Automation and assistance in aeronautics and automotive: Diversity versus homogenization?

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Abstract

Automobile automation is increasing. In the light of aircraft automation, this paper present a first account on a possible transfer from aeronautics to automobile (AtoA). The common aspect concerns the concept of information-intensive deeper interface between the driver and the mechanical parts of the vehicle in its environment. The automobile is integrating more information technology to improve safety, performance and comfort. We analyze various avionics systems that have been designed and could be taken as analog to automotive systems currently being designed. The AtoA transfer includes participatory design processes where potential users and designers share their viewpoints to incrementally derive a mature product. We are interested in the elicitation of cognitive functions that emerge from the use of prototypes.

Keywords

Human-centered automation, fly-by-wire, drive-by-wire, safety, performance, comfort, function allocation, emerging cognitive functions.

Introduction

Automation developed during the twentieth century to improve safety, performance and comfort. Over the years, automation was based and implemented using advanced technology and engineering sciences going from Watt’s regulators, to various kinds of automation theories, advanced software and finally the most sophisticated aerospace onboard systems. Automation led to get people happier, safer, more comfortable, more efficient, and eventually exposed to a few problems. We are interested in these problems. Automation is also a competition factor that manufacturers use to make a difference in our fast growing information society. The maturity of the resulting automated systems becomes a real issue to the point that surprises have to be taken into account seriously and avoided as much as possible. Human error and reliability lead to new types of incidents and accidents.

Maturity is a matter of co-adaptation of people and technology. It may take several years to master a new automated system. There are several aspects of the problem that include human-centered design, certification, training, maintenance and regulation. Technological evolution sometimes creates socio-technical jumps or breaks. At the end of the nineteenth century, people had to adapt to the revolution that made them move from horses to steam machines, as well as from agriculture to industry. During the late eighties, commercial pilots had to adapt to glass cockpits and fly-by-wire operations. We realized that pilot’s job moved from a very-high-skilled sensory-motoric activity to a management activity. Now the pilot is in charge of an organized set of artificial agents that include the autopilot, the navigation system, the
collision avoidance system, the communication system and the various systems that enable the crew to handle comfort, safety and performance. During the last two decades, we have also moved from manual control to flight management.

Today, cars become more automated. Information technology is more incorporated in the car in the form of navigation systems (GPS), power steering, collision avoidance systems, head-up displays (HUD) and so on. This means that the driver, like the aircraft pilot, has to manage several onboard systems moving from sensory-motoric to management activities. The main issue of this paper concerns the transfer of the automation experience that we accumulated in aeronautics to the automotive domain. Most of human-centered automation (HCA) was incrementally designed in the aviation domain. It is time to use HCA principles and methods in other domains and in the growing automobile automation process.

The paper supports the upcoming AtoA (Aeronautics to Automotive) project. AtoA ambition is to build bridges between aerospace and automotive sectors, together with computer science and engineering, automation and control theory, and human factors. An additional goal is to bring to European automotive research and industry a global awareness of performance and interaction among the various actors involved in the automotive business including drivers, passengers, maintenance people, road controllers and so on. This project will explore possible innovations, changes and emergence of new practices that come from the integration of information technology in the car. AtoA is a cognitive engineering project.

AtoA focuses on consistent definition and articulation of various elements and actors of the global automotive environment that includes weather, infrastructure, traffic and all actors involved in this environment. The main issue is the analysis and allocation of the cognitive functions involved in the management of this overall system, the same as for the air traffic management. In the same way, we plan on eliciting responsibilities, levels of automation, and the co-adaptation of technology and people. As in aerospace, the specification and validation of new technology should take into account human factors in order to optimize the automotive system as a whole, integrating human and machine components in the car and its environment.

Human-centered automation is developed both locally and globally with respect to safety, performance and comfort. AtoA objectives are both theoretical and pragmatic. Models will be incrementally developed starting on analog aerospace models when available. They will be validated experimentally using a variety of significant and representative scenarios. AtoA consists in developing a domain ontology centered in human-centered automation; developing behavioral models appropriate to automotive problems; define various target scenarios that will be used during the tests (both formative and summative evaluations); elaborate and propose a set of socio-technical principles; apply this approach to appropriate cases.

Aviation functions and related avionics onboard systems

Avionics is aviation electronics, i.e., all electronic systems designed for use on an aircraft. Seven categories of Embedded Avionics Systems (EAS) can be distinguished with respect to trajectory control, navigation, aircraft system management, communications, collision avoidance, weather management, and air traffic management. The number of these systems tremendously increased for the last three decades. In addition, onboard avionics systems have become very sophisticated pieces of software that tend to increase the distance between pilots and mechanical systems.
Glass cockpits started to be developed in the early eighties. They are called “Glass cockpits” because they include computer screens (previously cathode ray tubes) instead of electromechanical instruments. These screens tend to become larger in order to facilitate the display of useful information that could not be displayed on small screens without heavy unnecessary interaction. The most recent EAS are interactive in the office automation sense. Today pointing devices have been introduced onboard, on the A380 for example.

The “Dark Cockpit” (DC) was introduced by Airbus in the eighties, and is now successfully used in most current aircraft. The DC metaphor is used to present only information that is necessary to the crew. Anything that works well is not displayed. When a warning occurs, the pilot is required to “remove” the alarm by pushing the enlighten button. As a result, the system understands that the pilot is aware of the problem, and/or provides a checklist and a do-list that support the recovery procedure.

**Trajectory control**

There are two loops that need to be taken into account to control the trajectory of an aircraft. The first loop concerns the controlling aircraft attitude and position around its center of gravity using a side stick or a control column, and thrust levers. The time constant for this control loop is about 500 milliseconds. This control loop has been automated in order to automatically maintain an optimal attitude (roll, pitch and yaw). The second loop concerns guidance automation involving integrated digital autopilot and auto-throttles. It deals with high-level control modes such as climb and altitude hold modes. A flight control unit enables the pilots to set the appropriate parameters of these modes. The time constant for this control loop is about 15 seconds.

Aircraft handling qualities (HQ), which are related to these two loops, are key factors for flight effectiveness and safety. We usually make a distinction between longitudinal and lateral handling qualities. Controllability and observability of aircraft primary parameters are among the most important issues that are investigated, before deciding the best control strategy to be applied. Controllability is related to the possibility of forcing the system into a particular state by using an appropriate control signal. If a state is not controllable, then no signal will ever be able to force the system to reach a level of controllability. Observability is related to the possibility of “observing”, through output measurements, the state of a system. If a state is not observable, the controller will never be able to correct the closed-loop behavior if such a state is not desirable. Solutions to problems of uncontrollable or unobservable system include adding actuators and sensors.

**Flight management and navigation**

A third loop was designed and implemented during the mid-eighties, introducing the flight management system (FMS) that automated the navigation function, and started the new era of the glass cockpits. The main goal of this loop is to guide the aircraft on a prescribed flight plan. Therefore, the FMS has to be programmed, i.e., a flight plan has to be entered into the related computer via a control display unit. Consequently, the FMS is in charge of following the prescribed plan in flight. The time constant for this control loop is about one minute.

The FMS provides real-time horizontal and vertical navigation information, i.e., the route programmed by the aircrew, as well as standard departure and arrival procedures. A 2D moving map is incrementally computed and provided on a navigation display (ND). The FMS also computes performance data and a predicted vertical profile. The FMS computes the most
fuel-efficient vertical path based on aircraft weight, cost index, cruise altitude and predicted wind. The latest FMS systems also provide a 2D representation of the vertical profile below the moving map on the ND.

**Aircraft system management**

System failure management is an important part of pilot’s work. The ECAM (Electronic Centralized Aircraft Monitor) was introduced by Airbus in the A320. Boeing developed a similar system called EICAS (Engine Indication and Crew Alerting System). ECAM monitors aircraft functions and display messages that detail failures and most recovery procedures, i.e., color-coded do-lists and checklists taking into account corrective actions and system limitations. ECAM is now a commonly used system on the whole Airbus aircraft family. On the A380, the OIS (Onboard Information System) complements the ECAM by providing other operational procedures and appropriate system descriptions. The concept of an EFB (Electronic Flight Bag) is being developed toward reducing paper in the cockpit.

Several studies were carried out on operational documentation to further anticipate onboard electronic documentation (Blomberg, Boy and Speyer, 2000). Three levels clearly emerged: (Level 1) safety/legal/operating level (what to do), i.e., flight manual information for the cockpit (need-to-know) with very fast and very easy access (paper or electronic); (Level 2) philosophy of use/rationale (why it is so), i.e., FCOM for reference (nice-to-know); (Level 3) detailed information level (how it is done), i.e., training manual that provides rationale, notes and explanation, adapted to various regulations and requirements from authorities. These levels of information are currently used in the OIS.

**Communications**

Ground-based controllers direct aircraft on the ground and in the air. Their service is called *air traffic control* (ATC). Aircraft separation is a primary task of controllers, i.e., preventing aircraft coming too close to each other both horizontally and vertically. A secondary task is to plan traffic and provide information to pilots, such as radar traffic advisories, weather advisories, flight following, and navigation information. Anywhere the separation task is active, the air space is said “controlled”, otherwise it is “uncontrolled”. The International Civil Aviation Organization considers that “controlled airspace exists in areas where air traffic control is capable of providing traffic separation. These would often be areas where radar coverage is available, or at high altitudes where VFR\(^1\) flight is prohibited. This does not mean that air traffic control actually provides services to all flights in the airspace, only that such service is possible.”

Depending on the type of flight and airspace, ATC may issue *instructions* that pilots are required to follow, or merely *flight information* (in some countries known as *advisories*) to assist pilots operating in the airspace. In all cases, however, the pilot has final responsibility for the safety of the flight, and may deviate from ATC instructions if he deems it necessary for the situation (emergencies). ATC involves two main activities and jobs: terminal or airport control, and en-route or area control.

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\(^1\) VFR = Visual Flight Rules
Collision avoidance

Aircraft Collision Avoidance System (ACAS) improves air safety by acting as a last “resort” method for preventing mid-air or near collisions between aircraft. ACAS is an ICAO (International Civil Aviation Organization) standard specified in ICAO Annex 10 Volume IV, which provides pilots with a system independent of ATC to detect the presence of other aircraft that may present a threat of collision. The system provides an indication of a maneuver that will reduce the risk of collision, when the risk of collision is imminent. ACAS and TCAS (Traffic Alert and Collision Avoidance System) provide traffic alerts (TAs), which aim at helping the pilot in the visual search for the intruder aircraft, and vertical resolution advisories (RAs), which are indications given to the flight crew recommending maneuvers intended to provide separation from all threats; or maneuver restrictions intended to maintain existing separation. The next generation of ACAS/TCAS will provide TAs and RAs in both the vertical and horizontal planes.

CFIT (Control Flight Into Terrain) is another concern in the aviation domain (Boy & Ferro, 2000). CFIT constitutes by far the most important category of fatal accidents in civil aviation (Boeing, 2006). Moreover, in almost all the CFIT accidents, aircraft were totally destroyed and the number of fatalities is extremely high. CFIT is consequently the first issues to attack in order to significantly improve safety in civil aviation. It is widely accepted that CFITs are accidents related to collision with the ground or with fixed obstacles where crews were not enough aware of the relative position and/or trajectory of the aircraft with respect to the ground. The importance of CFITs motivated the development of the Ground Proximity Warning System (GPWS, in the 80's) and more recently that of EGPWS (Enhanced GPWS, in the 90's). Both systems are based on a detection of ground proximity from sensor information. EGPWS, in addition, provide the crew with cartographic information of terrain, centered on the aircraft’s position. Statistics clearly show that from the introduction of GPWS in 1985, the probability of CFITs decreased dramatically, but that it still remains high. Current thoughts about CFIT prevention are based on the improvement of crew awareness in order to better anticipate possible conflicts, improvement of procedures and means for navigation (e.g., RNP\(^2\), DGNSS\(^3\), constant slope approaches, crew surveillance procedures such as altitude/height verifications, consistency in the identification of all geographical waypoints among the different systems that refer to them, such as paper and electronic data).

Weather management

Weather is an important external factor in aviation. In particular, many landings and take-offs can be aborted in cases of reduced visibility (heavy fog) or low ceilings. Other factors such as turbulence, icing, strong winds and thunderstorms may disturb the flight, and sometimes cause fatal damage to an aircraft in flight. Weather is however not only a problem, it may be used for improving flight efficiency, by taking advantage of the jet stream tailwind for example. A particularly difficult weather condition is when there is a wind shear, i.e., a difference in wind speed and/or direction between two adjacent points in the atmosphere. Wind shear, either vertical or horizontal, is very dangerous during take-off and landing.

Current cockpits are equipped with 2D/3D Weather Displays (Boyer & Wickens, 1994). These displays enable the pilots to anticipate weather conditions by identifying intuitive

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\(^2\) RNP = Required Navigation Precision  
\(^3\) DGNSS = Differential Global Navigation Satellite System
weather objects. There is major distinction that needs to be considered between local and global weather situation. When the aircraft is within a weather situation, information must be provided to the pilots to help them handling this situation. When a severe weather situation can be anticipated, it should be displayed to the pilots.

Current technology limits the tools to weather detection and not weather prediction. Current on-board weather management equipments are only able to detect and display actual rain precipitation location and intensity. The pilot has to infer the weather conditions he will encounter upon reaching a location from his knowledge and expertise. Around airports, the pilot gets an augmented weather picture by combining indication from his on-board equipment with ground weather reports.

**Air Traffic Management**

Air Traffic Management (ATM) is an ongoing topic of investigation. ATM is matter of multi-agent interactive system. Agents are pilots, controllers and ATM-aware systems whether they are on-board or on the ground. The controller is in charge of the airspace. However, the pilot has final responsibility for the safety of the flight, and may deviate from ATC instructions in an emergency.

Even if appropriate technology is already available, human factors research is ongoing. In particular, the PAUSA (2006) project is currently being carried on authority distribution in the aeronautical system. PAUSA focuses on the introduction of ATM-aware systems such as the on-board automatic Traffic Collision Avoidance System software (TCAS), Automatic Dependent Surveillance-Broadcast (ADS-B), and Cockpit Display of Traffic Information (CDTI) and Airborne Separation Assurance System (ASAS). ASAS is an aircraft system that enables the flight crew to maintain separation of their aircraft from one or more aircraft, and provides flight information concerning surrounding traffic.

Among the current pieces of technology, CDTI provides an enhanced cockpit display that enables pilots to see other aircraft positions, distances between them, and other traffic information, such as, track, ground speed, and so on. This kind of technology contributes to move authority from ground to aircraft, and in particular to the concept of “free flight” that provides more autonomy to pilots.

**What could be transferred to the automotive world?**

In this paper, we will not provide a technology-centered description of an AtoA transfer, but rather a human-centered perspective. It is interesting to analyze the differences and commonalities of roles of various actors in both sectors in order to better understand the relevance of such as transfer.

**Who are the various actors?**

There are three main classes of actors in the aviation sector: pilots, controllers and maintenance people. We don’t count the designers and human factors specialists who are potentially transferring experience from one sector to the other, as we try to do it in this paper.

Drivers are very different from pilots. Unlike aviation, the automotive domain involves a large variety of drivers. There are about 150,000 airline pilots in the world today; they have similar professional profiles. They follow a long training and are selected with respect to very strong exams both theoretical and practical. There are millions of drivers who all of them
have very different profiles. Driving does not require heavy training, and selection is quite easy compared to aviation. Drivers can be very old, unlike pilots who stop when they are 60.

In aviation, controllers provide routes to pilots who follow them even if there are exceptions such as when pilots follow TCAS information. Air traffic control is centralized. Drivers are their own controllers. They control their trajectories, decisions to change their original routes and so on. Road traffic control is decentralized. Onboard radio provides information on traffic and weather conditions. In addition, onboard GPS (Global Positioning System) instruments provide useful graphically displayed information on routes to go from point A to point B. GPS facilitates navigation on the earth, on the sea or in the air. There are two opposite evolutions, i.e., the introduction of “free flight” and self-separation, for example, moves air traffic management from centralized to decentralized, and the introduction of telematics on both roads and vehicles, either by terrestrial networks or satellites, enables a more centralized road traffic management that contributes to reducing congestion and improving journey time reliability.

Automotive maintenance did not follow the same track as aviation maintenance because the variety of car users is much larger that the airline pilot community. For that matter, maintenance processes are different. In addition, aviation maintenance standardization and regulation are more advanced. With the introduction of electronic systems in cars, such standardization and regulation still need to be invented.

**From the management of a set of onboard systems to the use of an integrated human-centered automated vehicle**

Automation is an old story in aviation. The first autopilots were introduced in the 1930s and used ever since. However, aircraft were highly automated starting in the eighties, introducing various kinds of artificial agents on board. Pilots have become flight managers. The number of driver-assistant onboard systems increases in cars.

Currently, there is an increasing accumulation of onboard systems that assist the driver at various levels of the driving task (Michon, 1979; Van der Molen et Bötticher, 1988; in Boy 2003): strategic (the knowledge-based level according to Rasmussen’s terminology, 1986), tactical (rule-based level) and operational (skill-based level). The navigation system (GPS) assists the driver at the strategic level in planning and navigation tasks. At the tactical level, the driver deals with rule-based information processing using head-up display (HUD) systems and night vision systems, for example. Finally, the operational level is the most assisted. At this level, the driver controls the vehicle both laterally (steering) and longitudinally (acceleration, braking). Lateral control is assisted by various onboard systems such as the EPS (Electronic Power Steering), LKAS (Lane-Keeper Assistance System), ESP (Electronic Stability Program). Longitudinal control is typically assisted by the ABS (Anti-Blocking System), ACC (Adaptive Cruise Control), BAS (Brake Assisting System) and so on.

Currently, onboard systems can be considered as a group of individual assistants. Each of them has a role. They are not fully integrated, i.e., automation is not thought as a whole. In addition to regular driving, the driver needs to manage these systems on an individual basis. A integrated automation of a vehicle will have a direct impact on the way drivers will handle the resulting system, i.e., new practices will emerge. Emerging cognitive functions will have to be elicited (Boy, 1998). Such elicitation is an incremental process that is very difficult at design time. An iterative process of scenarios development and tests will have to be carried out. The experience and awareness that we accumulated during aircraft glass-cockpit development will
certainly be useful in the automotive sector. The automobile did not follow the same trend of the aeronautic, even if automation started to appear. “Fly-by-wire” was experienced for the last twenty years, “drive-by-wire” is still an on-going research activity.

X-by-wire can be described by saying that electronic systems replace electromechanical and mechanical systems. The state of the art in the automotive domain is more an incremental addition of electronic assistance systems than a fully integrated automated solution. The car of the future is expected to be fully electronic. Consequently, driving needs to be re-thought in the same way as flying became flight management. There will be an organized set of artificial agents that will need to be managed. New user interfaces will be designed with respect to new driving tasks. As in aviation, redundancy will be key. In particular, manual reversion to old instruments will be necessary at least during the first phase of the drive-by-wire delivery. After a while, redundancy may be though differently by providing to drivers ways of maintaining an acceptable level of cognitive and emotional stability. A vehicle system management will be necessary in the same way have an ECAM onboard commercial aircraft. The driver will have an integrated warning system that will not only provide awareness of potential failures, but also recovery procedures, backups and checklists.

**Comparing ATM and road traffic management**

In aviation, there are several ground equipments that contribute to trajectory control and flight management. For example, the Instrument Landing System (ILS) includes two radars that enable the guidance of the aircraft during approach and landing. It could be compared to the LKA (line-Keeping Assistance) developed by some constructors, and more generally automated trajectory control. In addition, there are beacons that enable the Flight Management System (FMS) to take care of the navigation. GPS is available in cars today, however it is not acting on the car as the FMS does. Such level of automation has to be further investigated. As in future air traffic management, cars will have to communicate among each other.

Road equipment will be very different from airspace equipment for traffic management. First, air traffic is strongly controlled, and therefore very anticipatable. Road traffic is not as much controlled, and therefore must be constantly monitored in order to elicit and synthesize usable and useful data. This data might then be used to equip roads with changeable message signs that drivers use to re-plan their trip and/or control their speed.

Air traffic communication is directed to a specific aircraft. We cannot apply such a method to road traffic, first because of the greater number of the vehicles. Instead, the CAR-2-CAR communication consortium of constructors is already developing an effort on the inter-vehicles communication (Car-to-Car, 2007). Communication between vehicles contributes to improving road safety and efficiency, as well as local traffic flow. Today, radio informs on traffic jams, weather forecast and state of the road, but this is for everyone listening to this radio frequency.

Aircraft separation is a matter of air traffic controllers today. Self-separation is becoming a serious research topic in aeronautics. More generally, our airspace will become more and more congested, as traffic estimated growth is around 4.5% for the last 20 years. Studying and structuring the airspace of the future is a worldwide topic. Both Europeans (SESAR, 2006) and Americans (NGATS, 2006) are studying this topic. A related human factors project started in France, i.e., PAUSA (2006) already mentioned. Again self-separation in the automotive domain might not involve the same human factors as in the aviation domain.
Unfortunately, there are much more incidents and accidents on the road than in the air. Therefore, their just-in-time reporting and management are key issues. Integration of information technology both in the car and on the road needs to be thought in this regard. Organization of critical care units is a related issue.

**Cognitive function analysis and allocation**

Function allocation is a key human-factors approach and technique. It is used to decide how tasks can be distributed among humans and machines. Function allocation can be static or dynamic, i.e., some tasks can be allocated permanently or, at least, in a relatively permanent context, or dynamically with respect to context changes. Designers may decide to definitively allocate some functions, performing appropriate tasks, to the machine, i.e., power steering. They may also decide to leave the decision to the driver to allocate a selectable function, e.g., cruise control. However, the driver may not be the only agent to make allocation choices, the machine may also be able to make such decisions. When people are not able to act fast enough, ultimate decisions may be made by the machine, e.g., the Auto-GCAS (Ground Collision Avoidance System) of the F16 was designed to significantly reduce critical fighter-aircraft mishaps resulting from pilot spatial disorientation, loss of situational awareness, G-induced loss of consciousness (G-LOC) and gear-up landings (F-16 Net, 2006). The same could be said for radar-based collision avoidance system on cars that would prevent or minimize a collision.

Intelligent interfaces, sometimes called deeper interfaces because they include large amounts of software, are developed on top of mechanical systems. Such interfaces remove pilots and drivers from the real mechanical effects. Sensory-motor feedback that was available before is now replaced by visual displays and/or auditory cues, and sometimes by sensory feedback. A major issue is to find the appropriate substitution, which might be a mix of the above modalities. Modes are introduced, e.g., climb or altitude holding modes. Such function allocation is highly dynamic and is generally set by pilots, but once they are set, the pilot may forget the allocation context. This is called mode confusion that sometimes led to fatal accidents unfortunately. This is why deeper interfaces have to be thought thoroughly. Aeronautical experience will be very helpful there.

There are many other issues that deserve to be mentioned and analyzed such as public transportation, freight transportation (especially transportation of dangerous matters), organization of the various types of vehicles with respect to various criteria such the number of people being transported, and so on. This paper states a position on what we think are the main differences and commonalities between aviation and automotive domains with respect to automation.

**Preliminary discussion on the AtoA project**

The key point of this paper is the integration of information technology in the car and on the road, and human factors that are associated. Aviation experience shows that development of related systems is not enough, even if industry is leading the game! We would like to avoid surprises and take benefit of aviation human-factors experience on advanced automation. We propose to analyze this integration by eliciting *emerging cognitive functions* that will guide an appropriate human-centered automation. Information needs to be available at the right time under the right format in order to motivate the right action.
Driver-vehicle interface will be determined from such cognitive function analysis putting to the front appropriate information content, density and priority. This is not possible without participatory design and an incremental development mixing formative evaluations and re-design. We need to better understand what drivers will be able to accept from three major viewpoints: safety, performance and comfort. For that matter, human modeling needs to be developed in order to rationalize and further anticipate human factors such as situation awareness, decision making and action taking. We know from the start that a human model that we use at the beginning of a design and development project will be incrementally modified during this project. Human modeling should be thought as a documentation process of the design process and its successive solutions. Note that we already have contributed in this direction by developing the concept of active design documents (Boy, 2005).

Prototyping should support human-centered design from the early days of the design process. Very simple paper-based prototyping is very useful in order to quickly share ideas with potential users. It is most often unproductive to ask users what they want because they don’t know it. Users are not designers usually! Designers should be able to show solutions in order to get viewpoints from potential users. Users are very good at providing what they think about a concrete solution. In addition, technological solutions and user profiles are incrementally co-designed. Therefore, the profile of a test user at the end of a design and development project will not be the same as his or her profile at the beginning. This co-adaptation should be taken into account. A rationalization of this co-adaptation in terms of cognitive functions helps. Aviation experience might help because we already have developed cognitive functions related to very similar highly automated systems. They may not be totally the same as in the automotive domain, but the possible AtoA transfer is expected to be useful.

To conclude, human reliability and human-machine resilience are key concepts that require more attention. In particular, complexity should be better mastered in order to avoid automation surprises. We already provided an account on perceived complexity that is distinguished from internal system complexity (Boy & Bradshaw, 2006). Most of the time in aviation, perceived complexity tremendously decreased when the automated product matured, sometimes after a difficult start where it was high to very high. We relate complexity to expertise and cognitive stability in human-machine systems, and more specifically in highly automated systems.

This paper is a preliminary contribution to possible transfer between aeronautical and automotive domains with respect to highly integrated automation. Each EAS that we described above should be analyzed in an automotive perspective. There is already an effort in the automotive domain to integrate such systems as trajectory control, collision avoidance, head-up display, navigation systems and so on. However, the key issue is integration and a holistic vision of how these systems could be coordinated in order to improve safety, performance and comfort.

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