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Aviation 4.0: More Safety through Automation and Digitization

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Additional information is available at the end of the chapter

Abstract

The world is talking about the Industry 4.0 or the fourth industrial revolution, that is, the current trend of higher level of automation, digitalization and data exchange in manufacturing technologies. It includes cyber-physical systems, Internet of Things and cloud computing among other technological assets. With more than 5000 sensors, which generate up to 10 GB of data per second, modern aircraft engines are an exponent of what digitalization and the Internet of Aircraft Things could furnish, as part of the upcoming Industry 4.0 revolution, in the aviation industry. This new era has the potential to improve air transport key performance areas. Particularly, in an industry where safety levels are so high and the margins for improvement are extremely tight, this upcoming era might imply a shift in safety improvement. In an attempt to define Aviation 4.0, this chapter discusses the stages of aviation development from basic VFR flight rules at Aviation 1.0 up to Aviation 4.0 where cyber-physical systems are designed to assist humans' unkind or hazardous work, to take decisions and to complete tasks autonomously. It illustrates the current and future cases of application of Aviation 4.0 to increase the aviation safety, while outlines how they might increase aviation safety levels.

Keywords: industry 4.0, aviation 4.0, digitization, IOT, big data, cyber-physical

1. Introduction

The manufacturing industry is going through remarkable changes. The fourth revolution, driven by the Internet of Things (IoT), is here. It is creating intelligent networks, connecting

machines, work, and systems that can independently interchange data and commands, initiate actions and control each other autonomously [1]. 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 [2].

However, what is the Industry 4.0? This is the question that the industry world is talking about. Industry 4.0 [3] is sometimes referred to as the fourth industrial revolution, after the steam-powered mechanical machines, the electrically powered mass production and the electronically/IT-powered automated manufacturing. It focuses on the establishment of intelligent products and smart production processes as well as on vertically and horizontally integrated manufacturing systems [4]. Smart products are distinctively distinguishable, may be situated at any moment in time, and record past and current information or status as well as alternative ways to attain their target. Smart production processes [5] are intelligent production processes in which the various steps in the lifecycle are integrated with each other, starting with the design phase and ending with the retirement phase. The four stages of the industrial revolution are illustrated in **Figure 1**.
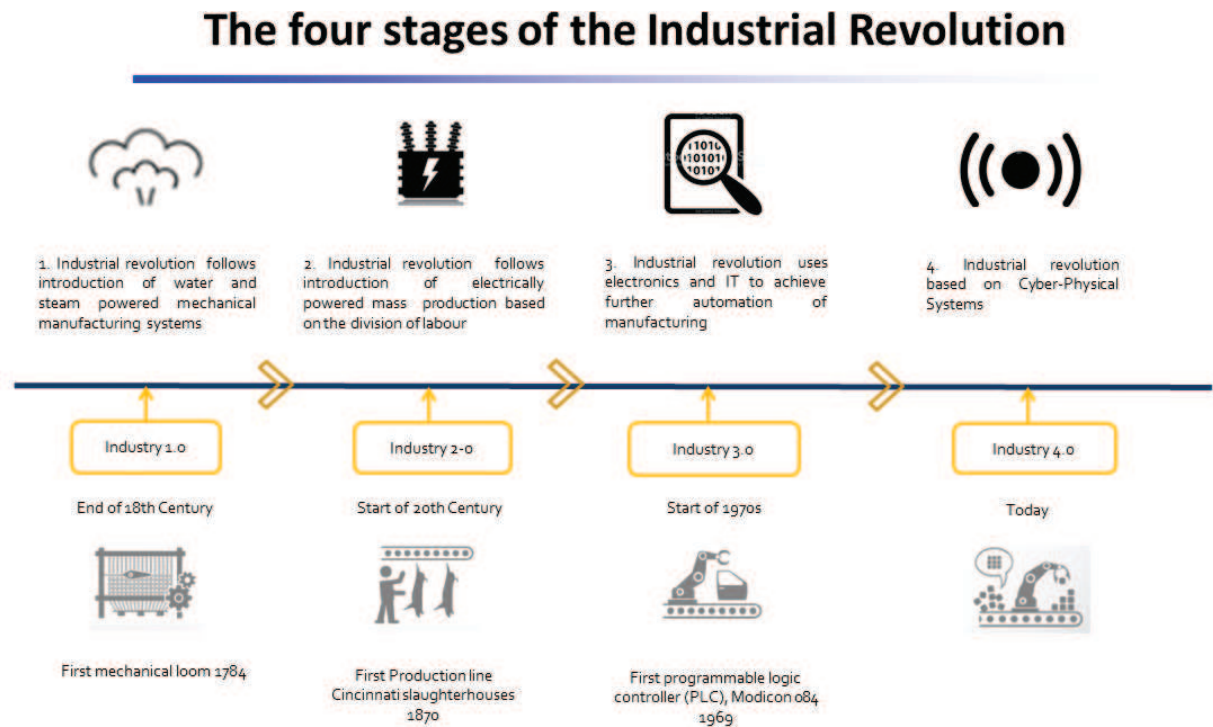
The concept is renamed locally according to the different initiatives going on in various geographical areas and industry branches. A few of them are:

- Internet of Things (IoT) [6] refers to the world in which all everyday objects and devices are completely interconnected for seamless interoperability;

- Industrial Internet of Things (IIoT) [7] is what you get when applying the concepts of IoT to an industrial setting, for example, in production;

- Smart Manufacturing is a term mainly used in the USA, and China2020 is a term mainly used in China [8];

- Factory of the Future is a large research initiative supported by the EU, in which new technologies (such as IoT) should be applied to factories;

- Industrial Internet (General Electric), Connected Enterprise (Cisco), and so on;

- Industrial Digitalization is a term used in Sweden, which stresses the impact and potentials of digitalization in both manufacturing and process industries.

The difference between these initiatives does not lie in the goals, but rather in the selection of enabling technical solutions (e.g., wireless or not, use of Internet or proprietary networks, point-to-point communication or not, cloud-based or not, etc.).

As far as aviation is concerned, the main applications of the Industry 4.0 concept so far are related to the aerospace manufacturing processes. Barbosa [9] provided a contextual outline of how robotics, additive manufacturing, augmented reality, IoT and simulation are currently applied at the aeronautics manufacturing industry. He illustrated some novelties in the aerospace industry related to Industry 4.0 and its day-to-day benefits.

Even if there is still a long way to go before the first fully automated airplane is produced, application of robots at Airbus and Boeing will make monthly production rates above 30 units

The four stages of the Industrial Revolution

1. Industrial revolution follows introduction of water and steam powered mechanical manufacturing systems

2. Industrial revolution follows introduction of electrically powered mass production based on the division of labour

3. Industrial revolution uses electronics and IT to achieve further automation of manufacturing

4. Industrial revolution based on Cyber-Physical Systems

Industry 1.0
End of 18th Century
First mechanical loom 1784

Industry 2-0
Start of 20th Century
First Production line Cincinnati slaughterhouses 1870

Industry 3.0
Start of 1970s
First programmable logic controller (PLC), Modicon 084 1969

Industry 4.0
Today

(Source DFKI Boss, 2011).

Figure 1. The four stages of the industrial revolution.

possible for some aircraft types. A new Airbus spin-off company, InFactory Solutions, is developing the corporation vision of the "Factory of the Future," with products and services for connected manufacturing under a fully connected and digital production environment. [10]

At the same time, some authors have pointed out the impact of Industry 4.0 key enabling technologies on how safety is managed at the production sites. Big data analytics can provide precise data for operational control, and IoT might improve equipment safety through a better maintenance [11–13].

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. This chapter discusses how the upcoming Aviation 4.0 era (Industry 4.0 for aviation) might imply a paradigm shift opportunity in safety improvement. It analyzes, 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. It also illustrates case studies of the application of the Aviation 4.0 concept to increase aviation safety.

2. The concept of aviation 4.0

Just as we can establish four stages in the industrial revolution, we can establish four stages in the evolution of commercial aviation. These four stages are closely related to the adoption

of higher levels of automation on board aircraft; and controversially, they do not correspond to a deliberate attempt of improving aviation safety in a steady way, but rather to a continuous adaptation to the challenges imposed by its environment following a trial-and-response approach. The four stages in commercial aviation revolution, from Aviation 1.0 to Aviation 4.0 are summarized in **Table 1**.

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. This era was dominated by the technological challenges posed by how to build and fly an aircraft. Very simple instruments constituted the so-called first steps toward "*virtualization of the environment*"; and provided basic indications required for the flight: first, anemometers and altimeters to indicate airspeed and altitude; pneumatic and electric gyroscopes to measure attitude and stabilize an artificial horizon; basic mechanical autopilots to keep a straight flight; servos and devices to perceive forces on aerodynamic surfaces (artificial feel load, Mach trim compensator), and so on. Mechanic inventions were progressively incorporated to flight controls in parallel with electric basic instruments to help pilots.

The second stage, Aviation 2.0 was dominated by the replacement of old mechanism by electric devices. Technological advances were driven by two important challenges imposed by the continuous and steady growth of aviation, with a higher number of aircraft operating in the same environment, under all weather conditions: (i) how to fly an aircraft under adverse meteorological conditions? and (ii) how to control multiple aircraft flying in dense traffic in the same airspace?

New instruments such as the VOR (very high-frequency omnidirectional range) and ILS (instrument landing system) allows the pilots to follow safely tracks and approach paths. On board

Stage of aviation development	Characteristics	Characteristics of signal processing	Main challenges
Aviation 1.0: VFR	Airspace	Visual signals	How to build and fly an aircraft?
Aviation 2.0: IFR	Frequency Space	Technical analog signals	How to fly an aircraft under adverse met conditions? How to control multiple aircraft flying in dense traffic in the same airspace?
Aviation 3.0: Assistance Systems; Safety Nets	Data Space (Digitization; Informatization)	Digital data processing; Digital data communication	To support the people with the help of aggregated, visualized, understandable information to make informed decisions; SWIM
Aviation 4.0: AFR, RPAS, Decentralized decisions by systems	Cyber Space (Automation; Artificial Intelligence)	Cyber-physical systems	Cyber-physical systems to assist humans' physically strenuous, unpleasant or dangerous work. Cyber-physical systems to take decisions and to complete tasks autonomously

Table 1. The four stages in commercial aviation revolution: From aviation 1.0 to aviation 4.0 [17].

innovations, such as electric autopilots, auto-throttle, flight directors, airborne weather radars, navigation instruments, inertial platforms, and so on, resulted in high safety enhancements. This evolution comes with a rise of information to be managed by the pilot, who might be confronted with more than 600 devices and indicators to be monitored and controlled in the cockpit.

Aviation 3.0, the third stage in the revolution of commercial aviation involved the massive incorporation of electronics in the cockpit, driven by the availability of reliable and usable digital data processing and data communication technology that invaded the market and society. At the beginning of this revolution, electronics significantly helped to diminish the clutter of instruments and replace the old indicators with integrated colored displays, cathode ray tube (CRT) and liquid crystal display (LCD), capable of providing a synthetic and analytic view of multiple parameters in a limited area of the cockpit. Technological solutions were progressively designed to support the operators (pilots and controllers) informed decisions, with the help of aggregated, visualized, understandable information. Operations onboard and outside of the aircraft shifted from tactical to strategic, and assistance systems and safety nets became crucial elements to increase the level of safety in commercial aviation.

The amount of information available in the system raised exponentially while became no longer immediately accessible and visible to the operator, who was forced to evolve his/her role from an active role (flying or controlling tasks) toward a monitoring role. This third revolution in aviation brings the emergence of the notion of the "electronic echo-systems." As an example, an A-320 incorporated around 190 computers, placed all through the fuselage, which interacts with them without the pilot being aware. The complexity of the "electronic echo-systems" is an epistemological obstacle for pilots and controllers, which might adversely affect the safety of the operation as far as they become sometimes "out of the loop."

Modern advanced aerospace systems will be characterized by a tight combination between onboard cyber systems (e.g., processing, communication) and physical elements (e.g., platform structure, sensing, actuation and environment), defined by researchers as "engineered systems that are built from and depend upon the synergy of computational and physical components" [14, 15]. Therefore, 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 [16].

Cyber-physical systems will make the Aviation 4.0 airframe a digital and smart airplane. The amount and diversity of operational data that can be collected onboard of the aircraft and by ground operations will raise exponentially. In Aviation 4.0, supervisory control in the manufacturing processes and big data acquisition and processing networks make possible automation and integration with IT systems. Airplane operations relay on a grand scale on the employment of CPS. Future Air Traffic Management systems are conceived as a cyber-physical system-of-systems (CPSS) that demand tight amalgamation to provide the required capacity, efficiency, safety and security system performance. In this scheme, examples of cyber components are aircraft digital communications, weather/traffic forecast, flight planning/optimization algorithms, situation awareness and decision support software, and so on, while example of physical components are mobile aircraft; dynamic airspace traffic, weather, pollution, noise; pilots, air traffic controllers, airlines crew, and so on.

Even today, with only a limited deployment of airborne cyber-physical systems, the available information is immense: maintenance messages/fault codes, quick access recorder (QAR) of flight and system parameters; maintenance action logs/test results/shop data; real-time data and real-time information management for decision-making, and so on. The great technological parallel developments in data analytics will support active reaction to these enhanced aircraft operations. To illustrate the diversity and the volume of data that the total deployment of aviation will imply 4.0, let us consider that the modern engines (such as the Pratt & Whitney's Geared Turbo Fan GTF engine) can have up to 5000 sensors generating up to 10 GB of data per second. A single twin-engine aircraft with an average 12-h flight time can produce up to 844 TB of data, 20% more data than Facebook daily accumulated data. While an Airbus A320 transmits about 15,000 parameters per flight, the figure is 250,000 for the A380 and 400,000 for the A350. It seems, therefore, that the data generated by the aerospace industry alone could soon surpass the magnitude of the consumer Internet. However, the wave of data is "useless" without targeted analysis.

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.

Industry 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 in an attempt to approach safety from different perspectives with the new tools that Aviation 4.0 makes available.

In the following sections, we revise up to six case studies that illustrate the application of Aviation 4.0 concept to significantly increase the safety levels in aviation.

1. Automatic flying in predefined situations in a rule-based way.

2. Developing a robust aircraft predictive maintenance.

3. Cockpit safety cognitive computing aid systems.

4. Real-time weather information update.

5. Improved search and rescue services especially in the oceanic or remote area.

6. Real-time human performance monitoring and alerting based on nonintrusive physiological sensors/signals and contextual information.

3. Automatic flying in predefined situations in a rule-based way

Recent aviation history is splashed with occurrences that have led researches to consider the concept of AFR "Automatic/Autonomous Flight Rules," which implies "Automatic flying in predefined situations in a rule-based way".

On 1 July 2002 at 23:35, flights DHL Flight 611 and Bashkirian Airlines Flight 2937 collided at 36,000 feet over the German town of Überlingen. The investigation identified the deficiencies in the air traffic control service and the error of one of the crew to follow the indications of the onboard aircraft collision avoidance system (traffic collision avoidance system—TCAS) in the origin of the accident. The TCAS was able to effectively anticipate the collision and generate proper and correct alarms to alert the crews and generate evasion trajectories to be followed by each crew. TCAS resolution maneuvers were correctly generated. If both crews had acted accordingly, following the "rules" and the TCAS resolution indications, the accident would have been avoided.

On 24 March 2015, the flight German Wings Flight 4 U 9525 crashed in the French Alps. The aircraft followed a descent trajectory guide by the pilot, who had set the autopilot to descend to 100 ft. (30 m) and augmented the descending speed of the aircraft. One minute before the aircraft hit the ground, the system that alerts of dangerous proximity of the aircraft to the terrain (enhanced ground proximity warning system—EGPWS) generated correct and proper warnings indicating to the pilot to ascend to avoid collision with the ground.

On both situations, the aircraft systems correctly detected the dangerous situation and "warnings" were generated properly, although not appropriately followed by the crew. Both cases would have been avoided if the warnings have been automatically followed when the crew was not taking appropriate action in due time.

These support the idea to develop "rules of flight" where the Aviation 4.0 cyber-physical (expert or AI) aircraft system will follow the warnings automatically, in case the crew is not taking appropriate action in due time.

Other recent occurrences raise the question about the capabilities of Aviation 4.0 to prevent or avoid particular accidents. Malaysian Airlines Flight MH370 left the cleared flight path and disappears from radar screen without any communication with ATC. Could an Aviation 4.0 FMS prevent from deviating from the filed flight plan in that massive way (without having activated/provided a feasible "alternate" routing)? In a more general approach, could an Aviation 4.0 FMS prevent from flying into a no-fly-zone (NFZ) or a restricted area?

Figure 2. Automatic flying in predefined situations.

Aviation 4.0, using the potential of automatic flying in predefined situations, as illustrated in **Figure 2**, and in a rule-based way, could help to overcome today's safety and security gaps, although key R&D work (Aviation 4.0 Research Agenda) is still needed to get it done, such as the:

- Identification and definition of automatic/autonomous flight rules.

- Predefinition of situations, where automatic (autonomous) flying to be activated and to be deactivated after the situation has improved.

- Standardization of "sensor" signals (data inputs) needed to determine, whether an in-flight situation is out of an acceptable "envelope."

- Safety Analysis for Aviation 4.0.

- Resolution of regulatory and liability issues.

Many puzzle stones needed are already available and in operational use, and developments and experiences from other domains can be taken on board. Missing links are topics for a future research agenda; however, no unsolvable issues identified so far. On the one hand, engineering and operational skills and experience are needed; on the other hand, skills and experience in (social) change management are not negligible.

4. 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

Parts and technicians ready

Augmented Work, maintenance and service

Fourth dimension facilitate guidance, remote assistance and documentation

Time of next Dispatch Condition occurrence.

Figure 3. Predictive and augmented maintenance.

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 the most complete documentation while on the job. Predictive and augmented maintenance applications are illustrated in **Figure 3**.

5. Cockpit safety cognitive computing aid systems

Cognitive computing is the capability of the computational systems to emulate the behavior of the human brain, that is:

- Manage and stock huge volumes of data and information in a wide variety of formats (pictures, sound, text, symbols, alphanumeric characters, conversations, etc.);
- Find optimal solutions and process situations that are never experienced before;

- Process information and inputs without requiring data to be organized or compliant with a predefined and close structure or format;

- Organize data and information to find patterns and obtaining hindsight from the information;

- Integrate and combine new data with previous past knowledge and experiences, making sense of such mixture;

- Learn from experience, retaining prior questions and contexts;

- Make decisions and provide intelligent answers to questions based on inferences from the information received;

- Refine and update of decision and answers from a continuous information gathering and processing.

Applications of cognitive computing in aviation safety are illustrated in **Figure 4**. A good exponent of a cognitive computing system is IBM's Watson. Watson is able to process questions expressed in natural human language, and gather and analyze unstructured information and assistance operators make enhanced sensitive choices. Information feed into Watson does not need to match any inflexible parsing. Watson learns from previous experience, prior information and questions, and the context where those questions were made. Moreover, the system is able to argument the evidence it relies on and therefore, the explanations behind its recommendations. All these capabilities for interpreting, evaluating and recommending solutions convert Watson (or other similar cognitive computing systems) into a key enabler for aviation safety improvement.

Airbus Group is working on the development of a Watson Cockpit Mentor, that is, studying how to use Watson technology to help guide pilots through crisis and reducing the information overload pilots during an emergency. In the case of a flight emergence, the system will be able
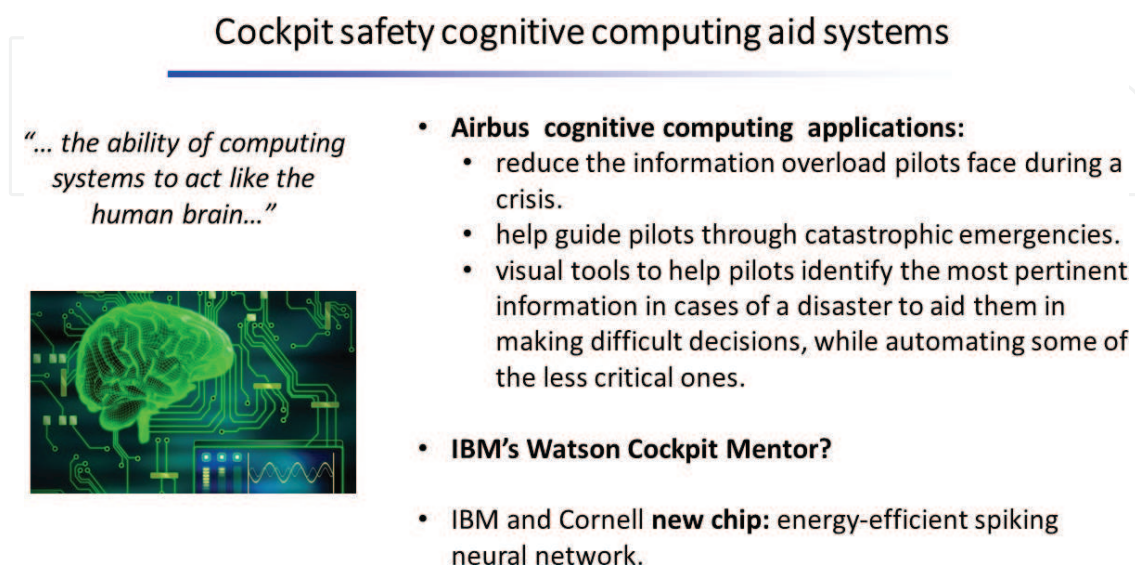

Figure 4. Aviation safety cognitive computing applications.

to interpret not only the information about the status and performance of the aircraft systems but also the pilot description of the problem in simple spoken natural language and the relevant technical materials and documents. Watson crew assistance will interpret the problem and all the information logically will discern critical information on the cabin relevant to the problem solution and make recommendations to the pilot. Those recommendations might concern a modification of the operation of the aircraft to mitigate the problem, a guide in the troubleshooting of the problem, and so on. The system might take care automatic control of less critical decisions and flight task, relieve the crew of nonessential emergency-related activities and therefore, allow the pilot to concentrate on these resources on the resolution of the emergence.

As much as this project might look like science fiction, it is actually one of the collaborative activities between Airbus and IBM. Airbus is also developing cognitive computing applications in other fields of the aircraft operation such as fuel efficiency, maintenance capabilities and operational optimization of the aircraft.

6. Improved search and rescue services especially in oceanic or remote area

Some recent accidents have involved aircraft disappearing, sometimes over the oceans without notice or communications, and very expensive and sometimes unfruitful rest recovery campaigns. The last unfortunate MF370 event has reinforced the efforts of the aeronautical community to develop the concept operations for the Global Aeronautical Distress and Safety System (GADSS). This system will track the aircraft everywhere and under all conditions, it will locate the aircraft when in distress, and it will ensure the timely recovery of Flight and Cockpit Voice Data.

The requirements for these systems are established for normal tracking conditions and for the location of an airplane in distress conditions. It has been establishing an aircraft-tracking time interval of 15 min whenever air traffic services obtain an aircraft's position information at greater than 15 min intervals for airplanes with a seating capacity greater than 19.

Requirements for the location of an airplane in distress (a state that if uncorrected could result in an accident) establish airplane to autonomously transmit information from which a position can be determined at least once every minute. This will provide a high probability of locating an accident site to within a 6 NM radius. This transmission can be activated:

- automatically based on flight behavior and triggered by abnormal or specific events;
- manually from the air crew; and
- manually from the ground.

These requirements will be applicable to new airplanes with take-off weight greater than 27,000 kg from 1 January 2021. The provisions relating to one-minute distress tracking are performance-based, not technology-specific, which means that airlines and aircraft manufacturers

Improved search and rescue services especially in the oceanic or remote area

Performance-based Standards and recommended practices for *distress* flight tracking

–Not technology-specific
–Location of an accident site within 6 NM
–Activated
 •Automatically based on flight behaviour
 •Manually from the air
 •Manually from the ground

–Power and position information autonomous from other a/c systems
–Applies to new built aeroplanes from 2021

Figure 5. Aviation 4.0 distress tracking systems.

may consider all available and emerging technologies which can deliver the one-minute location tracking requirement specified. Main characteristics of Aviation 4.0 distress tracking systems are summarized in **Figure 5**.

There is a range of already installed aircraft technologies/services that can be used for this purpose in the near-term (ADS-C, DS-B, stand-alone sitcom, ACARS, etc.). Mid-term solutions imply space-based ADS-B solutions based upon LEO polar satellite systems, expected to be available around 2018. Long-term solutions envisage automatic deployable flight recorders or real-time data streaming.

The advantages of aviation 4.0 IoT aircraft will allow real-time analysis of an airplane performance and operation, detecting deviations of normal behavior, not standard operating conditions and not desired aircraft states as well as precursors of dangerous conditions that might lead to an accident. IoT would help to connect the missing dots, proper alarm generation, proper tracking, administration, intercommunication among the stakeholders.

7. Real-time human performance monitoring/alerting

The ecosphere of wearable devices is probably one of the newest, more attractive and at the same time, challenging area of the Internet of Things (IoT). Its applications might vary widely and in particular, the possibilities in the field of aviation are just beginning to be explored. The design, production and integration of wearable devices in aviation operations are on the IoT cutting edge. Requesting to be the first airline to incorporate wearable technology in its operation, EasyJet has designed and produced advanced uniforms that integrate wearable

Figure 6. Real-time human performance monitoring and alerting based on nonintrusive physiological sensors/signals and contextual information.

technology for the in-crew and ground staff, with an aim to increase safety in the operation. Air New Zealand uses wearable devices to track unaccompanied children on short- and long-distance flights.

This technology allows sensing, storing, interpreting and communicating information about the wearer's body or surroundings by using reliable, not expensive and nonintrusive sensors and devices. Real-time human performance monitoring and alerting based on nonintrusive physiological sensors, signals and contextual information are illustrated in **Figure 6**.

Real-time integration of nonintrusive physiological sensors and signals combined with contextual information offers a great potential to tackle problems related to one of the aviation safety corner stones, human factors. This technology could help to:

- detect and alert the reduced human performance situations (fatigue, stress, lack of SW, etc.);
- develop better and more reliable human performance adaptive automation; and
- improve skills and rate of learning based upon neuro assessment of learning processes in aviation, and so on.

8. Conclusions

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 chapter analyzes, 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 authors establish 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.

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