ACADÉMIE DE L'AIR ET DE L'ESPACE
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AIR AND SPACE ACADEMY

PER HANC PROSUNT OMNIBUS ARTES
ACADÉMIE DE MARINE

LES DOSSIERS

TOWARDS UNMANNED SHIPS AND AIRCRAFT?

To what extent can humans be replaced by machines?

AAE Dossier # 50

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FOREWORD

This dossier builds on and extends the conference organised in December 2019 by the Académie de marine (AM) and the Académie de l'air et de l'espace (Air and Space Academy, AAE), the proceedings of which have been published on the AAE website[1]*. It expresses the joint views of the Air and Space Academy and the Académie de marine.*

Whereas the conference was held before the current health crisis, in a context of growth in air and maritime transport, this dossier was written during the crisis at a time when it was still difficult to predict the extent and duration of economic repercussions and therefore their impact on the development of air and maritime transport.

Nevertheless, we consider that many of the findings of the conference remain valid, and indeed are even more relevant in some cases.

The conference concluded that, with a few exceptions, the total absence of crew on board is a long-term hypothesis which may never come about or indeed be desirable.

So, with claims of better technical performance and safety than human operations still to be demonstrated, why move towards autonomous vehicles? Especially since there are many obstacles to be overcome and questions answered: liability, validation/standardisation, evolving skills, public and user acceptability and the essential issue of safety, whether real or perceived.

And yet increased automation, i.e. an extension of automated systems and the role they play, will continue to be a major development trend in both sectors. As is the

1. https://academieairespace.com/documents-et-medias/vers-des-navires-et-des-aeronefs-sans-equipage/

case for society as a whole, digital technologies will continue to make great strides in maritime and air transport. Such technologies, which form the basis for many assistance systems and handling aids, may involve the display of information to the crew, the interface between human and machine, or even systems with full authority over flight or engine controls, sometimes without any input from the crew.

But this enhanced digitisation requires maintaining firm control over the development and safety of software, that could self-construct with the emergence of artificial intelligence and deep learning; it also carries an increased risk of cyber-attacks.

Moreover, the ever greater role played by automated systems in the handling and operation of ships and aircraft requires crews to have total mastery and a full understanding of these automated functions, something the aviation sector has learned to its cost and that the maritime sector could learn if in-depth analysis were to be carried out into certain accidents.

Tackling the extreme question of full autonomy made for a dynamic, evolving approach to the issues of safety, the role and training of crew members other than pilots and the subjects of liability and insurance, enabling a fairly unique, cross-disciplinary vision.

In the end, it is clear that the role of humans in the front line of air and sea operations is essential and undoubtedly irreplaceable, and that automatic systems must first assist humans by adapting to them before replacing them in a distant and hypothetical future.

Yves DESNOËS
Former president of the Académie de marine

Michel WACHENHEIM
President of the Air and Space Academy

EXECUTIVE SUMMARY

For each topic, maritime and air transport were compared, despite the fundamental difference that exists between the two: maritime transport consists essentially of freight transport – 11 billion tonnes in 2018 – while air transport mainly involves the transport of passengers – 4 billion per year (before the health crisis). Nevertheless, this comparison enabled the pooling of information and generated some reflections and even proposals.

Today, no shipping company is contemplating a total, generalised elimination of the ship's crew. What shipping industry do expect from the development of automated systems is greater safety, a reduction in costs and polluting emissions, and an improvement in the reactivity and robustness of the entire maritime transport logistics chain.

For their part, air carriers do not presently consider the complete elimination of crew from airliners to be a goal, even in the long term. They are interested only in research on single-pilot operations, whose medium-term interest will have to be re-analysed in the wake of the current crisis. At an intermediate stage, the goal of limiting to two the number of pilots on board long-haul flights will bring economic and operational gains, but will require further research before implementation.

It would appear therefore that the expectations of air and sea carriers in terms of automation systems are based around safety, economy and performance, but that neither sector envisages fully eliminating the onboard handling crew. While remotely piloted and automated military vehicles are increasing in number in both air and naval forces, autonomous systems are still confined to niche applications in the civilian sector. Numerous technical difficulties remain to be resolved, particularly in terms of standardisation and organisation, before demonstrating the acceptable safety and security conditions required for more ambitious applications. In maritime transport, improving safety in an increasingly automated environment requires an *in-depth rethink of the respective roles of humans and automated systems, human-machine interfaces and the reliability of decision aids involving software standardisation and certification. For future aviation activities, the need to encourage research and innovation while maintaining the safety level will call for an evolution in regulations towards a more systematic use of risk analysis to complement the traditional standards-based approach.*

Cyber-risks have become the main risks in terms of security, and new practices in software development and use must be adopted by all players. The digital transformation may lead to further reductions in the number and severity of accidents but might also create new accident scenarios that are difficult to anticipate. Training and awareness-raising efforts are needed, not only for personnel using the new digital technologies but also for the designers of these digital tools. Software tools and automated systems will need to be sufficiently documented and their performance and reliability properly evaluated in their operational context, as shown by the recent accidents involving the B737 MAX.

The development of automated operating systems for moving objects, and the evolution of the latter towards complete autonomy, are already technically feasible. If, in addition, advanced artificial intelligence systems are put in place, the role of ground-based operational centres will be strengthened, and more and more responsibilities will be transferred to them. Their task will range from the mere supervision of mission parameters to emergency decision-making such as changing flight destination in the event of unforeseen events not directly related to the operation of the aircraft – the health of a passenger for instance or the closure of an airport or airspace.

Ports and airports are complex places that will continue to be managed by human operators. The availability of continuous, secure onboard-to-ground connections is a critical factor. In addition, the interaction and hierarchy of various land-based authorities (air and sea traffic control and management centres, operational control centres, port and airport authorities) will need to be clearly established and standardised.

This increase in automated systems will have only a moderate impact on employment in the long term, and training will have to be adapted, since humans will remain at the heart of the system. Air- and seamanship skills, which are necessary in all situations, will have to be maintained, indeed this is one of the fundamentals of both sectors.

The acceptability of these new technologies will strongly determine their spread. Passengers will undoubtedly need to have been accustomed to travelling on land vehicles without drivers (metro, trains, buses, private cars) for a fairly long period of time before they agree to board unmanned aircraft (taxis) or ships (ferries), because the air and sea environments are felt to be much more hostile. Aircrew, port and *airport staff express strong reservations, linked both to possible job losses and to the profound transformation in their jobs and qualifications brought about by automation. The capacity of autonomous systems to achieve a level of safety equivalent or superior to that obtained today is a major issue, particularly in the aviation sector.*

The increase in automated systems often makes it more complex to determine criminal liability in the event of an air accident, and it can therefore be assumed that the same will be true in the maritime sector as automated steering assistance systems become more widespread.

The law will not remain unaffected by current changes. Whether the evolution is gradual or the result of radical innovations, it will inevitably take place. Tomorrow's legislation will be the fruit of today's technological upheavals.

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RECOMMENDATIONS

Chapter 3.2

Recommendation No.1

Standardisation of safety and security aspects of software used for maritime navigation and ship automation:

- *convene a group of experts on software safety and security under the authority of the State, mandated to propose the introduction of adequate standards into regulations and a statement of the reasons justifying such action;*
- *present the subject to the relevant European bodies and seek the assistance of other European countries to support the project at the level of the International Maritime Organisation (IMO);*
- *seek the support of interested countries such as Australia and Korea, and others.*

Recommendation No.2

Give priority to supporting French industry in the development of demonstrable safety and security software; also promote the support of European industry for the same purpose.

Chapter 9

Recommendation No.3

Automation provides and will increasingly provide essential assistance for aircraft and ship handling and makes a decisive contribution to improving operational safety. In degraded situations, as in normal operations, crews must at all times maintain *their understanding of the functioning of these automatic systems so as to remain in full control of the situation, which means that systems and interfaces must be designed with this goal in mind. Organisations dispensing initial or continuous training will need to ensure that ship and aircraft handling crew receive in-depth training to ensure their understanding of automatic control systems; this training should be founded on a sound basic knowledge of the skills of their trade for all normal situations and in the case of unforeseen events.*

1. OPERATORS ARE NOT READY TO TOTALLY DISPENSE WITH CREWS

1.1 For maritime transport

For ship handling, bridge automation projects that correlate all sources of information are aimed at giving the navigating crew a better perception of the situation. It is not felt to be any real economic interest in further reducing the number of crew members. Automation must then result above all in improved safety and more cost-effective navigation rather than in a reduction of the handling crew.

*For Antoine Person, secretary general of Louis Dreyfus Armateurs, "*on a bulk carrier or oil tanker, crew costs represent 5% of operating costs; on a roll-on roll-off ship – a regular line vessel –, crew costs represent around 10% and on a special vessel, crew costs are between 20 and 25% because these are very high-tech ships whose crew members have very specific training. Placing 700-tonne packages at a height of 120 metres to assemble a wind turbine, while the ship is moving, requires very different qualifications to those required to operate a cargo ship"*. On the other hand, certain technical functions, such as maintaining precise dynamic positioning, can be better performed by automated systems, which means that the number of personnel assigned to these functions can be reduced. The automation of such tasks therefore improves both cost effectiveness and performance.*

*For his part, Rodolphe Saadé, chairman and CEO of CMA CGM group, the world's fourth largest maritime carrier, sees in the current crisis the need to "*consider new, more resilient supply chain models, with cleaner and more digitised maritime transport"*.*

From this point of view, will ship automation inevitably cause a reduction in crew members, even though their number has already been cut back sharply in recent decades? Shipping companies point out that, as well as operating the ship, the crew is also responsible for technical and maintenance functions, and that carrying out maintenance work while at sea reduces downtime during stopovers and cuts costs. A permanent onboard presence of personnel assigned to these tasks is therefore necessary.

No shipping company is currently considering full, large-scale elimination of the handling crew. On the other hand, carriers expect future automated systems, for navigation management for instance, to contribute to an improvement in safety, a reduction in costs and polluting emissions and a better response and resilience of the entire seaborne transport logistics chain.

1.2 For air transport

*Pascal Traverse, general manager Autonomy thrust at Airbus, announced that Airbus had taken the decision to study a completely new cockpit but "*to keep the pilot because they are better than the machine at analysing a situation or taking decisions*".*

*He also said that "*airlines wanted Airbus to work on a Single Pilot Operation (SPO) cockpit at least for certain cargo or short missions because of a shortage of pilots*".*

However, for general aviation, the American company Garmin recently marketed an automatic landing system, known commercially as "Autoland", which is intended to cover cases of total incapacitation of the pilot(s). Aircraft targeted by this equipment are top-of-the-range single-engine general aviation aircraft, and the first have already been certified.

This equipment is programmed to return the aircraft to the ground on a runway in emergency situations. The system can be triggered by a passenger or, if there are no passengers on board, can be auto-triggered when the pilots have not touched a control for an extended period of time and are not responding to the system's commands. The Autoland system selects a destination aerodrome for a safe landing. It is therefore a restricted use automatic landing system, reserved for cases of incapacitation of the pilot(s), and should not be used in normal operation. This is very different to an automatic landing system for commercial airliners, which can be used for every landing in low-visibility conditions on a runway equipped with a category III Instrument landing system (ILS).

For air carriers, faced with the obligation to take back-up pilots on board in addition to the basic two-pilot crew on long-haul flights, the main advantage of progress in automatic landing systems would be the possibility of reducing the number of pilots on board on these flights to two, whether for business aviation or scheduled transport. This simple and apparently modest objective can be achieved in a few years, but it does require the cockpit to be designed for the presence of a single pilot at the controls while the other is resting during the cruising phases, particularly in emergency situations.

Reducing the number of pilots during long-haul flights to two offers significant savings and operational flexibility. It requires technical adjustments and changes to operating procedures during the rest phases of one of the pilots.

The air transport crisis is likely to be serious and long enough to call the pilot shortage argument into question. Moreover, it is to be feared that manufacturers and equipment suppliers will see their budgets greatly reduced for whatever developments remain to be made, in particular to delegate deroutings to onboard automation and to compensate for pilot incapacity.

*Indeed, Marc Rochet, president of French Bee, is very clear: "*on modern aircraft such as the A330 or A350, for our part, we are not really looking for a reduction in the onboard crew or an aircraft flown by a single pilot, or even in a few decades with no pilot*".*

*According to Bruno Stoufflet, vice-president of Research and Development at Dassault Aviation, "*for the moment, we are working on the single-pilot in cruising flight stage, which is already a huge challenge*."*

As for the total removal of pilots on board, this could only apply to freight transport or small vehicles for a long time. No such plans are currently being envisaged for civil aircraft weighing more than two tonnes. This is because the potential savings have yet to be demonstrated and the challenges in terms of safety and integration into air traffic are complex to overcome. In any case, this will be linked to the acceptability to passengers of a flight with no pilot on board. Other sectors, rail or road for example, will probably have to get the public accustomed to automated transport beforehand.

In the short term, the value of the single-pilot cockpit is significantly reduced by the sharp fall in demand for air transport. In the medium term, though, the latter could restart on a new economic model, probably with fewer passengers on board, and the single-pilot cockpit would drastically reduce operating costs, particularly those of crews. This solution could, in this scenario, become essential.

Air carriers do not currently envisage the total elimination of crew from airliners, both for commercial reasons, because passengers are not ready, but also due to issues of safety and integration in air traffic.

Research is focused on the single-pilot cockpit, the medium-term interest of which will have to be re-assessed in the wake of the current crisis.

It therefore appears, ultimately, that the expectations of maritime and air carriers in terms of automation relate to safety, economy and performance, without any of these players considering totally dispensing with the flight crew on board.

2 THE DIGITAL TRANSITION OF MARITIME AND AIR TRANSPORT IS WELL UNDERWAY

2.1 Remotely controlled and autonomous vehicles are multiplying in both air and naval forces

2.1.1 UAVs

Technological progress has enabled military forces to develop operational aircraft without pilots[2] or people on board[3] since the Vietnam War. Since the mid-1990s, long-range UAVs have been able to remain in flight for more than a day at markedly subsonic speeds. They are multi-sensor and equipped with a characteristic dome containing a satellite antenna at the front:

- *Medium Altitude Long Endurance (MALE) UAVs fly below commercial traffic, e.g. the MQ-1 Predator (American, since 1995), the SIDM[4] Harfang derived from the Israeli Heron UAV, then the RQ-9 Reaper (American, since 2010) used by the French Air Force in Afghanistan and in the Sahel, and the European Remotely Piloted Aircraft System (RPAS) currently being defined;*
- *High Altitude Long Endurance (HALE) UAVs fly over commercial traffic, for example the RQ-A Global Hawk over land and its maritime derivative, the 12-tonne MQ-4C Triton, in service in the US forces.*

2. NATO definition of a pilot as an onboard driver.
3. Definition of French civil regulations.
4. SIDM: intermediary MALE UAV system.

Tactical drones represent three quarters of military drones and are very varied, using all types of aerodynes, rockets, aircraft, helicopters; they are generally single-sensor, with direct link and a weight of between a few hundred grams and one tonne. The lighter ones are very similar to commercial leisure drones. This family includes the Sagem Patroller, the Thales Spy ranger or the helidrone VSR700 from the Airbus Orka system. Some are now embarked on combat ships.

Several apparently stealth combat UAV demonstrators have been developed in the United States: the Boeing X-45 and X-46 and the Northrop Grumman X-47 Pegasus. In Europe, the nEUROn was successfully developed under project management from Dassault Aviation. It should be noted that the first operational UAV of this family, the onboard MQ-25A Stingray, will serve as an in-flight refueler for the US Navy air groups.

In addition, China has been very active in the field of armed UAVs for some fifteen years. It exports its products (UAVs and associated missiles) very widely, in particular MALEs of the CH series (also known as Rainbow) and the Wing Loong series (a contract for 300 Wing Loong 2s was signed with Saudi Arabia in 2017), and is fast becoming one of the world leaders in this activity. These results have been achieved thanks to highly competitive prices, varied equipment and a very liberal export policy. An armed stealth vehicle very close to the Israeli Protector was exhibited at the Zhuhai show in November 2018.

The general characteristic defining UAV systems is to consist of an aircraft comprising the ***equivalent of a flight director***[5] *and an autopilot, a mission calculator including the pre-loaded mission plan as well as the control of mission loads and transmissions. During flight, the mission is carried out via successive changes to the mission plan carried out by operators at a ground station and transmitted to the UAV via radio links. Direct remote flight control is commonly used only for the lightest UAVs. Some UAVs are armed; the weapons are deployed according to a well-defined chain of command in which the human operator has control of decisions.*

Military UAVs are currently subject to military operational traffic regulations.

2.1.2 Unmanned marine vessels

Developed in the early 2000s by the Israeli firm Rafael and the American Lockheed-Martin, the Protector is a remotely operated surface vehicle (Unmanned Surface Vehicle USuV) capable of carrying out local surveillance missions, anti-terrorist, anti-piracy or anti-trafficking identification and intervention missions with no operator on board. On a semi-rigid hull 9 m long, it is equipped with a remotely controlled, stabilised 7.62 mm machine gun. It has been adopted by the navies of Israel, Singapore and Mexico.

5. An FD gives instructions to the pilot, but here there is no pilot.

In France, the ECA group and the Sirehna company (Naval Group) have developed similar concepts and produced demonstrators on the basis of remotely operated multi-purpose platforms that can be rigged with different mission systems: surveillance, reconnaissance, interception, target training. Although remotely operated, these devices are able to carry out a given navigation programme with an autonomous capability to track, avoid obstacles and adapt to sea conditions.

There are also many demonstrations of Unmanned Underwater Vehicles (UUV), intended for hydrographic and hydrological surveys, intelligence gathering, surveillance: SeaCat from Atlas Elektronik, the Naval Group D-19 family, Hugin from Kongsberg. These devices can be deployed from the coast, or by a mother vessel. Given the difficulties of communication underwater, they are autonomous and must establish a surface link to transmit data or receive instructions from their operator (on land or embarked on another platform). Automatic deployment and recovery systems using submarines are being developed, in particular by Naval Group and the Swedish company Saab.

China, for its part, has developed, among other projects, a 7.5-tonne unmanned surface naval vessel with a propulsion system enabling it to reach a speed of 50 Kts. The development of unmanned vessels operating in swarms from a "mother" ship was underway in 2019. These formations would be used against enemy coastal patrol vessels, for minesweeping, surveillance and intelligence missions, and amphibious operations. The Marine Lizard is an amphibious unmanned craft that claims to reach 5 Kts on water and 20 km / h on land. This 12 m long trimaran is armed with anti-aircraft and anti-ship missiles with vertical launch. The first model began testing in 2019.

These devices, combined with onboard drones, extend the detection and action radius of combat vessels, increase advance threat warning and enhance self-defence capability. They are becoming increasingly common and their logistics and implementation are already changing the architecture of new ships and of their combat systems.

It is in the field of mine warfare – detection, identification and neutralisation of underwater mines – that unmanned devices find their most immediate application. The United States, France, the United Kingdom and Russia are developing new mine warfare systems based on remotely operated vehicles with a large autonomous capacity. The purpose of these systems is to keep ships and crews at a safe distance from hazardous mined areas. Launched in 2015, the Franco-British development programme Maritime Mine Counter Measures (MMCM) is based on a dual segment of unmanned vehicles: a first USuV transports a UUV to the area to search, identify and destroy mines. An equivalent concept proposed by Naval Group and ECA has just been adopted by the Belgian and Dutch navies.

Beyond that, discussions are taking shape, particularly in the United States, on the technology and operational concept of Large Unmanned Surface Vehicles (LUSV) and their submarine equivalent, Extra-large Underwater Unmanned Vehicles (XLUUV). Launched in the early 2010s, the Defense Advanced Research Agency (DARPA) programme to develop an ASW Continuous Trail Unmanned Vessel (ACTUV) led to the completion of a 40-metre autonomous vessel that is supposed to be able to navigate autonomously for 70 days, and to cover a distance of the order of 10,000 miles at 12 knots. This prototype, called Sea Hunter, was transferred to the US Navy in 2018 to continue its operational evaluation and is said to have made a round trip Hawaii-San Diego in 2019 in quasi-autonomous mode.

The US Navy wants to acquire these large unmanned vehicles as part of a strategy to evolve into a new fleet model organised around fewer large units and more large USuVs in order to meet the military challenges posed by directed energy weapons and hypersonic missiles.

2.2 In the civil sector, autonomous systems are for niche applications

2.2.1 In the maritime domain

Several demonstrations of port-to-port navigation in purely autonomous mode have been carried out in recent years. In the summer of 2017, from a control centre in San Diego, the Finnish company Wartsilä piloted an 80-metre supply vessel, the Highland Chieftain*, sailing in the North Sea off Aberdeen, and had it perform different manoeuvers at different speeds. At the end of November 2018, the same company announced a new experiment carried out on board an 85 m ferry, the* Folgefonn*. During the test, the autonomous pilot managed all navigation operations along the entire route from port to port: departure, port exit, transit, port entry, docking. A pilot on the bridge would only have had to press a button to start each leg of the journey.*

The Rolls-Royce Marine company, for its part, announced an experiment in early December 2018 aboard a 54 m car ferry, the Falco*, on a multiple route in the archipelago south of Turku in Finland. During this test, the vessel followed its route in fully autonomous mode – including obstacle avoidance and berthing – without incident. A human pilot oversaw the operation from land. As of 1st April 2019, Rolls-Royce's "marine" activities were transferred to the Norwegian company Kongsberg. Kongsberg was already involved in this technology, having planned as early as 2018 the construction of a small autonomous container ship intended for a coastal link between Porsgrunn, Brevik and Larvik in Norway. It should save 40,000* *truck journeys per year (Usine nouvelle, 14 February 2018). The ship Yara Birkeland has started its sea trials in October 2020. The demonstration of an autonomous barge is also included in the European research programme Autoship.*

Created in 2016, OneSea is a consortium of maritime industrialists (Kongsberg, ABB, Wartsilä, Meyer Werft) and technology companies (Eriksson, Inmarsat) designed to promote technological research around autonomous ships.

In early September 2020, after Rolls-Royce and Wartsilä, the company SeaOwl, in cooperation with the French Maritime Affairs Department, ADEME, Bureau Veritas and industrialists such as Total and Naval Group, remotely piloted from a laboratory in Ecole polytechnique in Saclay an unmanned French Navy supply tug based in Toulon. On 21 September, the Dutch company Kotug demonstrated the autonomous navigation of a tugboat on the Nieuwe Maas river in the port of Rotterdam, its route being optimised in real time by artificial intelligence software.

Faced with the increasing number of such experiments, in June 2019 the International Maritime Organization (IMO) published some Interim guidelines for Maritime Autonomous Surface Ships (MASS) trials. In parallel, since May 2018, it has been conducting a review of existing regulations (Regulatory Scoping Exercise) with the aim of adapting them to unmanned vessel traffic.

The main ship equipment manufacturers, and in particular the suppliers of navigation and steering systems, are pushing technological research in the direction of increased ship automation and are setting very ambitious development goals in terms of autonomy. For its part, the IMO estimates that "*Most predictions consider that the autonomous or semi-autonomous operation of ships would be limited to short voyages, for example from one specific port to another, over a short distance[6]*".

2.2.2 In the aviation sector

There is a proliferation of drone projects.

*According to Nicolas Marcou, drone programme director at the French civil aviation authority (DGAC): "*today there are 1,800 professional operators using more than 15,000 drones in France, with a growth of two hundred operators per year, and no end in sight for the moment. This sector has experienced strong technological development for 7 to 8 years. Recreational drones are subject to a light online training course on safety rules. Remote pilots of professional drones must have a certificate (theoretical knowledge, practical training). Fully automated drones (without remote control or surveillance) are still prohibited in France.*"*

6. www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

Beyond small leisure or surveillance drones, several ambitious applications are being considered, such as in the field of urban mobility, with autonomous, unmanned taxis transporting passengers or freight over long distances.

The 2010s saw the exponential development in the world of very low weight microdrones, equipped with rotary airfoils, often with four rotors, using electric motors powered by a LiPo (lithium-polymer) battery similar to those used in mobile phones.

These very light drones are remotely piloted from the ground by a human operator who is connected to the drone by radio link, often using freely usable frequency bands (such as WiFi wireless links). They must fly below 150 m, not overfly homes, and stay away from aerodromes.

The tremendous success of these microdrones has given many companies (especially "startups") the idea of developing larger drones that can carry freight or even passengers. Three applications have been identified for passenger transport: travel between city centres and their outskirts, between cities and airports located at their periphery, and between nearby cities that are poorly served by public transport. The taxi operator Uber has published specifications for the drone taxis it plans to put into service. The main aircraft manufacturers Airbus and Boeing have launched the development of prototypes of these new drones in accordance with these specifications. The European Aviation Safety Agency (EASA) has published a draft regulation for the certification of these air vehicles.

On a technical level, and regardless of their economic viability, the transport of passengers by these drones raises many questions:

- *they will have to fly over cities, which is currently prohibited for microdrones, and be able to land near airports, which is also currently banned: the applicable regulations will have to be changed;*
- *they must fly at a very low height so as not to interfere with air traffic, but must not produce noise pollution: a helidrone with several rotors is as noisy as a certified helicopter because of the noise of the blades;*
- *greenhouse gases must not be generated, thereby requiring the use of electrical energy, either by carrying batteries, whose heavy weight will reduce the weight of the payload, or by using an onboard source of electricity such as a fuel cell powered by hydrogen stored in liquid form;*
- *appropriate infrastructures must be deployed in the cities that decide to authorise their use;*
- *if the number of flights becomes significant, an air traffic control service will also have to be set up to manage these flights, and drones equipped so that they can be followed in flight and also for anti-collision with other drones;*
- *if flights were to be made at a greater height above the ground, these drones would also have to be equipped with an anti-collision system with other aircraft that can fly in the same spaces;*

- *passengers will also have to be convinced to agree to use these drone taxis, which requires great confidence in their reliability, safety and availability (in all weather conditions);*
- *security authorities will also have to be convinced that these new transport vehicles do not pose a threat to public safety, in particular in the area of cyberthreats;*
- *finally, as long as there are human beings on board, the question arises of their role in the operation of the aircraft: can we imagine that they remain completely passive, once the destination has been set and accepted; should they not have the possibility of taking over without requiring a pilot's qualification? Uber envisages taking on board a "non-paying passenger" who would be there to reassure passengers and perform simple tasks that do not require expensive training like that of professional pilots. However, at the start of the service, the manufacturers are proposing that these drone taxis be optionally controllable by an onboard pilot, who will not be withdrawn until the service has been shown to be reliable, and the passengers reassured as to automated flight.*

It can therefore be concluded that the technologies to develop unmanned sea and air transport might seem to be within reach. However, many technical, standardisation and organisational problems still need to be resolved in order to demonstrate acceptable safety and security conditions.

3 THE DIGITAL TRANSFORMATION LEADS TO DELEGATING MORE AND MORE SAFETY-CRITICAL FUNCTIONS TO AUTOMATION

Automation here means both a state and an evolution. As a state, automation refers to the greater or lesser role played by automated systems or handling software in the functioning and operation of the vehicle. This share has been growing for many years and one wonders about the implications of continuing this development, which can be called dynamic automation, and which could go so far as to afford automatic operation a large decision-making autonomy.

Both ships and aircraft are increasingly automated and can perform most handling operations without human intervention in normal or even degraded conditions. This trend will continue, possibly allowing further reductions in crews without necessarily leading to their complete removal. What are now generally called unmanned aerial vehicles, or drones, are highly automated devices, including in the area of mission management, but they are constantly supervised by an outside operator on land or on another vehicle. The notion of supervision itself varies between different functional and temporal degrees, from permanent surveillance with resumption of control by the operator in the different critical phases of the mission, to discontinuous human surveillance in response to an alarm, or even complete decision-making autonomy from the automated system.

The European Aviation Safety Agency (EASA[7]) roadmap classifies the progress to be made in artificial intelligence into three stages corresponding to increased levels of automation:

1) *Human assistance: routine assistance, such as that provided by the operational control of a major airline, or enhanced assistance, with a suggested scenario in the event of difficulty.*
2) *Human-machine collaboration, with two schools: piloting by humans and monitoring by the machine, or vice versa, with a distribution imagined according to the scenarios, the first solution being implemented in routine situations, and the second in unexpected and stressful cases.*
3) *Machine control without human intervention (maybe around 2040?).*

IMO, for its part, identifies four different levels of automation:

1) *The use of automated systems for the operation of the various installations of the ship, including its navigation system, under the supervision of the watch crew on board who can resume control at any time. This is already the current situation. Progress in data display and decision support will lead us in the near future to speak of "enhanced crew".*
2) *Remote supervision (control centre on land) which allows the crew to be assigned to other tasks (maintenance). The crew can resume manoeuvring on order or in special situations (coastal approaches, for example).*
3) *The vessel is unmanned, but supervised remotely and, when necessary, remotely operated, from the onshore control centre.*
4) *The vessel is unmanned and fully autonomous. It is capable of reacting to any event from start to finish of its mission, within a framework of defined limit parameters. If these limits are reached, an onshore control centre is alerted and an operator is able to take over.*

The digital transformation, which induces increased automation, therefore leads to the transfer to software chains of actions and functions previously performed by human operators.

3.1 Digital transformation in maritime transport: a need for new standards

The digital transformation of the maritime sector applies, at different rates, to all activities in the logistics chain: fleet planning and management, load optimisation, administrative, regulatory and commercial management of freight, operations,

7. www.easa.europa.eu

navigation and maintenance. This transformation, which is still in its early stages, raises many questions and concerns, whether about its implementation or its impact, particularly in terms of jobs. Among the functions concerned, some directly affect the safety of the ship: all those related to platform stability, navigation safety and, indirectly, the maintenance of essential components.

Regarding navigation, the equipment and systems used on board ships are increasingly automated, in particular through the use of ever larger and more complex software. Since software reproduction costs very little, the result is a downward trend in costs with unchanged functions. Satellite navigation systems are proliferating, giving increasingly accurate and reliable positions. Radars are becoming more sophisticated, inertial systems without moving parts with linked components are seeing their costs drop, the increasing automation of sounders reduces reading errors, optronics are becoming usable and automatable at moderate cost, and finally accident recorders can gather more and more information. Systems that use these sensors are also advancing. Official electronic charts are becoming widespread and the Automatic Identification System (AIS) provides vessels and traffic surveillance systems with the identity, status, position and route of vessels in navigation zone.

But all this progress has not yet brought the expected benefits in terms of the number of accidents, bridge productivity, nor ease of use for the handling crew. There is a strong need for increased automation, requiring the digitisation of a large amount of data that is still manual and the integration of previously separate systems, in particular many systems developed separately but which have to interoperate.

In maritime circles, e-Navigation refers to the digital acquisition, integration, exchange and exploitation, on board and ashore, of maritime information for navigation, safety and security at sea as well as the protection of the marine environment; in the figure below, e-Navigation corresponds to the services appearing on the left side of the figure, from maritime authorities to hydrographic services. E-Navigation is the object of a development strategy adopted by the IMO in 2014 (Strategy Implementation Plan, SIP). In application of this implementation plan, the competent international bodies, the International Hydrographic Organization (IHO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), have for several years been producing normative documents that have been taken up and further developed by international standardisation bodies, in particular the International Electrotechnical Commission (IEC). These standards apply, in particular, to a Common Maritime Data Structure (CMDS), to the Integrated navigation System (INS). For its part, IALA has produced a model architecture for land-based systems.

Between the very basic overall design and the detailed specifications of data formats, there is still a lack of intermediate descriptions that would allow complex automated exchanges to be specified without ambiguity. Clear progress must be made in this direction, giving priority to navigation safety.

Telecommunications are also critical for security. Links are being digitised (in particular with AIS and soon with the VHF[8] Data Exchange System (VDES)), and are increasingly automated for better spectrum utilisation, communication satellite systems are multiplying and the speed and accuracy of distress alerts from distress beacons is being improved with the use of medium-orbit satellites (Medium-Earth Orbit Search and Rescue, MEOSAR). Onboard-land data exchange is also subject to an IEC standard (Integrated communication system, ICS). However, the links between the ship and all shore services – public and private, port and non-port – remain complex and diverse, not to say disparate. Several of these links must be used on board to plan the route, decide on heading and speed, prepare a landing and manage the cargo.

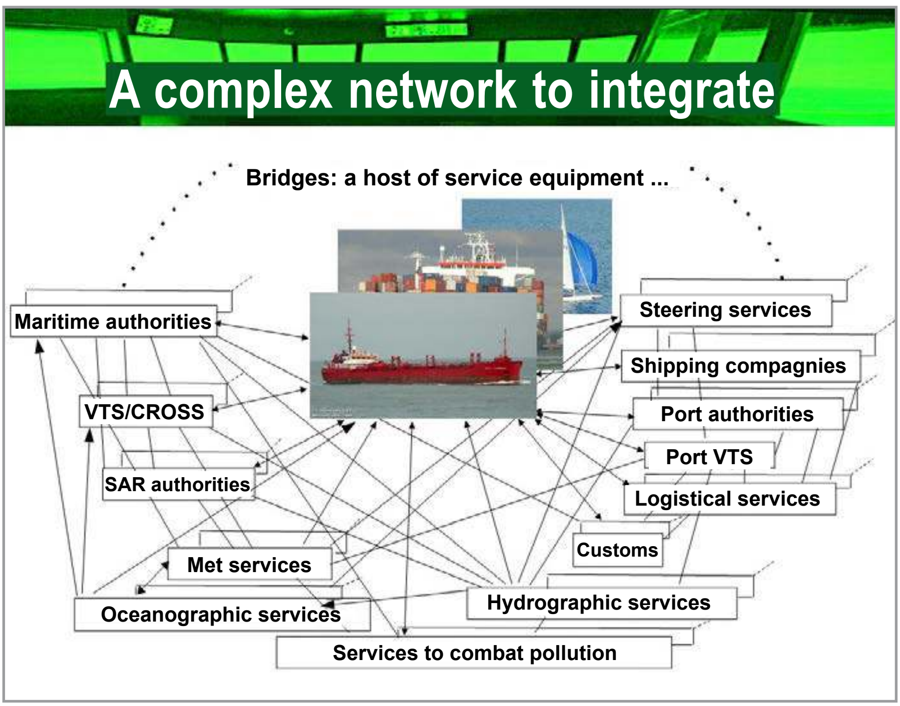

Illustration § 3.1 No.1: A complex network to integrate. *© Yves Desnöes*

8. Very High Frequency (30 to 300 MHz).

The different degrees of automated management of these various links and their use in an integrated bridge system will mean that significant work is required to standardise protocols and interfaces.

The digital transformation of maritime transport thus largely relies on space resources including satellite navigation systems such as the European Galileo system and Earth observation programmes such as Copernicus to optimise the routing of ships on an oceanic scale; satellites also of course act as transmission relays for the command and control of ships. The European Space Agency (ESA) has numerous cooperation agreements with shipping companies in order to collect user needs. But land links remain relevant, with high frequencies (HF) for offshore or VHF near the coast.

3.2 Digital transformation in the maritime sector: a need for additional certification

Software for maritime navigation is not subject to any certification or classification requirements. A comparison between aviation and maritime navigation highlights this shortcoming which, if corrected, would certainly further improve maritime safety. This will become increasingly necessary as ship operations become more and more automated.

To ensure that a piece of software will function correctly in the vast majority of cases, rigorous, detailed methods must be used in its development (and maintenance), applying the know-how accumulated by software professionals. This know-how is codified by standards imposed on software providers by the regulations. The authorities responsible for certifying those systems for which safety is important check that the appropriate standards have been applied.

The main specific standards in use are the DO-178 (Software considerations in airborne systems and equipment certification), published by the Radio Technical Commission for Aeronautics (RTCA) for aircraft, and the IEC 61508 and derived standards for most other industrial systems and vehicles. These standards are very exacting, especially when human lives are at stake; they describe measures capable of producing systems with very low failure rates (for example, no more than one dangerous failure per 100 million operating hours on average). We can see that observation times of the same order of magnitude would be needed to statistically measure such magnitudes a posteriori and that the systems must therefore be put into service on the basis of confidence in the development process and not on the basis of statistically significant measurements.

*In the maritime world, the know-how summarily described above is applied to most of the equipment or management software, but not to those which centralise interconnected automation (navigation and communication systems). This is made explicit in the International Association of Classification Society (IACS) Unified Requirement E22 on the use and application on board ships of computer-based systems. There is likewise no requirement for the software of these systems in other URs used for ship classification. As part of the work on e-Navigation, the IMO approved a circular a few years ago: "*Guideline on Software Quality Assurance and Human Centred-Design for E-Navigation*", which also refers to IEC 61508. However, this circular has not been implemented as far as software is concerned, and it will take years for any new measures to be decided upon. And yet the multiplication of highly automated, even autonomous vessel projects, increases the probability of accidents linked to software failures*[9]*.*

Note NI 641 from Bureau Veritas, which describes what could be a directive for autonomous shipping, provides that the life cycle of "computer-based systems" should be based, inter alia, on IEC standard 61508 (with a similar requirement for telecommunications). What applies to autonomous systems should also apply to highly automated systems, after all what is the difference between giving false indications to a human operator and giving them to sophisticated driving software?

*In recent shipping accidents where failures of automatic systems may have been involved, seafarers have been held responsible because it is considered they have the possibility of verifying the information they are using. However, it has been proven that the behaviour of operators is strongly influenced by their working environment and the tools at their disposal and a general tendency has also been observed to place the emphasis on looking for human error rather than questioning the organisation or systems (cf. "*Engineering a Safer World*" by Nancy G. Leveson – © 2011 Massachusetts Institute of Technology).*

Improving safety in an increasingly highly automated environment requires in-depth rethinking of the respective roles of humans and automated systems, human-machine interfaces and the reliability of decision aids.

9. In the grounding of the *Kea Trader* in 2017, the display on screen of erroneous (because too low) margins of uncertainty was not considered to be a cause of an accident; in another case, navigation was recorded near hazards without a sufficiently accurate electronic chart, which the system should have signalled to the navigator. Such accidents could have been avoided by carrying out basic risk analyses in the systems design.

Recommendation No.1

Standardisation of safety and security aspects of software used for maritime navigation and ship automation:

- *convene a group of experts on software safety and security under the authority of the State, mandated to propose the introduction of adequate standards into regulations and a statement of the reasons justifying such action;*
- *present the subject to the relevant European bodies and seek the assistance of other European countries to support the project at the level of the International Maritime Organisation (IMO);*
- *seek the support of interested countries such as Australia and Korea, and others.*

Recommendation No.2

Give priority to supporting French industry in the development of demonstrable safety and security software; also promote the support of European industry for the same purpose.

3.3 New certification challenges in the aviation sector

As an activity essentially devoted to passenger transport, air transport had from the outset to impose high safety standards, without which its development would have been very limited. Because of its international nature, with respect both to aircraft operation and construction, safety rules and their terms of application were harmonised between all States at a very early stage under the aegis of the International Civil Aviation Organization (ICAO).

These safety rules primarily concern the technical requirements for the certification of aircraft which, in practice, are drawn up in a closely coordinated manner by the two major manufacturing states or groups of states: the United States, under the responsibility of the FAA (Federal Aviation Administration), and the European Union, under the responsibility of EASA (European Aviation Safety Agency). These two administrations are also responsible for certifying the aircraft produced in the territory for which they are responsible in accordance with these regulations.

The set of rules applying to civil aviation also concern the various aspects of operations: flight operations, maintenance, pilot instruction and training, air traffic control and airports.

As far as Europe is concerned, it is up to the States to oversee the various bodies responsible for operations within the framework of the regulations adopted at European level.

The flight safety control system has been built up over time according to a normative framework, based on compliance with rules designed to ensure the required level of safety, defined more or less explicitly.

This traditional approach has begun to evolve towards a complementary approach oriented more towards risk analysis, better more suited to an industry that is evolving technically and organisationally, without having abandoned the traditional approach.

Quality control is ensured by a set of feedback mechanisms, at the level of operators or manufacturers. Safety investigations into accidents and more serious incidents carried out by independent authorities ensure that appropriate measures are taken by the various parties responsible in order to maintain the required level of safety.

Today, the authorities responsible for the certification of aircraft and the control of their operation are faced with the emergence of new technologies, some of which appear to break with current technologies.

This is particularly the case for increased automation, single-pilot flight, aircraft that are remotely piloted or possess a certain degree of autonomy, and even those with electric propulsion. In addition to these new risks, which can still be managed in a traditional deterministic framework, risks are also emerging whose assessment is based on factors that are more difficult to quantify, such as those related to cybersecurity or learning-based artificial intelligence.

It should be noted, however, that human behaviour has been taken into account up to now on the assumption that it conforms to an expected model, for example that the pilot would react in a certain way given their training, published checklists, etc. However, the experience drawn from the analysis of certain accidents has shown the limits of these models. Progress in the field of cognitive sciences must allow system designers and regulatory authorities to take better account of the major parameter that is human behaviour.

The aviation world has so far integrated new technologies without compromising the levels of safety already acquired, thanks to a safety culture widely shared by the traditional players, and a capacity to react to new risks linked to technological developments. It will therefore have to ensure that access to airspace by new innovative players with a different safety culture does not result in a slackening of these goals, which presupposes cooperation with these new partners at a very early stage.

The systematisation of risk analysis methods, which has already been largely initiated within the framework of safety management systems, is undoubtedly the means of reconciling the search for innovation with maintaining the level of safety expected from aviation activities.

3.4 Will artificial intelligence meet future requirements?

Today, starting from a situation report provided by the information system, the autonomous operation of the vehicle is controlled by deterministic algorithms covering all imagined events or situations requiring the triggering of a predetermined reaction. Depending on the applications requested, these software programmes can correspond to varying degrees of quality, security and reliability. They can only respond to anticipated situations. The use of artificial intelligence, in particular deep learning (often qualified as non-deterministic), is often mentioned as the basis of tomorrow's embedded intelligence, due to its ability to interpret a considerable amount of data and to deduce optimised behavioural strategies from an almost infinite number of possible solutions.

However, it throws up important questions related to the existence of a probability of error and uncertainty intrinsic to these concepts. By construction, artificial intelligence software can only interpret situations and act according to its learned data. Accumulating data for a multitude of events, including the least likely, will require an "infinite" amount of time and memory in order to enable such systems to handle the unexpected. The testing and validation-certification capacity of such software will face identical difficulties, with validation and certification all the more difficult since the system will over time build its own experience and its modes of reasoning which, at the current stage, are mostly without rational explanation.

For as long as cooperation is expected between onboard artificial intelligence and a human operator, whether on board or on land, the logic of the automated system will need to be fully intelligible to the operator, which should rule out the use of non-deterministic processes in driving or piloting functions involving the safety of the vehicle for a very long time.

4 CYBER RISKS HAVE BECOME THE MAJOR SECURITY RISKS

4.1 In maritime transport

The digital transformation of the maritime domain is accompanied by an increase in the vulnerability of operational and management systems. Many of the numerous digital ship and port infrastructure systems come from standard market products (commercial off-the-shelf COTS) often designed with little or no consideration of cyber risk. However, the reality of the cyberthreat in the maritime domain has now been proven by several attacks that have seriously affected maritime operations.

In June 2017, the Maersk shipping company, the world's largest container carrier, was hit by a cyberattack. More than 70 of its terminals were blocked, impacting the entire transport chain. Maersk estimated the cost of this cyberattack at $ 300 million. In July 2018, the operations of COSCO, the largest Chinese shipping company, in San Diego were shut down for almost a week. In the same year, the infrastructure of several ports, including Barcelona and San Diego again, came under attack.

On a ship, there are many, varied digital systems: internal and external telecommunications systems, navigation, positioning and identification systems, propulsion and energy management systems, auxiliary installations, management and service systems for freight and passengers, public networks (Internet, entertainment), administrative and regulatory management software. These systems are potentially corruptible, either directly, during maintenance or simply by local connection via a flash stick, or remotely through the ship-to-shore links (see figure §3.1).

The port is a mandatory interface between ship and land. Many of the functions of the port services are also digitised and present the same risks of corruption, both for themselves and for the ship in port. One can for example cite the hacking of the Port of Antwerp (second European port) discovered in 2011. A criminal organisation had succeeded in infiltrating the container management system in order to facilitate drug trafficking.

The IMO International Ship and Port Facility Security code (ISPS code) adopted in 2004 to counter terrorist acts mentions the risks associated with the vulnerability of computer systems but does not define a binding legal framework. Recognising this shortcoming, the IMO published a series of recommendations for managing cyber risks in 2017.

The European Union plays a major role in the integration of systems and software that manage maritime transport. The European transcription of the ISPS code makes certain optional cybersecurity provisions mandatory. The Network and Information System Security (NIS) directive of 2016 frames the European cybersecurity effort and includes the maritime domain in its scope. In November 2019, based on this directive, the European cybersecurity agency, ENISA, published the guide to good practices for cybersecurity in the maritime sector[10]*. Finally, the European Cybersecurity Act 5 of 2019 introduces for the first time an EU-wide cybersecurity certification framework for all products, services and processes using digital technologies.*

In France, a decree of 2016 defines the Operators of Vital Importance (OIV) in terms of cybersecurity, which include a number of maritime operators. The decree also specifies the obligations governing OIVs. These are two general obligations: the obligation to declare systems of vital importance and the obligation to report security incidents. The decree also details a corpus of technical and organisational rules. However, ships themselves are explicitly excluded from the directive. In November 2019, a Cybersecurity Council for the Maritime World (C2M2) was set up at the General Secretariat for the Sea, to identify needs and coordinate maritime cybersecurity approaches in the various national and European initiatives.

Bureau Veritas regulation NR 659 of 2018 applies to the cybersecurity of maritime systems based on computer technologies for information exchange (Information Technology, IT) or for operational functions (Operational Technology, OT). However, like the unified IACS requirement UR-E22, NR 659 does not necessarily apply to navigation or telecommunications systems.

10. www.enisa.europa.eu/publications/port-cybersecurity-good-practices-for-cybersecurity-in-the-maritime-sector

In a transitional phase, for existing software, operating measures are recommended by NR 659 in order to best manage the risks of compromised cybersecurity. This is known as "cyber managed systems". For the installation of new software, NR 659 requires intrinsic security by design (cyber secure systems).

The challenge for cybersecurity management now lies in the application of directives and recommendations on board ships and in ports through a cybersecurity system involving shipowners, insurers and cyber certification bodies. A new legal regime is also emerging around the concept of cyber-liability between ship owners, ports, shipbuilders, maintenance providers and terminal operators. Involving maritime operators in the cost of cyber attacks is a fundamental lever for increasing the level of cybersecurity. The law may help to clarify an assessment of these costs.

Cybersecurity is subject to different standards to those relating to safety, but the two areas concern the same software and the quality assurance procedures they require are similar. It would therefore seem logical to develop software systems with consistent levels of cybersecurity and security.

4.2 In air transport

The pursuit of greater efficiency in air transport and the increased passenger demand for new services have been made possible by broad connectivity achieved through the increasing digitisation of the aviation world. But this connectivity may impact flight safety. The risks associated with cyber attacks have evolved considerably in recent years and the aviation community has mobilised to face these threats. The Air and Space Academy studied this subject in order to take stock of the risks incurred by air transport in the face of cyber attacks, publishing Dossier 45, which can be downloaded online from the AAE website[11]*.*

The world of air transport forms a System of systems made up of the following elements: commercial aircraft, air traffic control organisations, airports, airline operational control centres, aircraft manufacturing plants, engine manufacturers, equipment manufacturers, aeronautical maintenance companies, terrestrial and satellite radiocommunications networks, terrestrial and satellite radionavigation means and surveillance means.

All these players are increasingly interconnected and exchange essentially digital data. They are also connected to the Internet and to "clouds", which risks introducing potential loopholes that can be used by cyber attackers.

11. https://academieairespace.com/publications/les-dossiers/dossier-n-45-cybermenaces-visant-le-transport-aerien

Cybersecurity in commercial civil aviation needs to be addressed with a system approach and end-to-end data flow mapping. The analysis carried out shows that there may be vulnerabilities in the air transport ecosystem. The following points needing vigilance can be mentioned:

- *digital telecommunications between the aircraft and the ground;*
- *cabin equipment contributing to passenger entertainment;*
- *individual equipment (mobiles, tablets, computers) whether they belong to passengers or flight crew;*
- *data links on the ground, aircraft at the gateway or taxiing;*
- *equipment maintenance chain.*

Attacks against air transport can be by "denial of service" or by jamming, which consists of blocking signal reception. Other possible attacks on communication links can result in deception with the transmission of false data, either on the ground or on board aircraft. Depending on the corruption of this data, the consequences can be serious if no means of verifying the availability, authenticity, integrity, confidentiality and traceability of the information is provided. These attacks can also affect operational software, on board or on the ground. The presence of malicious code programmed to trigger harmful actions at a certain time is obviously a major threat.

Cyber-attack threats are not only aimed at flight safety; there are also more classic threats of attacks on the information systems of air transport operators, airlines, airport managers and service providers. These are either denial of service attacks, data theft, or ransomware. These attacks are very common, in particular for airport managers: according to a recent study by the European Aviation Safety Agency, an average of 1,000 airports fall victim to cyber-attacks each month around the world. Attacks on airlines are likely to be widespread but are seldom made public. During the Covid crisis, EasyJet was the subject of an attack with theft of the customer file including all the personal information of travellers (9 million customers). British Airways, Cathay Pacific (9.4 million customers) and Air Canada were victims of attacks in 2018.

Cyber attackers are able to exploit loopholes in fixed system defences, including firewalls and other protections. Physical protection, without wired or radio communication, is no longer possible in a digitised, interconnected world. However, a few fairly simple measures can slow down most attackers.

These defence actions have repercussions on the organisation and management of systems, and require the establishment of trustworthy human resources skilled in the latest technologies, including inventive professional hackers, working as closely as possible with their colleagues in cybersecurity organisations from friendly countries. ICAO must lead and coordinate at the global level all activities that contribute to strengthening cybersecurity in civil aviation.

5 CAN THE NUMBER AND SEVERITY OF ACCIDENTS BE FURTHER REDUCED?

5.1 In maritime transport

In maritime transport, the number of total ship losses (merchant ships over 100 gross tonnage, a measure of the useful volume of the ship) is steadily decreasing. In about twenty years, this number fell from 207 in 2000 to 132 in 2009, dropping to 46 in 2018, while at the same time the volume of goods transported rose from 6 billion tonnes to over 11 billion tonnes.

The factors behind this decrease are multiple: tighter regulations and controls, renewal of fleets, improvement of design methods and strengthening of safety systems and procedures.

The European Maritime Safety Agency (EMSA)[12] notes a similar trend in the number of human lives lost at sea with a steeper drop since 2015.

On the other hand, the total number of accidents, all severities combined, which are the subject of a claim for insurance compensation (more than 26,000 in 10 years for an amount of nearly $10 billion), remains relatively constant (2,700 in 2018), despite the significant increase in traffic. The same observation, although on a significantly different basis, is made by EMSA.

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12. https://safety4sea.com/wp-content/uploads/2019/11/EMSA-Annual-Overview-of-Marine-Casualties-and-Incidents-2019-2019_11.pdf
EMSA records events (including in particular those involving fishing vessels) occurring in European waters (maritime and inland waterways) or involving vessels under the European flag.

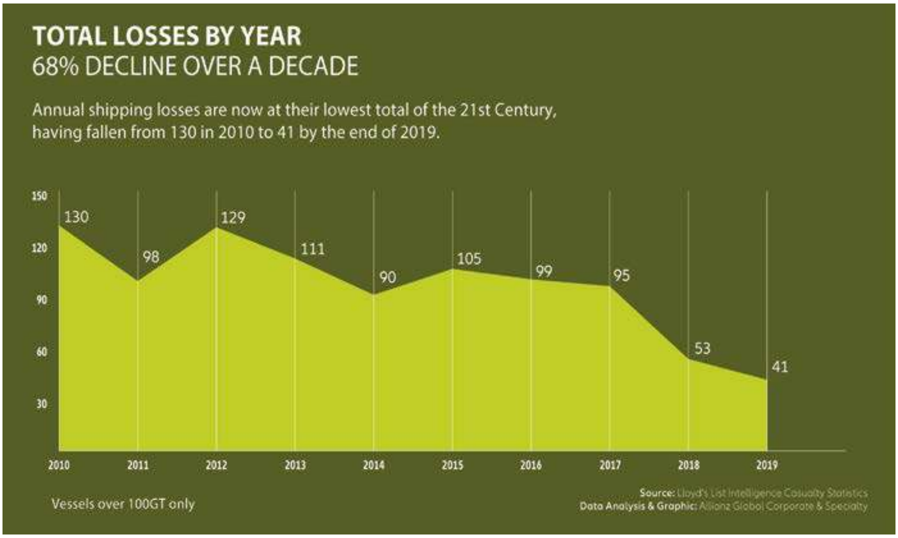

Illustration § 5.1 No.1: Number of vessels (> 100 gross tonnage) lost at sea per year[13]. *© Lloyds/Allianz*

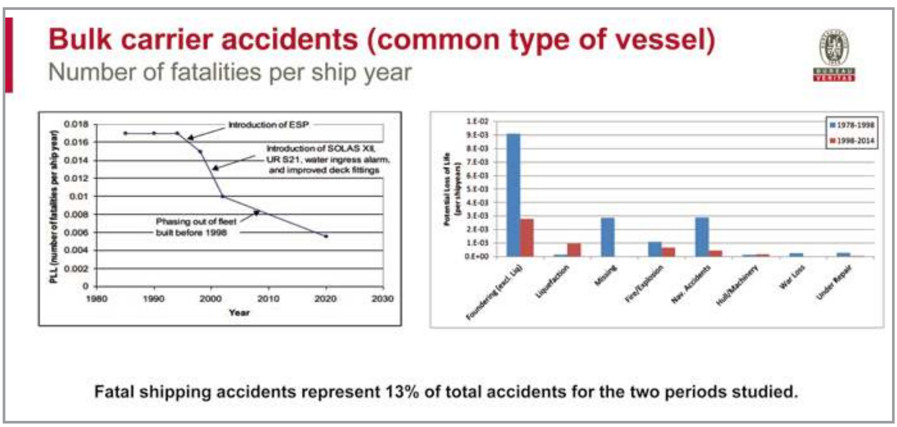

Illustration § 5.1 No.2: Bulk carrier accidents per year. *© Bureau Veritas.*

The causes of accidents and incidents are difficult to analyse because they are usually the result of a chain of different events and failures. According to EMSA, nearly 55% of accidents are navigation accidents (collision 26.2%, impact with a floating object or dock 15.3%, grounding 12.9%).

13. www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2019.pdf
Allianz's annual Safety Shipping Review lists all accidents and incidents (casualties) involving ocean-going vessels over 100 gross tonnage that have been covered by insurance.

Not all navigation accidents are due to a conning error, but EMSA estimates that 65% of total accidents are due to human action and 20% to equipment failure and, based on recommendations from the investigation reports, gives an analysis of the main factors of human failure (cargo ships only, excluding passenger ships, special vessels and fishing).

Allianz, for its part, estimates that 75 to 96% of maritime accidents are due to human error. It is therefore widely believed today that replacing human actors with automated systems would eliminate not only the risks and damage suffered by the crew, but also most accident causes.

However, no experiment or simulation today allows us to confirm this, even if it can be envisaged, in a hypothetical future in which all maritime traffic and users would be automated. For the time being, it is important to consider the consequences for the safety of maritime traffic of the interaction between automated systems and human actions, which is not always harmonious.

A significant proportion of maritime accidents, more than a third according to Allianz, involve a propulsion failure. Remote monitoring and, soon, real-time automatic control of onboard installations are being developed using the Internet of Things. We can expect these developments to result in safer, more relevant and, ultimately, more economical e-maintenance of these installations, in particular through better anticipation of breakdowns and technical stoppages.

Climate change, with the seasonal drop in waterway levels and harsher weather conditions at sea, increases the risks and severity of accidents. Better forecasting of sea conditions thanks to satellite observations and oceanic simulations, combined with routing software that integrates the hydrodynamic behaviour of the vessel in extreme seas, helps improve navigation safety.

Fires and explosions of transported goods are on the increase. Erroneous or fraudulent declarations and inappropriate packaging are involved in most of these accidents and also make the fight against them more difficult. Information technologies and the Internet of Things are expected to provide better traceability of goods. On board, automating the means of locating, identifying and fighting fires makes the reaction more immediate and greatly limits the consequences of an outbreak of fire.

On the other hand, digital technology has led to new risks, in particular that of loss of attention and involvement of operators reduced to observing screens, or over-reliance on digital information and automated systems outside their field of validity, which is not always well described (cf. 3.1 above). This over-confidence can also be attributed to a lack of training on the systems and their limits, inadequate documentation of these systems and insufficient vigilance when approaching these limits.

Efforts must therefore be made to train and raise the awareness of personnel using new digital technologies. This of course requires software tools and automated systems to be sufficiently documented and their performance and reliability correctly assessed.

The question of the navigation of unmanned vessels within traditional traffic operations arises due to a number of ongoing or planned sea trials. Meeting safety requirements for ship automation requires an evolution of all functions performed on board. This implies a review of the relevant conventions of the International Maritime Organization (CSR exercise initiated in 2018) and classification procedures.

5.2 In air transport

Air transport has seen a continuous increase in its safety level over the past few decades, all the more remarkable in that this has been accompanied by an equally continuous increase in traffic, at least until the recent abrupt halt related to the coronavirus pandemic.

Illustration § 5.2 No.1: Steady improvement in safety. *© Aviation Safety Net – FSF*

How can these results be explained?

Comparing what has and has not changed can provide answers:

- *breakdowns, anomalies and malfunctions are still part of daily airline operations, even if some have decreased (particularly with regard to engines);*
- *human errors are still present (pilots, controllers, mechanics, ground operations);*

- *short-term safety-critical decisions are still taken on board;*
- *pilots still work in pairs;*
- *landings are still under manual control (99%).*

On the other hand, a great deal of progress has been made in the last 20 years with regard to flight operations:

- *pilots now have access to interfaces, automatic systems and decision aids that are better suited to managing the most critical situations: ground proximity warning devices, anti-collision systems, prevention of runway overruns on landing;*
- *the cooperative work of pilots (detection and recovery of crew errors) and in-flight risk control have become more effective;*
- *the volume, quality and processing of information on in-flight events has improved considerably;*
- *programmes for systematic analysis of recorded parameters have become widespread with the cooperation of the pilots;*
- *airlines, air traffic control, maintenance, manufacturers and authorities have set up standards and a common language for explicit risk management;*
- *feedback from experience on operational events, by making it possible to analyse and correct safety factors, has played a key role:*
    - *within the framework of systematic investigations carried out by specialised authorities in the event of an air accident or serious incident, leading to safety recommendations;*
    - *through a permanent dialogue between authorities, operators and manufacturers aimed at systematically exploiting significant events, at the individual or statistical levels;*
    - *by flight analyses carried out within airlines.*

The effectiveness of feedback from experience presupposes the existence of a climate of trust between actors so that safety events, when they result from a simple human error or failure, can be reported without fear of punishment: this is the principle of "non-punitive culture" now widely accepted in the aviation world. The maritime sector could usefully draw inspiration from it to further improve its safety.

It is this combination of manufacturers, authorities, procedures, training, management and pilots that constitutes defences and brings results in terms of safety. This system is dynamic, constantly adapting, as illustrated by Reason's well-known model of failure control plates.

For their part, manufacturers highlight progress achieved in aircraft design, particularly with regard to automation and interfaces associated with piloting and decision-making aids.

The following graph shows the progress made from one generation to the next.

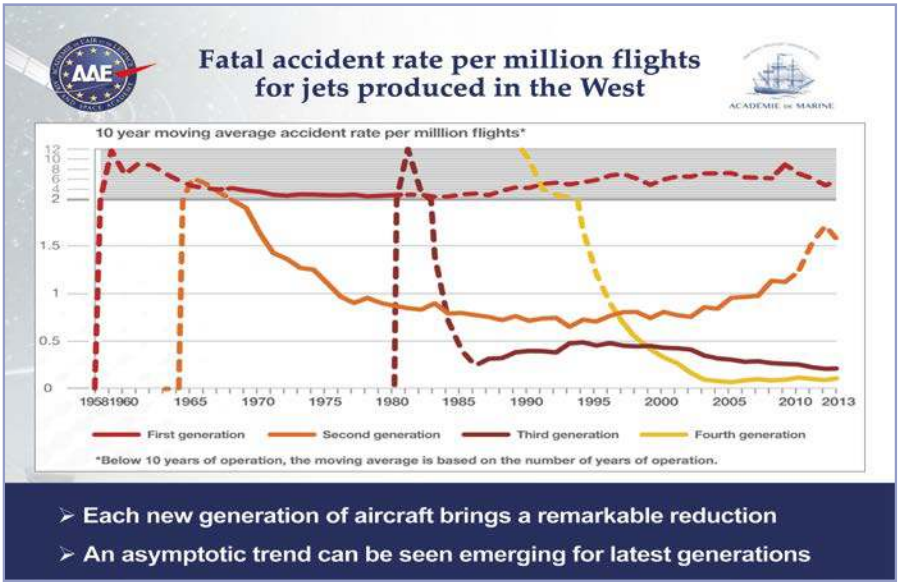

Illustration § 5.2 No.2: Fatal accident rate per million flights. *© Airbus*

These successes in terms of safety were achieved within the framework of a two-pilot crew and, in this context, further progress is still expected, in particular through better consideration by system designers and regulatory authorities of the major parameter that is human behaviour and a better understanding of the many potentially dangerous situations recovered by the crew.

The move towards a crew made up of a single onboard pilot threatens this balance, the issue undoubtedly being less one of pilot incapacitation (sudden temporary or permanent incapacity), a relatively rare occurrence but one which must nevertheless be taken into account, than the elimination of cooperative work between the two pilots that enables detection and recovery of errors. Sufficiently advanced automation will have to be designed to replace the absent pilot, a kind of artificial intelligence, unless one can imagine useful assistance from an operator on the ground.

The economic benefit of such a development will have to be demonstrated and will obviously depend on the size of the aircraft and its use. The foreseeable situation of air transport for the years to come will undoubtedly delay this further.

As for the evolution towards complete autonomy, which may be technically feasible if advanced artificial intelligence systems are developed, it will come up against the need to maintain supervision from the ground, if only to change the flight destination in the event of an unforeseen occurrence related to circumstances not directly linked to the aircraft operation – the health problem of a passenger, closure of an airport or airspace – and therefore will need the guarantee of absolutely secure communications.

6 THE TRANSFER OF RESPONSIBILITIES FROM VEHICLE TO GROUND WILL INCREASE

6.1 Surveillance of maritime navigation

The surveillance of maritime navigation in France is governed by the decree of 30 December 2011.

It has been carried out since 1970 by the Regional Operational Surveillance and Rescue Centres (CROSS), which also perform other functions. They are supported by the French Navy semaphore network. CROSS centres also feed into the European SafeSeaNet information exchange system.

The surveillance of maritime navigation consists of three functions:

- *monitoring maritime traffic, the purpose of which is to collect the information and mandatory reports provided by vessels in transit along the French coast; this information is entered into a common European database (SafeSeaNet) to which all maritime surveillance centres and ports are linked;*
- *the so-called "coastal" maritime traffic service, which consists of monitoring and assessing the behaviour of ships in traffic flows, detecting risky situations and, if necessary, providing ships with the information required for traffic safety, especially by means of traffic lanes or "rails" and the Traffic Separation Scheme (TSS);*
- *the Maritime Assistance Service (MAS), which organises information, aid and assistance to ships following an incident or accident.*

However, today, the role of the CROSS network is limited to monitoring and informing ships and operational authorities. They have no authority over the traffic but can alert the maritime zone commander so that authoritative action can be taken.

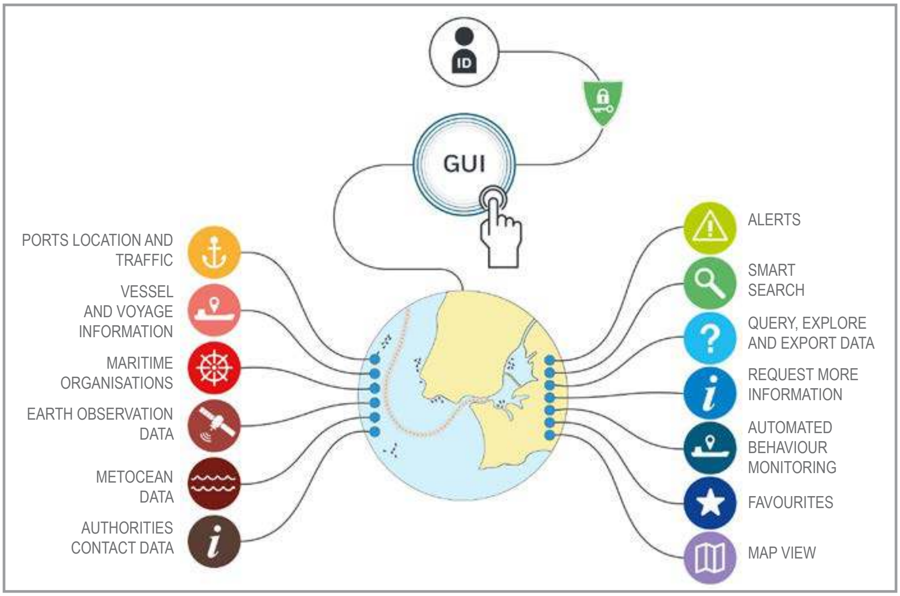

Illustration § 6.1 No.1/ SafeSeaNet Ecosystem Graphical User Interface (SEG).
© EMSA

SafeSeaNet is a maritime traffic monitoring and information system, set up by EMSA (European Maritime Safety Agency) in the form of a maritime data exchange network, linking maritime authorities across Europe. It enables EU Member States, Norway and Iceland to provide and receive information on ships, their movements (real-time tracking of AIS Automatic Identification System signals) and dangerous cargoes. EMSA also has a Maritime Support Services (MSS) Operations Centre in Lisbon that can coordinate maritime operations in the event of a disaster.

Developed in the 1990s, AIS was made mandatory in 2002 by the IMO on all ships over 300 gross tonnage. The horizontal range of signals is limited to 75 km, limiting its application to coastal waters and ship-to-ship links. EMSA and ESA are developing a SAT-AIS satellite link system that will eventually provide worldwide coverage of the AIS system.

ABM (Automated Behaviour Monitoring) systems, which are linked to the use of AIS data, are designed to detect and automatically alert on risky behaviour in ships: collision routes, grounding, navigation in prohibited areas, deviation from the rail.

Artificial intelligence is already capable, on an experimental basis, of detecting "abnormal" behaviour that may suggest damage, criminal intent or an act of piracy.

The exponentially growing volume of information available in real, or near-real time cannot be processed on board. Processed on land, this information provides onboard decision aids for the crew, or direct commands in the case of automatic steering. With the exception of the small, visually-operated boats mentioned in Chapter 2, only a few experiments have been carried out on the second case. In the first case, the crew, which remains responsible for decisions and actions, is not always in a position, especially in emergency situations, to assess the accuracy and reliability of the information it receives or to interpret non-standardised human-machine interface (HMI) displays. Furthermore, the level of synthesis of this information can vary widely depending on the operational functions under consideration.

6.2 Civil air traffic control centres

According to ICAO rules, global airspace is divided into Flight Information Regions (FIR) whereby responsibility for air traffic control is assigned to a State. According to the three main functions: (Airspace Management (ASM), Air Traffic Flow Management (ATFM) and Air Traffic Control (ATC), air traffic control must ensure a safe and orderly flow: safe, by means of instructions, known as clearances, issued by controllers to pilots to ensure anti-collision between aircraft when necessary, and orderly, because this must have as small an impact on traffic as possible.

The three recurring topics for 50 years have been automation, responsibility between the ground and the aircraft and the evolution of the telecommunications, navigation and global satellite surveillance infrastructure.

It is not known when an aircraft will leave until it takes off. Only then does the pilot accurately know their flight path and arrival time if everything goes as planned. Air traffic control is therefore a decision-making process in which there is a great deal of uncertainty. Projects such as the Automated En-Route Air traffic control (AERA)[14] *programme of the Federal Aviation Administration (FAA) in the United States in the 1980s and Onera's more recent "Innovative Future Air Transport System" (IFATS)*[15] *have remained at the level of theory because they are based on a deterministic vision of the system which does not correspond to reality. Computer systems are only decision support tools for controllers presenting the position of the aircraft,*

14. www.tc.faa.gov/its/worldpac/techrpt/em81-3.pdf
15. www.onera.fr/fr/actualites/automatiser-le-transport-aerien-une-utopie

more recently with a 20-minute anticipation. This may seem short compared to the aircraft's known trajectory in its Flight Management System (FMS), but to date all plans to transmit the so-called 4D trajectory to the ground have failed.

Air traffic controllers have at their disposal a two-minute proximity alert system called the "Short Term Conflict Alert" (STCA) which detects risks of non-compliance with regulatory separations and thus the precursors of a risk of collision.

Following the collision of a Boeing 727 and a Cessna 182 in San Diego (California), installation of the Traffic Alert and Collision Avoidance System (TCAS), this time on board aircraft, was made compulsory. This is a last resort, 40-second warning system that gives instructions to pilots to avoid an impending collision.

The incompatibility between the instruction given by the air traffic controller to the crew of one of the aircraft and that given by TCAS to the crew of the other aircraft was one of the causes of the collision on 1 July 2002 between Bashkirian Airlines Flight 2937 and DHL Flight 611 near Überlingen and Lake Constance (Germany) that killed all 71 people on board the two aircraft. Measures were taken to prevent this problem, which stemmed from air traffic control not taking the functioning of TCAS into proper account.

In areas of the world where the ground infrastructure is inadequate and traffic is low, aircraft may be able to perform their own collision avoidance without ground intervention. Attempts to generalise this "free flight" mode to areas where traffic is dense have failed because in such cases air traffic control can reduce the potential number of collisions by ordering the traffic. This is the purpose of Air Traffic Flow Management (ATFM).

This is provided in Europe by the Eurocontrol real-time Network Manager[16] which took over from the Central Flow Management Unit (CFMU) set up in 1988. In the United States, it is provided by the equivalent Air Traffic Control System Command Center (ATCSCC)[17], set up in 1981. This trend towards strengthening the role of the ground-based system was confirmed in April 2019 by the Wise Persons Group on the future of the Single European Sky, which included the recommendation: "Confirm and strengthen Eurocontrol's Network Manager role by providing it with the necessary executive powers to manage the ATM network".

The dream of a global satellite telecommunication, navigation and surveillance infrastructure dates back to ICAO's Communication, Navigation, Surveillance (CNS/ATM)[18] concept of the 1970s and resurfaced with the Boeing "Working Together"

16. www.eurocontrol.int/network-manager
17. www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/nas_ops/atcscc/
18. www.icao.int/sustainability/Pages/FR/eap-im-systemes-cns-atm.aspx

project in the 1980s[19]*. The obstacle arises from the fact that air traffic control alone cannot justify a satellite infrastructure and must link up to an infrastructure built for other users.*

This is the case for localisation with GPS and Galileo positioning systems and the Aireon[20] *system with systems embedded on the Iridium NEXT satellites.*

Vocal transmission by VHF and radar surveillance means date back to the Second World War and the major programmes NextGen[21] *in the United States and SESAR*[22] *in Europe have not, to date, contributed anything new, as the special report No.11/2019, published by the European Court of Auditors*[23]*, points out.*

*Provided that cybersecurity is properly managed, hope for progress in air traffic control systems could come from the global mobile internet and the possibilities of "clouds", thus bringing them into the 21st century, as advocated in the Wise Persons Group's report already cited, Recommendation No.3: "*Implement a Digital European Sky*", with the remote provision of air traffic services, made possible if all the necessary data are accessible through the network.*

As far as minidrones or "aircraft taxis" are concerned, one might think that the easiest way will be to continue to separate them, as with light aviation.

As for the integration of autonomous aircraft into the air traffic control system, it will depend on the level of autonomy: if the aircraft is truly autonomous, it will have to ensure its own anti-collision; this will only therefore be possible for light traffic. If there is a pilot on the ground, the anti-collision will be dependent on their link with the autonomous aircraft.

*As Marc Baumgartner explained at the conference: "*At the moment, military UAVs are not integrated into civilian traffic". *They follow military operational traffic rules in airspace reserved for their use.*

However, when these devices interfere with civilian traffic, the lack of information on their trajectory and the inability of the controller to communicate with them places restrictions on civilian traffic. It would be unacceptable for the inclusion of autonomous civilian aircraft in general civil air traffic to impose this type of constraint, which could make their development problematic, since air traffic control would not be able to give them flight path instructions.

19. www.boeing.com/news/frontiers/archive/2002/december/i_atm.html
20. https://aireon.com/
21. www.faa.gov/nextgen/
22. https://ec.europa.eu/transport/modes/air/sesar_en
23. www.eca.europa.eu/fr/Pages/DocItem.aspx?did=%7BB92E9AA1-0FE7-4CE6-8ED4-B04A4E0F42DD%7D

The same problem exists, to some extent, with single-pilot aircraft, in situations of transition to automatic flight due to pilot incapacitation. However, these are extremely infrequent situations that are probably manageable by air traffic control.

6.3 Maritime operational control centres

Major shipping companies, such as CMA CGM, have operational control centres. These centres provide real-time fleet management, linked to integrated port management systems (Cargo Community Systems, CCS, and Port Community Systems, PCS) and the networks of other players in the logistics chain. Receiving meteorological information and the various shipping notices, they plan the allocation of loads, transit routes and the preparation of stopovers. Thanks to automatic readings and measurements, they anticipate maintenance needs in conjunction with equipment manufacturers.

With the proliferation of onboard sensors, satellite observations and data links, onshore control centres receive infinitely more data than the ship and its crew can process. They are thus able to develop and adapt strategies in real time to optimise the various functions of the vessel: loading, destination, route, propulsion/consumption and maintenance work. Thanks to the "digital twin", these shore-based centres will be able to simulate and optimise any intervention by the crew, either for maintenance or in the event of damage. On the other hand, crews will continue to perceive the reality of their environment visually and physically.

This progressive transfer of information from ship to land can lead to an increasingly developed remote operation at the cost of disempowering and demotivating onboard personnel, which can even lead to risks of incomprehension or negligence.

In areas of heavy traffic, particularly in coastal and port areas, at least three responsibilities will overlap: that of the crew, that of the land-based centre and that of the traffic surveillance authority, not to mention, at an uncertain date, the emergence of autonomous automated systems. The coordination of these different operators and their hierarchy in emergency reactions will need to be regulated and their interfaces standardised.

As is the case for autonomous automatic systems, it is necessary in all cases to clarify as precisely as possible the limits of intervention and responsibility of the onboard crew and the shore-based centre.

Finally, this transfer means that the safety of the ship is even more dependent on the quality and safety of ship-to-shore transmissions. Appropriate action by the crew must, in any event, be able to compensate for any interruption or failure of all or part of these transmissions.

Illustration § 6.3 No.1: CMA CGM Fleet Navigation and Port Operations Centre in Singapore. *© CMA CGM*

6.4 Air operations control centres

In order to optimise daily management of flight (several thousand for some) and to coordinate management of commercial, technical and even political and health hazards in the safest, most cost-efficient way, the larger airlines have created operations control centres (OCCs).

These centres are equipped with IT tools to carry out their functions: flight preparation and monitoring, route optimisation in accordance with air traffic control constraints, and updating of aeronautical and meteorological information.

The specific role of assisting the flight captain is assigned to dispatchers. In addition, in the event of a major event, the OCC houses the crisis unit.

In the United States, the function of dispatcher is recognised by an official qualification[24] *which makes him or her co-responsible with the captain for flight preparation.*

24. https://pea.com/courses/airline-dispatcher

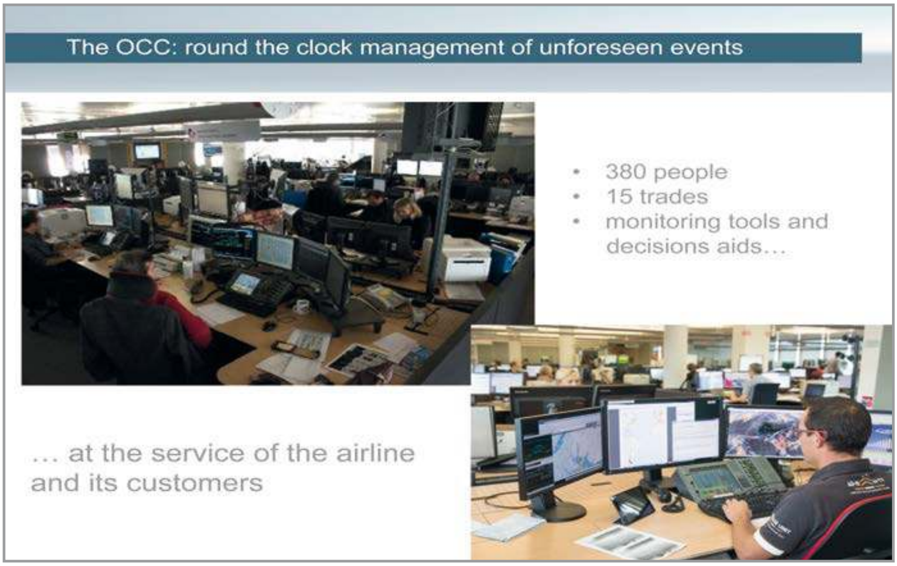

Illustration § 6.4 No.1: Air France Operational control centre (OCC)[25].
© Air France

Another very important step forward is the in-flight monitoring of the operation of engines, which are equipped with increasingly sophisticated monitoring systems capable of making diagnoses. In the event of an anomaly, when the data is transmitted in real time, the OCC is alerted and its maintenance component can decide what action to take, either immediately, during a stopover (for example by delivering the necessary parts), or during a subsequent visit.

This monitoring must be in place, at least in a reduced and strictly regulated format, in the event of long-haul twin-engine operations known as Extended-range Twin-engine Operation Performance Standards (ETOPS)[26]. This engine monitoring can be carried out by engine manufacturers to support their customers. Recently, aircraft manufacturers Boeing[27] and Airbus (Skywise project[28]) began to offer this type of service for aircraft systems with systematic real-time recording of flight data.

According to Tan Sri Tony Fernandes, group chief executive officer of AirAsia: "Skywise will enable us to achieve new perspectives on the operation of our aircraft,

25. Excerpt from a presentation by Catherine Jude, former CCO Manager Air France. www.ataf.fr/2016%20gestion%20VI/Catherine%20JUDE%20AF.pdf
26. Extended-range Twin-engine Operation Performance Standards ETOPS is an International Civil Aviation Organization (ICAO) regulation allowing commercial aircraft equipped with two engines to use air routes with sectors more than one hour from an emergency airport, in particular oceanic routes.
27. www.predictiveaircraftmaintenance.com/big-data/
28. www.airbus.com/aircraft/support-services/skywise.html

optimise decision-making as regards our maintenance, engineering and flight operations and reduce our costs*".*

These transmissions are made by radio or by satellite, and in the latter case will be facilitated by global internet satellite projects (Starlink, Oneweb, etc.), which will require risks associated with cyber-attacks to be dealt with.

Increased supervision of flights in real time by an organisation on the ground requires that the respective roles of the captain and dispatcher be well established so that responsibility for flight handling remains with the captain.

This need for assistance will be greater in the case of single-pilot operations. However, it will probably not be possible to take control of the aircraft from the ground in the event of pilot incapacitation since, as Marc Rochet pointed out during the conference, this solution presents no economic advantage.

As for the prospect of autonomous aircraft, this would impose operating methods on ground supervisory organisations that have yet to be invented.

7 PORTS AND AIRPORTS ARE COMPLEX PLACES

7.1 Sea and river ports

Logistical hubs in the transport chain, ports are at the heart of the global economy. In 2018, nearly 50,000 ships transported over 11 billion tonnes of goods, a record level after a decade with an average growth of around 3% per year, a pace that will be halted in 2020 by the health crisis. Closely linked to global economic activity, maritime transport accounts for 80% to 90% of trade in goods by volume, and 70% by value. Ports have always been in fierce competition, both in Europe and worldwide, and part of the development of their economic catchment areas, commonly referred to as the hinterland, depends on this competition. This competition traditionally hinges on port capacities (ease of access by sea and by land, availability of quayside space, draught, etc.) and tariffs (cost of moving goods). Other differentiation strategies, called "smart port" strategies, have recently been developed with the help of digital technologies to increase port productivity: since one hour of immobilisation of a container ship costs around €80,000, reducing the access time and stay of ships in port is, indeed, a major competitive issue.

A port is a complex area involving many players and the development of digital technologies is profoundly changing their relationships and respective responsibilities. Digital integration of the various functions and data sharing through the "cloud" and the "blockchain" (blocks of secure data entered by the various players and accessible by all) enable and require increased collaboration between all links in the chain. Digital transformation affects the entire workflow, as described below.

Preparation for a ship's entry into port begins several days before its arrival by providing information to the harbour master's office and to customs about the ship and its crew, on the one hand, and the goods transported, on the other. Advance transmission and analysis of this data while the vessel is still at sea enables the ship's berth to be determined, all stakeholders to be informed, and early examination by customs of importation declarations, so as not to delay the release of goods once unloaded.

Piloting, towing and mooring services ensure safe entry of the ship into the port channel as soon as it arrives, then berthing and mooring at the quay.

While the administrative formalities are taking place, the stevedore then begins unloading the goods which will be stored at the terminal awaiting their "exit slip", then loading those intended for export. These handling operations are increasingly automated. In some ports, particularly in Asia but also in Rotterdam, containers are moved by driverless trolleys, controlled either by decision aid systems or fully automated systems from an operations centre located in the terminal. The digital transformation therefore particularly affects the highly unionised profession of dockworkers, who are seeing their profession impacted by automation and remotely controlled operations, just as it was by containerisation fifty years ago.

Ports are also one of the zones where the greatest diversity of vehicles intersect: ships, handling equipment, trains, trucks and cars, in extremely dense traffic (12,000 trucks and 200 trains pass through the Hamburg port area every day). Therefore, having a global view of traffic and a short-term forecast of its evolution enables handlers to facilitate the reception of lorries delivering or loading goods, and each user to optimise their travel time. Several ports are now equipped with such shared information systems.

Digital technologies also facilitate the traceability of goods, which requires the identification, authentication, location and security of the objects concerned. Technologies such as Near Field Communication (NFC) chips and Radio Frequency Identification (RFID) are commonly used today. Soon the Internet of Things (IoT), will make it possible to track the position, transport conditions or status of a cargo of goods in real time. Digital transformation also concerns support functions such as port administration, maintenance and port security.

Port Community Systems (PCS) allow the instant, collaborative exchange of information between all players whether private (shipowners, freight forwarders, stevedores, shipping agents, carriers, etc.) or public (port authority, customs, phytosanitary services, etc.), with the aim of streamlining the exchange of goods and information between all actors in the logistics chain before the ship arrives in port.

Cargo Community Systems (CCS) offer a scope of application that goes beyond maritime transport, taking into account multimodal transport (maritime, river, road and rail). The latest generations of CCS, including those developed in the port areas of Marseille (CI5) and Le Havre (Soget One), connect around fifteen professions covering the entire logistics process for imported, exported or transhipped goods, in a secure manner, enabling significant time savings throughout the logistics chain.

Indeed, the use of the "blockchain" makes it possible to ensure the authenticity of the documents used. The Bill of Lading for example, the veritable title of ownership of the goods loaded on a ship, is being replaced by electronic documents secured by the blockchain. Companies using these collaborative systems (PCS and CCS) store enormous amounts of information (Big Data) in the form of databases in their computers or in the "cloud" which, coupled with that coming from the Internet of objects, will feed AI software and help predict customer demands, the fill level of terminals and warehouses, traffic congestion, etc., thus generating very significant productivity gains which will strengthen the competitive position of the port concerned.

But, as indicated in the ENISA report cited above, the increasing sophistication and interconnection of all these systems make them an extremely complex whole that is difficult to master. In France, for example, the major ports do not offer identical interfaces and services. This complexity also brings vulnerabilities.

The development of the Smart Port initiatives is not only based on economic, safety and security issues, but also on ecological and societal priorities, namely making the port a more environmentally friendly place and rebuilding the sometimes broken link between the port and the city.

The acceptance by local populations of the environmental and noise pollution generated by port activity has in fact become a central issue for port authorities and shipowners in recent years.

The Smart Port proposes various initiatives in this direction: identifying hazardous components in the air and water and measuring their concentration, predicting their diffusion according to atmospheric factors, managing energy exchanges and consumption thanks to smart grids and the concept of a circular economy, managing waste in a centralised way, etc.

In Marseille, for instance, ferries to and from Corsica connect to shore power as soon as they dock in order to avoid running their engines during the stopover, thus significantly reducing their carbon footprint. Marseille's Grand Port Maritime is also planning to invest €30 million to supply electricity to cruise liners in port, thanks to the intelligent real-time management of electricity consumption enabled by the smart grid.

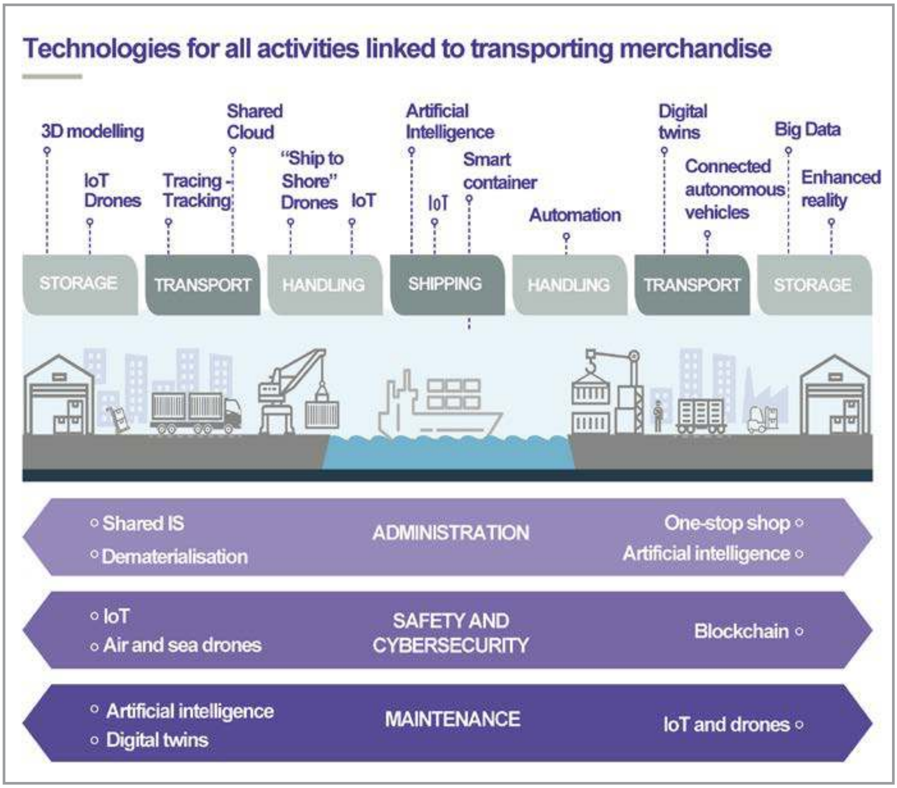

Illustration § 7.1 No.1: Digital technologies in port activities. *© Wavestone*

Likewise "Le Havre Smart Port City" is a €240 million project aimed at making the Le Havre region a laboratory for innovation along three axes: a world-class technological transition serving a high-performance logistics economy; the building of an exemplary, environmentally innovative area on the scale of the Seine Estuary; the construction of a city-port interface, a laboratory for new urban and port uses.

Drones are also one of the components of the digital transformation. They find their application in ports for the surveillance of the port area, biomonitoring to fight pollution, and the transport of goods.

The GIE HAROPA, for example, an economic interest group which includes the port of Le Havre, is planning to use drone technologies for aerial surveillance and biomonitoring on the Seine and at the port access points. And the Port of Singapore is testing an Airbus-designed system for delivering parcels between land and ships. Soon, drones will take off with a payload of 4 kg and will navigate autonomously along predetermined air corridors, up to 3 km from the coast.

Illustration § 7.1 No.2: Shore-to-Ship drone delivery project by Airbus – Port of Singapore. *© Airbus*

Conversely, while the digital transition generates significant productivity gains and helps reduce the environmental footprint, it also gives rise to new risks related to cybercrime. Numerous ports and shipping companies (Antwerp, New York, Rotterdam, Barcelona, San Diego, Maersk, etc.) have fallen victim in recent years to hacking, extortion, threats, blackmail, etc. which have cost them tens of millions of dollars. Ports are therefore investing significantly in protection systems against computer piracy. For example, the port of Marseille has revealed that it records several thousand attacks per week on its management system. The digital transformation of ports therefore requires increased vigilance and efforts to combat cybersecurity.

7.2 Airports

This paragraph does not address passenger management and information, nor security checks, or now health security checks, on passengers and baggage for which smartphone applications and biometrics, with connected objects, are evolving constantly with many automated processes.

The subject here is the effect of digitisation for flight handling including landing in this complex environment that is the airport. Landing, even more than flight, remains dependent on weather conditions, the proximity of other aircraft, the sharing of information with many actors and the cohabitation with other vehicles, all situations the aircraft does not have to face in flight.

It is difficult to imagine how an "autonomous" aircraft could fit into such an environment, indeed, despite many projects, automation cannot yet be seen to have brought any notable progress.

1) ***Landing**, despite supposedly automatic landing, remains a delicate manoeuvre in difficult weather conditions, with gusts of wind, snow and fog, local phenomena that are the most difficult to predict, and with a level of runway grip that is difficult to measure, hence runway excursions with sometimes serious consequences. Another risk factor is the presence of foreign debris that are difficult to identify.*
2) ***For take-off,** the greatest risks are the incursion of a vehicle or another aircraft on the runway and engine failure.*

Although the number of accidents linked to runway incursions between 2008 and 2016 is very low, the number of incidents remains high (one report per day according to data from the International Air Transport Association, IATA[29]).

Decades of work in this area and projects for runway monitoring systems (Advanced Surface Movement Guidance and Control System, A-SMGCS) have not been successful, mainly because of the many vehicles other than aircraft circulating on the ground.

Some solutions may appear worthy of interest, but they require human skills to make decisions and they assume that all mobiles in the risk zone in which the aircraft are moving are known to the system and can at least communicate their position and dialogue with it.

3) Information sharing

The need to improve punctuality and minimise the impact of unfavourable conditions (weather, traffic, runway closures, etc.) on flight operations has led to Airport-Collaborative Decision Making (A-CDM). This concept is based on the sharing of information between stakeholders on the real-time status of each flight – defined with "milestones" (set moments in the chronology of a flight). Each stakeholder is responsible for updating specific milestones – for example, the ground manager with the Target Off Block Time, which is the time scheduled for the flight to leave the boarding gate. A software application consolidates all these inputs and provides take-off times. With A-CDM, the airport community, including air traffic control, can work with "Target times" that reflect the reality on the ground rather than theoretical estimates. Reducing uncertainty and increasing transparency makes operations more efficient. This is a win-win solution because all the information known to the system allows all operators to act more efficiently and makes it possible to use all the capacities and resources of an airport.

29. www.icao.int/Meetings/GRSS-2/Documents/GRSAP_Final_V01_2017-11-16.pdf

The extension of the concepts of A-CDM to the whole airport is called Total Airport Management (TAM), with the idea of creating Airport Operations Centres (APOC). An APOC would be a centre for anticipation, oversight and decision-making bringing together all stakeholders in airport operations – including air carriers, airport operators, air navigation service providers, apron management service providers, ground managers, transit agencies, law enforcement and immigration, etc. – with data collected by sensors in the field.

The implementation of A-CDM and APOC are objectives of the ICAO Global Air Navigation Plan 2016-2030[30]*. The main Paris airports, for example, are already equipped with it.*

But there are many players involved, all with different objectives; above all, despite the dream of a deterministic air transport universe, this environment is fundamentally uncertain: for various technical and operational reasons, we do not know whether an aircraft will take off nor when it will do so if it even does! (Besides, it first had to land, but at what time?). It is the goal of the CDM and APOC to ensure that uncertainty on such fundamental issues is as low as possible.

Not only have dreams of fully automated systems never come to fruition, but one can only hope that the contribution of digitalisation is limited to what it can actually deliver.

So how could an "autonomous" aircraft fit into such a complex environment, whatever its degree of autonomy? In as complex an environment as the airport, one must take into account the multiplicity of operators who first must learn to work together and then to automate their exchanges of information. All things considered, we are more or less at the beginnings of automatic aircraft handling! It is possible that an autonomous aircraft in flight could fit into the airport system, but with human operators on the ground from different cultures with their own decision-making timelines.

30. www.icao.int/WACAF/Documents/edocs/9750_cons_fr.pdf

8 THE CONSEQUENCES ON EMPLOYMENT WILL BE MODERATE OVER TIME

8.1 In maritime transport

History shows that technological breakthroughs in the maritime sector (e.g. the switch from sail to steam power) have not resulted in net job losses over time, given the creation of new jobs. The situation is characterised in the long term by an increasing differentiation between skilled and unskilled jobs. Will this be the same with the ship automation process? What will be the consequences in terms of employment?

There is currently a constant shortage of officers, and automation will primarily result in job changes. A reduction in ship handling duties will be offset by new tasks on board, notably in the area of maintenance. Increased recruitment of officers in Asia will require European countries to provide new training courses on site and ensure their certification.

These developments will depend on a revision of the conventions undertaken by IMO to adapt them to automation (conventions on sea rescue, training of seafarers and safety). Implementation of these amended conventions will rely on standards to be produced by the major standardisation organisations, including the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). This will be a lengthy process and will slow down the spread of automation. IMO has also defined Maritime Autonomous Surface Ships (MASS) and their different degrees of autonomy.

The health crisis has had a major impact on international maritime transport due to a drop in volumes to be transported resulting from the fall in global industrial *production. The gradual resumption of economic activity together with the reopening of borders will enable a revival of international trade and maritime transport. The negative consequences of this crisis on maritime employment will therefore only be temporary.*

In addition, the highly publicised major outbreaks of infection on the Charles de Gaulle aircraft carrier and also on large cruise ships have had a very strong psychological impact on customers, some of whom may be dissuaded from taking up this type of leisure activity. The duration of this effect is difficult to determine and we must be careful of making predictions about the future of this sector, which has experienced particularly strong, steady growth over the last few decades.

Offshore maritime pilotage, which has the most potential for automation, remains a marginal activity. Coastal pilotage, a complex activity with much manoeuvring, is little concerned.

8.2 In air transport

The abrupt halt in air transport due to the 2020 Covid crisis has made employment prospects in air transport very uncertain. We have suddenly gone from a situation of extreme tension in all the specialised aviation professions (pilots, mechanics, air traffic controllers) to massive staff reduction plans, the effects of which will take years to be reabsorbed.

In terms of employment, the objective for some time to come will therefore no longer be to alleviate the scarcity of resources but to seek to make savings. Among the main possibilities offered by automation, it is the project of limiting the number of pilots in long-haul flights to two that seems the most promising. The interest of "single pilot" operations would seem for the moment to be limited to low capacity aircraft, once again on condition they offer an acceptable cost-to-safety balance.

9 TRAINING WILL HAVE TO BE ADAPTED TO INCREASED AUTOMATION SINCE PEOPLE WILL REMAIN AT THE HEART OF THE SYSTEM

9.1 In maritime transport

The training of sailors and then shore-based operators must be at the heart of the reflection on the gradual emergence of highly automated vessels. International standardisation of seafarers' training, which is one of the specific features of this profession, takes on a whole new dimension when faced with the knowledge that highly automated ships will initially cohabit with traditional ships in the same maritime space.

The IMO has always endeavoured to harmonise the fairest training standard possible, in particular to avoid too great a disparity in employment levels between countries. There is no doubt that the technologies accompanying Maritime Autonomous Surface Ships (MASS) will favour the employment of officers to the detriment of the crew, who are more numerous on board. The minimum crewing plan necessary to operate a ship (safe manning) is generally below the numbers of the actual workforce, particularly in terms of execution because maintenance and servicing tasks are carried out on board and very rarely at the quayside, except for short periods of technical stoppages.

An analysis of requirements to operate a ship with a high level of autonomy is a bit like an iceberg. The visible part, that of the bridge, attracts attention because ship *automation mainly concerns handling. The submerged part concerns the engine and operations departments, which together account for 80% of the crew and are the most difficult to automate.*

The bridge control function, the one that requires the least maintenance personnel, is clearly identified as it is limited in the vast majority of cases to three officers responsible for keeping watch and steering the vessel, relaying each other every four hours. Added to this is the captain who, although seconded from the watch, takes full responsibility for the ship.

Much more tricky than steering automation, it is above all automation of engine and power generation maintenance which is still difficult to achieve due to the technical level of these units.

This is why the IMO has defined four levels of autonomy in the prefigured evolution of the regulations.

The first two include crew members on board, when control and management of ships in local autonomy or remotely controlled can be taken back at any time by the crew. A bridge is therefore still necessary. The last two levels have no crew members on board. For the third level, the ship is controlled by a remote centre under the authority of a commander. The last level is completely autonomous.

Initially, only the first two levels should be subject to changes in IMO regulatory codes and conventions. For the time being and for obvious safety reasons, this reflection excludes passenger ships for which the management of people on board in the event of a disaster cannot be envisaged without the assistance of a crew trained in crisis management.

In its pragmatic approach, without opposing technological developments, the IMO considers that the presence of a minimum number of qualified people on board is still necessary to respond to damage, tackle an incident and take over management of the ship in a degraded environment. Under these circumstances, it is more the size of the crew than their level of qualification that is likely to be reduced. On the other hand, we can expect a change in the areas of competence of officers whose qualification spectrum is already very broad: team management, versatility in the maintenance of engine or deck systems, operational management of these systems and of the ship.

Perspectives and recommendations

The IMO's international convention governing the training of seafarers is the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). It should be thoroughly overhauled. It defines the content of training with the objectives to be achieved and the means to achieve and monitor them.

Training centres will certainly need to be equipped with increasingly sophisticated simulators to immerse their trainees in a virtual operational environment. It will be necessary to learn to remotely manage breakdowns and degraded situations. The officers will have to develop knowledge on all information transmission infrastructures, in particular satellite, but also all interconnections (navigation coordination centres, logistic centres of ports, voyage planning centres).

For nautical steering, the automation of some of the functions of the bridge with the integration of positioning and propulsion systems can already be found on so-called dynamic positioning vessels. These vessels, dedicated to offshore and wind power work as well as scientific measurements, can be seen as the precursors of MASS. The supervision, whether locally or remotely, of an automated ship will require in-depth knowledge of computers and cybersecurity to ensure the security of the transmission networks through which all the data for the command, control and maintenance of the systems will transit.

Seafaring experience will still be necessary in the remote control centre to assess the risks. This is already the case in the "Fleet Centre" of large companies, the forerunner to remote control centres, where the routing coordination of several ships is provided by a titular commander.

In order to meet these new challenges, the training schools for officer-engineers, the French Navy or the Merchant navy are joining forces with other schools and institutions to set up partnerships or qualifying training courses, in cybersecurity for example, such as the specialised master's degree in "Cybersecurity of maritime and port systems" organised in partnership with the École Navale, the Écoles nationales supérieures maritimes, the Institut Mines-Telecom Atlantique and the École nationale supérieure de techniques avancées.

Another aspect of the profession which is likely to shake up the shipping world when levels 3 and 4 of autonomy come into effect is the area of responsibility of the captain, who is still defined as such in a shore-based control centre. Many regulations and codes will need to be amended to define the level of responsibility of a decision-maker who is not in the direct presence of the event to be managed. Maritime law, shipowner's liability, insurances, collision avoidance rules (COLREGs) and assistance at sea will all need to be taught from a new angle. However, these areas will have to remain in line with the traditional practice of the seafarer's profession for an indefinite period of time.

9.2 In air transport

Airlines, grouped within IATA (International Association of Air Transport), and manufacturers are faced with a heterogeneity of conditions under which operating licenses are issued by States to operators and their pilots.

This led Airbus to create its own reference system which aims to define a standard for operating methods and skills, both technical and non-technical. This standard is implemented in all training centres and promoted to the authorities.

For its part, IATA defined a complementary certification system for airlines via safety audits (IOSA: International Operational Safety Audit), which guarantees the homogeneity of the operating and safety conditions of the beneficiary airlines.

The question of managing automated systems is clearly central to pilot training. These systems are of course increasingly present to help pilots take a step back and are a real support in the event of a degraded situation. They enable pilots to take their place in an overall environment which is becoming very complex indeed. Ultimately, progress in artificial intelligence will allow a more concise overview of the situation in the cockpit and of the associated documentation and procedures, thus relieving the mental load of the crew.

The management of critical situations caused by unexpected events has been the subject of much work of the Air and Space Academy.

The rarity and dangerousness of these situations require pilots to demonstrate great self-control, a basic quality that is innate but that can be partially improved by appropriate training. It must be detected at selection level, especially in the scenario of a single onboard pilot.

However extensive it may be, automation will never eliminate the need to resume direct control of the situation, particularly that of the flight path in manual piloting, i.e. the direct, immediate action of the pilot on the evolution of the speed vector and simultaneously on the management of the three energy parameters (speed, altitude, thrust) by means of manipulators (levers, steering wheels, control sticks, etc.), via flight control systems and engines. This is why EASA recommends that pilots periodically conduct departures and arrivals under manual piloting.

Physical and mental skills neglected in favour of automation must be rehabilitated in training and maintained in commercial operation. This does not dispense with the obligation to practice selecting the use of automated processes in all their modes of operation, whether normal or degraded: trying to memorise operating procedures alone, without understanding and practising them, is contrary to basic pedagogy as applied to the use of dynamic functions of complex systems.

This requires a review of the basic qualities and skills for selection and training. Here the question arises of the rigour of the stakeholders: airlines, training centres and authorities. The risk of relaxing hiring and training criteria due to the massive pilot recruitment needs experienced before the air transport crisis linked to the pandemic is undoubtedly less present today. But there will always remain the threat of cost reductions being sought for this position.

The "seamanship" and "airmanship" qualities that are necessary in a serious situation must be maintained. This is one of the fundamentals of both sectors. The characteristics of this sixth sense evolve in the same way as the professions themselves: seamanship on sailing boats, for instance, is not the same as for ships with steam power.

Recommendation No.3

Automated systems provide and will increasingly provide essential assistance in the operation of aircraft and ships and make a decisive contribution to improving operational safety. Nevertheless, not only in degraded situations, but also in normal operations, it is essential that crews constantly maintain an understanding of the functioning of these automatic systems in order to remain in full control of the situation. Training organisations providing initial or continuing courses must therefore ensure that they give ship and aircraft handling personnel in-depth training in understanding automatic systems, particularly in the event of an unforeseen event, skills supported by a solid basic knowledge of their profession. In addition, designers of these automated systems and interfaces must ensure that they design systems that are intelligible to human operators, thus enabling recovery by the latter in all cases of malfunction.

10 THE ACCEPTABILITY OF THESE NEW TECHNOLOGIES STRONGLY DETERMINES THEIR DEVELOPMENT

The central issue behind the acceptability of the automation process to the public and the market (passengers) is one of safety. It can be demonstrated that automation improves safety, up to a point. Nevertheless, human presence on board a ship or aircraft is still perceived as a factor of safety, regardless of the various technical demonstrations. Ancient history and imagery (e.g. the captain as sole master on board after God) keep this perception anchored in the collective unconscious. At the present time, the possibility of a human taking over from a machine in a dangerous situation, whether on board or from the ground, can only partially mitigate this perception.

Maritime and aviation history are first and foremost human stories, and the maritime and aerial culture thus forged are major components of our civilisation. Should this essential dimension to our activities be sacrificed on the altar of technical progress?

Do we really want to banish all human presence from on board our ships and aircraft when this presence contributes to the positive image the population has of our activities, all for a marginal increase in competitiveness, which is far from being guaranteed?

These social questions having been raised (and remaining to be explored), the acceptability of these new technologies will strongly determine their development. This will involve transparency on the part of operators, guidance for staff and communication to the general public. In the maritime sector, acceptability will vary *according to the type of vessel: it will be simpler for bulk carriers and container ships than for cruise ships, and more acceptable on the high seas than in port approaches, since the latter are more complex and contain conflicts of use (presence of fishermen, yachts, etc.). Public acceptability also determines the development of civilian drones in the city (noise, fear of espionage, risk of collision, etc.). Generally speaking, it will improve over time given the inevitability of automation and the services provided (decision support, lower costs). The sedentary nature of the resulting jobs will also make automation more acceptable to staff.*

It is interesting to read the Nautilus Report[31] *which examines the attitudes of maritime professionals to autonomous navigation.*

According to this survey, 84% of seafarers questioned believe that automation is a threat to their jobs, and 66% think that the introduction of new technologies holds no benefit for maritime transport (one third think the opposite though despite the fact that their jobs are at stake).

31. www.nautilusint.org/en/news-insight/resources/nautilus-reports/autonomous-shipping-research

11 THE LEGAL FRAMEWORK WILL ADAPT TO TECHNOLOGICAL DEVELOPMENTS

11.1 Liability will fall on the same actors

***In maritime transport**, there are two levels of liability:*

- *the shipowner's liability for damage to third parties, i.e. those who have no contractual link with the operation of the ship;*
- *the carrier's liability for the goods, i.e. vis-à-vis the shipper, on whose behalf the goods are transported.*

These two partners can organise their relationship within the framework of a contract for which they negotiate the terms. Up to now, this liability has been limited, depending on the tonnage of the ship, but we will most likely move towards flat-rate limitations.

The emergence of new transport operators, taking advantage of software allowing complete management of the maritime transport chain, could lead to changes in these notions of liability.

***In air transport**, this owner/carrier duality is not applicable, and liability is sought mainly from the operator and the manufacturer. That of the owner, who is either the operator or a leasing company, does not usually appear as such.*

How does growing recourse to increasingly complex automated processes change the determining of responsibility? In theory, it doesn't, because there will still be an owner and a transporter and clearly identified pilots, operator and manufacturer.

The search for criminal liability, which is systematic in the event of an accident under French law, will always obey the same principles, based notably on expert assessments involving the disciplines in question. However, the increasingly complex interactions between human operator and automated systems, particularly in the event of a malfunction of these systems, will require recourse to new scientific disciplines, qualified as neurosciences[32]. These should provide a clearer analysis of human behaviour, especially in the face of unexpected situations, and also are useful to system developers.

Increasing digitisation is thus introducing complexity into the determination of criminal responsibility, which will probably always be sought. It can be assumed that the same will be true in the maritime sector, with the development of automated conning assistance systems.

As for the establishment of civil liability, which largely determines the distribution and amount of damages, it is essentially based on presumptions[33] which, added to insurance mechanisms, mean that victims can be compensated even in the absence of certainty as to causes, contrary to criminal law which requires certainty in order to convict.

11.2 Towards an evolution of the law?

The evolution towards vehicle autonomy is of particular concern to the legal profession since this reality is recognised by law (law on mobility).

Consequently, two schools of thought oppose each other:

- *one considers that lawyers must go ahead and create, as of now, a new type of legal personality for robots, in order to support, but also to secure and legitimise, technical development. However, simply observing that the degree of intelligence of the most developed systems today does not exceed that of an ant is enough to render this thesis unrealistic for a long time to come;*
- *the other believes that the law guarantees social stability thanks to the continuity of legal concepts. The set of norms with which we live enable us to resolve a large part of any problems arising and to answer the essential questions thrown up by technological development. According to this category of jurists, it is therefore useless to create new concepts. It should be left up to judges to develop the interpretation of texts in a way that accompanies scientific evolution.*

32. Neuroscience is the scientific study of the nervous system, both in terms of structure and function, from the molecular level to the level of organs, such as the brain, or even the entire organism.
33. Such as the presumption of liability of the carrier which does not bring their passengers safely to the point of disembarkation.

In maritime transport, responsibility will remain with those who fail to detect software failure or an insufficient level of information. It is therefore very likely that liability will continue to be placed on the owner or charterer of the vessel, especially as they are often the only ones who can afford to pay it.

In air transport, vehicles and their systems will be certified by authorities on the basis of known regulations and will be operated under the responsibility of an identified operator. The situation will not be legally different from the current situation.

The law will adapt and will not be an obstacle to autonomy.

Several studies and experiments on autonomous vehicles in the aviation and maritime sectors are at present being justified by expected gains in performance and safety and reduced environmental impact. However, there are many obstacles to overcome and many questions regarding rules of responsibility, software validation-standardisation, skills development and user acceptability, in addition to the essential issue of safety, both real or perceived.

Tackling the question of full automation made it possible to address these issues through a uniquely transversal vision. What emerges clearly is that the role of humans at the centre of air and maritime operations is essential, and that automated systems must first assist humans by adapting to them before replacing them in a distant and hypothetical future.

This Dossier 50 builds on and extends discussions from the conference organised in December 2019 by the Académie de marine and the Académie de l'air et de l'espace and includes recommendations for decision makers.

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