OVERHAUL (MRO) PROCESSES

Maintenance, Repair and Overhaul (MRO) processes have a major impact on life cycle costs and thus play an important role in life cycle engineering. The purpose of MRO is to keep machines and facilities running without loss of efficiency. In case of old machines, a decision should be given for replacement or modernization at the right time. MRO operations are not successful when they are performed by machine owners or third party companies which have little knowledge about machine configuration and functionality. A maintenance plan is generally considered to be confidential. Repair processes are in general unique processes, because of different failure cases. e.g. a crack on a engine part has a certain depth, length and shape. Whereas little cracks can be repaired bigger ones require exchange by a spare turbine blade which is either in stock, must be ordered or remanufactured. This process includes a lot of manual work with measurement technologies, diagnosis and decision making. New inspection technologies are needed to digitally capture, interpret and unambiguously describe product condition to enable decision making. In many cases IT systems in the MRO sector like ERP (Enterprise Resource Planning), PDM (Product Data Management), DMS (Document Management System) and CMMS (Computerized Maintenance Management System) are neither integrated horizontally with customers, suppliers and OEMs nor integrated vertically with MES (Manufacturing Execution System), SCADA (Supervisory Control and Data Acquisition) or PLC (Programmable Logic Controller). Beside there is a lack of information and data exchange between design and MRO phase within the life cycle. This makes traceability of product configuration changes during life time a difficult task and has to be considered in a holistic configuration management approach. These difficulties prevent MRO process automation and induce huge costs for machine downtimes. New IT concepts and PSS solutions are needed to close the digital life cycle chain. The innovation field MRO Planning and Digital Support of Fraunhofer’s Innovation cluster MRO addresses these issues and aims for improvement through digital MRO support by innovative information and communication technologies as well as 3D data generation and visualization. Focus lies on digital assistance and functional validation, adaptive MRO scheduling, information and configuration management, collaboration tools, virtual training and augmented reality.

In Industry 4.0, MRO systems will make it possible to execute all the administration, planning, and organization of operation and maintenance work, including documentation, in a single integrated system. This means that any changes due to service bulletins and maintenance operations will be communicated through the digital thread, in real time, to both engineering and services departments. Safety will also be improved through “virtual training” that also optimizes maintenance work.

Aviation Voice cites three major trends for 2017; The Internet of Things (IoT) driving adoption of Aircraft Health Monitoring System (AHMS) health checks and condition-based maintenance. Expect to see a rise in the number of operators adopting AHMS, driven by affordable IoT-enabled sensors, powerful data processing systems, and machine learning—all enabling airlines to make processes smarter and maintenance leaner.

- **Maintenance training:**

Effective maintenance training is key to successful airline operations and digital maintenance training is more comprehensive and flexible, digitization in this field will ensure more airplane knowledge transfer to technicians, also with digitization courses can be delivered to companies anytime and at any suitable locations which mean less transport costs and no paper.

- **Predictive maintenance:**

Designed to reduce overall lifecycle management costs, expect to result in dramatic savings –in time and money- and for defence it improves weapon system availability and performance, can also be applied to infrastructure and support equipement, Airbus has already approached plans to digitize predictive maintenance, one of this plans called PRM (Prognostics and Risk-Management), Delta Airlines is a launch customer after a year-long collaboration with Airbus.

This Web-based application combines calculations based on a tailored aircraft condition monitoring system report loaded in an aircraft, parameters collected inflight and sent to the ground via ACARS, and algorithms to detect aircraft system degradations, By using PRM for three sets of parts, Airbus has saved operators $550,000 over 12 months from monitoring just a few parts on 40 Airbus A330s.

- **Reliability analysis:**

Examining changes in the reliability of repairable systems over time and the number of failures expected during a particular time period, it's better to use technology and software's for no faults, and to reduce fleet maintenance costs and down time.

- **Maintenance Programs:**

Very heavy manuals, transporting it is hard, if there is any problem, searching at it will not be easy, clock clock time is running, specially fore line technicians with the few time they have, working pressure is a lot this lifts the value of errors a lot (for example 'Air Algérie' line technicians declared because shortage of time sometimes they really don't have time to fill the procedures, and with some bad communication between groups this can take to rework) sure this is a big lose in time, money, and labor, what is the solution? Making their job easier, eLog book, eDocumentation, eManuals, eRecords, eArchives, Auto - ID Parts Identification, and Electronic Signature will change a lot.

- **Developing a robust predictive aircraft maintenance**

Although most commercial jets still operate engines with limited sensing capability (around 250 sensors), the last onboard maintenance systems manage to enable structure preventive maintenance services. Typically, A380 preventive maintenance system is able to generate a list of "pending items to fix" to prevent the next failures causing MMEL issues affecting aircraft dispatch. Ground statistical analysis of fleet historical aircraft maintenance messages and aircraft condition monitoring are used to start preventive maintenance actions upon preventive conditions. Nevertheless, these systems are not able to provide information about the real-time remaining tolerance margin before the occurrence of the next impacting MMEL item, in terms of additional remaining failures of line replaceable units, failure combination and quantified risk.

However, with the advent of Aviation 4.0, the challenge of achieving a real-time effective predictive maintenance capability is becoming a new market for the aeronautical industry. The A350 is able to record in-flight 400.000 parameters, what combine with big data analytics have the potential to comprehend the comportment of the aircraft deeply enough to conduct the maintenance interventions before failures occur. To exploit this market, Airbus and Rolls-Royce have already established a partnership to offer a global expertise in predictive maintenance on A350.

Predictive maintenance has the potential to avoid accidents and extend the aircraft's lifetime by the anticipation of problems before they worsen and spread, and even by programing maintenance of replacement just before the failures or problems occur. The advantages of Aviation 4.0 IoT aircraft extend to fuel costs and efficiency. Real-time analysis of an airplane engine's sensors can detect and correct the operating inefficiencies that translate to increased fuel consumption.

The potential of predictive maintenance combined with synchronized logistics will have the potential to improve turnaround times, diminish maintenance interventions and the time and number of inactive aircraft in hangars while waiting for parts and service. Real-time reception of the onboard data will allow ground maintenance teams to have parts and technicians ready before the plane lands, so the technical interventions might be done in the minimum time, reducing affections to the flight schedule.

If additionally combined with augmented work technologies, the maintenance work could be transformed into an enhanced troubleshooting environment where technicians might have in a single view of all necessary maintenance information pertinent to the problem. This will reduce the occurrence of human errors during maintenance interventions, impacting positively the probability of accidents due to maintenance errors as well as improving both efficiency and economics. This information is useful for maintenance purposes after the flight has landed, and the data are downloaded and evaluated. What if centralized maintenance and aircraft condition monitoring data were received in real-time by maintenance personnel on the ground? Or combined in real-time with data analytics, centralized maintenance and logistics information? Or used to integrate aircraft preventive diagnosis with information coming from prognostics?

Data received in real-time by personnel in charge of the maintenance while they are on the ground waiting for the flights will allow the maintenance teams to anticipate any problems before the flight lands, and it will allow technicians to have the parts and specialist ready for a quick intervention. Data analytics and interconnected smart sensors will allow to combine predictive maintenance with synchronized logistics system and reducing not only the risk of in-flight failure but also the cost of aircraft awaiting parts and service.

Maintenance technicians are alerted of a maintenance problem from ACARS messages, voice messages, the aircraft crew logbook and/or conversation with the flight crew. But until now, the troubleshooting information needed to combat the problem has not been centralized, and is not easily accessed while the technicians are on the ramp working on a plane. Technologies like Google Glasses have the potential to recreate complex diagrams and technical information in a 3D-augmented reality environment that boosts the perception of the technicians about the problem and its possible solutions. Maintenance teams might benefit from augmented work technologies to enhance the maintenance and service. An enriched troubleshooting environment with an integrated view of all necessary maintenance information pertinent to the problem might become a fourth dimension that enables remote assistance and guidance as well as real-time access to the most complete documentation while on the job.

- Industry Has Moved from Talk to Action

The buzz around Industry 4.0 has moved from what some had earlier seen as hype to investment and real results today. The aerospace, defence and security participants in our survey plan to invest 5% of annual revenue in digital operations solutions over the next five years, in line with the level of investment reported across all the industries that we surveyed.

It is a significant amount in the context of a sector where margins can be tight. Although the commercial aerospace side of the industry has the benefit of a very long-term order book and production horizon, it also has the need for very tight near-term delivery discipline. Investing in capacity-boosting innovation carries risk and uncertainty, particularly for smaller and medium-sized companies below tier one level. And on the military side, investment continues to be framed by constraints and uncertainties in government spending.

Chapter 3

Airlines compagnies

Aerospace is a whole integrated industry with each other, we can’t split any part of it away at the other, and when industry 4.0 have introduced to aerospace leaders, it included all the fields in this industry, so we can’t talk about production or thinking to take a design without thing about the customers ‘Airlines compagnies’

Ⅴ. Chapter 4 : The smart airport

Today's airports are no longer just places where airplanes take off and land. Instead, airports are vital economic generators providing gateways to their cities, states, regions and countries. Airports are important for tourism and other business, handling people and goods traveling by air and offering transport connections between aircraft and with all other modes of transportation. In 2014, aviation's total contribution (direct, indirect, induced and tourism-catalytic) to the global gross domestic product exceeded US$2.7 trillion1 and none of that contribution would have been possible without airports.

In this very competitive environment, airports are focused on expanding and enhancing their appeal to increase their community's share of air travel and tourism, innovating and maintaining a strong focus on enhancing customer experience. While safety and security always remain airports' top priorities, their leaders also focus on ways to streamline airport business and operations. They leverage technology to meet and exceed goals and objectives. In today's digital world there is no escaping the power of data, so harnessing its benefits is key.

Airport leaders acknowledge that business success is not just about the deployment of new technologies, simply because IT systems and applications change too quickly. Instead, success is about transforming the business of airports, adapting to customers, staff, community and cultures and leveraging existing and new technologies to meet objectives and goals.

Countries throughout the world are promoting transformation with visions such as that of Singapore: "harnessing of technology to the fullest with the aim of improving the lives of citizens, creating more opportunities, and building stronger communities," a Smart Nation is "built upon the collection of data and the ability to make sense of information." Similarly, the city of Barcelona, Spain, applies innovative solutions in its management of services and resources, all to improve the quality of people's lives. With the help of Hitachi, vast amounts of data generated in the city of Copenhagen, across public and private websites, have been homogenized into an easily accessible format and used to make the city "smarter," driving productivity, supporting sustainability and improving the quality of life for those who live and work there.4 The Netherlands is a world leader in smart-city applications and in the fields of autonomous driving and e-mobility.

Now is the time for airport leaders throughout the globe to embrace the digital transformation. As such, Airports Council International (ACI) has set out to develop a guideline document to help leaders understand what digital transformation is; what digital transformation means to the airport business, its customers and operations; approaches for evolving the organization; and, the high-level impact of digital transformation on risks and opportunities.

Digital transformation for the airport is about evolving processes and services to deliver a better experience to all passengers and customers, by adopting and implementing new technologies and integrating them with existing ones.

From the viewpoint of the passenger, a better experience means a personalized and individual experience which offers a seamless flow through the airport. It starts before the passenger even arrives at the terminal.

From the moment travelers start planning their journeys they have numerous choices for obtaining additional information, offerings and enhanced services from the multitude of websites and applications offered by traditional and non-traditional travel companies. At the airport terminal, a multitude of programs makes it nearly impossible for passengers to know which one will be the most informative. This becomes a big challenge for airports throughout the world as they vie for the digital and physical attention of passengers. If an airport is not successful in gaining direct engagement with its customers, there is a great risk that a third-party disrupter will fill the gap, diverting customers away from the airport and taking control of the attention of passengers, even inside the terminal, putting at risk any loyalty to that airport. As soon as passengers purchase their airline tickets, they should be able to plan their journeys to and through the airport and reserve offered services such as parking, security fast track, lounge access, concierge treatment and food and concession promotions.

From the staff's perspective, an understanding that the assessment, application and results of digital transformation belong to the entire team will help create a culture that promotes speed and agility; governance and incentives; and, risk-taking and experimentation.

Digital transformation should provide a number of strategic goals and benefits. In terms of internal gains (which includes operations and staff), the focus is on cost savings, e.g., improving overall productivity, introducing Internet of Things (IoT)/Smart Building management, and digital touchpoints. Major drivers for airports in providing external benefits are their customers (passengers and visitors, airlines, ground handlers, local communities, etc.), enhanced services, improved collaboration and increased revenue. Furthermore, digital channels and distribution not only will drive results but will also create completely new business models such as use of commercialized Application Programming Interfaces (APIs).

1. How to become a digital airport

Many companies in the aviation sector think they are digital-ready in offering a digital mobile app here, or a redesigned website there. However, this is only a small part of the overall transformation. Having learned why digital transformation matters and what this transformation actually is about, it is important to discuss the technologies and building blocks that can be applied to drive real change within your organization.

Next figure shows a possible path to becoming a digital ready airport. This path is not meant to be the only way of achieving this goal; the order of enablers may vary depending on your airport's current situation. Nevertheless, it shows dependencies in a typical, reasonable sequence.

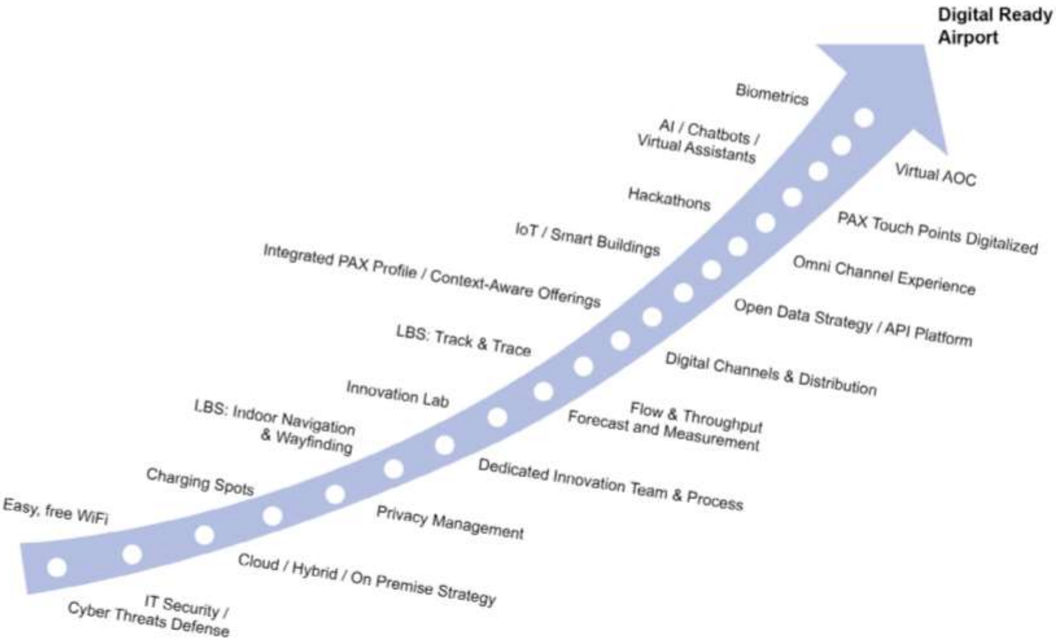


Fig 34. Enabling technologies for becoming a digital airport

To assist airports further, the ACI Airport Digital Transformation work group has also produced a Digital Airport Survey, which includes the latest technologies. The intent is to enable self-assessments so you can identify your airport's status along this evolution

2. Process

As described in Section 3, digital transformation is already happening. So airport managements at all levels should not be thinking about if it will happen, but rather how it will do so, in order to leverage technology to maximize business and operational objectives. This chapter focuses on key steps to help airports through their own digital transformations.

To begin, each airport must truly understand the full scope of the environment in which it operates. Next, it should align its business and operational objectives to the environment. Only then is it possible for an airport to understand how to leverage technology and transform itself to meet these objectives.

While each airport's outcome will be unique, the basic steps of digital transformation are common:

1. Airport environment assessment: A multi-dimensional review of the airport's characteristics, including but not limited to its physical, customer, market, local community and economic characteristics and socio-political influences upon it;
2. Airport plans and objectives: A specific step for airport C-level management to agree on the priority and actions of specific digital plans and identify areas where technology (existing or new) will improve the outcome or desired results; and,
3. Internal organizational review and requirements: An assessment of the current organization and competencies versus what is needed to remain flexible and agile through the digital transformation and beyond.

Finally, it is important to acknowledge that because speed of evaluation, trial, adoption, etc., is critical and technology evolves quickly, airports should review these steps every few years to ensure that the right solutions are in place to provide the best results (financial, business, operational, customer service, etc.).

3. Where does an airport begin to apply digital transformation?

The short answer is everywhere; however, this is not realistic. Taking into account the airport's current environment as well as its business context and objectives, the airport should prioritize and create specific digital transformation plans. Within each digital transformation plan, assessments of different areas such as potential functional areas of applications, internal team readiness and structure and the external market and partner landscape are recommended, in order to define where and how to begin the digital transformation journey.

4. Potential functional areas of application of digital transformation

Digital transformation impacts all aspects of the airport, so in order to focus on the most promising area it is critical to identify key domains where the digital strategy should be deployed to improve significantly processes and services such as:

- ✓ Airport operations: While "digital" is often interpreted as "business disruption," it is important to understand that the digitalization of the core business is often a good way to start to realize benefits. A few examples of digital applications for core processes can illustrate some of the benefits. A resource management system leveraging the IoTs can provide more comprehensive solutions as it considers systems beyond just aircraft estimated time of arrivals (ETA) and estimated time of departures (ETD). Employee efficiencies will increase by leveraging collaborative and web-services platforms; financial services to streamline and dematerialize Account Payables and Receivables processes will improve revenue recognition and fund availabilities; and intelligent building management will reduce electricity and gas usage and lower utility bills.

- ✓ Security: Security remains a high priority for all airports. In combination with video infrastructure, leveraging artificial intelligence can deliver significant enhancements such as biometric recognition, unusual behavior detection, profiling, unattended-baggage management and monitoring and control of building and fencing access.
- ✓ Capacity management: A deep understanding and monitoring of passenger flow can help to optimize the capacity of airport infrastructure and retail services offerings, as well as offering predictive maintenance that will reduce maintenance costs and maximize airport-asset utilization.
- ✓ Passenger services and intimacy: Customer-focused mobile applications coupled with big data and Customer Relationship Management (CRM) can help airports to provide personalized and differentiating e-services to passengers, allowing them to prepare and enhance their airport experience and enhance their consumption of airport services.
- ✓ Stakeholder management: A successful digital transformation can provide tangible and economic benefits to every airport stakeholder— airlines, passengers, investors, local communities and employees. Digital technologies can be a great help in enhancing airport stakeholders' relationship management, using collaborative tools to provide and gather information.
- ✓ External: It is important to assess physical and functional areas not only inside an airport but also outside it, in the local and virtual communities in which the airport is situated. Airports are encouraged to leverage market innovation through strategic partnerships with key solution providers and service and/or technology providers, because these will help to accelerate digital transformation. This can be done in multiple ways depending on the airport's environment and local needs.

Building an open ecosystem will help to anticipate business-model evolution and increase the airport's agility to respond to business needs and create more value for all stakeholders. This can be done through multiple channels such as strategic alliances, capital investments, joint ventures or even strong commercial relationships with key vendors in the market.

5. Big Data applications in digital transformation of airports

Fig 35. Data technology

Widely accepted as a disruptive force which changes management mind sets, business processes and business models, digital transformation has been evolving for decades – ever since the first automated baggage sorting systems appeared in the 1990s and the first e-ticket was issued in 1994.

Today, terms like connected traveler; smart airport; self-service airport; in-terminal location-based services; and management process visualization are now in common usage, but what do we mean by digital transformation? The concept is defined by three separates, but intertwined, drivers: Digitization, Connectivity and Data.

6. Big Data applications

Big Data is the end result of the digitization process and the evolution of connectivity. Trends in digitization and connectivity define the airport of today, but Big Data will define the airport of the future.

The sheer volume of data handled by businesses necessitates Big Data Analytics (BDA). Airports are now recognizing this need as they focus on optimizing processes, improving productivity and minimizing costs; while evolving from B2B to B2C organizations.

Many of the analytics solutions currently used by airports relate to Business Intelligence (i.e. management dashboards and reporting) to support performance management and traffic flow forecasting for short- and long-term planning.

In future, however, airport managers will use analytics to help them visualize airport operations in 3D and based on real-time data inputs. It is also conceivable that airport systems will be taking automated actions on behalf of managers to remove bottlenecks and improve efficiency. This will be the first manifestation of Artificial Intelligence (AI) in the airport environment.

7. Benefits to airport managers

The benefits to airport managers can be summarized as follows:

- Process Optimization:
  - ✓ Enabling an airport's Business Process Improvement (BPI) team to identify problem areas, measure performance and take necessary actions
  - ✓ Allowing both short term and long-term planning
  - ✓ Improving employee productivity
  - ✓ Delivering synergies amongst stakeholders
  - ✓ Reducing costs
- Business Model innovation
  - ✓ Allowing the development of new non-aeronautical revenue streams, thereby enhancing the creative campaign process
  - ✓ Enables, for the first time, airports to know and segment airline passengers in order to offer new services to the right people at the right time and at the right price
- Customer Experience improvement
  - ✓ Improvement will come through process optimization and business model innovation, but could be targeted specifically through digital transformation
  - ✓ Allows airports to develop unique services to facilitate the passenger journey through each and every airport touchpoint

8. Risks

The biggest risk to any airport will be to ignore digital transformation. Every business and organization will be impacted by digital transformation, either directly or indirectly, and airports are certainly not immune to digital disrupters.

In addition, airports should not believe that technology is the silver bullet of digital transformation: Digital transformation will not solve all issues, challenges and risks. ACI believes that successful digital transformation arises not from implementing new technologies but from transforming organizations so they can leverage the possibilities new technologies offer.

Cyber-security and data protection are high on the risk register, because digitalization of operational processes and customer interaction is reinforcing the negative impact of malfunction and is increasing the threats posed by cyber-criminality.

Finally, because digital transformation is touching all aspects of airport organizations and processes, it is important for the airport's C-level managements to build and manage a digital transformation plan to define targets and priorities. This will help to prevent scattershot implementations and the risk of not delivering step changes.

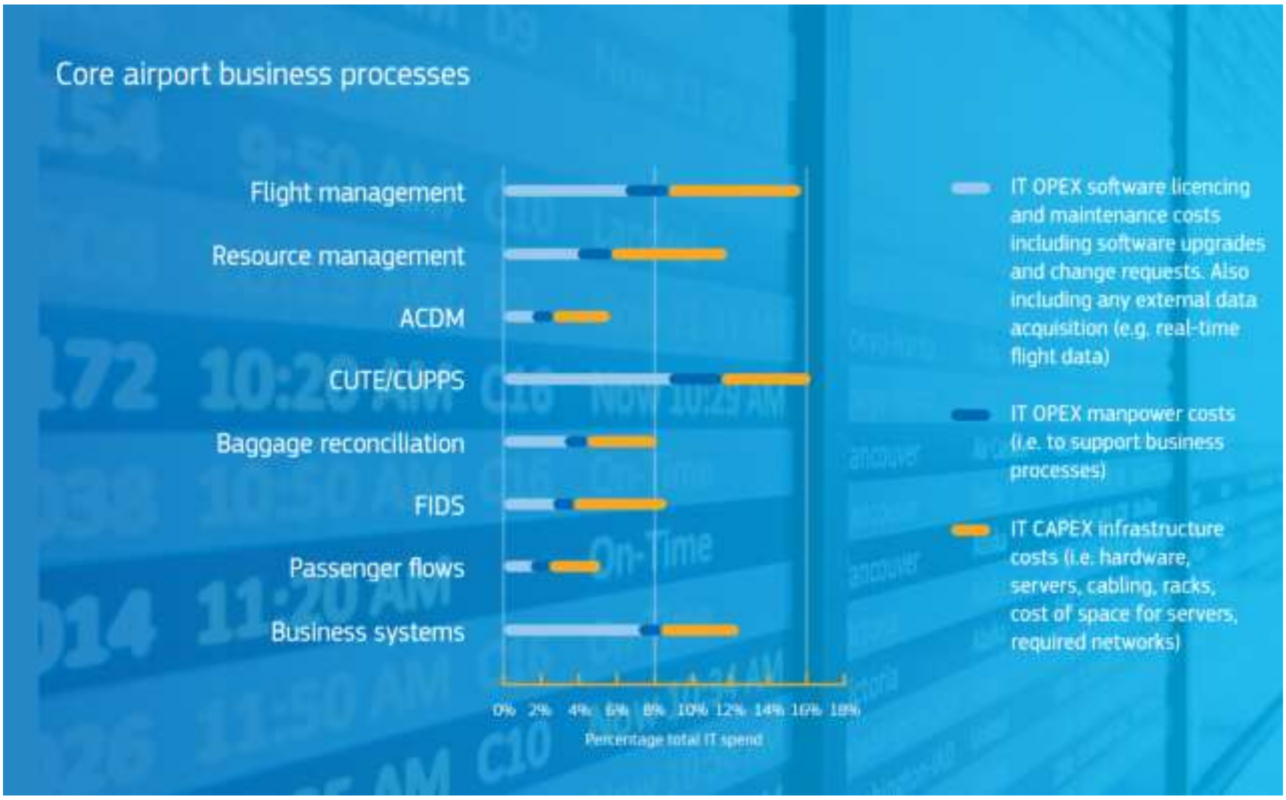
9. Digitalization in Air Cargo

The air cargo shipment has to be accompanied by many shipment papers, which are necessary for declaration or description of the content could be drone electronically. Therespectivefactors(paperstransmittedelectronically/papersintotal) in Frankfurt differs from airline to airline, from forwarder to forwarder, but does not exceed 30% so far. Penetration rate of electronic airway bills (eAWB) just reached the global 50% mark and is lagging behind the expected development. Several activities have been conducted, by the International Air Transport Association (IATA), or the local collaboration platform increase the digitalization share, but did not show fundamental success by now

10. The role of digital in driving cost and efficiency benefits:

If the focus in recent years has been on the development of advanced big data and analytics capabilities, then looking to the future, what is the role that digital can play to help airports to reduce their total cost of operations and improve the efficiency of core airport processes?

To address this question, the study first considered the relative IT cost and efficiency of eight core airport business processes, ranging from resource management and baggage reconciliation to FIDS and business systems (see next Figure). Following this, airports and other industry experts were consulted to provide specific insights into how they expect digital solutions be applied to reduce the cost and enhance the efficiency of these processes in the future



. Fig 36. Core airport business processes

11. Series conclusion

As with any industry, airports can be classified as innovation leaders, innovation laggards, or somewhere in between.

Some airports, such as Geneva, Doha International and Dubai International, have defined clear objectives on using digital technologies to build brand equity and be seen as industry innovators. Düsseldorf went a step further by deciding fund innovation.

Others, such as London Gatwick may prefer to take smaller steps and focus on improving processes in smaller areas with a multitude of measurable benefits. There is no right or wrong approach in the speed of innovation, nor in the project size, as long as there is a clear vision (call it the “End State”). After all, the digital roadmap should be linked to the strategy map, whether the airport is building a digital terminal or a smartphone application.

Digital transformation of airports is intensifying and manifested by digitization, connectivity and big data trends – covered individually in the three parts of this series:

- ✓ Part One: Digitization of Airport Processes
- ✓ Part Two: Connectivity of systems, people and things
- ✓ Part Three: Big Data applications

Chapter 4

The smart airport

Airports are a very important part from aerospace industry, that we can’t just talk about it in small paragraphs, the perfection of costs reduction need to take care about all the parts

VI. Chapter 5: Digitalisation application, an Aerospace drone:

1- Introduction:

Technology is disrupting the way air traffic is managed both in the sky and at airports. This is especially true when considering the speed at which drone technology is advancing and impacting operations.

Drones and their larger cousin, remotely piloted aircraft systems (RPAS), will therefore be a key consideration for airports going forward. All forecasts show that civil drone and RPAS use growing hugely in the years ahead. The drone services market is expected to grow substantially.

Estimates vary between €10bn by 2035 and €127bn for the coming years. A recent forecast predicts that by 2020 the global drone market size will grow by 42% in precision agriculture, 26% in media and entertainment, by 36% in inspection and monitoring of infrastructures, and by 30% for leisure activities.

Airports are deliberating how they will use this new technology. It is likely, for example, that drones will be used for a host of regular inspections. A recent survey amongst ACI members suggests that routine activities, such as aircraft checks, aerial photography for planning, mapping or marketing purposes and the inspection of runways, airport perimeters and airfield for damage or for security reasons are seen as promising applications for drones on airports.

Airports can also acquire new revenue streams by allowing larger drones or RPAS to land. But drones can also mean having to rethink surface operations and investing in geofencing technologies to safeguard existing manned traffic.

Some of these challenges are reflected in ACI EUROPE's position paper on drones in January 2018.

1. Keeping airports safe from unauthorised drone activities especially by leisure drone pilots or criminal acts, while

2. Facilitating the use of drone technology where it adds value to an airport's operations or commercial activities.

2- Quadrotor history:

Etienne Oehmichen was the first scientist who experimented with rotorcraft designs in 1920 [(54)]. Among the six designs he tried, his second multicopter had four rotors and eight propellers, all driven by a single engine. The Oehmichen used a steel-tube frame, with two-bladed rotors at the ends of the four arms. The angle of these blades could be varied by warping. Five of the propellers, spinning in the horizontal plane, stabilized the machine laterally. Another propeller was mounted at the nose for steering. The remaining pair of propellers was for forward propulsion. The aircraft exhibited a considerable degree of stability and controllability for its time, and made more than a thousand test flights during the middle 1920. By 1923 it was able to remain airborne for several minutes at a time, and on April 14, 1924 it established the first-ever Fédération Aéronautique Internationale (FAI) [55] distance record for helicopters of 360 m. Later, it completed the first 1 kilometer closed-circuit flight by a rotorcraft.

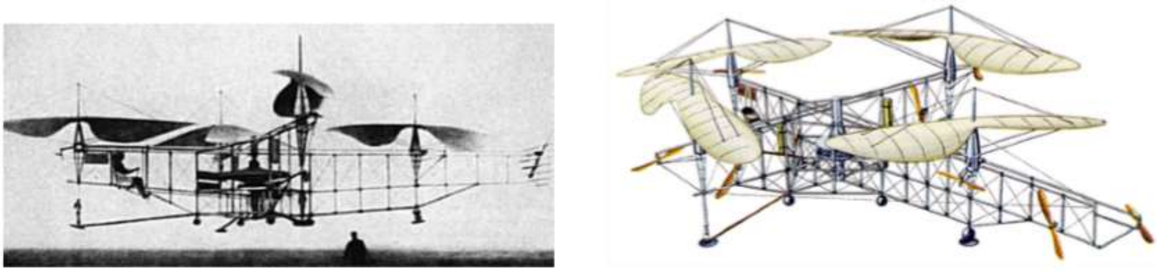


Fig 37. Oehmichen No.2 Quadrotor [54]

After Oehmichen, Dr. George de Bothezat and Ivan Jerome developed this aircraft [54] with six bladed rotors at the end of an X-shaped structure. Twosmall propellers with variable pitch were used for thrust and yaw control. The vehicle used collective pitch control. It made its first flight in October 1922. About 100 flights were made by the end of 1923. The highest it ever reached was about 5 m. Although demonstrating feasibility, it was underpowered, unresponsive, mechanically complex and susceptible to reliability problems. Pilot workload was too high during hover to attempt lateral motion.

Fig 38. The de Bothezat Quadrotor [54]

Convertawings Model A Quadrotor (1956) was intended to be the prototype for a line of much larger civil and military quadrotor helicopters [54]. The design featured two engines driving four rotors with wings added for additional lift in forward flight. No tail rotor was needed and control was obtained by varying the thrust between rotors. Flown successfully many times in the mid-1950s, this helicopter proved the quadrotor design and it was also the first four-rotor helicopter to demonstrate successful forward flight. However, due to the lack of orders for commercial or military versions however, the project was terminated. ConvertawingsproposedaModelEthatwouldhaveamaximumweightof19,000 kg with a payload of 4,900 kg.

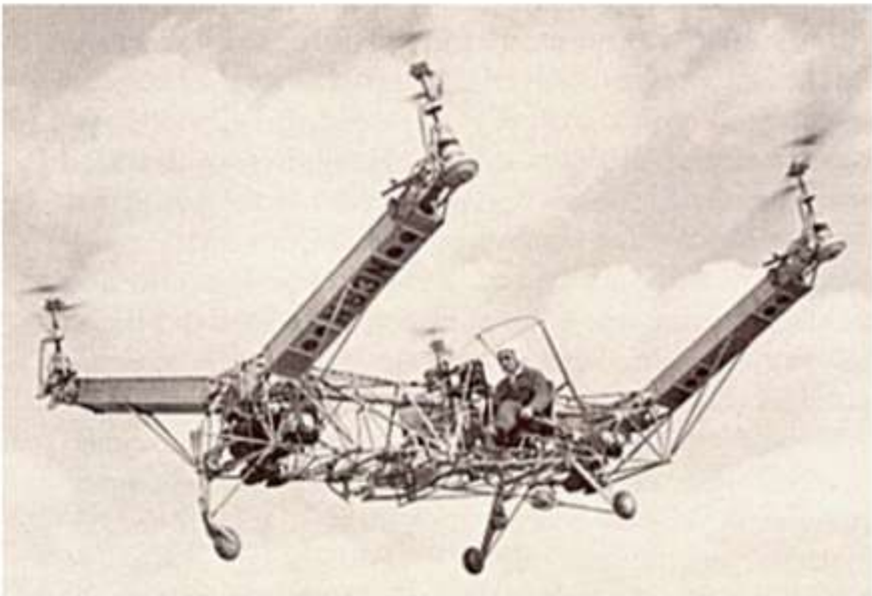


Fig 39. The de Bothezat Quadrotor (54)

3- Commercial Uses of Drones:

From agriculture and filmmaking to insurance and online shopping – and even international humanitarian organizations – drones are being used to great effect in widely differing industries. Here are some highlights of the applications that are really moving the needle of how drones can be a transforming technology in 2018.

- Farming & Agriculture

Drones in agriculture bring a level of precision and automation tech that, when combined with a farmer’s know-how, make for a powerful combination. Drones can perform complex tasks that are simply impossible for farmers to do themselves on the scale and with the accuracy that the UAVs are able to:

- Monitoring soil and crop health
- Applying water and fertilizers to the fields
- Tracking weather
- Collecting and analyzing data to develop short-term action plans, as well as long-term yield estimations

- Business

With new applications arising all the time, it’s difficult to create a comprehensive list of how drones are being used by various businesses. But, suffice to say, UAVs are already changing the status quo, even if many of the uses listed below are still in early stages, currently without large-scale adoption:

- Photography and videography technology
- Shipping/delivery services
- Aerial surveying/mapping
- Site inspections
- Video tours for real estate

- Drones in construction

The success of drones in the construction sector is due to their well-thought-out implementation by many large companies. In the construction industry, unmanned aerial vehicles provide easy access to large or hard-to-reach facilities, as well as to complex or high-rise facilities. They are able to provide aerial photography data, map information and images used for:

✓ land surveying;
✓ building inspections;
✓ provide visual materials to customers and employees;
✓ monitoring the progress of work on the construction site;
✓ security control;
✓ mappings.

What the future of the construction industry looks like thanks to the growth of intelligent solutions, automation and the use of unmanned aerial vehicles

- Aerospace

The aerospace industry is also exploring the use of drones to provide inspections of commercial aircraft. With traditional technology, visual inspections can take up to six hours, but drones could significantly reduce the amount of time and provide increased accuracy and ease of documentation. When combined with visual processing algorithm systems, the footage gathered by the drones could send service work orders to an aircraft's maintenance team as soon as a fault is identified. This could lead to greatly reduced maintenance service costs and improved overall safety.

4- Drone Regulations

As often happens with new technologies that achieve a wide level of exposure and popularity in a short period of time, UAVs have been operating under what amount to temporary regulations, created by governing bodies that did not yet have enough data to create fully fleshed-out rules. Right now, for instance, the FAA treats all UAVs the same under its regulations, from small drones marketed at hobbyists to large, complex UAVs that can transport large parcels over great distances. The main aim of these regulations is to prioritize the safety of the airspace being travelled by traditional manned commercial and private aircraft, but they do not address the vastly different experiences and objectives of hobbyist's drones vs. business drone users. Drones are utilized in many industries and each company can use drone tech differently.

In June 2018, the European Union passed EU-wide safety standards for the manufacture and operation of drones. Among other things, these regulations include design requirements that would allow for collision avoidance and automated landing systems, drone operator training requirements and national drone registry requirements for all EU member states.

While the FAA has regulations in place, they are trying a different tack to achieve their vision for fully integrating unmanned aircraft systems (UASs) into the National Airspace System (NAS), reaching out to the drone pilot community to help create regulations based on how drones are actually being used. The UAS Integration Pilot Program recently chose its first 10 participants, which included local, state and tribal governments as well as several businesses.

5- The Continuing Role of Drones in the Future

Drones have the potential to save significant time in checking product inventory as they can reach high-up areas that operators cannot easily access from the ground. The American retailer Walmart is currently developing and testing a drone system for this purpose. The drone is manually controlled, and automatically reads labels on the stock using a camera. Walmart estimate that this drone system will complete an inspection in 1 day, rather than the 30 days to carry out the inspection manually.

Internal inspection drones may also find uses in inspecting finished assemblies. For example, a drone can be used to detect minor cracks, missing rivets and scratches on an aircraft assembly. A key enabler for this drone application is image recognition technology. Even though a drone won't become fatigued and lose concentration like a human operator, it is still critical that every imperfection is recognised, meaning that this technology is still some way from commercial implementation.

Delivery drones such as those being tested by the likes of Amazon and UPS, are perhaps the most exciting commercial application of drones. For instance, internal delivery drones can act as delivery systems for small components. Drone are particularly suitable for applications with low-medium throughput, but with a large variety of delivery paths. However, the prospect of a drone flying above worker's heads is something which may cause some concern, especially considering many mid-size drones weigh greater than 10kg including payload. Another issue is drone noise, as a drone is approximately as loud as a vacuum cleaner. Possible solutions to these problems include using safety netting, and routing flight paths away from operators.

Delivery drones can carry packages for up to roughly 40 minutes on a single charge. Most drones on the market cannot fly for this length of time because of non-maximised battery capacities. Presumably the cost of extra batteries and the potential for advertising improvements in the future, are reasons why manufacturers do not maximise their flight time.

For fully autonomous drone systems to work effectively, automated charging stations are necessary. The latest method for automatic drone charging is by using inductive charging pads. A drone simply has to land on the pad, without the need for an operator to plug in a charging cable. For situations where the drone needs to operate almost continuously, there are battery swap stations. Although complex and expensive, these enable very high utilisation of the drone.

The widespread implementation of drones in industry looks to be inevitable. PWC (PricewaterhouseCoopers) are predicting revenues from commercial applications of drones to massively expand from the current $2B to $127B by 2020. The benefit of using a drone inside a building is that there are currently no FAA regulations which apply. This means there is almost complete freedom for companies to test drone capabilities inside a facility, providing health and safety guidelines are met. Companies should therefore make the most of this freedom, and push to test and develop this technology for the future.

6- Our Idea:

Our idea from the beginning was to realize a drone with the ability to use it in aerospace industry, we choose a multirotor because it's big ability to maintain it's stability in different situation, easy to control and manoeuvre with and without human, have the ability to hover, can fly vertically and horizontally (proper for the shape of the aircraft), take off and land vertically, more compact in size, a lower flight speed which it is consider good in or case and can land in designated spot.

7- Mathematical model:

- Preliminary notions:

The quadrotor, an aircraft made up of four engines, holds the electronic board in the middle and the engines at four extremities. Before describing the mathematical model of a quadrotor, it is necessary to introduce the reference coordinates in which we describe the structure and the position. For the quadrotor, it is possible to use two reference systems. The first is fixed and the second is mobile. The fixed coordinate system, called also inertial, is a system where the first Newton's law is considered valid. As fixed coordinate system, we use the O_{NED} systems, where NED is for North-East-Down. As we can observe from the following Figure 40, its vectors are directed to Nord, East and to the centre of the Earth.

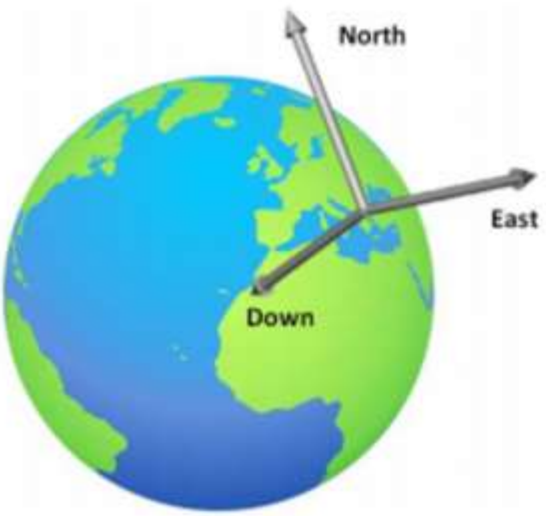


Fig 40. O_{NED} fixed reference system

The mobile reference system that we have previously mentioned is united with the barycenter of the quadrotor. In the scientific literature it is called O_{ABC} system, where ABC is for Aircraft Body Center. Figure 41 illustrates underlines the two coordinate systems.

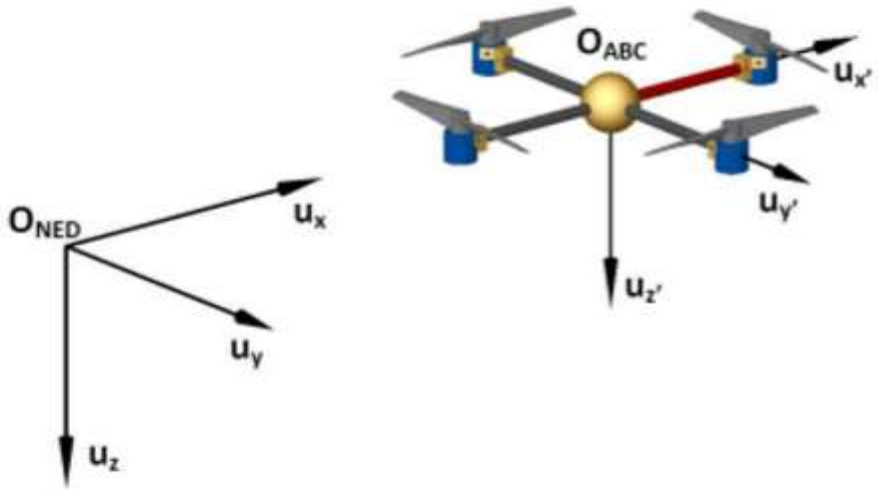


Fig 41. Mobile reference system and fixed reference system

The attitude and position of the quadrotor can be controlled to desired values by changing the speeds of the four motors. The following forces and moments can be performed on the quadrotor: the thrust caused by rotors rotation, the pitching moment and rolling moment caused by the difference of four rotors thrust, the gravity, the gyroscopic effect, and the yaw in g moment. The gyroscopic effect only appears in the light weight construction quadrotor. They awing moment is caused by the unbalanced of the four rotors rotational speeds. The yawing moment can be cancelled out when two rotors rotate in the opposite direction. So, the propellers are divided in two groups. In each group there are two diametrically opposite motors that we can easily observe thanks to their direction of rotation. Namely, we distinguish:

• front and rear propellers (numbers 2 and 4 in Figure 42), rotating counterclockwise;

• right and left propellers (numbers 1 and 3 in Figure 42), rotating clockwise.

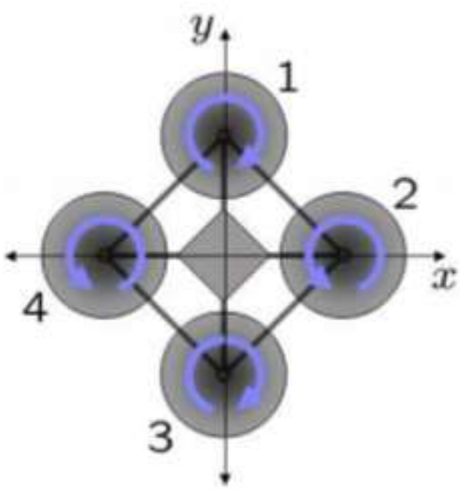


Fig 42. Direction of propeller's rotations

The space motion of the rigid body aircraft can be divided into two parts: the barycenter movement and movement around the barycenter. Six degrees of free dom are required in describing any time space motion. They are three barycenter movements and three angular motions, namely, three translation and three rotation motions along three axes. The control for six degrees of freedom motions can be implemented by adjusting the rotational speeds of different motors. The motions include forward and backward movements, lateral movement, vertical motion, roll motion, and pitch and yaw motions. The yaw motion of the quadrotor can be realized by a reactive torque produced by the rotor. The size of the reactive torque is relative to the rotor speed. When the four rotor speeds are the same, the reactive torques will balance each other and quadrotor will not rotate, whereas if the four rotor speeds are not absolutely same, the reactive torques will not be balanced, and the quadrotor will start to rotate. When the four rotor speeds synchronously increase and decrease is also required in the vertical movement. Because of four inputs and six outputs in a quadrotor, such quadrotor is considered an underactuated nonlinear complex system. In order to control it, some assumptions are made in the process of quadrotor modeling: the quadrotor is a rigid body; the structure is symmetric; the ground effect is ignored. Depending on the speed rotation of each propeller it is possible to identify the four basic movements of the quadrotor, which are showed in Figures 43 to 46.

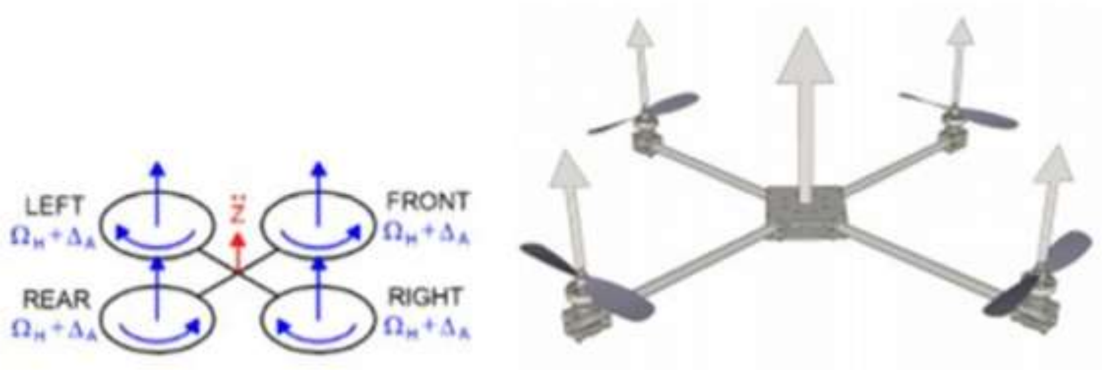


Fig 43. Thrust

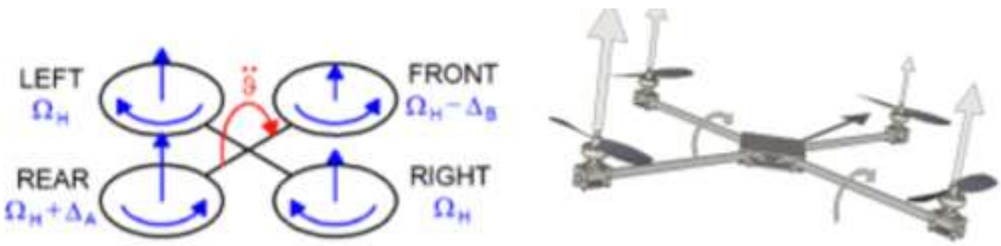


Fig 44. Pitch

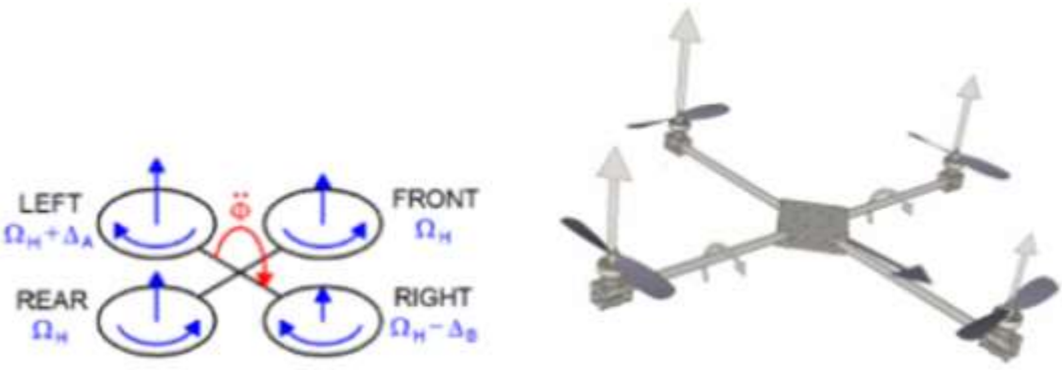


Fig 45. Roll

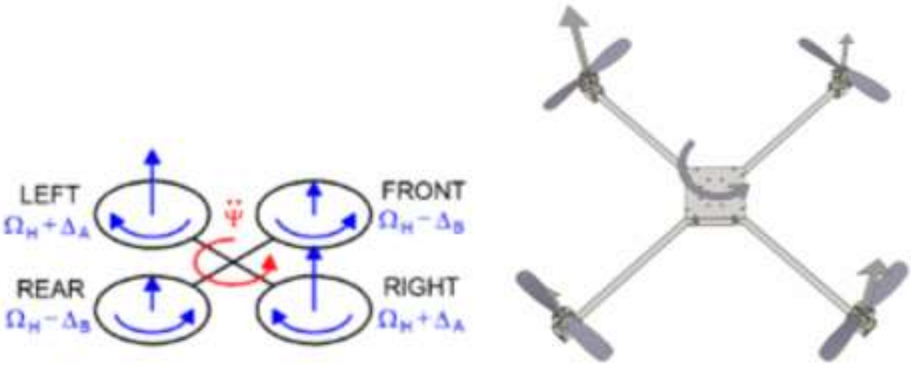


Fig 46. Yaw

8- Euler angles:

The Euler angles are three angles introduced by Leonhard Euler to describe the orientation of a rigid body. To describe such an orientation in the 3-dimensional Euclidean space, three parameters are required. They can be given in several ways; we will use ZYX Euler angles[56] . They are also used to describe the orientation of a frame of reference relative to another and they transform the coordinates of a point in a reference frame in the coordinates of the same point in another reference frame. The Euler angles are typically denoted as $\varphi \in]-\pi, \pi]$, $\theta \in]\pi/2, \pi/2[$, $\psi \in]-\pi,\pi]$. Euler angles represent a sequence of three elemental rotations, i.e. rotations about the axes of a coordinate system, since any orientation can be achieved by composing three elemental rotations. These rotations start from a known standard orientation. This combination used is described by the following rotation matrices [57]:

(5.1)

$$\mathbf{R}_x(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c(\phi) & -s(\phi) \\ 0 & s(\phi) & c(\phi) \end{bmatrix}$$

(5.2)

$$\mathbf{R}_y(\theta) = \begin{bmatrix} c(\theta) & 0 & s(\theta) \\ 0 & 1 & 0 \\ -s(\theta) & 0 & c(\theta) \end{bmatrix}$$

(5.3)

$$\mathbf{R}_z(\psi) = \begin{bmatrix} c(\psi) & -s(\psi) & 0 \\ s(\psi) & c(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Where $c(\phi) = \cos(\phi),\ s(\phi) = \sin(\phi),\ c(\theta) = \cos(\theta),\ s(\theta) = \sin(\theta),\ c(\psi) = \cos(\psi),\ s(\psi) = \sin(\psi)$,
So, the inertial position coordinates and the body reference coordinates are related by the rotation matrix $R_{zyx}(\varphi,\theta,\psi) \in SO$:

$$R_{zyx}(\varphi,\theta,\psi) = R_z(\psi)\cdot R_y(\theta)\cdot R_x(\varphi)$$

(5.4)

$$= \begin{bmatrix} c(\theta)c(\psi) & s(\phi)s(\theta)c(\psi) - c(\phi)s(\psi) & c(\phi)s(\theta)c(\psi) + s(\phi)s(\psi) \\ c(\theta)s(\psi) & s(\phi)s(\theta)s(\psi) + c(\phi)c(\psi) & c(\phi)s(\theta)s(\psi) - s(\phi)c(\psi) \\ -s(\theta) & s(\phi)c(\theta) & c(\phi)c(\theta) \end{bmatrix}.$$

This matrix describes the rotation from the body reference system to the inertial reference.

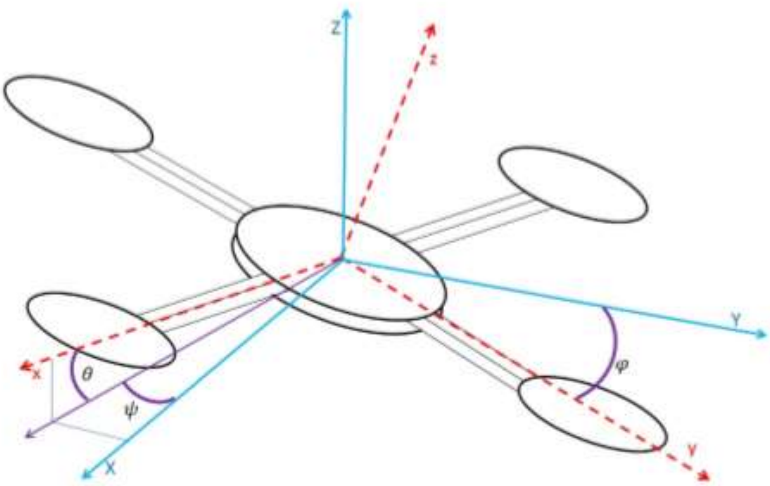


Fig 47. Euler angles

9- Quadrotor mathematical model:

We provide here a mathematical model of the quadrotor, exploiting Newton and Euler equations for the 3D motion of a rigid body. The goal of this section is to obtain a deeper understanding of the dynamics of the quadrotor and to provide a model that is sufficiently reliable for simulating and controlling its behavior. Let us call $[x\ y\ z\ \varphi\ \theta\ \psi]^T$ the vector containing the linear and angular position of the quadrotor in the earth frame and $[u\ v\ w\ p\ q\ r]^T$ the vector containing the linear and angular velocities in the body frame. From 3D body dynamics, it follows that the two reference frames are linked by the following relations:

(5.5)

(5.6)

$$\mathbf{v} = \mathbf{R} \cdot \mathbf{v_B},$$

$$\boldsymbol{\omega} = \mathbf{T} \cdot \boldsymbol{\omega_B}$$

$$\mathbf{v} = \begin{bmatrix}\dot{x} & \dot{y} & \dot{z}\end{bmatrix}^T \in \mathbb{R}^3,\ \boldsymbol{\omega} = \begin{bmatrix}\dot{\phi} & \dot{\theta} & \dot{\psi}\end{bmatrix}^T \in \mathbb{R}^3,\ \mathbf{v_B} = \begin{bmatrix}u & v & w\end{bmatrix}^T \in \mathbb{R}^3$$

$$\boldsymbol{\omega_B} = \begin{bmatrix}p & q & r\end{bmatrix}^T \in \mathbb{R}^3$$

and T is a matrix for angular transformations

(5.7)

$$\mathbf{T} = \begin{bmatrix} 1 & s(\phi)t(\theta) & c(\phi)t(\theta) \\ 0 & c(\phi) & -s(\phi) \\ 0 & \frac{s(\phi)}{c(\theta)} & \frac{c(\phi)}{c(\theta)} \end{bmatrix}$$

Where $t(\theta) = \tan(\theta)$. So, the kinematic model of the quadrotor is:

(5.8)

$$\begin{cases} \dot{x} = w[s(\phi)s(\psi) + c(\phi)c(\psi)s(\theta)] - v[c(\phi)s(\psi) - c(\psi)s(\phi)s(\theta)] + u[c(\psi)c(\theta)] \\ \dot{y} = v[c(\phi)c(\psi) + s(\phi)s(\psi)s(\theta)] - w[c(\psi)s(\phi) - c(\phi)s(\psi)s(\theta)] + u[c(\theta)s(\psi)] \\ \dot{z} = w[c(\phi)c(\theta)] - u[s(\theta)] + v[c(\theta)s(\phi)] \\ \dot{\phi} = p + r[c(\phi)t(\theta)] + q[s(\phi)t(\theta)] \\ \dot{\theta} = q[c(\phi)] - r[s(\phi)] \\ \dot{\psi} = r\frac{c(\phi)}{c(\theta)} + q\frac{s(\phi)}{c(\theta)} \end{cases}$$

Newton's law states the following matrix relation for the total force acting on the quadrotor:

(5.9)

$$m(\boldsymbol{\omega}_B \wedge \mathbf{v}_\mathbf{B} + \dot{\mathbf{v}}_\mathbf{B}) = \mathbf{f}_\mathbf{B}$$

Where *m* is the mass of the quadrotor, $\wedge$ is the cross product and $f_B = [f_x \;\; f_y \;\; f_z]^T \in R^3$ is the total force.

Euler's equation gives the total torque applied to the quadrotor:

(5.10)

$$\mathbf{I} \cdot \dot{\boldsymbol{\omega}}_\mathbf{B} + \boldsymbol{\omega}_B \wedge (\mathbf{I} \cdot \boldsymbol{\omega}_B) = \mathbf{m}_\mathbf{B},$$

where $m_B = [m_x \;\; m_y \;\; m_z]^T \in R^3$ is the total torque and I is the diagonal inertia matrix:

$$\mathbf{I} = \begin{bmatrix} I_x & 0 & 0 \\ 0 & I_y & 0 \\ 0 & 0 & I_z \end{bmatrix} \in \mathbb{R}^{3\times3}$$

So, the dynamic model of the quadrotor in the body frame is:

(5.11)

$$\begin{cases} f_x = m(\dot{u} + qw - rv) \\ f_y = m(\dot{v} - pw + ru) \\ f_z = m(\dot{w} + pv - qu) \\ m_x = \dot{p}I_x - qrI_y + qrI_z \\ m_y = \dot{q}I_y + prI_x - prI_z \\ m_z = \dot{r}I_z - pqI_x + pqI_y \end{cases}$$

The equations stand as long as we assume that the origin and the axes of the body frame coincide with the barycenter of the quadrotor and the principal axes.

10- Forces and moments:

The external forces in the body frame, f_B is given by:

(5.12)

$$\mathbf{f_B} = mg\mathbf{R}^T \cdot \hat{\mathbf{e}}_\mathbf{z} - f_t\hat{\mathbf{e}}_\mathbf{3} + \mathbf{f_w}$$

where $\hat{e}_z$ is the unit vector in the inertial *z* axis, $\hat{e}3$ is the unit vector in the body *z* axis, *g* is the gravitational acceleration, f_t is the total thrust generated by rotors and $f_w = [f_{wx}\ f_{wy}\ f_{wz}]^T \in R^3$ are the forces produced by wind on the quadrotors. The external moments in the body frame, m_B are given by

(5.13)

$$\mathbf{m_B} = \boldsymbol{\tau_B} - \mathbf{g_a} + \boldsymbol{\tau_w}$$

where g_a represents the gyroscopic moments caused by the combined rotation of the four rotors and the vehicle body, $\tau_B = [\tau_x\ \tau_y\ \tau_z]^T \in R^3$ are the control torques generated by differences in the rotor speeds and $\tau_w = [\tau_{wx}\ \tau_{wy}\ \tau_{wz}]^T \in R^3$ are the torques produced by wind on the quadrotors. g_a is given by

(5.14)

$$\mathbf{g_a} = \sum_{i=1}^{4} J_p(\omega_B \wedge \hat{\mathbf{e}}_3)(-1)^{i+1}\Omega_i$$

where J_p is the inertia of each rotor and Ω_i is the angular speed of the i^th rotor. According to (58), the J_p term is found to be small and, for this reason, the gyroscopic moments are removed in the controller formulation. In addition, there are numerous aerodynamic and aeroelastic phenomenon that affect the flight of the quadrotor, such as the ground effects: when flying close to the ground (or during the landing stage), the air flow generated by the propellers disturbs the dynamics of the quadrotors. So, the complete dynamic model of the quadrotor in the body frame is obtained substituting the force expression in (5.11):

(5.15)

$$\begin{cases} -mg[s(\theta)] + f_{wx} = m(\dot{u} + qw - rv) \\ mg[c(\theta)s(\phi)] + f_{wy} = m(\dot{v} - pw + ru) \\ mg[c(\theta)c(\phi)] + f_{wz} - f_t = m(\dot{w} + pv - qu) \\ \tau_x + \tau_{wx} = \dot{p}I_x - qrI_y + qrI_z \\ \tau_y + \tau_{wy} = \dot{q}I_y + prI_x - prI_z \\ \tau_z + \tau_{wz} = \dot{r}I_z - pqI_x + pqI_y \end{cases}$$

11- State-space model:

Organizing the state's vector in the following way:

$$\mathbf{x} = \begin{bmatrix} \phi & \theta & \psi & p & q & r & u & v & w & x & y & z \end{bmatrix}^T \in \mathbb{R}^{12}$$

(5.16)

it is possible to rewrite the equations of the dynamics of the quadrotor in the state-space from (5.8) and (5.15):

(5.17)

$$\begin{cases} \dot{\phi} = p + r[c(\phi)t(\theta)] + q[s(\phi)t(\theta)] \\ \dot{\theta} = q[c(\phi)] - r[s(\phi)] \\ \dot{\psi} = r\frac{c(\phi)}{c(\theta)} + q\frac{s(\phi)}{c(\theta)} \\ \dot{p} = \frac{I_y - I_z}{I_x} rq + \frac{\tau_x + \tau_{wx}}{I_x} \\ \dot{q} = \frac{I_z - I_x}{I_y} pr + \frac{\tau_y + \tau_{wy}}{I_y} \\ \dot{r} = \frac{I_x - I_y}{I_z} pq + \frac{\tau_z + \tau_{wz}}{I_z} \\ \dot{u} = rv - qw - g[s(\theta)] + \frac{f_{wx}}{m} \\ \dot{v} = pw - ru + g[s(\phi)c(\theta)] + \frac{f_{wy}}{m} \\ \dot{w} = qu - pv + g[c(\theta)c(\phi)] + \frac{f_{wz} - f_t}{m} \\ \dot{x} = w[s(\phi)s(\psi) + c(\phi)c(\psi)s(\theta)] - v[c(\phi)s(\psi) - c(\psi)s(\phi)s(\theta)] + u[c(\psi)c(\theta)] \\ \dot{y} = v[c(\phi)c(\psi) + s(\phi)s(\psi)s(\theta)] - w[c(\psi)s(\phi) - c(\phi)s(\psi)s(\theta)] + u[c(\theta)s(\psi)] \\ \dot{z} = w[c(\phi)c(\theta)] - u[s(\theta)] + v[c(\theta)s(\phi)] \end{cases}$$

12- Linear model:

Set u the control vector: $u = [f_t\ \tau_x\ \tau_y\ \tau_z]^T \in R^4$. The linearization's procedure is developed around an equilibrium point $\bar{x}$, which for fixed input $\bar{u}$ is the solution of the algebric system: or rather that value of state's vector, which on fixed constant input is the solution of algebraic system:

(5.18)

$$\hat{\mathbf{f}}(\bar{\mathbf{x}}, \bar{\mathbf{u}}) = \mathbf{0}.$$

Since the function $\hat{f}$ is nonlinear, problems related to the existence an uniqueness of the solution of system (5.18) arise. In particular, for the system in hand, the solution is difficult to find in closed form because of trigonometric functions related each other in no-elementary way. For this reason, the linearization is performed on a simplified model called to small oscillations. This simplification is made by approximating the sine function with its argument and the cosine function with unity. The approximation is valid if the argument is small. The resulting system is described by the following equations:

(5.19)

$$\begin{cases} \dot{\phi} \approx p + r\theta + q\phi\theta \\ \dot{\theta} \approx q - r\phi \\ \dot{\psi} \approx r + q\phi \\ \dot{p} \approx \frac{I_y - I_z}{I_x} rq + \frac{\tau_x + \tau_{wx}}{I_x} \\ \dot{q} \approx \frac{I_z - I_x}{I_y} pr + \frac{\tau_y + \tau_{wy}}{I_y} \\ \dot{r} \approx \frac{I_x - I_y}{I_z} pq + \frac{\tau_z + \tau_{wz}}{I_z} \\ \dot{u} \approx rv - qw - g\theta + \frac{f_{wx}}{m} \\ \dot{v} \approx pw - ru + g\phi + \frac{f_{wy}}{m} \\ \dot{w} \approx qu - pv + g + \frac{f_{wz} - f_t}{m} \\ \dot{x} \approx w(\phi\psi + \theta) - v(\psi - \phi\theta) + u \\ \dot{y} \approx v(1 + \phi\psi\theta) - w(\phi - \psi\theta) + u\psi \\ \dot{z} \approx w - u\theta + v\phi \end{cases}$$

which can be written in the compact form

(5.20)

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{u})$$

12- 1. Controllability and observability of the linear system

Controllability and observability represent two major concepts of modern control system theory [58]. These concepts were introduced by R. Kalman in 1960. They can be roughly defined as follows.

- ✓ Controllability: In order to be able to do whatever we want with the given dynamic system under control input, the system must be controllable.
- ✓ Observability: In order to see what is going on inside the system, the system must be observable.

The concepts of controllability and observability for a linear time-invariant dynamical system can be related to suitable linear systems of algebraic equations. It is well known that a solvable system of linear algebraic equations has a solution if and only if the rank of the system matrix is full. Observability and controllability tests will be connected to the rank tests of certain matrices: the controllability and observability matrices. For the purpose of studying its observability, we consider the linear system:

$$\mathrm{A} = \frac{\partial \mathbf{f}(\mathbf{x},\mathbf{u})}{\partial \mathbf{x}}\bigg|_{\substack{\mathbf{x}=\bar{\mathbf{x}}\\ \mathbf{u}=\bar{\mathbf{u}}}} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -g & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ g & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

(5.21)

$$\dot{\mathbf{x}} = \mathbf{A}\cdot\mathbf{x} \qquad \mathbf{x}(t_0) = \mathbf{x_0}$$

where A is given and with the corresponding measurements:

$$y = C\cdot x \quad (5.22)$$

Of dimensions $x \in R^{12}$, $y \in R^{12}$, $A \in R^{12x12}$, $C \in R^{12\times12}$. The observability matrix is given by:

(5.23)

$$\mathcal{O} = \begin{bmatrix} \mathbf{C} \\ \mathbf{C}\cdot\mathbf{A} \\ \mathbf{C}\cdot\mathbf{A}^2 \\ \vdots \\ \mathbf{C}\cdot\mathbf{A}^{11} \end{bmatrix} \in \mathbb{R}^{144\times12}$$

The linear continuous-time system (5.21) with measurements (5.22) is observable if and only if the observability matrix has full rank. The controllability matrix is given by:

(5.24)

$$\mathcal{C} = \begin{bmatrix} \mathbf{B} & \mathbf{A}\cdot\mathbf{B} & \mathbf{A}^2\cdot\mathbf{B} & \cdots & \mathbf{A}^{11}\cdot\mathbf{B} \end{bmatrix} \in \mathbb{R}^{12\times 48}$$

where B is given

$$\mathbf{B} = \left.\frac{\partial \mathbf{f}(\mathbf{x},\mathbf{u})}{\partial \mathbf{u}}\right|_{\substack{\mathbf{x}=\bar{\mathbf{x}}\\ \mathbf{u}=\bar{\mathbf{u}}}} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & \frac{1}{I_x} & 0 & 0 \\ 0 & 0 & \frac{1}{I_y} & 0 \\ 0 & 0 & 0 & \frac{1}{I_z} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{1}{m} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The linear continuous-time system (5.21) with measurements (5.22) is controllable if and only if the controllability matrix has full rank.

To check its observability and controllability, we used Matlab. The linear system results to be controllable and observable

13- PD (Proportional and Derivative) and PID control

Understanding this is very important to truly understand how quadcopters work. Since we need a F_{Res} = ma to ascend or descend the quadrotor to a desired height x, we can write a (acceleration) as a = d^2x/dt^2 (second order derivative) = x''.

Also, let us introduce u = 1/m * F_{Res}.

Therefore, we now have a second order derivative equation with the input as 'u' and the variable x, such that u = x'' (since 1/m*F_{Res} = a = x''). That is, second order dynamic system, u = x''.

The goal here now is to determine the input 'u' such that the quadcopter goes to the desired position x. That is to find a control input u (t) so that x (t) follows the desired trajectory x_{des}(t).

The difference between the desired trajectory of the quadcopter and the actual trajectory is the error of the trajectory.

That is, $e(t) = x_{des}(t) – x(t)$.

Our goal is to minimize the error, making it converge exponentially to zero.

Hence, to do this, we find u (t) such that,

$$e'' + K_v * e' + K_p * e = 0 \quad \text{where } K_v, K_p > 0$$

By finding values of K that are > 0, we can guarantee that the error will go exponentially to 0.

The equation for the control input is given by $u(t) = x''_{des}(t) + Kv * e'(t) + Kp * e$. With this, the error will converge exponentially to 0 and ensure that our desired trajectory is achieved. Here, $K_p * e$ is the proportional gain while the $K_v * e'(t)$ is the derivative gain (since e' is the derivative of the error, e here). The $x''_{des}(t)$ is the feed forward term, which is the second derivative of the $x_{des}(t)$.

This is the control law, PD control law that is used to drive the motors of the quadcopter. With this in application in the code, the quadcopter trajectory may first start off with a slight error, but will eventually converge to 0 error, even if the error offshoots to the negative direction.

The proportional control acts like a spring. The higher the proportional term in the control law equation, the springier the quadcopter gets. Higher the proportional gain, the more likely the quadcopter is to offshoot its trajectory to negative error.

The derivative control acts like a dampening agent. High derivative gain will make the quadcopter converge its error to zero very slowly but is less likely to offshoot its trajectory to negative error.

- PID Control

In cases where there are external disturbances like wind or presence of unknown errors such as the mass of the quadrotor being unknown, PID control is used, which is a more complex version of the PD control. This is how quadcopters work better today.

The equation for this is $u(t) = x''_{des}(t) + K_v * e'(t) + K_p * e + K_i$

Where is the extra term? Note that this equation goes into the third order derivative.

For the PD system, when Kp and Kv > 0, the quadcopter becomes stable.

When Kp > 0 and Kv = 0, the quadcopter becomes marginally stable.

When both the values < 0, the quadcopter becomes unstable.

14- Simulation results:

In this part we show the results obtained with Matlab/Simulink and we analyze the differences between the several controllers illustrated above. For each control, we show the step response of the output variables x, y, z, ψ.

```
%-----------------------------------------------------------------------%
%                                                                       %
%   This script simulates quadrotor dynamics and implements a control   %
%
%   algrotihm using the Simulnk Block Diagram file QuadrotorSimulink.mdl
%                                                                       %
%                                                                       %
%-----------------------------------------------------------------------%
% Add Paths
addpath utilities

%% Initialize Workspace
clear all;
% close all;
clc;

global Quad;

%% Initialize the plot
init_plot;
plot_quad_model;

%% Initialize Variables
quad_variables;

%% Run Simulation

SimOut = sim('QuadrotorSimulink');

%% Run The Simulation Loop
for S = 1 : 1 : size(SimOut,1)

    Quad.X = X_out.signals.values(S);
    Quad.Y = Y_out.signals.values(S);
    Quad.Z = Z_out.signals.values(S);
    Quad.phi = Phi_out.signals.values(S);
    Quad.theta = Theta_out.signals.values(S);
    Quad.psi = Psi_out.signals.values(S);

    % Plot the Quadrotor's Position

        plot_quad
%         campos([A.X+2 A.Y+2 A.Z+2])
%         camtarget([A.X A.Y A.Z])
%         camroll(0);
        drawnow;

end
```

```
%% Plot Data
figure();
plot(SimOut,X_out.signals.values)
hold on;
plot(SimOut,X_desired.signals.values);
title('X');

figure();
plot(SimOut,Y_out.signals.values)
hold on;
plot(SimOut,Y_desired.signals.values);
title('Y');

figure();
plot(SimOut,Z_out.signals.values)
hold on;
plot(SimOut,Z_desired.signals.values);
title('Z');

figure();
plot(SimOut,Psi_out.signals.values)
hold on;
plot(SimOut,Psi_desired.signals.values);
title('Psi');
```

Results:

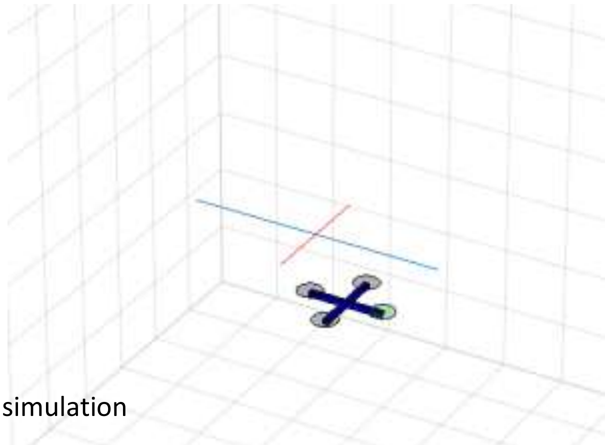
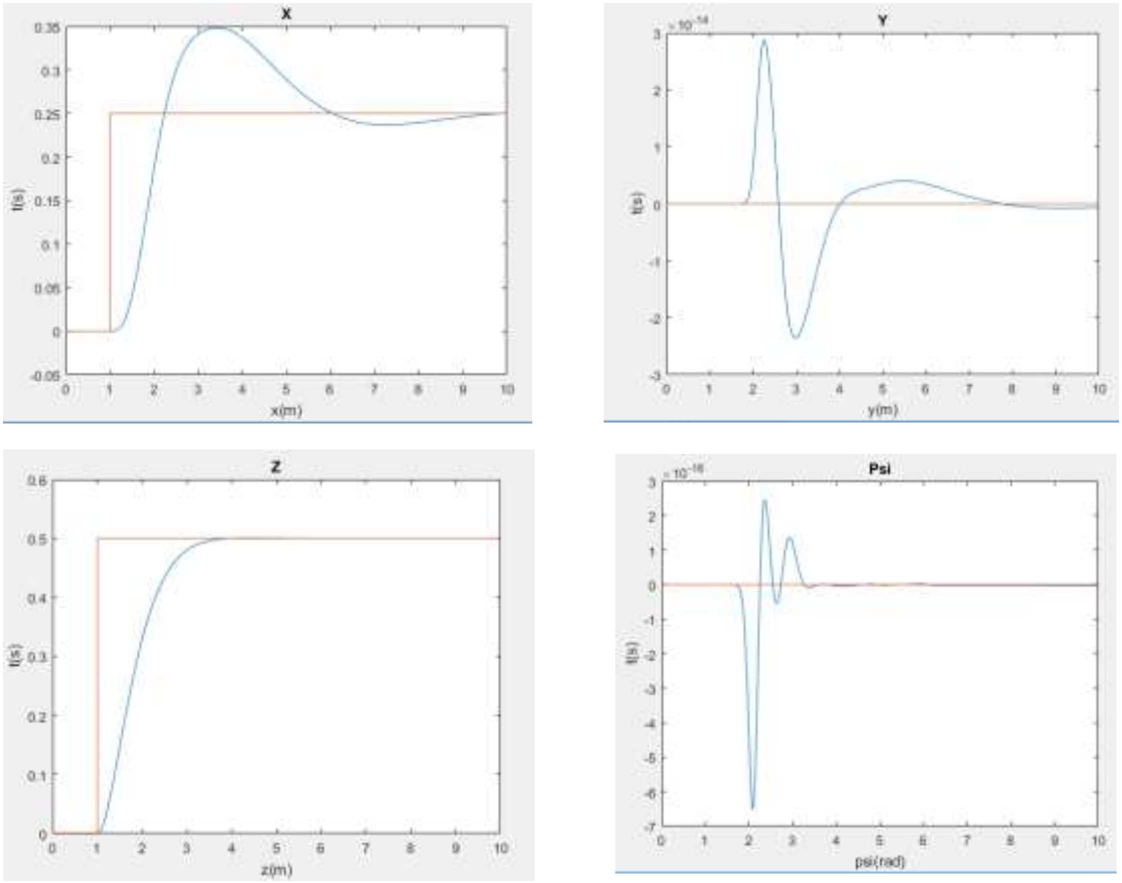


Fig 48. Simulink quadcopter simulation



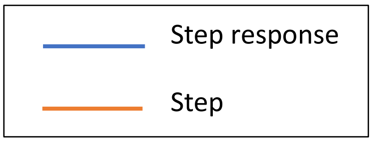


Fig 49. Position and yaw response of the Linear Quadratic Regulator to a step input

- PID Control simulation:

```
% Add Paths
addpath utilities

%% Initialize Workspace
clear all;
close all;
clc;

global Quad;

%% Initialize the plot
init_plot;
plot_quad_model;

%% Initialize Variables
quad_variables;
quad_dynamics_nonlinear;

%% Run The Simulation Loop
while Quad.t_plot(Quad.counter-1)< max(Quad.t_plot);
```

```
    % Measure Parameters (for simulating sensor errors)
      sensor_meas;

    % Filter Measurements
%     Kalman_phi2;
%     Kalman_theta2;
%     Kalman_psi2;
%     Kalman_Z2;
%     Kalman_X2;
%     Kalman_Y2;

    % Implement Controller
    position_PID;
    attitude_PID;
    rate_PID;

    % Calculate Desired Motor Speeds
    quad_motor_speed;

    % Update Position With The Equations of Motion
    quad_dynamics_nonlinear;

    % Plot the Quadrotor's Position
    if(mod(Quad.counter,3)==0)
        plot_quad

%         campos([A.X+2 A.Y+2 A.Z+2])
%         camtarget([A.X A.Y A.Z])
%         camroll(0);
        Quad.counter;
        drawnow
    end

    Quad.init = 1;
%Ends initialization after first simulation iteration
end

%% Plot Data
plot_data
```

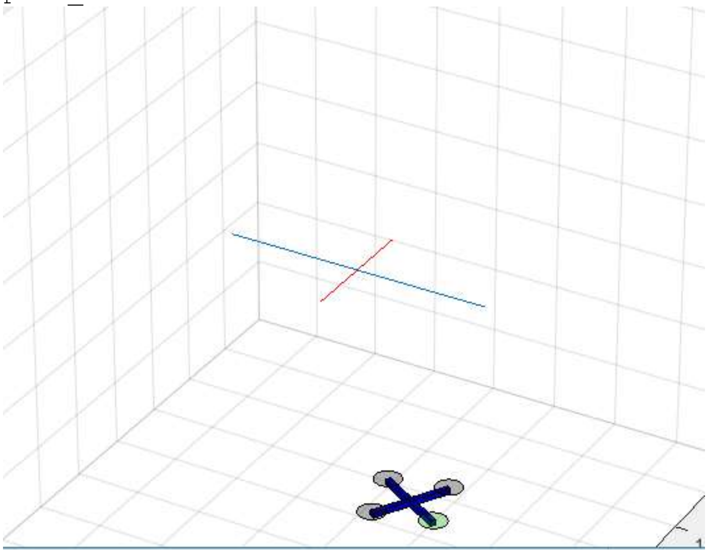


Fig 50. Plot quad model

Results:

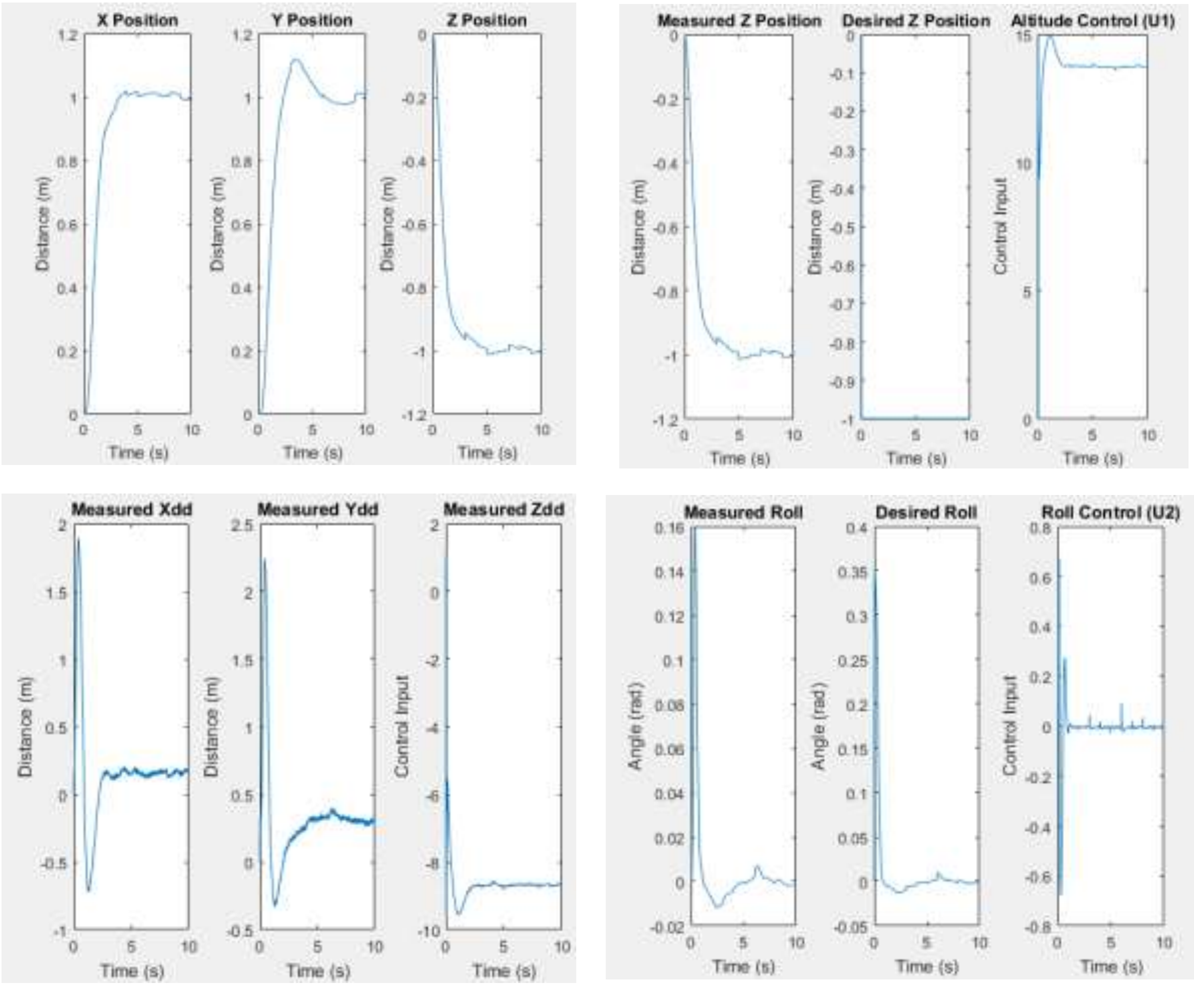


Fig 51. Comparing simulated and ideal trajectory with dynamic inversion with zero-dynamics stabilization

15- Simulink:

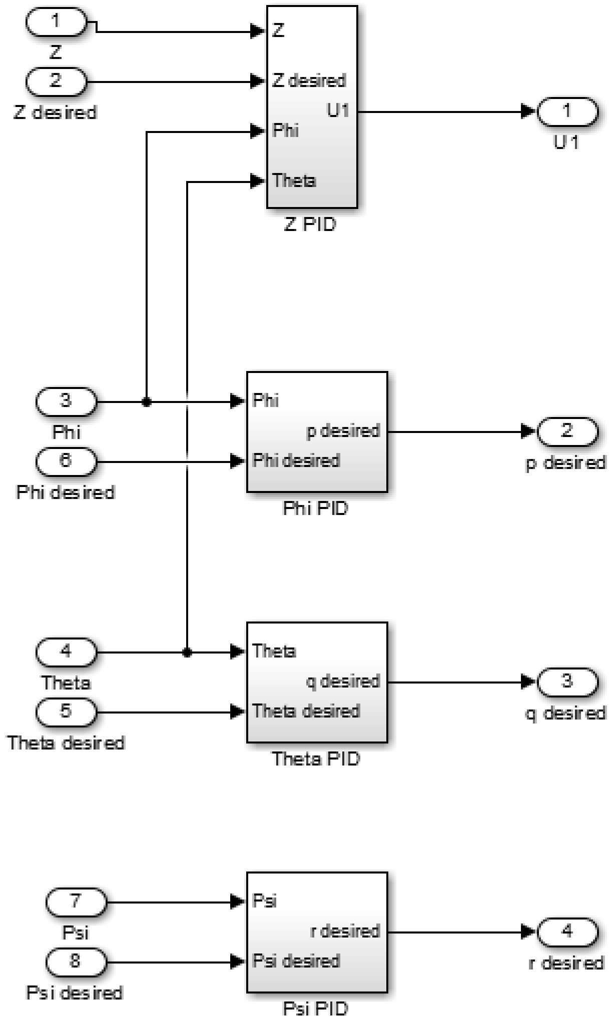


Fig 52. Attitude/Altitude Controller

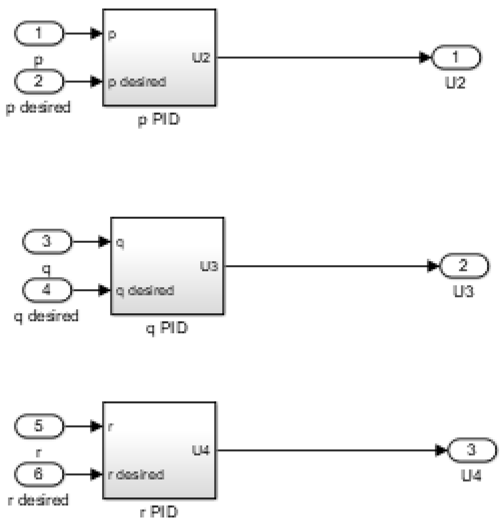


Fig 53. Angular Rate PID Controller

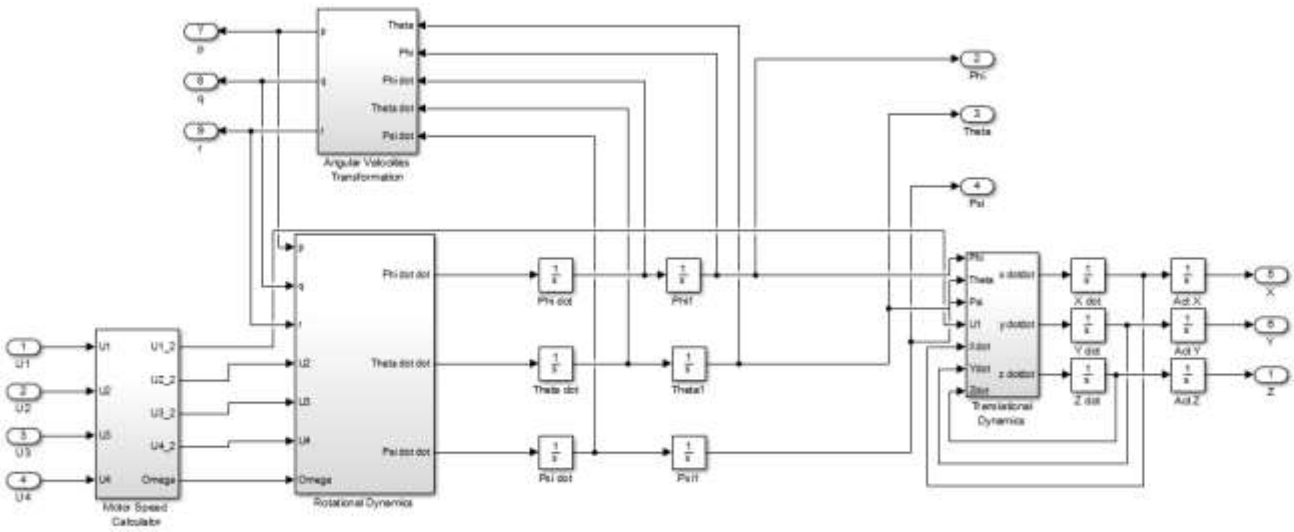


Fig 54. Quadrotor System

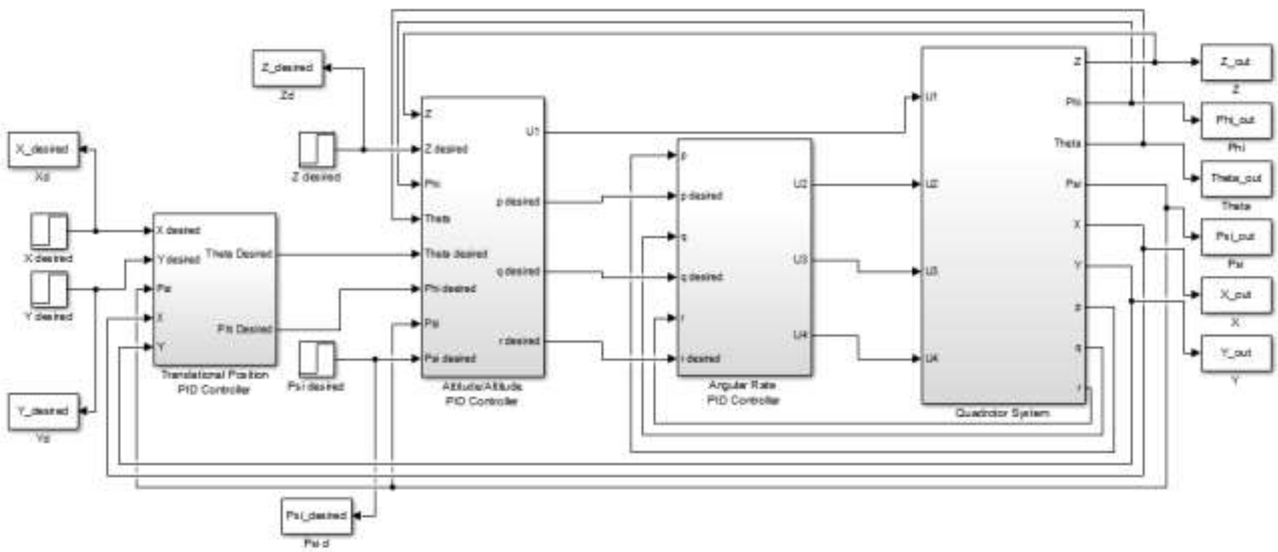


Fig 55. Quadrotor Simulink

16- 3D Animation:

The Simulink 3D Animation package provides apps for linking Simulink models and MATLAB algorithms to 3D graphics objects. This package can be used to visualize and verify dynamic system behaviour in a virtual reality environment. Objects are represented in the Virtual Reality Modelling Language (VRML), a standard 3D modelling language. You can animate a 3D world by changing position, rotation, scale, and other object properties during desktop or real-time simulation.

Because of matter of time and knowledge our 3D animation wasn't by MATLAB but by another software which is Blender, it explains very well in a short video our idea about the inspection by drone and how it could be (Figure 56-59)

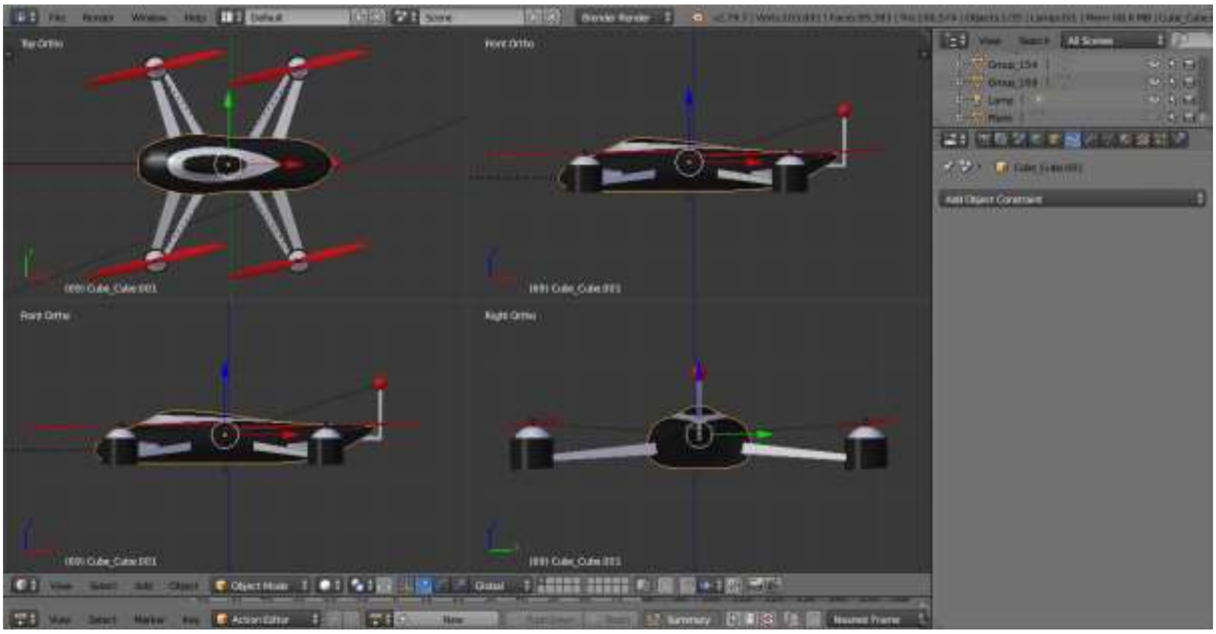


Fig 56. The complete Design by blender

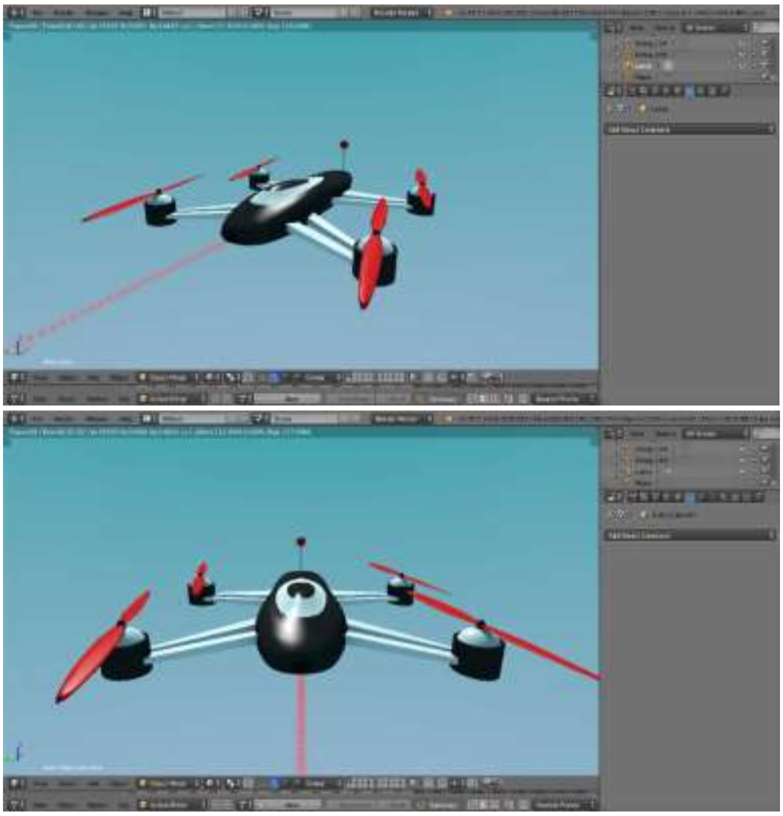


Fig 57. The quadcopter design in Blender showing the necessary laser senor

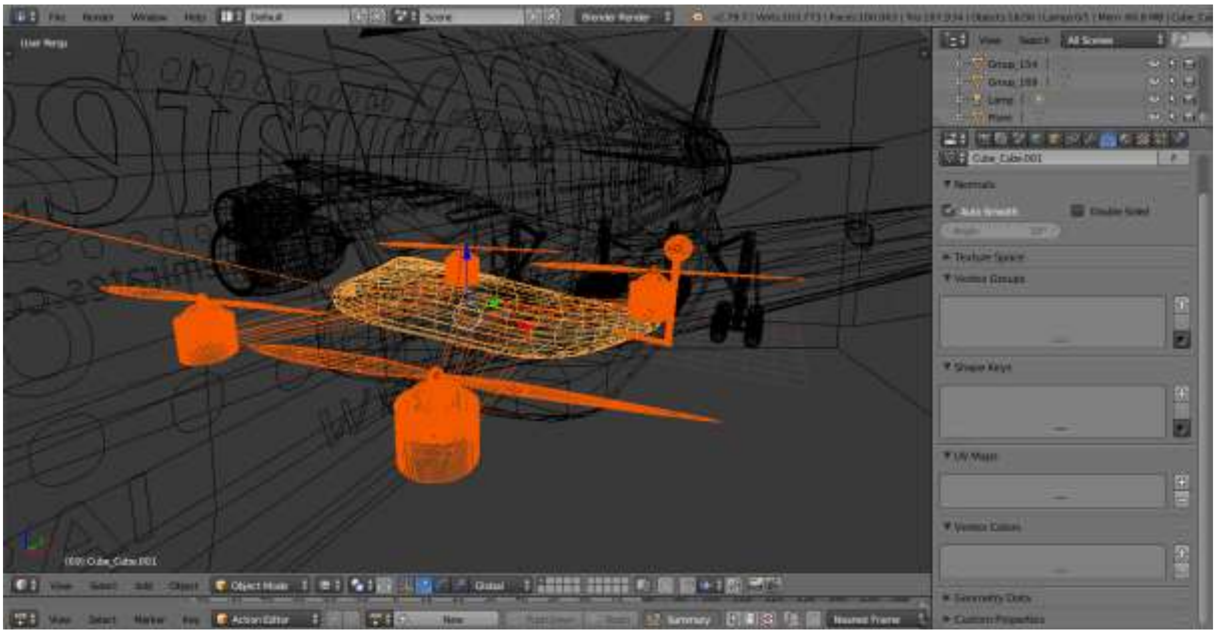


Fig 58. Before flight inspection by Blender

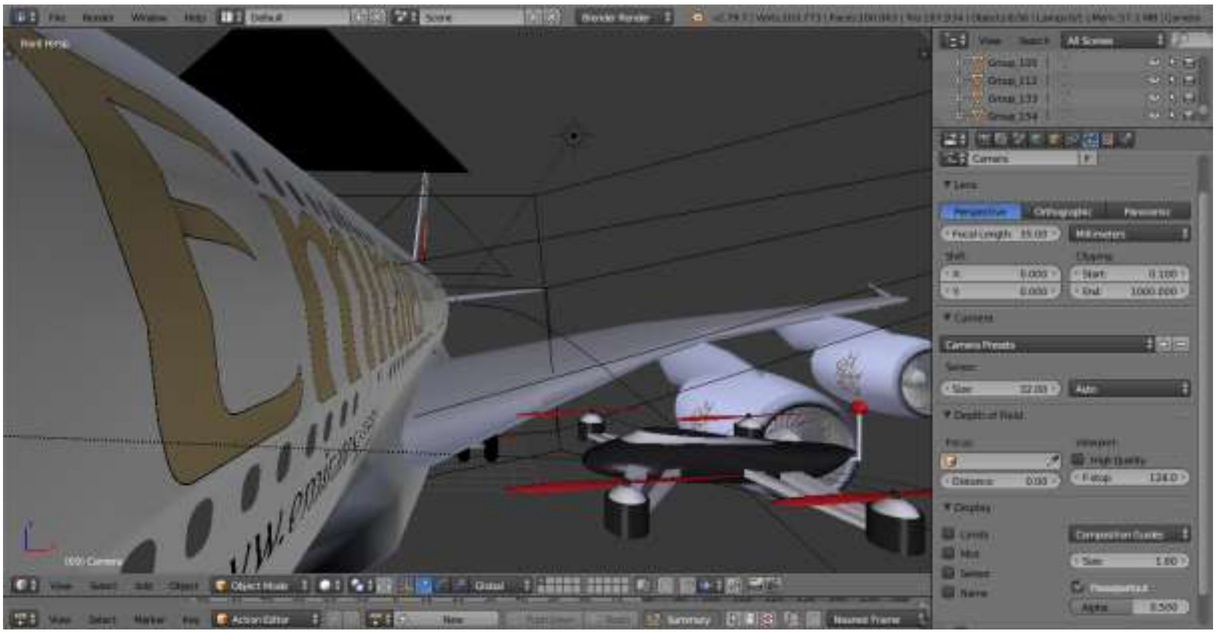


Fig 59. Before flight inspection by Blender

17- How quadcopters work & fly :

17-1. Basic components of a quadcopter/multirotor:

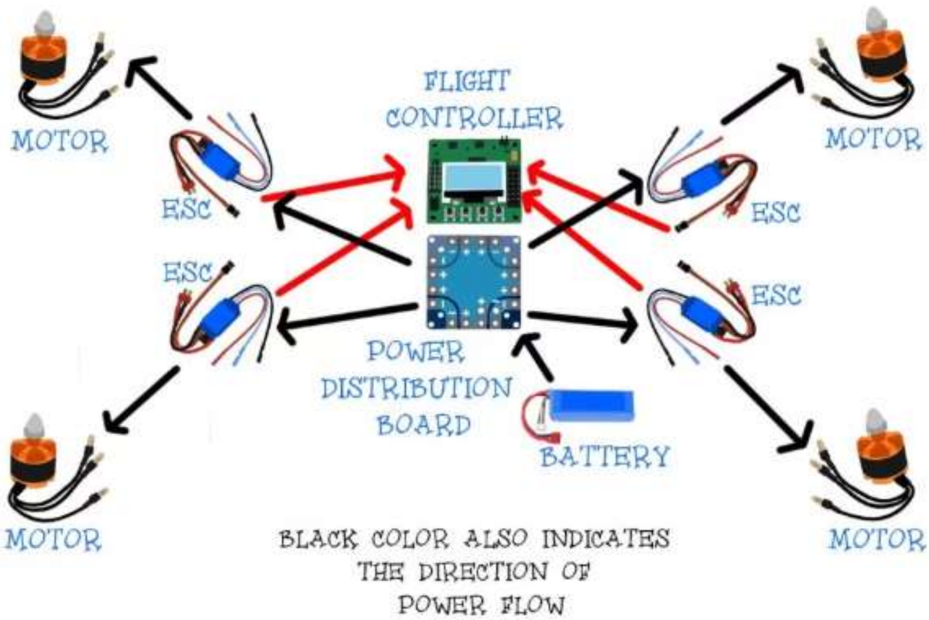


Fig 60. Basic components of a quadcopter

17-2. The body frame:

The frame or body is what holds everything together. They are generally designed to be strong and lightweight and consist of a center plate where the main flight controller chip and sensors are mounted and arms where the motors are mounted. It is most often made of carbon fibre, fibreglass, aluminium or steel. Some cheaper, smaller models also use plastic.

The frame comes in varieties for different multirotor types: Tricopter, quadcopter, hexacopter, octocopter. It also varies on different builds, depending on whether it is used for aerial photography, FPV drone racing etc.

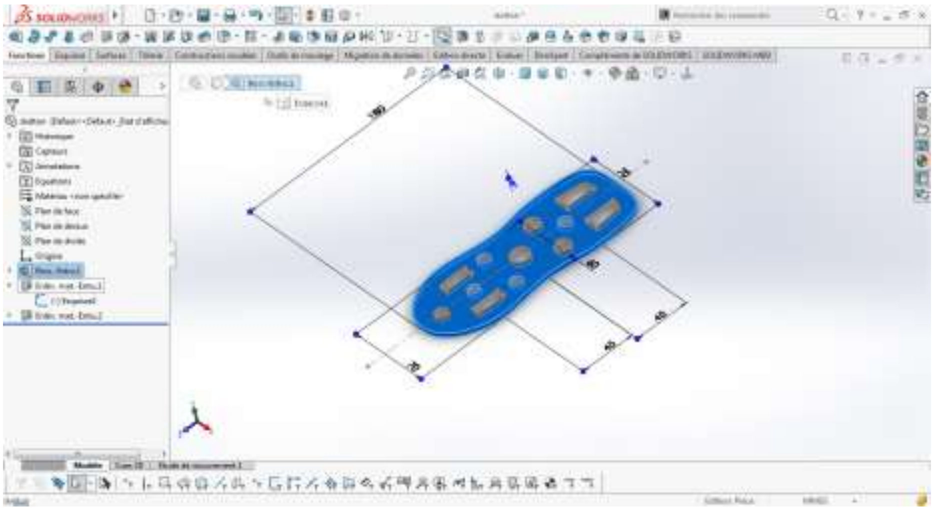


Fig 61. Our frame design by Solid Works

17-3. Motors

The motivation behind using motors is to turn the propellers, which is responsible for providing thrust for countering gravity and drag. Every rotor ought to be controlled separately by a speed controller. Motors are the the primary force behind how quadcopters fly.
They are somewhat like typical DC motors in the sense that coils and magnets are utilised to drive the shaft. The brushless motors do not have a brush on the shaft that deals with iterating the power in the coils, hence, the ‘brushless’ reference.

The brushless motors have 3 coils on the inside center of the motor, which is settled to the mounting. On the external side, it contains multiple magnets mounted to the cylindrical structure that is appended to the turning shaft.

Hence, the coils are fixed and there is no need for brushless. Brushless motors turn a lot quicker and utilize less power at the same speed relative to DC motors. Unlike DC motors, they don’t lose power in the brush-transition, so it is a lot more vitality productive.
The Kv (kilovolts) – rating in a motor demonstrates how various RPMs (Revolutions each moment) the motor will do per volt. The higher the kV rating is, quicker the motor rotates at a steady voltage.

17-3. ESCs

Motors spin, but in order to fully understand how quadcopters work, we need to understand how the motor is controlled. The electronic speed controller or (ESC) is what tells the motor how to spin. It is responsible for controlling the rate at which the motor it is connected to, spins. Since the multirotor motors are supposed to spin at variable speeds, depending on control inputs, ESCs are crucial. In a multirotor, each motor will have an associated ESC connected to it.

The ESCs are connected to the batteries via the power distribution board within the multirotor's frame. Most ESCs come with a battery eliminator circuit (BEC) which acts as a voltage regulator, allowing other electronic components like the flight controller and receiver to power up without connecting them directly to a battery.

17-4. Flight Controller

The flight controller is the mind or 'brain' of the multirotor. This board is what sits at the center, controlling the firmware within the ESCs, consequently controlling the spin rate of the motors. This is how a quadcopter flies.

Essentially, it takes the inputs from the receiver (Throttle, Elevator, Rudder and Aileron) and adjusts the motor RPM accordingly, via ESC.

Flight control systems house additional sensors to enhance control and stability of the craft. The controller usually contains gyroscope, accelerometer and barometer. GPS can also be added onto the flight controller to feed coordinate information and altitude information of the multirotor.

17-5. Transmitter and Receiver

The radio transmitter and receiver is used to control the quadcopter. In order for a quadcopter to work, four channels (throttle, elevator, aileron rudder) are required. Getting a transmitter with 6 or 8 channels is recommended for additional functionalities.

Quadcopters can be programmed and controlled in totally different ways. However the most common ones are in either rate (acrobatic) or stable mode. In rate mode, only the gyroscope is used to control the quadcopter balanced, it does not self-level.

If switched to stable mode, the accelerometer gets activated, helping to stabilize the quadcopter. The speed of the 4 motors can be adjusted automatically and perpetually to keep the quadcopter balanced.

A transmitter may also have an FPV screen on which a camera mounted on the multirotor beams video in real time. This gives the pilot a unique experience of flying by seeing what the multirotor sees.

17-6. Batteries

Lithium Polymer (LiPo) batteries are the most famous power source for controlling multirotors (or 'drones') today. Without going a lot into detail, the principle explanation behind this is on the grounds that they are rechargeable and ordinarily have expansive limits.

LiPo batteries can have discharge rates sufficiently expansive to control even probably the most taxing multirotors. This settles on them the favoured decision over different choices, for example, the Nickel Cadmium (NiCd) battery. This is likewise the essential reason they can be a genuine fuel source for multirotors.

17-7. Most important sensors and their roles

- Accelerometer

The accelerometer measures the change in the object's speed (to tell whether it is going up or down). It senses both static gravity acceleration (which happens even when the object is not actively moving) and dynamic acceleration, to detect motion.

The unit of measurement used is g (9.8 m/s^2) or in metre per second squared. Note that the accelerometer measures acceleration in three different axes in the 3D world (x, y and z axes). The accelerometer senses both what direction the ground is, by sensing the earth's gravitational pull and linear motion.

- Gyroscope

Unlike the accelerometer, the gyroscope measures the rate of rotation of an object about its axis, in degrees per second or rotations per minute (RPM). The gyroscope is mounted on the quadcopter in a way that it is aligned with its axes, giving information on the orientation of the quadcopter.

- Inertia measurement unit (IMU)

In order to accurately measure the orientation, velocity and location of the quadcopter, an accelerometer or a gyroscope alone may not be enough. This is where the inertia measurement unit (IMU) comes in.

The IMU is a board that combines both multi axes gyroscope and accelerometer to get the best of both. The IMU may also contain a magnetometer to correct the errors in the gyroscope feedback.

17-8. How quadcopters fly better: Additional options

- Barometer

The barometer is essentially a pressure sensor that senses changes in air pressure. As you may know, air pressure changes with altitude. Barometer can detect even the smallest changes in pressure and so can be used to measure the altitude of the quadcopter. This is becoming increasingly important these days, with the advent of new regulations.

- **GPS**

The global positioning system ('GPS') receives data from multiple satellites that are in orbit around the earth in order to pinpoint the geographical location of the quadcopter. With the GPS system in place, you can even set specific coordinates for your quadcopter to fly to. GPS also enables the RTH (return to home) function which enables your craft to fly back to you in case it flies beyond your line of sight and beyond your controller's range.

- **Magnetometer**

The magnetometer is used to measure the earth's magnetic field (like a compass). This sensor usually serves the purpose of correcting the drift of the gyro and also to serve as an ancillary to the GPS system.

- **Distance**

Distance sensors use ultrasonic or light-based systems to complement the barometer in order to give a more accurate reading of the altitude. These sensors can also tell if the quadcopter is about to collide with a building, a lamp post and son on.

18- Quadcopter 3D design

As we saw before in figure 61, the design of the frame by solid works, we'll see in the next photos the design of the whole drone

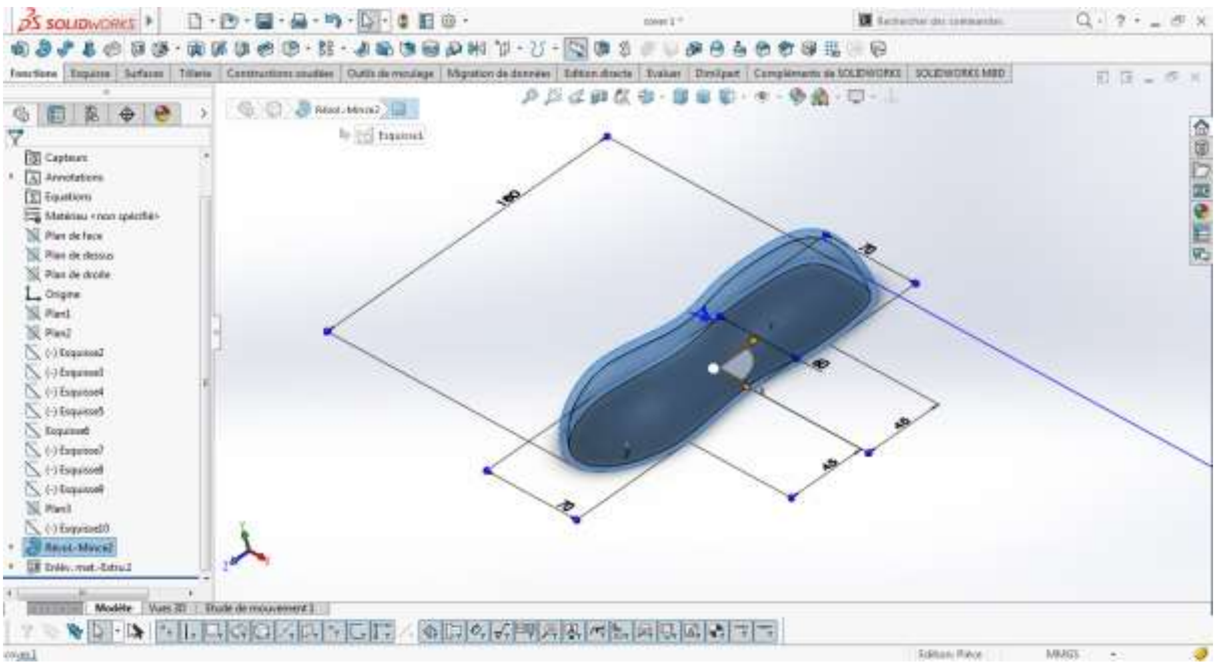
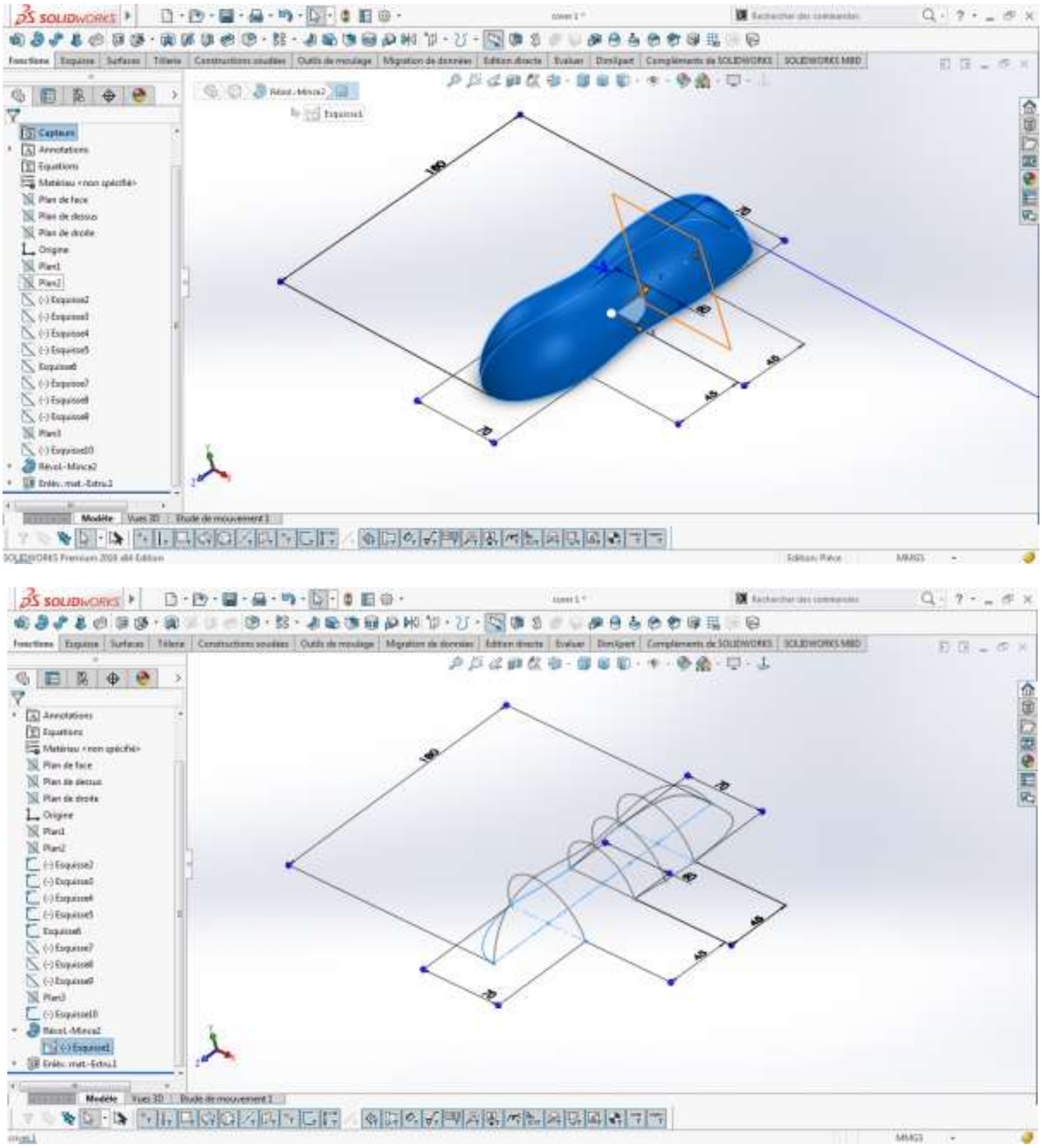


Fig 62. Cover design



After the assembly of all the pieces together, the four arms, which are a part from the frame should be strong enough to carry this payload and answering in the same time on SOM (Strength of materials) and long enough to avoid the accident between the propeller and outer structure

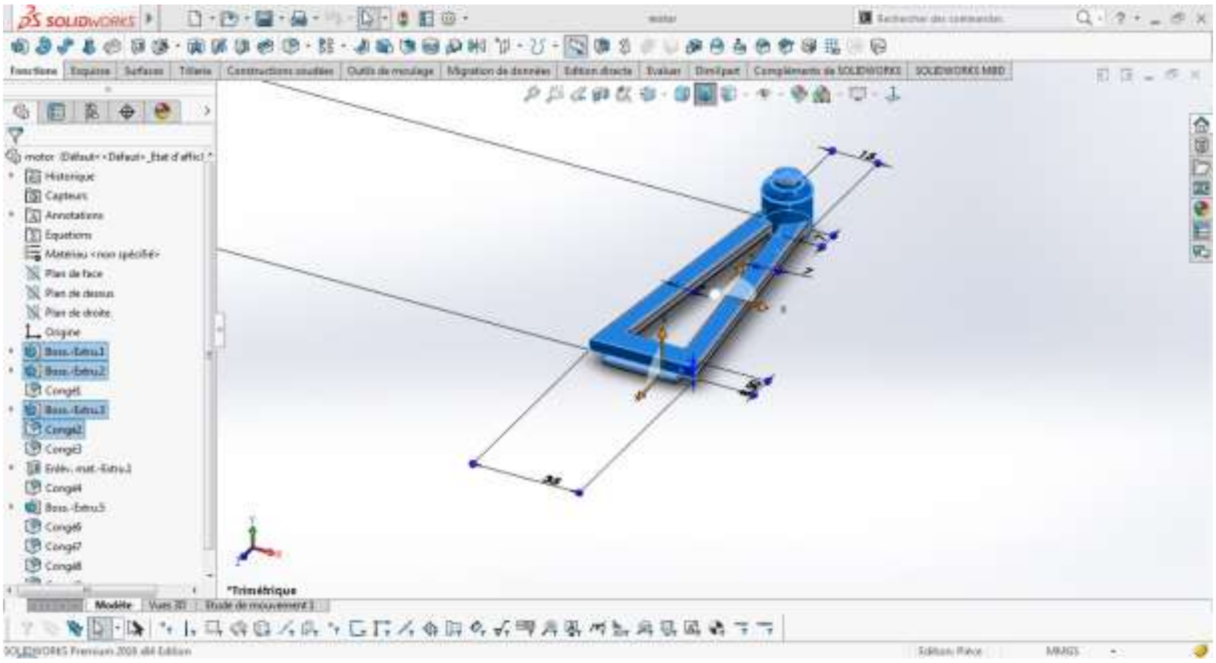


Fig 63. Arms design

The propeller which depends on our brushless engine should be strong enough to resist at a rotational power and generate enough thrust to make our drone floatat on air

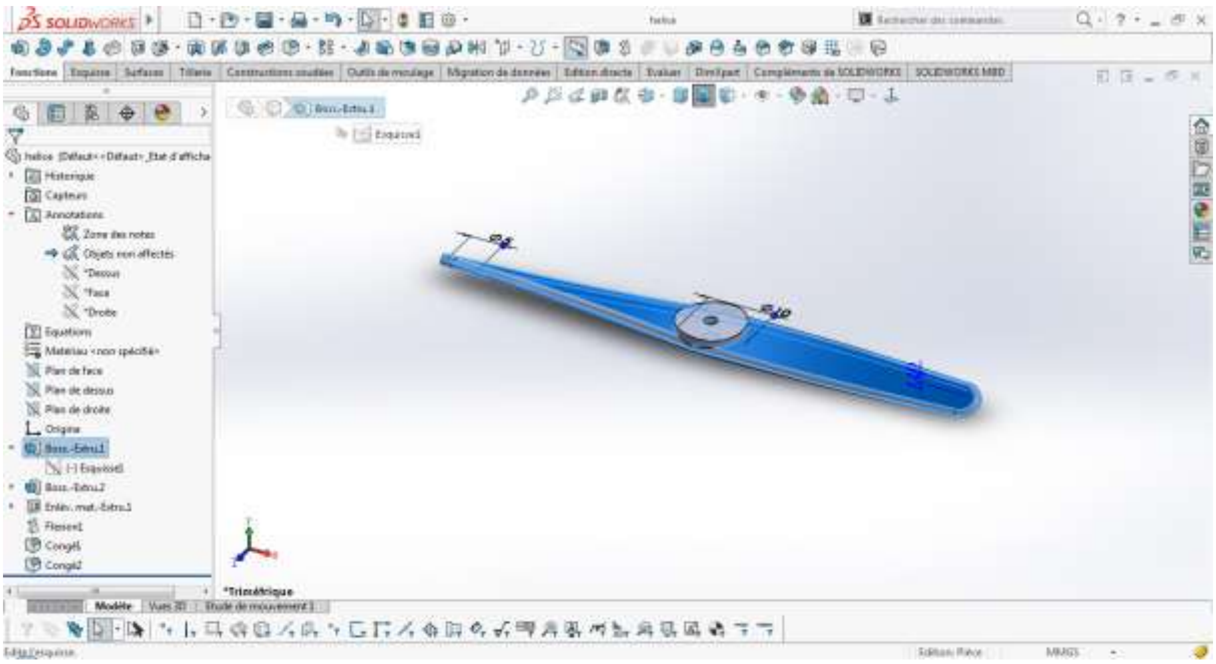


Fig 64. Propeller Design

Chapter 5

Aerospace Construction Digitalization

Drones are the perfect prof at digitalization efficiency. Today, we are living in a world testing drones near to aircrafts, tomorrow it will be an airport necessary.

References

1. Abernathy, W., J. Utterback. 1978. Patterns of Industrial Innovation. Technology Review 4147

2. Alavi, M., D.E. Leidner. 2001. Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. MIS Quarterly 25(1) 107-136.

3. Youngjin Yoo, Case Western Reserve University. Digitalization and Innovation, article research gate 2010

4. Roland Berger "Top Management Issues Radar 2016" Survey

5. Christian Streiff, Reported in 'Airbus A380 delay', Aerospace News, http://blog.seattlepi.nwsource.com/aerospace/archives/107302 (03/10/2006)

6. Tim Carroll Integrated Supply Chain Vice President IBM Corporation, The smarter supply chain, Insights from the Global Chief Supply Chain Officer Study

7. Airbus's cost effectiveness gets a lift with greater supply chain visibility and automation. IBM Corporation. October 2008

12. Airspace magazine/ how things work: winglets

13. Upgrading Your C-130 Avionics… The Cost of Doing Nothing, from Rockwell Collins and HOC

14. Wagels C, Schmitt R (2012) Benchmarking of Methods and Instruments for Self-Optimization in Future Production Systems. In 45th CIRP Conference on Manufacturing Systems, pp: 161-166.
15. Barbosa GF, Carvalho J, Filho EVG (2014) A proper framework for design of aircraft production system based on lean manufacturing principles focusing to automated processes. The International Journal of Advanced Manufacturing Technology 72: 1257-1273.
16. Hermann M, Pentek T, Otto B (2015) Design Principles for Industrie 4.0 Scenarios: A Literature Review. Technische UniversitÃ¤t Dortmund FakultÃ¤t Maschinenbau.
17. Seitz F, Steele LW (1985) The Competitive Status of the U.S. Civil Aviation Manufacturing Industry. National Academy Press, Washington DC.
18. Barbosa GF (2012) Desenvolvimento de um modelo de anÃ¡lise para implantaÃ§Ã£o de automaÃ§Ã£o na manufatura aeronÃ¡utica, orientado pelos requisitos das metodologias de Projeto para ExcelÃªncia (DFX â Design for Excellence) e ProduÃ§Ã£o Enxuta (Lean Manufacturing). Ph.D. dissertation, Dept. Mechanical Eng., Escola de Engenharia de SÃ£o Carlos da Universidade de SÃ£o Paulo (USP).
19. Composites Forecasts and Consulting LLC.

References

20. Lasi H, Fettke P, Kemper HG, Feld T, Hoffmann M (2014) Industry 4.0. Business & Information Systems Engineering. 6: 239-242.
21. Lins T (2015) IndÃºstria 4.0 Desafios Parte 1. iMobilis. LaboratÃ³rio Imobilis ComputaÃ§Ã£o MÃ³vel.
22. T Richardson, Gilbert S, Holub J, Thompson F, MacAllister A et. al. (2014) Fusing self-reported and sensor data from mixed-reality training. In Proc. Interservice/Industry Training, Simulation, and Education Conference, pp: 1-12.
23. The Engineer (2015) In touch with reality: the digital future of the factory. Available on, May.
24. IFR (2015) Industrial Robot Statistics. International Federal Robotics World Robotics.
25. Broetje Automation (2014) Integrated Section Assembly Cell. Available on.
26. Barrette B (2014) M Top 5 Robotic Applications in the Aerospace Industry. Robotiq.
27. BCG â Boston Consulting Group (2016) The Nine Pillars of Technological Advancement. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries.
28. Staff, ATP Electronics (2015) Automation Industry Industry 4.0 Challenges and Solutions for Storage Devices.
29. Kuka AG (2016) Hello Industrie 4.0_we go digital. KUKA Aktiengesellschaft ZugspitzstraÃe 140, 86165 Augsburg, Germany, 2016.
30. Dassault SystÃ¨mes (2016) DELMIA DPM Assembly Process Simulation 2 (APS), Delmia.
31. Silva RJ, Barbosa GF, Carvalho J (2015) Additive Manufacturing of Metal Parts by Welding. IFAC-PapersOnLine, 48: 2318-2322..
32. Global Manufacturing (2015) Boeing reduces lead time and saves money by 3d printing aircraft parts. Accessed on.
33. Airbus Group (2017) 3D printing Building from the inside. Factory of the future. New ways of manufacturing factory of the future.
34. 3Ders (2015) Northwestern University study confirms 3D printed metal parts help reduce aircraft weight by 7%. 3D printer and 3D printing news.
35. Siemens (2015) RFID-Tags: Rewriting the Rules of Logistics. Pictures of the Future â The Magazine for Research and Innovation.
36. Ehinger C, Hoffmann A, Reif W, Reinhart G, Strasser G (2010) Automated cutting and handling of carbon fiber fabrics in aerospace industries. 6th IEEE International Conference on Automation Scienceand Engineering, CASE 2010, Toronto, pp: 861-866.
37. Wiedemann M (2009) CFRP status of application in airframe structures and future development process. NAFEMS World Congress, Crete, Greece.
38. Modern Airliners. Boeing 787 Specs, Dreamliner Materials Pictorial.
39. Rouse M (2016) Internet of Things (IoT). IoT agenda. Techtarget.
40. Margaret R (2016) Augmented Reality (AR) Whatsls.com.
41. Waurzyniak P (2015) Aerospace Automation Stretches Beyond Drilling and Filling. SME Manufacturing Engineering.

References

42. Weber A (2015) Assembly Automation Takes Off in Aerospace Industry. Assembly magazine.
43. Gates D (2013) Painting robots speed production of Boeing 777s. USA today.
44. Gates D (2016) Boeing South Carolina no longer playing catch-up to local plants. The Seattle Times.
45. RadioBreizh.bzh (2015) SuccÃ¨s Pour Les Un An Du Plateau Technique Compositic.
46. ABB (2014) ABB unveils the future of human-robot collaboration YuMiÂ®.
47. Universal Robots (2015) Universal Robots quadruples injection molding output at Dynamic Group.
48. Agarwal T (2015) RFID â A Basic Introduction & Simple Application. EL-PRO-CUS.
49. Advance Materials in Space (2015) Sandwich structures.
50. Rosenbaum R (2015) How Internet of Things affects your corporate network. BITSIGHT Technologies.
51. WN.com (2005) DELMIA Delivers Version 5 Release 5, Enhanced Solutions Supporting Digital Manufacturing.
52. Development of aircraft and aviation equipment.
53. Barbosa GF (2016) Uso da tecnologia RFID (Radio Frequency Identification) para gestÃ£o de ferramentas no ambiente da manufatura. CONEM - Congresso Nacional de Engenharia MecÃ¢nica.

56. B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo. Robotics. McGraw-Hill.

57. D. Lee, T. Burg, D. Dawson, D. Shu, B. Xian, and E. Tatlicioglu, “Robust tracking control of an underactuated quadrotor aerial-robot based on a parametric uncertain model”, in Systems, Man and Cybernetics, 2009.SMC 2009. IEEE International Conference on, 2009, pp. 3187–3192.

58. Fondamenti di controlli automatici, P. Bolzern, R. Scattolini, N. Schiavoni

8. https://www.nasa.gov/aero/nasa-makes-aircraft-safer.html
54. http://krossblade.com/history-of-quadcopters-and-multirotors/
55. http://www.fai.org/

Conclusion

The manufacturing industry is going through amazing fourth evolution driven by technological breakthroughs such as the Internet of Things (IoT), intelligent networks, connecting machines, work and systems, that can independently interchange data and commands, initiate actions and control each other autonomously. New manufacturing focuses on intelligent products and smart production processes as well as on vertically and horizontally integrated manufacturing systems. Even if renamed locally according to different initiatives going on in various geographical areas and industry branches, the concept is universal. Experts estimate that 85% of enterprises will implement Industry 4.0 solutions in all important business divisions in 5 years. By 2020, it will be equivalent to an annual expenditure of €140 billion only at European level.

As far as the aviation is concerned, the main applications of the Industry 4.0 concept so far are related to the aerospace manufacturing processes such as robotics, additive manufacturing, augmented reality, IoT and simulation. However, the potential of Industry 4.0 key enabling technologies to increase the extremely tight safety levels in aviation operation has not yet been addressed, besides for the consideration on how safety is managed at the production sites. This chapter discusses the potential of Industry 4.0 key enabling technologies to increase the extremely tight safety levels in commercial aviation, and how the upcoming Aviation 4.0 (Industry 4.0 for aviation) might imply a paradigm shift opportunity in safety improvement.
This thesis analyses, from an evolutionary perspective, the stages of aviation development, from basic VFR flight rules at the Aviation 1.0 up to Aviation 4.0 stage where cyber-physical systems will be designed to assist humans' physically strenuous, unpleasant or dangerous work, to take decisions and to complete tasks autonomously.

The four stages in the evolution of commercial aviation, which are similar to the four stages in the industrial revolution. These four stages are closely related to the adoption of higher levels of automation on board aircraft. The first evolutionary stage, Aviation 1.0, corresponded to the beginning of the commercial aviation were flight evolved under visual flight rules, following visuals clues and signals, and there was hardly any instrumental aid to help pilots to fly. The second stage, Aviation 2.0 was dominated by the replacement of old mechanism by electric devices. Aviation 3.0, the third stage in the revolution of commercial aviation involved the massive incorporation of electronics in the cockpit. Finally, Aviation 4.0 is concerned with the design of cyber-physical systems (CPS) that are able to assist humans' demanding work by helping them to take decisions and to complete tasks autonomously, and with its integration of cyber-physical components in Future Aviation Information Systems. Cyber-physical systems will make the Aviation 4.0 airframe a digital and smart airplane. Aviation 4.0 technologies (automation, IOT, artificial intelligence, cognitive computing, big data analytics, digitization, etc) have the potential to generate a paradigm shift in the aviation industry, generating new mechanisms to make it not only more efficient but also safer. Unexplored concepts and approaches to safety start to being discovered by companies and researchers to approach safety from different perspectives with the new tools that Aviation 4.0 makes available. The authors have finally illustrated six case studies of the application of the Aviation 4.0 concept to increase the aviation safety, which is a reality nowadays:

• Automatic flying in predefined situations in a rule-based way.
• Developing a robust aircraft predictive maintenance.
• Cockpit safety cognitive computing aid systems.
• Real-time weather information update.
• Improved search and rescue services especially in the oceanic or remote area.
• Real-time human performance monitoring and alerting based on nonintrusive physiological sensors/signals and contextual information.

However, this revolution is not exempted of defies. Challenges related to information assurance and cyber security include the certification of cyber security requirements for e-Enabled airplanes; the development of anti-tamper avionics hardware and software and the collaboration of industry and governments to address the cyber threat to aviation. There are also very important technological challenges for airplane operations, which are as follows:

• worldwide aeronautical networks interoperability, including signal processing and wireless performance as well as the aircraft interfaces to the Internet;
• verification and validation of the onboard software, how to secure end-to-end entire SW supply processes, the understanding of cyber-physical life-cycle scale;
• improvement of airplane health, control and prognostics by exploiting sensor networks and data fusion, information management and data analytics and, critical real-time data sharing, appropriate end-to-end information exchange, distributed decision-making; and finally
• human-automation interface issues such as visualization, keeping human-in-the-loop and connection between aircraft controls and air traffic systems.

Being late will cost a lot: Research shows that first movers are transforming into digital enterprises. Industrial companies need to act now to secure a leading position in tomorrow’s complex industrial ecosystems. Those who are slow to explore them may find it difficult to compete. In an increasingly cost-competitive market, no company in the aerospace, defense and security sector can afford to lose opportunities to improve their cost and revenue position against their market peers.

*[1] 100 cents per gallon until the year 2004 and it almost tripled itself to 305.3 cents per gallon in 2008
*[2] 20 to 30 percent of operating costs (Air Transport Association 2009)
*[3] The all energy absorbed from ground, Tesla was never finished the project because he ran out of money, but the time changed now
*[4] CATIA (an acronym of computer aided three-dimensional interactive application) is a multi-platform software developed by the French company DASSAULT systems, it's applied by a wide variety of industries, especially aerospace and defense, it changed the old view, gived to aviation new keys, they asked the right question.

*[1] Going digital and fly smart is a generic offer across Airbus fleet providing ground & onboard applications, training, tailored services, and support, aiming to optimize Aircraft operations and to reduce Airline’s costs

*[2] Papers can affect a lot at company costs, first by its price ‘the cost of paper something cannot be ignored’, and second by its weight, it’s so heavy which mean more money for transport and wasting time in searching at simple information.

Conclusion

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