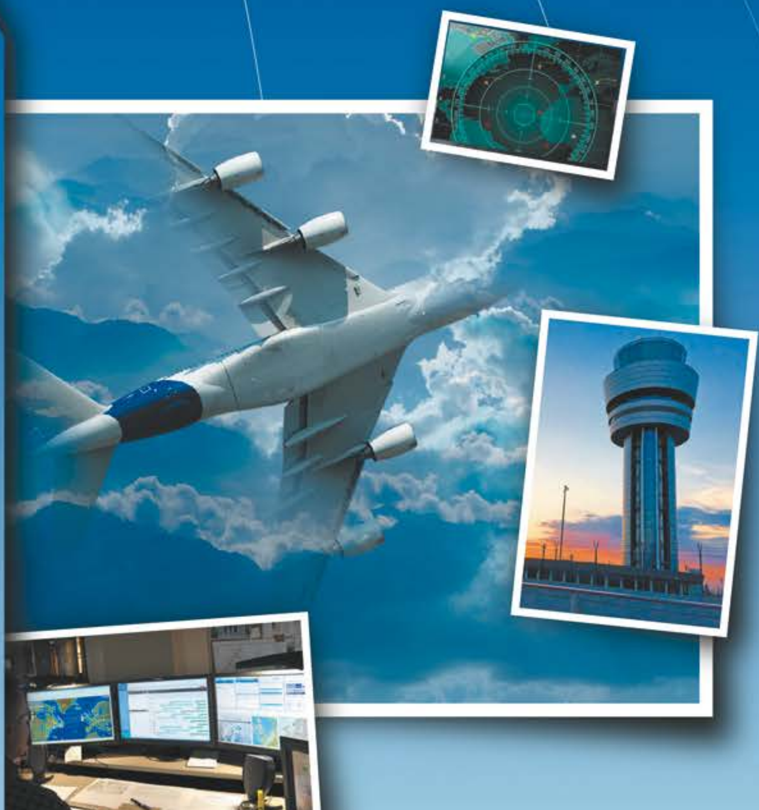
ACADEMIE DE L'AIR ET DE L'ESPACE
AIR AND SPACE ACADEMY

LES DOSSIERS

MISSING AIRCRAFT

An issue facing air transport



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FOREWORD

On 8 March 2014, a Boeing 777 disappeared in flight with 239 people on board. So began the saga of Malaysia Airlines MH370 and its host of attendant questions. Three years on, no explanation has been found for this disappearance.

The Air and Space Academy (AAE) could not remain indifferent to such a dramatic event.

But what should be done? It was not the role of AAE to involve itself in the investigation, nor did it have the means. It could however take a systemic approach to examining the circumstances behind the plane's disappearance in order to suggest ways of enhancing air safety. This is what was done.

Dossier 41 presents the findings of a working group set up to look into questions concerning both the technical means enabling reliable positioning of aircraft in flight and the definition of air-ground communication, with the aim of preventing any further cases of missing aircraft, seen as more and more unacceptable by society as a whole.

This group brought together members from four sections of the Academy, experts in the different areas involved, whether technical, legal or organisational. I would like to take this opportunity to thank all members for their work, in particular C. Roche and P. Goudou, who successively chaired the group. Although some recommendations have already been taken into account, we thought it important to provide you with the full findings of the AAE study.

Anne-Marie Mainguy

President of the Air and Space Academy (AAE)

SUMMARY

Our society has become accustomed to access to information in real-time. The media and social networks have turned the Earth into a global village where any newsworthy event is immediately relayed the world over, or at least this is what we imagine. The internet gives us all armchair access to an ever greater stream of constantly updated information, leaving the impression of unlimited access to information and the conviction that technology has no limits.

All-powerful technology has also brought any point of the globe within reach of all the Earth's inhabitants. Aviation has entered our lives and our societies, inspiring at once fascination and fear. Flying has become commonplace, and yet each aircraft incident or accident generates media coverage out of proportion to other means of transport and sets off in-depth investigations. Each tiny detail is dissected, analysed and published. With some rare exceptions, specialists end up with a reasonably clear idea of what occurred, even when the aircraft has been destroyed.

So how can we accept the idea that an aircraft can apparently disappear forever, that nobody will ever know where it is nor what happened to it?

*Such is the case of the Malaysia Airlines flight MH370 that went missing in March 2014 (*references to this accident are given in roman type in the text*). It also took a week to locate the wreckage of the Egyptair MS 804 flight after it crashed into the Mediterranean Sea in May 2016, even though the accident happened not far from the coast and that the aircraft was being tracked by radar, since radar becomes ineffective when aircraft drop below the beam (as the investigation is still in progress, no more will be said about this accident).*

Here is what must be known to comprehend the incomprehensible:

- *with very few exceptions, airlines do not permanently track their aircraft in flight (*Malaysia Airlines was no exception*);*

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- *air traffic management, because of its fragmentation (many handovers from one control organisation to another), cannot provide continuous flight tracking;*
- *the fact that flights are displayed on certain Internet sites does not guarantee that these aircraft are permanently monitored in whatever circumstances;*
- *it can be very complicated to locate a plane which came down over the ocean or in inhospitable or poorly accessible regions (on average a little over one case per year);*
- *because of defects in current ATM communications and monitoring systems, it is not uncommon to lose contact with a plane for a time even during normal flight (*the loss of contact with flight MH 370 was not so surprising therefore at the time for the various controllers involved*);*
- *loss of contact with a plane can indicate a potential threat for the country over which it is flying. This is why the air defence systems of some developed countries have the task of dealing with these missing planes. This requires coordination between civil and military air traffic control and action on the part of Air Defence (*it should be noted that such means were not implemented in the case of the MH 370*).*

This dossier gives examples of aircraft that went missing after accidents and draws up a list of the issues involved. It then examines the current state of communications between ground and air, studies the tracking systems used by air traffic control services and airlines as well as those available to the public on the Internet, and explores how states can exercise sovereignty over their airspace thanks to the different missions and means of their air forces.

This dossier also comments on the recommendations and announcements made by various players at the High Level Safety Conference (HLSC) of the International Civil Aviation Organization (ICAO), in early February 2015, which dealt, in particular, with "Global Tracking".

The dossier goes on to explore the following four major themes:

- *aircraft tracking;*
- *improving search and rescue;*
- *developing ground/air co-operation;*
- *transmission of vital data before accidents;*

which give rise to the following four recommendations.

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► ***Recommendation 1***

Thanks to improved satellite services it will be easier and less expensive for airlines to permanently track their aircraft in flight, even over zones with no radar cover. It is highly desirable that this tracking be made obligatory, with a position report every minute when a serious anomaly is detected; this would make it possible to locate an aircraft rapidly in the event of a crash, thereby meeting the needs of the aeronautical community (investigations and flight safety) and the victims' families. Aircraft manufacturers and airlines should set up tracking systems that cannot be disconnected, to prevent wilful action being taken on board to make an aircraft "disappear".

► ***Recommendation 2***

Loss of contact with an aircraft should always be regarded as a serious event requiring rapid implementation of appropriate means to dispel any doubt, although the response should be progressive, ending up with the highest level of intervention from air defence. No passiveness should be tolerated. The necessary means and procedures should be set up to ensure interconnectivity between the air traffic services of adjacent countries and cooperation between civil and military authorities.

► ***Recommendation 3***

An in-depth study should be launched into the criteria and means to be set in place for detecting and perhaps helping to resolve an emergency situation. This study should also comprise an analysis of the advantages and disadvantages of new resources.

► ***Recommendation 4***

Rapid collection of all information needed to elucidate an accident is a prerequisite for aviation safety. In certain circumstances, but not always (poorly accessible areas for example), deployable recorders would be an acceptable solution. But it is clearly much better to transmit the relevant data prior to the accident, guaranteeing access to information in all circumstances. Joint experiments should rapidly be launched by manufacturers and operators, on new aircraft in particular, to build up a clearer picture of this solution, before it can become a credible alternative to the requirement for deployable recorders.

This study also threw up questions which go beyond the scope of this dossier. Certain preliminary proposals, in particular concerning emergency situations, could be put forward in a future AAE dossier dealing with hijacking of aircraft.

1) *Aircraft must be tracked permanently. Who would be tasked with this? With what technical resources? And what funding?*
2) *What are the criteria for detecting an emergency on board a plane in flight? What is the relevant information and how can it be relayed so that the ground team is informed of this emergency? What new systems will ensure that transmission means cannot be disconnected? And that the confidentiality of possibly real-time audio and video communications to the ground is respected? What would be the role of the air forces in such situations?*
3) *How to restrict access to protected data destined for the investigation if it is transmitted by radio before the crash?*
4) *How to make more consistent the current disparate set of ground/air communications and positioning systems? How to ensure protection from the threat of malevolent acts targeting these currently unprotected systems, in particular ADS-B?*
5) *How to reconcile the multiplicity of legal, cultural, religious and ethical claims surrounding recovery of the victims' remains, a potentially extremely expensive operation, particularly when the technical data has already been obtained without visiting the wreck?*

* * *

In this dossier, acronyms are clarified the first time they appear and are explained in the glossary (Annex 11).

1 AIRCRAFT THAT GO MISSING AFTER AN ACCIDENT ARE USUALLY FOUND, THOUGH SOMETIMES WITH GREAT DIFFICULTY

Annex 10 contains a list (issued by the French Bureau d'Enquêtes et d'Analyses, BEA, probably incomplete) of the 57 public transport aircraft that have disappeared at sea or over inland waters since 1969, i.e. a little over one a year on average. This list does not reveal any reduction in the rate of such disappearances in recent years.

A review of searches carried out for these aircraft reveals that, out of these 57 cases:

- *in 12 cases the wreck was never found, either for technical reasons or because no search was launched due to lack of funding. In one case, it was found by chance long after the search was abandoned;*
- *in 12 cases the wreck was found but neither or only one of its recorders was located;*
- *in several cases, both wreck and recorders were found but the latter were illegible (this can also happen in the case of accidents occurring in easily accessible places).*

There are also several cases of accidents in mountainous or densely forested areas for which the search for the wreck was frought with difficulties.

When an aircraft goes missing in a difficult area – the open sea, marshes, rivers or shallow sea areas with muddy water or strong currents, tropical forests or high altitudes – the search comprises certain challenges not met satisfactorily by current monitoring, tracking and flight data recovery devices.

Numerous issues - operational, technical, commercial, ethical and even religious in nature – can arise in particular from lack of information on the positioning of a commercial transport aircraft.

In normal operation, lack of knowledge on an aircraft's position represents an operational and commercial handicap for airlines that have to manage connections and possible delays or re-routings.

But it clearly becomes much more serious in the event of an accident:

- *the search for the wreck takes a long time (two years for the Air France flight AF447 Rio-Paris) and can be unsuccessful (*which seems to be the case today for Malaysia Airlines flight MH370*);*
- *such timelines rule out any possibility of rescuing potential survivors;*
- *the costs involved in such search operations are very high because of their length and difficulty due to the characteristics of the region in which such an accident occurs. A depth of water greater than a few hundred meters, for instance, necessitates highly sophisticated equipment (underwater robots).*

As a result of this:

- *accident causes are identified after a considerable delay, or not at all if the flight recorders are either not found or are illegible. And yet the high safety level enjoyed by air transport relies heavily on feedback from experience;*
- *victims' relatives, in addition to the trauma of the accident itself, also suffer from this lack of explanation and from the absence of a body as most societies nowadays consider that any deceased person is entitled to a proper burial;*
- *families play a key role in maintaining pressure for searches and their lack of comprehension fosters rumours and erroneous, sometimes farfetched hypotheses;*
- *the media, whose job is to provide answers to questions, relay all scenarios and theories that are advanced;*
- *without flight recorder data, invalid hypotheses can flourish and lead to inappropriate safety measures. Legal procedures aimed at determining responsibilities cannot be carried out properly;*
- *finally, an unexplained accident represents a highly traumatic experience for the air transport world in general and particularly for the airline concerned…*

2 AN AIRCRAFT CAN DISAPPEAR MOMENTARILY…

… despite Air Traffic Control

A description of air traffic control can be found in Annex 1 along with an appendix on its communications and monitoring means, currently limited to radio equipment (VHF and HF), "secondary" surveillance radars (SSR) that interrogate aircraft (transponder), and possibly ADS receivers (Automatic Dependent Surveillance).

As it stands, contrary to appearances, air traffic control does not perform full, continuous tracking of aircraft in flight.

The requirement for aircraft of varying ages and technologies to share the same airspace and for all planes to have access to almost all airspace leads to great inertia in the introduction of new concepts and materials: civil aviation appears "prehistoric" in many ways!

Communications and surveillance presuppose that the aircraft's onboard systems (radio and transponder) are "active". And for them to be active the radio must be on the "right frequency" and the transponder on the "right code".

However:

- *the frequency to select on the radio unit at each control sector transfer is transmitted verbally by the controller to the pilot who "displays" it manually. There is a risk of error from both controller (wrong frequency indicated to the pilot) and pilot (incorrect frequency displayed). As an indication, a two-hour* *flight over Europe involves ten or so manual frequency changes*[1]*. The air traffic controller cannot call the plane directly once an incorrect frequency has been entered on board. A distress frequency does exist, like Channel 16 at sea (121.5 MHz), but is not systematically monitored by aircraft in flight. For oceanic flights, there is the possibility of making a selective HF*[2] *call (Selcal), so the controller can call a plane directly. But no such system exists for continental flights. In Europe, in 2013 alone, 56 cases of prolonged loss of communication caused air defence alert aircraft to take off from NATO's European AoFR zone (Area of Functional Responsibility), for want of an effective system to restore contact;*

- *the secondary four-digit radar code (transponder), broadcast in the same way as the radio frequency, is prone to the same errors, except when it is allocated for the duration of the flight and checked from the outset by the first radar controller to manage the plane. This means that the plane can disappear from the screens of the secondary radar or be mistaken for another. For the radar system known as Mode S (S for Selective), the more elaborate internal code of the transponder is supposed to give the identity of the plane. But sometimes when the transponder is changed, during maintenance for example, the wrong code is introduced, once again leading to mistaken identity.*

Only ADS-based systems, when they are available (in range, with a good state of operation of the whole chain), can locate a plane without error.

With regard to flight MH370, all radio and radar communications were lost, and it was impossible to establish if this was ascribable to a deliberate human act (in the cockpit or the electronics compartment) or to technical failure. The suspicion of it being a wilful act comes from the fact that the aircraft disappeared when it reached the limits of the airspace managed by Malaysian civilian air traffic control. Procedures can sometimes be rather vague at this moment of transfer. It took Vietnamese ATM 19 minutes to alert Malaysian controllers to the fact that it did not have contact with the transferred plane.

In the case of the AF447, the failed transfer between Brazil and Dakar led to several hours' delay in launching the search effort.

1 As if the public had to be instructed by an operator to change frequency on their mobile phone with each change of "cell".

2 High frequencies (3-30 MHz)

... despite Operations Control Centres

Annex 2 contains a description of the role and means of communication of Operations Control Centres (OCCs), with a description of the Air France OCC in appendix.

Contrary to what their name might suggest, the OCCs of the major airlines do not control individual flights, they coordinate the entire operations of a fleet.

The crew can contact the OCC at any time, via various channels, to raise questions, relay events on board or announce any changes to plan. Such communications use long-distance HF radio connection (often of poor quality) and more recently satellite telephone networks (SATCOM), more and more common on long-haul aircraft. The ACARS system (Aircraft Communications Addressing and Reporting System) is also exploited on all types of aircraft by means of SMS type text messages. Messages are written on board and sent via the FMS (Flight Management System) alphanumeric keyboard then received on a printer. ACARS uses either VHF connections, over zones with the appropriate equipment, or satellite networks. It should be noted that ACARS does not meet any ICAO standard and functions rather poorly.

The "monitoring" function (but not the "tracking" function), when it exists within the OCC, is associated with flight assistance. It is obligatory in the case of ETOPS[3] *operations (Extended-range Twin-engine Operation Performance Standards), at least in a reduced, strictly regulated format. Information thus transmitted relates to state of engines and rerouting airports, but this transmission by ACARS of engine information is not obligatory in the regulations. It is a possibility some airlines choose to put in place. Above all, there is no legal requirement for transmission of position.*

Neither British Airways, Lufthansa nor EasyJet, for instance, offer monitoring or assistance for their long- and medium-haul flights. Air France, Emirates and Alitalia provide monitoring and assistance for long-haul only. Delta Airlines, United Airlines, Air Canada, KLM (and soon Air France) provide monitoring and assistance for long- and medium-haul flights.

In short: Does the existence of an OCC necessarily presuppose continuous tracking of the aircraft? The answer is no. Many airlines do not see any economic advantage to it, as long as estimated arrival times are known and irregularities are reported by radio by the crews.

Despite having an OCC, with no tracking and no call from the pilot, Malaysia Airlines had no reason to worry!

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3 An ICAO regulation allowing commercial aircraft with two engines to operate on air routes including sectors over an hour away from a relief airport, in particular ocean routes.

(With regard to monitoring of engine operation, more detailed information can be found in Annex 2.)

Modern transport aircraft are equipped with digital avionics which enable information to be exchanged and processed between various points on board and also with the ground via radio connections. Their engines are connected to the rest of the aircraft and to the ground via the Engine Health Monitoring System (EHMS).

In the case of ETOPS, airlines meet regulations if they simply record engine parameters and process them before the following flight.

In the event of an anomaly in flight, when the data is transmitted in real time, the airline's OCC is alerted and can decide on the maintenance action to be carried out, either immediately (with operational consequences if there is rerouting), at a stopover or during a forthcoming maintenance session.

Rolls Royce has developed tools for monitoring its engines and has even created a subsidiary company OSyS (Optimized Systems & Solutions) to provide support to its civilian and military customers, but this has nothing to do with tracking aircraft. SAFRAN-SNECMA and the other manufacturers have similar offers.

In the case of the MH370, transmission of engine parameters was interrupted when ACARS cut out.

... despite coordination between civil and military air traffic services

There are two types of military air traffic:

- *"en-route" air traffic, controlled either by purely military control centres or by mixed civil-military centres. In both cases, coordination is aimed at avoiding collisions between two users of the same airspace and is subject to many national and international documents and procedures.* ***This coordination is not the object of the present document;***
- *"operational" air traffic (training, air policing, interception, combat), carried out entirely by military control centres (even if they are sometimes located on the same site as civilian centres). Anti-collision is the responsibility of military control. Coordination between military and civil control is usually at the initiative of the military, mainly to clear up doubts as to identification. Civil to military coordination actions are rarer (aircraft disappearing from civil control) and can be non-existent or much too slow in certain countries.* ***This is the type of coordination that is discussed in the present document.***

Detection and possible interception of "intruders" is the responsibility of national defence and is not handled by ICAO. However, chapter 7 of ICAO Document 9554-AN/932 "Manual concerning safety measures relating to military activities potentially hazardous to civil aircraft operations", drawn up after the destruction of the Iranian Airbus A300 flight IR655 on 3 July 1988, contains elements on "the identification of civil aircraft".

Civil and military authorities have different goals and responsibilities regarding the monitoring and assistance they can provide for civil flights in abnormal situations.

Here a description is given of the role of military authorities in developed countries in the case of loss of contact between a civil aircraft and air traffic control.

In all countries with an air force, the latter has responsibility for air defence and therefore possesses a permanently functioning network of primary radars[4]. In addition, the major air forces have a Quick Reaction Alert (QRA) facility, made up of one or more aircraft on permanent alert, with take-off decided by the Combined Air Operations Centre (CAOC).

These resources can be very useful, on the one hand for recovering primary radar contact in the event of loss of secondary contact by civil control and, on the other, to "go and see" how the lost aircraft is behaving and even observe its crew.

Moreover, in many countries, the air force's missions include one of flight assistance, authorising QRA aircraft to bring back an aircraft with radio failure or which is lost (a common occurrence with private pilots of small aircraft). In some countries, the air force is delegated by the Ministry of Transport to coordinate Search and Rescue (SAR) activities in the event of loss of an aircraft or a confirmed accident.

In the case of flight MH370, it is astonishing to note that there was no real-time response from the Malaysian air force. And yet the CAOC did indeed have primary radar contact since recordings later helped reconstruct part of the flight path of the aircraft. Interception and interrogation of the plane would perhaps have clarified the crew's situation.

This question of lack of response also applies to the air forces of adjacent countries or those whose airspace was flown through without knowing whether the lost plane had been located.

These observations raise questions concerning the effectiveness of civil/military coordination and the tracking quality and reactivity of air defence, and also highlight the confused conditions under which this event occurred.

One can thus note a lack of coordination between the various tracking systems existing within airlines, civil air traffic control and air defence services: the

4 A primary radar uses an echo sent by the observed aircraft, which is itself completely passive and possibly unaware that it is observed.

disappearance of an aircraft that was being tracked by civil air control should immediately have been announced to the air defence of the country concerned and those of adjacent countries.

... despite flights being displayed on the Internet

Annex 3 lists the addresses of sites displaying flights and describes the principles on which they function.

In the past, only civil or military air traffic control services, airlines and airports could roughly track planes, as seen in the preceding paragraphs.

Today, a simple internet search with the keywords "aircraft real time" is enough to call up dozens of sites or smartphone applications that "permanently" identify and track aircraft.

This is possible thanks to the different networks helping site operators to update charts in real or slightly delayed time. These networks consist of those official control centres that have agreed to take part as well as a multitude of ADS-B receivers (B for broadcast; see Annex 1) spread over the planet, particularly in airports, which receive identification and tracking information for aircraft in range of their antennas that are equipped with ADS-B. These receivers belong to the site operators or to amateur enthusiasts who agree to share their data. Certain airlines have signed agreements with such site operators for the exchange of data flows.

These sites are used by the general public, particularly the countless aviation enthusiasts, vastly outnumbering all the air traffic controllers and OCC staff worldwide!

Such sites raise security issues: anyone equipped with a basic receiver linked to a computer, or indeed simply connected to one of these sites, can identify and track many planes in real time.

This problem is a familiar one in the maritime domain. Pirates have not been slow to equip themselves, indeed the only reason one cannot see ships off Somalia on maritime sites like Marine Traffic is because the boats tend to shut down their transponders to avoid being spotted by the pirates. This solution, however, is not possible for air transport since ADS-B generally emits via the transponder which is also used by the ultimate collision prevention tool, TCAS. Without the possibility of turning off the transponder above troubled zones, it is best not to fly over them, but attention must be given to a possible threat near airports.

Despite the impression given of "continuity" and "permanence" in the flow of information, heightened by ease of access, if a plane "disappears" from official radar *screens, whether voluntarily or involuntarily, for reasons described above, it also disappears from these sites.*

One can expect crews to benefit[5] *sooner or later from the development of Aeronautical Passengers Communications (APC), i.e. vocal or video communication with friends and families on the ground which, for obvious commercial reasons, will be much more extensive and elaborate than communications between ATM and airlines.*

Once its transponder and ACARS had been turned off, the MH 370 also disappeared from all websites ...

5 But not in a "regulatory" way since this would require a reliable, robust, certified system.

3 THE OUTCOME OF THE ICAO HIGH LEVEL CONFERENCE ON SAFETY OF FEBRUARY 2015 IS DISAPPOINTING

Annex 4 describes the roles of those responsible for developing civil aviation regulations.

Two working groups were set up to prepare ICAO's High Level Conference on Safety[6]. The first group, under the aegis of the ICAO secretariat, worked on the GADSS (Global Aeronautical Distress and Safety System) operational concept.

The second group, entitled ATTF (Aircraft Tracking Task Force), under the aegis of IATA, analysed inadequacies on the part of the air traffic control organisations and airlines in terms of global tracking. After taking stock of possible means of improvement, ATTF proposed the setting in place within 12 months of automatic position reports, at least every 15 minutes and more often in the event of an incident.

This report was rejected by the IATA secretariat and was finally presented to the Conference by the ICAO secretariat.

6 *Their reports can be consulted on the following site: www.icao.int/Meetings/HLSC2015/Pages/WorkingPapers.aspx*

The GADSS concept involves more than Global tracking. It also deals with SAR (Search and Rescue) aspects, with a very detailed description of the processes, players and equipment. Above all, it lays down a frequency of one position report per minute in the event of an incident and sets out the criteria that should trigger more regular reports.

Annex 5 of this document presents the "Summary of discussions, conclusions and recommendations of the HLSC/15-WP/102 conference, Revised".

What emerges from this document is that the only subject tackled thoroughly was "permanent tracking".

One recommendation relates to the proposal for a position report every 15 minutes by the end of 2015. Press releases, including those issued by IATA, gave the impression that this measure met the public's need to "know where aircraft are"; actually the distance covered in 15 minutes at cruising speed is approximately 120 Nm, i.e. over 200 km. We are very far then from having the kind of precise information on position that would help locate a plane in the event of a crash in zones situated outside radar coverage.

The specific case of a deliberate shut down of the tracking system was not tackled.

One of the possible scenarios for the disappearance of the MH370 is thus not dealt with.

The sections on emergency situations and data recovery in the event of accident give rise only to recommendations aimed at continuing "work in progress". The idea of increased frequency of position reports in the event of incident has even disappeared.

Actually, as seen above, most airlines have only a rough idea of the position of their aircraft in flight. Air France, on the contrary, has set up an effective procedure which improves flight tracking in the event of an incident. The ACARS data transmission software on its long-haul aircraft has been modified to automatically emit a position report every minute if the plane drops below Flight Level 150 during cruise. The distance covered in one minute at low altitude is put at around 6 Nm. The chances of locating a missing plane are thus greatly enhanced.

Reservations expressed by IATA in the name of its member airlines were based on the imposed deadlines (end 2015), the fact that the obligation went beyond the fleets they consider necessary to equip and quite simply that not all airlines had the structures needed to include a tracking function in their operations. Finally, the efforts required to set up this global tracking seemed to be asked entirely of airlines; nothing was said as to the contribution of ATC to progress in this area.

Several air transport players have already reacted in the media:

- *China is apparently planning to make these systems obligatory across the board*[7]*;*
- *in the United States, Rep. David Price, D-N.C., introduced the "Safe Aviation and Flight Emergency Tracking Act of 2015". "The bill would require the Federal Aviation Administration to mandate aircraft be equipped with technology enabling continuous tracking of information regarding the aircraft during flight and the timely and cost effective recovery of the cockpit voice recorder and flight data recorder in the event of a crash or other serious incident";*
- *the director general of Qatar Airways, Akbar Al-Baker, on entry into service of the A350, went much further, declaring that "Qatar Airways is carrying out tests to become the first airline in the world where all flight data recordings are streamed directly from the plane "black box" to the ground while in flight."*[8]

In short, a regulation could thus initially be imposed on long-haul carriers and/or flights out of range of radars. It is an initiative which the civil aviation authorities of the main aeronautical states are in a position to adopt.

7 See "After Disappearance Of Malaysia Airlines Flight 370, China To Require Satellite Systems On Commercial Aircraft" (www.ibtimes.com/after-disappearance-malaysia-airlines-flight-370-china-require-satellite-systems-1805600)

8 www.news.com.au/travel/travel-advice/flights/european-airlines-cannot-keep-up-qatar-airways-chief/news-story/04344ceb6f0ce00bf95fc7cfac116111

4 SOME PROPOSALS FOR INSUFFICIENTLY TACKLED ISSUES

Flight tracking by airlines

Technical solutions undoubtedly exist, or will soon exist, for permanent tracking, even over zones not covered by radar.

Annex 6 "Satellite transmission of information from commercial aircraft flying over oceanic or desert zones" deals with the main obstacle to permanent flight tracking: i.e. zones situated outside radar coverage.

As IATA's ATTF working group indicates, the situation is different above inhabited zones:

> *"Because ATM services use the location and identification of an aircraft in order to manage separation, such information also can serve as a form of aircraft tracking. In fact, a large number of commercial aircraft operators currently use ATS surveillance services for the purpose of tracking their aircraft, particularly in medium to high density airspace".*

Surveillance systems could thus be enhanced, moving towards global monitoring with facilitated provision to airlines, but this aspect is not the current priority of work which remains centred on oceanic or remote zones.

The Canadian, Italian, Irish and Danish air navigation service providers (ANSP) have joined Iridium Communications, which has entrusted development of a new satellite constellation to Thales Alenia Space (TAS). This is no.2 of the four possible options described in Annex 6.

These ANSPs took advantage of the ICAO conference to promote their Aireon LLC consortium, by means of a free "loss leader":

> *"Aireon LLC, developer of the world's first space-based ADS-B global air traffic surveillance system, today announced that the Aireon Aircraft Locating and Emergency Response Tracking (Aireon ALERT) service will be managed from the Irish Aviation Authority's (IAA) North Atlantic Communications Centre in Ballygirreen on the West Coast of Ireland. The Aireon ALERT service, a global emergency tracking solution that will be provided as a public service to the aviation community, free-of-charge, will allow rescue agencies, air traffic control providers or airlines to request the location and last flight track of any 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS–B) equipped aircraft in distress. It is expected that approximately 90 percent of the world's commercial fleet will be ADS-B equipped in the near future"*[9].

The idea of removing the possibility of disconnecting tracking transmissions was tackled in the ATTF working group's report:

> *"The ATTF also considered the issue of human intervention with respect to equipment on board aircraft. Equipment such as transponders that are used for ATS surveillance can be disabled by the flight crew for operational or aircraft safety reasons. A malfunctioning airborne component may adversely impact ATC operations. For this reason it is necessary that means exist to deactivate such components if they are not working properly. From a safety perspective, all electrical components on board an aircraft must have the ability to have their power source interrupted in the event of an electrical system malfunction or fire. While these types of operational and safety related events are rare, the fact remains that equipment on board aircraft can be disabled".*

Radios and transponders currently in place must be able to be disconnected therefore. Any solution must, then, involve new systems capable of communicating with the ground, with their own energy supply and sufficient protection in the event of fire not to risk damaging the plane.

9 www.iaa.ie/news/2015/11/13/aireon-alert-global-emergency-tracking-service-response-centre-to-be-located-in-ireland

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► ***Recommendation 1***

Thanks to improved satellite services it will be easier and less expensive for airlines to permanently track their aircraft in flight, even over zones not covered by radar. It is highly desirable that this tracking be made obligatory, with a position report every minute when a serious anomaly is detected; this would make it possible to locate an aircraft rapidly in the event of a crash landing, thereby meeting the needs of the aeronautical community (investigations and flight safety) and the victims' families. Aircraft manufacturers and airlines should set up tracking systems that cannot be disconnected, to prevent any attempt on board to make an aircraft deliberately "disappear".

Improving search and rescue (civil/military coordination)

Triggering criteria for SAR and their corresponding procedures should be made stricter for both civilian and military control centres in order to launch searches as soon as possible. This means improving civil and military coordination so as to clarify the distress situation of the aircraft beyond all doubt.

The aim of current coordination efforts is mainly to ensure identification by air defence of aircraft that are lost to civil air control authorities, as well as to initiate assistance in open sea.

The recommendation is for such possibilities to be enshrined in procedures between civil and military control, to be implemented as soon as civil ATM has clearly established loss of secondary radar contact and/or communications (see Annex 7).

The texts in force could be adapted in practice in the following way:

ICAO, in charge of the civil component of this subject, has developed procedures primarily aimed at preventing inoffensive civilian aircraft from being targeted by state air defence on the basis of mistaken identification or wrongly attributed intentions by the air defence authorities (Doc identification. 9554-AN/932).

But ICAO could decide to take this framework of coordination and extend it to the opposite situation: military assistance in the event of loss of contact with a civilian aircraft. In practice, this already goes on within the framework of the air forces' assistance missions. An international text (ICAO or other) would have the advantage of calling on all countries with air defence to act accordingly.

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Article 3bis of the ICAO Doc 7300 Convention clearly recognises the right of interception and sets its limits (no possibility of safety risk to civilian aircrafts). Moreover, one can consider that a plane such as the MH370, i.e. no longer following its flight path, is acting counter to article 3c "no state aircraft of a contracting State shall fly over the territory of another State or land thereon without authorization by special agreement" and can thus be justifiably intercepted.

► ***Recommendation 2***

Loss of contact with an aircraft should always be regarded as a serious event requiring rapid implementation of appropriate means to dispel any doubt, although the response should be progressive, with intervention from air defence representing the highest level of reaction. No passiveness should be tolerated. Means and procedures should be set up to ensure interconnectivity between the air traffic services of adjacent countries and cooperation between civil and military authorities.

Developing ground/air co-operation

Airlines should have dedicated means and procedures for communication with the crew (cockpit and cabin) in the event of a crisis. Appropriate connections should be systematically set up between airline operations control centres (OCC), ATM and air defence. Protocols governing communication, mutual information and the handing over of responsibility should be made more effective and rigorous between all corresponding ground centres, whether belonging to the same country or to neighbouring countries.

The transmission to the ground of images and sounds from the cockpit and cabin or, failing that, the transmission of the cockpit area microphone (CAM) channel of the CVR (Cockpit Voice Recorder) as soon as an emergency is detected on board could help dispel any doubt, as evoked previously, in the event of loss of communication. But other risks could result from the difficulty of interpreting images or sounds in real time in such circumstances. Studies on this subject would help gauge the various consequences (triggering criteria, transmission channel and volume, organisation due to receive and exploit this transmission channel on the ground, protection…).

► ***Recommendation 3***

An in-depth study should be launched into the criteria and means to be set in place for detecting an emergency situation and possibly contributing to its resolution. This study should also comprise an analysis of the advantages and disadvantages of using new resources.

Transmission of vital data before accidents

In addition to relief operations and victim recovery, lack of precise knowledge of the position of the plane is a recurrent problem in attempts to retrieve flight data in the event of accident.

In the near future, the flight data enabling elucidation of the accident could be transmitted before the crash (recovery of flight recorders would then become unnecessary). Or the recorders could be easily recoverable (deployable recorders).

Access to the wreck could however be desirable to obtain additional information necessary to the investigation and for cultural or legal reasons linked to the victims' identification and burial.

Since this has not been decided on an ICAO level, it would at least be useful to recall the BEA's recommendations following the AF 447 accident(10)*.*

R 03	*Regular transmission of basic parameters (for example: position, altitude, speed, heading)*
R 15	*Triggering of data transmission to facilitate tracking as soon as an emergency is detected on board*
R 16	*Activation of the Emergency Locator Transmitter (ELT) as soon as an emergency is detected on board*
R 04	*Deployable recorders*(11)

In the USA, on 22 January 2015, the NTSB published recommendations for the FAA(12)*:*

R 01	*"that all aircraft used in extended overwater operations […] be equipped with a tamper-resistant method to broadcast to a ground station sufficient information to establish the location where an aircraft terminates flight as the result of an accident within 6 nautical miles of the point of impact."*

10 www.bea.aero/docspa/2009/f-cp090601/pdf/f-cp090601.pdf

11 Used for decades on military aircraft, these deployable recorders detach themselves from the aircraft at the time of an accident and float to the surface, emitting a satellite distress signal that makes them easier to find. This technology is due to equip the long-haul Airbus A350 and A380 aircraft, which would become the first civil aircraft to be thus fitted out. The European airframe manufacturer is not ruling out equipping new versions of its A330 and A320 aircraft with such a system.

12 www.ntsb.gov/safety/safety-recs/recletters/a-15-001-008.pdf

In the event of an emergency, the plane's position should be known to within about 6 NM and, in the case of deployable recorders, the system should be equipped with a locator beacon that would be recoverable from the surface of the water or on the ground.

However, precisely locating the wreck does not guarantee access to information on recorders. Access to the wreck can be very difficult and recorded information illegible.

Given the number of parameters recorded on modern planes, an analysis of recorders can sometimes be enough to complete the safety investigation, although physical examination of the wreck remains preferable. And yet modern technologies are paving the way to rapid, reliable transmission of recorded flight information to a designated ground organisation, independently of physical access to the wreck.

One of the NTSB's recommendations can be interpreted in this sense:

R 03	*"that all newly manufactured aircraft […] required to have a CVR and an FDR, be equipped with a means to recover, at a minimum, mandatory flight data parameters; the means of recovery should not require underwater retrieval. Data should be captured from a triggering event until the end of the flight and for as long a time period before the triggering event as possible."*

Whatever the technical solutions adopted, they will need to guarantee that organisations involved in the investigation will at the very least have access to the same information as they do at present, i.e. to all information contained in the flight recorders, until the moment of impact.

Data transmission via radiocommunication raises specific problems of recording and storage, and of restricting access to information to investigators alone. The current legal protection of flight recorders is described in Annex 8.

- *Volume to be transmitted: particularly if transmission is triggered only by detection of an emergency situation, the lapse of time between the beginning of the transmission and the crash landing must be sufficient to allow all recorded data to be transmitted, and the attitude limits of the plane preventing transmission should be determined. Elements on required data flow and volume are given in Annex 9.*
- *This information must also be rapidly accessible and reserved for use in safety investigations according to same principles of confidentiality as those applied to onboard recorders. In order to prevent this information from being put to other uses than safety investigations, provisions must be made to guarantee that investigators alone have access to this data, by recording it on a protected, accredited server, for example. This information should then be erased once the flight is over, after a certain delay for possibly recovery by investigation officers.*

► ***Recommendation 4***

Rapid collection of all information needed to elucidate an accident is a prerequisite for aviation safety. In certain circumstances, but not always (poorly accessible areas for example), deployable recorders would be an acceptable solution. But transmission of the relevant data prior to the accident is clearly preferable, since it guarantees access to information. Joint experiments should rapidly be launched by manufacturers and operators, on new aircraft in particular, to build up a clearer picture of this solution, before it can become a credible alternative to the requirement for deployable recorders.

5 FOLLOW-ON ACTION

In addition to the four recommendations above, work on this dossier threw up many questions which, though important, went beyond the framework of the study. These questions are as follows:

1) *Aircraft must be tracked permanently. Who would be tasked with this? With what technical resources? And what funding?*
2) *What are the criteria for detecting an emergency on board a plane in flight? What is the relevant information and how can it be relayed so that the ground team is informed of this emergency? What new systems will ensure that transmission means cannot be disconnected? And that the confidentiality of possibly real-time audio and video communications to the ground is respected? What would be the role of the air forces in such situations?*
3) *How to restrict access to protected data destined for the investigation if it is transmitted by radio before the crash?*
4) *How to make more consistent the current disparate set of ground/air communications and positioning systems? How to ensure protection from the threat of malevolent acts targeting these currently unprotected systems, in particular ADS-B?*
5) *How to reconcile the multiplicity of legal, cultural, religious and ethical claims surrounding recovery of the victims' remains, a potentially extremely expensive operation, particularly when the technical data has already been obtained without visiting the wreck?*

They require specific, in-depth study, some of which will be carried out, at least partially, within the framework of a reflection into "hijacking" of commercial airliners. The latter may be the subject of a specific study.

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ANNEX 1: AIR TRAFFIC MANAGEMENT

Each state is sovereign within its geographical borders.

If it is a member of the International Civil Aviation Organization (ICAO), it cannot prohibit civil aircraft from flying through its airspace. It can however introduce restrictions and impose charges for services rendered. Within its own airspace, and according to its own capabilities, it either provides or delegates air navigation services (spacing between planes and aeronautical information) as well as search and rescue activities. The resulting distribution of ATM services and airspace according to political borders is a complex one. In maritime areas, ATM is allocated to certain states by ICAO.

Increased operating range of aircraft and the development of air transport worldwide have led to much adjustment and delegation of ATM but the principle of sovereignty has constantly limited the scope of such actions and prevented global integration.

Additional constraints, both technical (range of radar, radio transmitters and relays) and systemic (traffic flow, task distribution per control centre, etc.) have also contributed to airspace being sliced into small "sectors".

When entering each "airspace" or "sector" on their flight path, pilots must make verbal contact on a new radio frequency. And unlike mobile phones, which switch automatically from one provider to another by changing "cell", nothing is automated for aircraft. Controllers verbally communicate the new frequencies to pilots who must then enter them manually. As an indication, a two-hour flight over Europe requires ten or so manual frequency changes.

Finally, ANSPs have no responsibility for planes once they have left their airspace. Their responsibility is purely local, within the space assigned to them. No organisation or global system exists to date to perform this task.

These provisions, which can appear antiquated, are the consequence of the fragmentation of ANSPs.

To be more precise, aircraft are tracked inside each control "sector" by means of:

- *so-called "secondary" ground radars that remotely interrogate transmitter-responders (transponder) on board each plane to elicit the identification and altitude of the aircraft; the secondary radar locates the plane by means of distance and azimuth;*

- *radio communication for controllers to transmit the transponder identification codes pilots have to display manually and, in airspace not equipped with radar, for regular transmission of their position by pilots;*
- *automatic position transmission systems - ADS (Automatic Dependent Surveillance) - which are gradually equipping aircraft and control centres.*

These monitoring services can however be interrupted in a planned or unplanned way due to maintenance problems or lack of availability of equipment. Ground-based radars can experience permanent or periodic range limitation because of obstacles and the natural curve of the Earth.

In low density, oceanic or "remote" airspace, aircraft are tracked and identified in a different way. The information is often provided by regular oral HF position reports between the crew and the air traffic control organisation. In certain airspaces, a more recent system - Automatic Dependent Surveillance Contract, or ADS-C – involves the plane sending position reports, generally by satellite. However, this use of ADS-C is limited, either because ground systems cannot deal with this function, because planes are not equipped or for reasons of cost to airlines (frequency of reports).

The fact that aircraft of varying ages and technologies have to share the same airspace and that all planes must have access to almost any airspace gives rise to considerable inertia in the introduction of new concepts and materials: civil aviation appears "prehistoric" in many ways!

All these systems require onboard equipment (radio and transponders) to be activated and in order to be active, the radio must be on the "right frequency" and the transponder on the "right code".

However:

- *the radio frequency to be displayed (selected on the plane) at each control sector transfer is transmitted verbally by controller to pilot, who manually enters it, with the corresponding risk of error. A little like the general public being instructed by an operator to change frequency on their mobile phone with each change of "cell". Once the aircraft is on an incorrect frequency, ATM cannot call it directly. A standby frequency of 123.5 MHz does exist, like Channel 16 at sea, but is not systematically monitored by civil centres. For oceanic flights, a selective HF (High Frequency) call capability enables controllers to call aircraft directly. But this system does not exist for continental flights, which use VHF (Very High Frequency). In 2013 alone, for instance, 56 cases of prolonged loss of communication in Europe required early warning aircraft to take off within NATO's European AoFR (Area of Functional Responsibility);*
- *the four-digit secondary radar code (transponder) is transmitted in the same way as radio frequency and is prone to the same errors, except when*

allocated for the duration of the flight. This means that the plane can disappear from screens or be mistaken for another. A more sophisticated radar system, known as Mode S (S for Selective), involves an elaborate internal transponder code which gives the identity of the plane. But when changing transponder, during maintenance for example, the wrong code can be introduced, leading to similarly mistaken identity.

Admittedly there are procedures to mitigate these errors, but in certain cases they have led to losses of separation, and could have led to collisions.

Appendix: Current onboard/ground communication and surveillance means

Communication networks

- *On the one hand the Aeronautical Fixed Telecommunication Network (AFTN) for the exchange of flight plans, in particular, between ground stations;*
- *on the other, the aeronautical mobile service between planes in flight and air traffic management. This service uses long-distance HF (high frequency) links, short distance VHF (very high frequency) links and Aeronautical Mobile-Satellite Service (AMSS) satellite links.*

Data links

CPDLC (Controller-Pilot Data-Link Communication) transmits either pre-formatted messages or short, free-text messages.

ACARS

The Aircraft Communication Addressing and Reporting System (ACARS) is a radio communications system by data link between an aircraft and a ground station. Physical onboard/ground communication is broadcast either by VHF or by satellite via AMSS, according to the position of the aircraft. The ground network is provided by two operators, ARINC[13] and SITA[14]. ACARS sends and receives SMS-type text messages.

ACARS is primarily used by airlines for information on the state of the planes with a view to maintenance.

In the 1980s, airlines developed this ACARS data link communication system to meet their own needs. It was mainly used over continents, for the usual reasons of communication costs, and for fleet tracking for commercial purposes (to manage

13 www.aviation-ia.com

14 www.sita.aero

delays and connections). Since the appearance of ETOPS flights (Extended range Twin-Engine OPerations: flights with a duration of over one hour above uninhabited zones), airlines are requested to record all engine operation parameters in flight and to analyse them when the flight is finished, to forestall any risk of breakdown on the following flight. Certain engine manufacturers offer to transmit these parameters in flight for their customer companies via the ACARS system.

This system is also used as a back-up to ADS-C messages (see below) thanks to the addition of the function in onboard systems. ACARS can also be used to send manual or automatic position reports for planes not equipped with ADS-C or when the ANSP is not equipped to deal with them.

ADS

ADS (Automatic Dependent Surveillance) enables aircraft to periodically broadcast their position (determined on board by navigation systems specific to the plane), identity and other information (heading, following report points, etc.) at regular intervals according to needs, without being interrogated.

ADS exists in two forms: ADS-B (B for Broadcast) and ADS-C (C for Contract) which differ technically only by their transmission means. ADS-B uses an omnidirectional radio (generally a transponder) as a means of transmission while ADS-C uses ACARS.

ADS-B functions in "Broadcast" mode, i.e. anyone possessing an adequate receiver (ATM, other aircraft, private receivers, etc.) can access the information without the need for an established connection. Emission frequency is set by the onboard system. ADS-B messages are not encrypted and the transmitted position is not dated. ADS-B is primarily transmitted via VHF, but a satellite offer also exists (AIREON, cf. Annex 6).

ADS-C functions in "Connected" mode, i.e. it requires the station in question and the aircraft being tracked to be connected, with exchanges governed by the "Contract" drawn up between these two entities (type of information and refresh rate). It calls for satellite data link, but has been proposed in VHF.

A major problem associated with the use of ADS-B and -C for oceanic monitoring is the need for relay satellites: the satellites used at present are geostationary satellites characterised by expensive onboard installation and high communication costs. This could change, nevertheless, with Inmarsat's proposal, following the disappearance of flight MH370, to provide airlines with the position of planes equipped with ADS-C every 15 minutes, free of charge.

New passenger services could help absorb the costs of installing ADS equipment but for the moment, given the densities of traffic in the airspaces concerned, exchanges of ADS-C data with the ground are kept to a minimum in order to reduce communication costs for airlines or ATM.

The ICAO standard also allows the use of low-orbit satellites of the Iridium constellation, which have the advantage of covering the entire globe, including the polar regions. Today, it is mainly business aircraft that use this system.

COSPAS-SARSAT

The Russian acronym COSPAS is short for Cosmicheskaya Sistyema Poiska Avariynich Sudow (space system for the search of vessels in distress). The English acronym SARSAT means Search and Rescue Satellite-Aided Tracking.

COSPAS-SARSAT was developed in 1979 through international co-operation between the United States, Canada and France, with the USSR joining in 1980. The system was declared operational in 1985 after several years' assessment. An intergovernmental agreement between the four founding countries consolidated the system in 1988. The countries participating in COSPAS-SARSAT (43 by the end of 2010) set up, maintain, coordinate and operate a system of satellites capable of detecting signals from emergency radio beacons that meet the specifications and standards of COSPAS-SARSAT, and of determining the positions of these beacons at any point of the globe to within a few hundred meters.

It is a global alert and tracking system by distress beacons based on two complementary satellite systems: LEOSAR (Low-Earth Orbiting Search and Rescue), with six satellites in low orbit crossing the poles, and GEOSAR (Geostationary Search and Rescue), with five satellites in geostationary orbit. All these satellites receive signals emitted on the international distress frequency of 406 MHz.

New generation navigation satellites - Galileo, GPS, Glonass - will carry COSPAS-SARSAT receivers, ensuring permanent cover on any point of the globe: this is the MEOSAR concept.

GNSS

GNSS (Global Navigation Satellite System) is the generic name given to navigation systems providing global positioning for civil use (GPS, Galileo, the Russian GLONASS, the Chinese Beidou and the Indian IRNSS, as well as the complementary systems WAAS, EGNOS and MTSAT).

Flight Surveillance

In civil aviation, the need for flight tracking and therefore flight surveillance has until now been linked to ATM and the need to maintain separation. In continental airspace, which accounts for most traffic, aircraft movements can be tracked by radar with sufficient precision to guarantee proper separation between planes. Above oceans, deserts or inhospitable zones, the low density of traffic until the end of the eighties meant that plane surveillance in these zones was not an issue. Indeed no technology was capable of offering the service at the time.

When radar does not exist or is not available, as is the case outside of continental zones, the only way of tracking flights is for the pilot to transmit the plane's position by radio to the air traffic controller. This radio connection is made either via the VHF band (118-137 MHz) for short and medium distance connections (less than 400 km), or the HF band (2850-22000 Khz) for long distance connections, or by satellite communication (SATCOM).

An extract of DOC 9718 of ICAO dating from 2013:

> *"Current and future use of HF frequency bands. Current use of the HF frequency bands is still very significant. An analysis for the NAT Region showed that for flight over the North Atlantic, the distribution of contacts for all aeronautical stations was:*
>
> - *73 % was over HF channels*
> - *26.23 % was over general purpose VHF channels*
> - *0.14 % was over SATCOM channel*
>
> *This analysis showed that the expectations from the FANS Committee towards the future use of SATCOM and the replacement of HF by satellite communications did not materialize over the years".*

Something of an understatement!

Technological developments have paved the way to other forms of surveillance than radar-based ones. ADS is a good example (see above).

The ICAO standard theoretically enables intelligent operation of ADS-C in the sense that it provides for:

- *a varying transmission rate of position reports, from every 68 seconds to every 68 minutes.*
- *the possibility of automatically increasing this rate in the case of events such as a sudden variation in speed, flight level, heading, etc.*

Unfortunately the reality is quite different: aircraft onboard systems only possess a subset of these functions for historical reasons (the system was implemented before the ICAO standard was issued) and the ground systems used by air traffic control centres to manage oceanic airspace are not all compatible with ADS-C or capable of managing events.

All this leads to a system that is underused but which, for the moment, meets the demand for surveillance needs. Where possible then, ADS is used with position reports approximately every 10 to 20 minutes. This enables communications costs to be kept to an acceptable level (a message currently costs around 20 centimes and could soon be free of charge for a refresh rate of 15 minutes). One might recall that at the time of the disappearance of AF447, the Dakar centre was testing the ADS-C functions of its system and had not received the flight plan, preventing flight AF447 from being connected to the system. In the case of the MH370, the planned *flight path comprised an overwater flight between Malaysia and Vietnam that was too short to plan the use of ADS-C.*

The aircraft tracking requirements of airlines, together with the cost of communications, renders the current periodicity of tracking information incompatible with the needs of surveillance or search and rescue. Following the disappearance of AF447, Air France, followed by several other airlines, set up an ADS-C contract for its own purposes, enabling it to receive the position of its long-haul flights every 10 minutes, with the rate of reports increasing in the presence of abnormal events.

Radar surveillance relies on a piece of onboard equipment - the transponder - which provides, among other information, the altitude of the plane. This equipment is activated by the pilot and, although it plays an important role in ensuring that the plane's position is known to ATM services, redundant systems are not always provided since it is nonessential to maintaining the aircraft in flying condition. The same principle applies to the ADS-C application, whose installation on board aircraft varies according to manufacturer. ACARS, for instance, the system used for the communication part, is not regarded as critical. Moreover, the ACARS system was developed to meet the needs of airlines and not those of air traffic control; as a result it does not meet any ICAO standard. Its communication performances are very poor. It should in time be replaced by the ATN communication protocol, which meets an ICAO standard and is more powerful and more robust.

ANNEX 2: THE ROLE OF OPERATIONS CONTROL CENTRES

Contrary to what their name might suggest, the Operations Control Centres (OCC) of the major airlines do not control individual flights, they coordinate the entire operations of a fleet. It is essential to fully grasp this distinction if we are to understand current issues surrounding "Global Tracking". Below is the present distribution of roles and responsibilities between pilots, controllers and airline ground services.

From the moment the aircraft leaves its initial parking bay until it arrives at the destination parking area, the captain and their crew perform all flight operations. The captain takes legal and regulatory responsibility for these actions. Once the flight is over, the captain is accountable to their operations directorate, for economic and commercial aspects, and to their civil aviation authority for legal aspects.

During this time - from departure parking area to arrival parking area - the ANSPs (air traffic controllers), in liaison with pilots, ensure separation between aircraft (preventing collisions in flight), coordinate with subsequent ANSPs, transmit information necessary to the flight (weather, state of infrastructures, etc.), inform air defence as to the "normal" progress of the flight, and sound the alert in the event of any incident or accident.

In this space of time, with the task distribution described above, pilots and controllers are in a position to carry out flights alone. But the major carriers perform more than a thousand flights daily (1,000 flights for Air France and up to 6,000 for United Airlines). For obvious commercial and economic reasons, these airlines must coordinate and synchronise their operations, manage any glitches to schedule, balance out planning choices, and collect and process data passed on by crews during flight. To this end, they have developed OCCs, which are active 7 days a week and 24 hours a day.

According to vagaries encountered, OCCs have the task of deciding whether or not to modify an aircraft or crew roster, change schedules, cancel a flight, switch aircraft or add on an additional flight. If a major event occurs, it falls to the OCC to set up a crisis unit.

The crew can make contact with the OCC at all times by means of various channels of communication to ask questions, relate events on board or announce any *changes to plan. Such communications use long-distance HF radio connection (often of poor quality) and more recently satellite telephone networks (SATCOM), more and more common on long-haul aircraft. ACARS systems with SMS-type text messages are also used on all types of aircraft. On board, messages are written and sent from the FMS (Flight Management System) alphanumeric keyboard and received on a printer. ACARS uses either VHF connections, over zones with the relevant equipment, or satellite networks.*

It should be noted that the ACARS system was developed to meet the needs of airlines, and not those of air traffic control. It does not meet any ICAO standard but is nonetheless useful for delivering departure clearances (from the ground) or "oceanic" clearances, for entry into oceanic spaces. "ATIS" messages (Automatic Terminal Information Service), giving information on weather conditions at airports, can also be received directly on ACARS printers. ACARS should in time be replaced by the ATN (Aeronautical Telecommunication Network) protocol, which meets an ICAO standard and is more powerful and more robust.

Does the existence of an OCC necessarily presuppose continuous tracking of the aircraft? The answer is no. Many airlines see no economic justification for recruiting and training dedicated staff to track flights when estimated arrival times are known and any irregularities are reported by crews.

The "surveillance" function, but not the "tracking" function, when it exists within the OCC, is associated with the flight assistance function, under the responsibility of "dispatchers". The "dispatcher" becomes the single interlocutor for each crew in flight. This function has been in place for a long time in most of the large American carriers.

Monitoring must obligatorily be in place, at least in a reduced format, and strictly regulated, in the event of operations known as ETOPS[15]. The information collected relates to the state of the engines and re-routing airports, but does not involve regulatory transmission of information either on the engines or the aircraft position.

With the exception of ETOPS flights (for which dedicated support remains mandatory), neither British Airways, Lufthansa nor easyJet monitor or provide assistance for long-haul or medium-haul flights. Air France, Emirates and Alitalia provide monitoring and assistance for long-haul only. Delta Airlines, United Airlines, Air Canada, KLM (and soon Air France) provide monitoring and assistance for long- and medium-haul flights.

Concerning Air France, which along with KLM has one of the most advanced OCC's in Europe, tracking is provided on the one hand through the ACARS network and on the other hand via ad hoc, unprocessed information provided by air traffic control organisations ... and finally by the use of an Internet site.

15 An ICAO regulation allowing commercial aircraft with two engines to operate on air routes including sectors over an hour away from a relief airport, in particular ocean routes.

With regard to monitoring engine operation

Modern transport aircraft are equipped with digital avionics which enable information to be exchanged and processed between various points on board and also with the ground via radio connections. The engines equipping them are connected to the rest of the aircraft and to the ground via the EHMS (Engine Health Monitoring System). This system comprises:

- *sensors which measure physical parameters such as the number of revolutions of the turbine, temperatures, pressures, flows and even levels of mechanical vibrations: an engine is equipped with twenty or so sensors;*
- *a system to collect measurements, known as ACMS (Aircraft Condition System Monitoring), which can have several operating modes: measurements are taken either at precise moments of the flight (takeoff, climb, cruising) or, in the event of an anomaly, can be carried out more regularly. The data is in digital form. It can be displayed on the screens of the cockpit, to be transmitted to the ground in real time or recorded on board and processed at the end of the flight;*
- *an information transmission system, either in real time by radio connection, via the ACARS system in VHF or by satellite, or on arrival, via an aeronautical WiMax system (AERO Macs) which larger airports are investing in;*
- *a system of data analysis and processing which diagnoses the engine's operation; if transmission is in real time, processing will be also in real time, otherwise the processing will take place on arrival of the plane. This processing system is exploited either directly by the airline, or by the engine manufacturer (a paid service offered to customer airlines);*
- *in the event of an anomaly in flight, when the data is transmitted in real time, the airline OCC is alerted and can decide on action to be carried out either immediately, during a stopover or during the next scheduled maintenance.*

For long-haul aircraft carrying out ETOPS flights, engine operation monitoring is obligatory with, as a minimum, onboard recording, data analysis on arrival and a diagnosis confirming proper state of the engines before the following ETOPS flight. The EHMS (Engine Health Monitoring System) is a major element in certification of airlines to perform ETOPS flights.

Appendix: The example of Air France's OCC

The OCC brings together in the same service, under the responsibility of a duty manager and their deputies:

- *experts in various fields of the company who intervene in flight regulation (passenger and cargo schedules, aircraft maintenance, flight crew and cabin crew rostering, representatives from the flight division (pilots and flight attendants);*
- *the flight analysis service and dispatchers who look after preparation, flight plan monitoring and optimisation of routes in relation to air traffic constraints, update of aviation and meteorological information, and assistance to pilots from flight briefing up to arrival at destination;*
- *the commercial sector.*

50 people are on call at any one time out of a total of approximately 300 people assigned to this entity. The crew may contact the OCC at any time by various means with questions or to tell them about an incident on board or a change in plans.

Within the OCC, the dispatch function carries out flight assistance and monitoring. In airlines possessing this function, the dispatcher is the crews' single interlocutor for the whole chain from preparation of the flight to assistance in the course of the flight. Specially qualified for this function, they are experts in the geographical area of the flights they have to monitor and assist.

The crisis centre works around the clock 7 days a week and can call on representatives from each branch of the airline, as well as a network of 4,000 trained volunteers on call at any time. Moreover, each station has a local emergency plan. Once activated, the crisis centre handles the incident. It coordinates various structures: telephone call centres, contact with relatives, volunteer management, press relations etc. and takes the decision to activate the toll-free, round-the-clock number to handle calls from the public.

ANNEX 3: INTERNET SITES FOR TRACKING AIRCRAFT

The wish to be able to see aircraft and know where they are? For a long time, amateur enthusiasts have been taking photos and filming aircraft from the edge of the runway and listening in to radio frequencies; families or friends of passengers want to know when to go to pick someone up from the airport; residents want to check flight paths of planes; not to mention possibly ill-intentioned people…

In the past, as seen previously, the only ones with sophisticated enough systems to roughly locate aircraft were civil or military air traffic control services, with their radars and processing systems, and airlines and airports for purposes of timetable management.

Only these official bodies held and controlled this information. The question arose on several occasions of making this information public.

For example there exists:

- *the FAA's Air Situation Display*(16)*;*
- *EUROCONTROL's Network Operational Portal*(17)*;*
- *schemes such as VITRAIL, a system developed by Aéroports de Paris for measuring noise and visualising air trajectories*(18)*.*

Today, a simple internet search with the keywords "aircraft real time" is enough to bring up dozens of sites that "permanently" identify and track aircraft either free of charge or for a fee. Apps also exist for smartphones, free or paid.

And just as Shazam can recognise the title of a song in just a few seconds, a passing plane can be identified by means of WolframAlpha, along with its altitude and its destination.

Before looking into how this is possible, it is worth noting that despite the impression given of "continuity" and "permanence" in the flow of information, heightened by ease of access, if a plane goes missing from official radar screens, whether voluntarily or involuntarily, it also disappears from these sites. In either case, the aircraft would at best remain identified by so-called primary radars used by air defence, as long as it is with their range.

16 www.fly.faa.gov/ASDI/asdi.html

17 www.public.nm.eurocontrol.int/PUBPORTAL/gateway/spec/index.html

18 www.developpement-durable.gouv.fr/riverains-des-aeroports-parisiens#e5

ADS-B automatically transmits the identity and position of planes equipped with the system by omnidirectional radio, although without dating and encoding.

A few years ago, an ADS-B receiver was worth $750 or $1,000 US, and only a handful of diehards would buy themselves one to share information on the web (like those who buy weather stations and share their information on wunderground[19]). Now, however, you can buy an ADS-B receiver for only $10 US! One can very well imagine an explosion in this informal network of amateur enthusiasts.

In the meantime, many "professional or semi-professional operators" have developed Internet sites such as:

- *Flight Radar 24[20], set up in 2007 by Swedish company Svenska Resenätverket AB, which claims to receive more than 100,000 visits per day, 6 million in a month;*
- *Radar Virtuel[21], created by the French Laurent Duval;*
- *Plane Finder[22], set up by the social network Pinkfroot which also created Ship Finder[23] based on the AIS Automatic Identification Systems for boats;*
- *Flight Aware[24], an American start up created in 2015;*
- *Aeroseek[25];*
- *Flight Wise[26], formerly FBOWeb;*
- *etc.*

An example: FlightAware and ADS-B

> *"In addition to receiving over fifty different government air traffic control and private datalink sources, FlightAware operates a worldwide network of ADS-B receivers that track ADS-B-equipped aircraft flying around the globe. FlightAware owns and operates these receivers at dozens of airports around the world in conjunction with airport operators.*
>
> *FlightAware designs and manufactures FlightFeeder, a network ADS-B receiver that receives ADS-B data and feeds the data to FlightAware's servers over any available Internet connection.*
>
> *We also invite customers and professional users to connect to FlightAware's network and feed additional ADS-B data from their receivers using the methods described below. ADS-B data contributed is made available on FlightAware's free web site and mobile apps."*

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19 wunderground.com
20 flightradar24.com
21 radarvirtuel.com
22 planefinder.net
23 shipfinder.co
24 flightaware.com
25 aeroseek.com/webtrax
26 flightwise.com/flighttracking

In terms of maritime applications (e.g. Marine Traffic[27]), where one can track the progress of the Hermione, sites are free or fee-paying depending on the economic model of the applications: they are generally free, with advertising, for use by the general public, and fee-paying for more sophisticated utilisations.

Certain airlines have come to confidential agreements with site operators by which they give them "data flows" (from their data bases) and in return receive information on aircraft location. Boeing and Airbus adopted the same approach in order to track their aircraft during tests. The identification of non-commercial flights is now screened on FR24, and military flights have been fully protected for some time. Thanks to agreements with these providers, manufacturers of business aircraft can obtain statistical data unavailable to IATA on the flights of such planes.

These public websites are replete with "forums" using the social networks - Facebook, Twitter, or others (a new one is created just about every month…) and many more people observing planes and making comments than the combined number of air traffic controllers and airline OCC operators. One is thus up against the qualities and failings of the Wikipedia syndrome: i.e. true and false information which it is very difficult to disentangle:

- *on the one hand, after a turnaround of an Air France plane between Paris and Caracas, the most insane rumours started to circulate that very night;*
- *on the other, surfers are more than happy to highlight identity mix-ups by transponders after transponder maintenance, or discrepancies in the positions of planes… with relation to landing strips…*

Lastly, security issues are raised, since nowadays anyone can have real-time access to the position and identification of aircraft, although data provided by the FAA is deferred five minutes on certain sites. This problem is a familiar one in the maritime domain. Pirates were not slow to equip themselves, indeed the only reason one cannot see ships off Somalia on maritime sites like Marine Traffic is because they tend to shut down their transponders to avoid being spotted by the pirates. This solution is not possible for air transport: rather than switching off the transponder above a zone occupied by ISIS, it is better not to fly over it…

Is there any way now of "putting the cat back in the bag"? Of course not.

Would it be possible, at least for a first defence level, to have a version of ADS-B sending encrypted messages? There is work on the subject, such as "Evaluation of Cryptographic Security Scheme for Air Traffic Control's Next Generation Upgrade", whose conclusion is:

> *"Although possible, simply encrypting ADS-B messages is nontrivial. Key management within a symmetric cryptosystem is a difficult problem. Indeed this is a major hurdle that must be overcome before considering*

27 marinetraffic.com

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> *a symmetric cipher as a feasible solution to the surrounding ADS-B security concerns. Future research efforts involve implementing a secure controller/pilot datalink communication link to enable out of band key transmissions. Similarly, the advantages of incorporating dynamic tweaks are being evaluated".*

Thus after research, the industrial application would have to be developed and made obligatory in a TCAS 7.3, even a TCAS 8, and planes would need to be equipped with it. There is a new version under development known as ACAS-X which would deal with close parallel tracks, but it does not tackle security.

As for TCAS, even if cyber security begins to be recognised as a major concern, a serious event would be needed for any decision to be made… and the funding found in NEXTGEN and SESAR.

There would seem to be a growing awareness on an ICAO level, particularly in the Asia Pacific zone[28]*.*

But this is moving away from the area tackled in this document and would deserve to be dealt with in another dossier.

28 See ADS-B-SiTF 2014 meeting: www.icao.int/APAC/Meetings/Pages/2014-ADSB-SITF13.aspx

ANNEX 4: CIVIL AVIATION REGULATORS

The purpose of this annex is to help understand the role of all those involved in elaborating regulations.

States, the 1948 Chicago Convention and ICAO

Freedom of movement for aircraft is granted to aircraft operators registered in states which have signed the Chicago convention and which, under the control of these same states, satisfy Standards and Recommended Practices (SARPs) described in 19 annexes drawn up by ICAO.

The annexes pertaining to this dossier are:

- *Annex 6 Operation of Aircraft*
- *Annex 8 Airworthiness of Aircraft*
- *Annex 10 Aeronautical Telecommunications*
- *Annex 11 Air Traffic Services*
- *Annex 12 Search and Rescue*
- *Annex 13 Aviation Accident and Incident Investigation*

These standards and recommendations are minimal requirements and states can set more stringent demands; each state can also, exceptionally, obtain a derogation from certain ICAO provisions after formal notification and justification.

The FAA, EASA and authorities of the "manufacturing" countries

Previously to 1948, aircraft manufacturing countries had set up organisations with the function of elaborating regulations and enforcing their application. Today these organisations - the FAA (Federal Aviation Administration) for the United States and EASA (European Aviation Safety Agency) for the states of the European Union - continue to set standards at least as stringent as those of the ICAO, particularly in terms of Annexes 6 and 8 which need regularly updating to take into account technological developments and evolving operating conditions. Other countries (China, Russia, Brazil, Canada, Japan…) have their own regulations, sometimes derived from or even based entirely on EASA or FAA regulations.

These standards are elaborated as follows:

- *in the United States, the FAA prepares for regulations by issuing NPRMs (Note of Proposed Rulemaking) which include a process of consultation.*

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Because of the historical importance of aviation in the United States, Congress plays a strong role;

- *in Europe, since competencies have been transferred from states to the European Union, it is EASA that prepares regulations. The agency issues NPAs (Notice of Proposed Amendment) which are subject to broad discussion and consultation. Regulations are approved by the European Commission in "comitology" before a pro forma agreement from the European Parliament. Certification Specifications (CS) and Special Conditions, i.e. the European requirements for certification, are, on the contrary, approved by EASA alone.*

Safety investigation agencies

In France, the BEA (Bureau of Enquiry and Analysis for Civil Aviation Safety[29]) is the French body in charge of safety investigations relating to accidents or serious incidents occurring over the whole French territory; it takes part in investigations led by foreign states in accordance with ICAO rules, particularly when France is the "State of Design" (Airbus, Dassault Aviation and Safran, among others).

In the United States, the NTSB (National Transportation Safety Board) is responsible for investigations into aeronautical, road, maritime, and railway accidents, as well as those involving pipelines (gas and oil pipelines).

Because of the Airbus/Boeing duopoly, the BEA and the NTSB are the two most important world players and are funded by their respective states. These budgets, designed for routine investigations, can turn out to be insufficient in the case of exceptional events, such as an accident in the open sea. The cost of corresponding searches is then financed on a case-by-case basis.

Safety investigation agencies carry out the investigations with which they are charged in full independence. When they take part as "accredited representatives" in investigations carried out by third countries, they are consulted on the final report and their observations must be taken into account or annexed to the report.

Investigation reports contain "recommendations" for the attention of the safety authorities (EASA, FAA…), manufacturers and operators, designed to improve safety. In theory, these are not binding, but they are difficult to ignore given the justification associated with each recommendation, all the more so as European regulations, for instance, require recipients to justify any refusal to take them into account.

29 www.bea.aero/fr/bea/qui-sommes-nous/mission.php

ANNEX 5: ICAO HIGH-LEVEL SAFETY CONFERENCE OF FEBRUARY 2015; DECISIONS ON GLOBAL FLIGHT TRACKING[30]

HLSC/15-WP/102 Revised: Summary of discussions, conclusions and recommendations for Theme 1: Reviewing the current situation[31]

The conference reviewed:

- *HLSC/15-WPs/2, 11, 48, 49, 50, 53, 74 and 91, 97 on updating the Global Aeronautical Distress and Safety System (GADSS) and its future use, presented by Ireland, Italy and Denmark; Canada; Australia; International Coordinating Council of Aerospace Industries Associations (ICCAIA) and the ICAO Secretariat;*
- *HLSC/15-WPs/12, 65, 84, 97 and 99 on timelines for normal tracking Standards and Recommended Practices (SARPs), presented by Latvia on behalf of the European Union (EU) and its Member States and the other Member States of the European Civil Aviation Conference (ECAC) and by EUROCONTROL; Malaysia, International Air Transport Association (IATA) and the ICAO Secretariat;*
- *HLSC/15-WPs/21, 53 and 81 on regional search and rescue (SAR) training exercises, presented by Sudan; China and the ICAO Secretariat.*

The conference noted the developments related to global flight tracking, which were initiated during the Multidisciplinary Meeting convened at ICAO Headquarters on May 2014 following the disappearance of Malaysia Airlines Flight MH370. That meeting concluded that global flight tracking should be pursued as a matter of urgency and as a result, two groups were formed; the ICAO Ad hoc Working Group, which developed a concept of operations to support future development of a Global Aeronautical Distress and Safety System (GADSS) and the Aircraft Tracking Task Force (ATTF), an industry-led group under the ICAO framework that identified near-term capabilities for normal flight tracking using existing technologies.

30 All working papers can be consulted on the following site: www.icao.int/Meetings/HLSC2015/Pages/WorkingPapers.aspx

31 www.icao.int/Meetings/HLSC2015/Documents/Summary_of_Discussions/wp102_rev_en.pdf

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The GADSS concept of operations

The GADSS concept of operations was presented to the conference to gain feedback and the conference noted the plan to finalize it by the third quarter of 2015. The conference provided suggestions and recommendations to enhance the GADSS with specific text; proposals for provisions; and that a performance-based approach should be included in the concepts of operation.

Latest results of the search for MH370 and lessons learned from this tragic occurrence

The Secretariat outlined the planned timelines for a proposed amendment to Annex 6 – Operation of Aircraft, Part I – International Commercial Air Transport – Aeroplanes regarding normal flight tracking. The conference agreed that ICAO should continue developing performance-based provisions for aircraft tracking, which provide industry with viable options, as a matter of urgency.

Flight tracking technology

The conference noted the ATTF Report which detailed existing technologies which are already installed on aircraft and which could be used to perform global aircraft tracking. This range of technologies and related services will enable operators to take a performance-based approach when implementing aircraft tracking capabilities. The ATTF report contained a set of performance-based criteria that could be used to establish a baseline level of aircraft tracking capability. Additionally, the report also identified future technologies that could support flight tracking in oceanic and remote airspace such as satellite-based automatic dependent surveillance – broadcast (ADS-B).

In this regard, the conference supported that ICAO should encourage States and the International Telecommunication Union (ITU) to discuss allocation requirements at the World Radiocommunication Conference in 2015 (WRC-15) to provide the necessary frequency spectrum allocations to enable global air traffic services (ATS) surveillance. The conference strongly encouraged industry to begin implementing flight tracking on a voluntary basis.

The conference agreed that ICAO should lead an implementation initiative designed to expedite integration of best practices in use today, including but not limited to operator flight monitoring; air traffic services; search and rescue; and civil/military cooperation. Industry stakeholders agreed to support this effort. Additionally, the conference agreed that the implementation initiative should be conducted in a multinational context and that planning should begin shortly after the HLSC and be concluded by 31 August 2015 to enhance guidance material used to advance normal tracking procedures.

The conference noted the challenges and suggestions to improve search and rescue (SAR) activities through regional SAR organizations. The conference agreed *that regional SAR training exercises related to abnormal flight behaviour can serve as a means to maintain proficiency on seldom used emergency procedures and also provide feedback to further develop the GADSS in the future. This is particularly the case when cooperation amongst several stakeholders is essential.*

Increase cockpit voice recorder (CVR) recording duration

The conference, recognizing the essential role of cockpit voice recorders (CVR) in the prevention of civil aviation accidents and the need to increase CVR recording duration in order to prevent the loss of relevant data, noted and fully supported the ongoing work on extending the recording duration of cockpit voice recorders (CVR).

Improve interaction between Annex 12 and Annex 13

The conference supported the conduct of a review to improve the interaction between Annex 12 — Search and Rescue and Annex 13 — Aircraft Accident and Incident Investigation when search and rescue operations are completed but searching continues to locate the aircraft for investigation purposes.

Improve civil/military coordination

The conference, recognizing that recent occurrences had demonstrated the need for improvements in the coordination of civil and military flights in high seas airspace, called upon Contracting States to ensure proper civil/military coordination so that due regard is taken by military aircraft when using high traffic density areas over high seas.

Finally, the conference acknowledged the work under the leadership of ICAO of the Ad hoc WG and the ATTF in developing the GADSS and the ATTF Report and recognized those documents as a good way forward.

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ANNEX 6: SATELLITE DATA TRANSMISSION OF INFORMATION FROM COMMERCIAL AIRCRAFT FLYING OVER MARITIME OR DESERT AREAS

Four solutions exist for satellite data transmission from planes flying over uninhabited areas (oceans or deserts).

***The first solution**, already up and running, is provided by operators Inmarsat or Iridium and involves automatic transmission of position via the ACARS system. The Inmarsat service relies on geostationary satellites, which do not cover high latitudes, whereas the Iridium service is based on low orbit satellites covering the whole globe. To have access to these services, airlines must take out a satellite communications subscription service from a provider such as SITA or ARINC.*

When ACARS is available by satellite, it is possible for airlines to receive automatic transmission of information on the state of aircraft systems and the location of the plane, activated automatically. This location can be transmitted by the airline to air traffic control and search and rescue centres, on their request. Air France decided to adopt this solution for all its long-haul flights following the accident of the Rio-Paris flight.

Inmarsat has announced its proposal to regularly track aircraft equipped with an Inmarsat terminal and make this information available to airlines. It does not specify when the service will be available nor if airlines will need to modify terminals on board planes.

When a control centre is equipped for this, the ADS-C satellite service is available in the airspace in which the flight takes place (for France for instance, the oceanic control centres of Papeete and Cayenne are equipped). The control centre receives the position of all equipped planes at regular intervals or in the event of an onboard incident. The aircraft must have an Inmarsat or Iridium terminal and a contract with a service provider. ADS-C also requires ACARS to be activated. It does not allow for transmission of technical information on the functioning of the aircraft systems.

In order to ensure that transmission cannot be interrupted by a malicious act on board, steps will have to be taken to make it impossible to deliberately disconnect satellite communication terminals on the aircraft.

***The second possible solution** in the medium term is ADS-B, by means of receivers on board satellites. ADS-B messages are emitted by the mode S radar transponder fitted onto all commercial aircraft. The tracking information transmitted comes from the plane's onboard systems, GPS receiver, inertial measurement unit or FMS. Two satellite operators propose to offer this service: Iridium and Globalstar. The Iridium solution will function correctly only above areas with a low level of air traffic, such as oceans. Elsewhere, there will probably be a tangle of ADS-B messages on a level of the satellite payload. The performances of this system still need to be verified. ADS-B via satellite requires the onboard mode S radar transponder and the source of tracking information to be active.*

Iridium is currently equipping its 66 new Iridium Next satellites (being produced by Thales Alenia Space) with ADS-B payloads. The equipment is funded by the Aireon consortium, which includes several ANSPs (Nav Canada and some European services, including ENAV in Italy). This consortium is to centralise data processing and diffusion to customers. ADS-B messages are decoded on board satellites. Data is then transmitted to a US ground station using the other satellites as relays. This service will enjoy worldwide cover and should be available from 2018.

Globalstar is also deploying a new constellation of 48 satellites designed to relay ADS-B information transmitted by planes via Globalstar's mobile telecommunication system to ground stations, on condition that the system is in sight of these satellites (ALAS system). The ADS-B message data is transmitted via the Globalstar link, using the message transmission capability of the system. Messages are decoded in ground stations, just like other alphanumeric messages. The aircraft-ground station link is only possible when the satellite is simultaneously within sight of the aircraft and the station. The effective cover of this service, then, depends on the number and positioning of ground stations. There is no ICAO or RTCA standard for onboard Globalstar terminals and it is likely to take time for such standards to be issued. It will be moreover be necessary to fit aircraft with a Globalstar terminal, which is also likely to meet opposition on the part of operators.

***The third solution** is the future MEOSAR system of Cospas-Sarsat, based on satellites orbiting at medium altitude, such as Galileo, GPS or Glonass navigation satellites. This new system is currently being deployed and will be declared operational only when the total number of satellites in orbit is sufficient (2018-2020). The satellites will be equipped with a 406 MHz receiver to detect emissions from distress beacons and relay them to a ground station (MEOLUT). When an emitting beacon is within sight of four satellites simultaneously, it will be possible to locate it instantaneously. It will also be possible to locate distress beacons on board aircraft in flight, as tested by CNES at the time of the accident of the Egyptair flight on May 19 2016.*

Moreover, future Cospas-Sarsat distress beacons, with return signal, will soon be available, when Galileo is deployed in 2018-2020. The return signal makes it *possible to remotely control the beacon's emission from the ground. Positioning is possible immediately if four Galileo satellites are in sight of the beacon simultaneously. The new beacons will have to be equipped with a Galileo receiver in order to receive the return signal.*

To use the return path in the event of doubt surrounding the plane's position, air traffic control centres will need to be able to connect to the Galileo satellite control centre and request activation of the beacon. EUROCAE's WG98 and RTCA's SC229 working groups are currently elaborating performance specifications for automatic activation of these new aeronautical distress beacons in flight.

***The fourth solution** uses in-flight entertainment systems proposed to airline passengers, enjoying more and more possibilities of connection to the outside world above 10,000 ft (for Internet and television). These systems are baptised IFEC (In-Flight Entertainment and Connectivity). There are three possibilities of broadband satellite connection, in L, Ku and Ka bands:*

- *in L band (1-2 GHz): this is the Swift Broad Band service offered by Inmarsat, based on its fourth generation geostationary satellites, currently in service, which covers the whole of the globe except the poles. The band-width is limited to 4 channels of 224 kbps, i.e. approximately 900 kbps;*
- *in Ku band (10-20 GHz): this service is offered by private operators using commercial geostationary communications satellites; global cover depends on the use of numerous satellites belonging to different operators and the need to manage transfers between zones of cover. Panasonic has announced on its Internet site that it has fitted out 850 planes. The data flow lies between 10 and 20 Mbps according to onboard equipment;*
- *in Ka band (20-40 GHz): Thales IFE already markets a Ka-band regional service in the United States - and soon in Europe - which uses commercial communications satellites. Today around 200 planes are equipped and flying on the American territory, offering a flow of 50 Mbps. A global service will soon be offered by Inmarsat using the new generation satellites currently being deployed. Inmarsat already has three satellites in orbit. The service is baptised Global Xpress. Airlines will be able to subscribe to the service via Value Added Resellers, including Thales IFE.*

In theory the IFEC onboard system is completely separate from the aircraft handling systems, with only one exception: transmission of positioning information, ground speed and altitude, necessary to the drop-down menu available for passengers in the cabin.

The use of this IFEC satellite connection is possible in the event of a serious event incident on board, in order to transmit position-speed-altitude of the aircraft, and even audio and video from onboard digital cameras. It should be possible to activate this use on board or from the ground.

ANNEX 7: RECOMMENDATIONS ON THE ROLE OF AIR DEFENCE

In the case of flight MH370, leaving aside questions pertaining to organisation of air defence systems, the absence of reaction in real time of the Malaysian air force must be examined, taking into consideration the difficult conditions in which the event occurred:

- contact was lost when the transponder was silenced (whether deliberately or not), precisely at the time of transfer between two ATCs, thus increasing confusion;
- "incoming" ATC took 20 minutes to warn "outgoing" ATC that it had no contact with the transferred plane, which is a considerable time;
- for the Combined Air Operations Centre (CAOC), the unidentified radar track had initiated inside national airspace, a factor which would not tend to draw the attention of operators, trained mainly to watch for possible threats coming from the outside;
- the event occurred in the middle of the night and it is the case that night interception, followed by assembling and interrogation, require specific skills on the part of the Quick Reaction Alert (QRA) pilot, as well as suitable equipment.

Given the variety of situations pertaining to missing planes, some recommendations can be made in order to make best use of the possibilities offered by air forces in the face of such events which, although exceptional, nonetheless can have grave consequences:

- *"incoming" ATC should not wait for more than a few minutes for initial radio contact from a plane being transferred to them. They must seek to establish contact and if unsuccessful, should warn "outgoing" ATC;*
- *interconnecting ATC systems between neighbouring countries must be encouraged in order to exchange flight plans and radar tracks. An aircraft that went missing during transfer would thus be immediately detected and announced to the CAOC;*
- *generally, when ATC loses both radio and secondary radar contact with an aircraft, it must immediately warn the CAOC. Corresponding instructions must be established for both ATC and CAOC;*
- *this implies excellent, permanent civil-military coordination (with the corresponding means of communication) for routine operations as well as for exceptional events. As far as possible, ATC and air defence systems must be*

inter-connected so that the military can benefit from radar tracks that have been feature enhanced by ATC;

- *air defence should not tolerate a radar track through its airspace that has not been identified and features added, even if this track was initiated inside national space;*
- *QRA pilots must be trained to intercept, assemble and interrogate aircraft in distress. If possible, this should be possible at night, requiring specific training (due to the tricky nature of night assembly) and special equipment (radar with the relevant functions, interrogation headlight, possibly infra-red sensor and night vision binoculars);*
- *air defence command must be reachable without delay at any hour of the day and night.*

It is worth noting that the last three recommendations only apply to countries where air defence has a permanent "air policing" mission in peacetime. This is not the case in certain countries possessing surveillance radars for times of crisis, but which have made the peacetime choice of not having their air defence systematically monitor all aircraft flying through their airspace which do not have QRA.

However, the loss of a plane in flight by ATC constitutes a crisis which must be treated as such by means of proper civil-military coordination and suitable decisions on the part of CAOC so as to at least have primary radar detection, and then identify and monitor the behaviour of the plane concerned.

Finally, triggering criteria for SAR phases and their corresponding procedures, for both ATC and CAOC, must enable search efforts to be launched as soon as possible.

The high number of PLOCs (Prolonged Loss Of Communications) noted each year argues for better coordination procedures between civil and military air traffic control. In 2013, in NATO's European AoFR (Area of Functional Responsibility) alone, 56 cases of PLOC required a Scramble (takeoff of alert planes). However such situations, which are not without risk, should remain the exception. Civil ATM should have other means of dispelling doubt.

ANNEX 8: LEGAL PROTECTION OF FLIGHT RECORDERS

Investigations into aviation accidents and incidents are regulated on a state level or, for the European Union, on a European level, in line with the recommendations from Annex 13 outlined above.

It fixes the principle of the responsibility of the "State of Occurrence" to lead investigations in the event of aviation accidents or incidents, with the assistance if necessary of the "State of Registry", "State of Design" or "State of Manufacture" of the aircraft.

In Europe, the principles of Annex 13 are written into the EU 996/2010 regulation of 20 October 2010. Legal protection of flight recorders has the double aim of protecting both the integrity and the confidentiality of data.

Protecting integrity of data

Annex 13 of the Chicago Convention and, in the case of Europe, article 13 of the EU 996/2010 regulation rule that the investigative authority of the country of occurrence must make all necessary provisions to conserve the evidence and guarantee the integrity of the accident site and of the wreck.

Recovery and handling of the flight recorders, in particular, must be entrusted only to qualified personnel, to avoid any risk of deletion or damage during playback or copying operations. They must be closely monitored between recovery and processing, by entrusting them to the legal authority for example.

Protecting confidentiality of data

International rules on the matter are aimed at avoiding the use of recordings for ends other than those of the safety investigation following an accident; this applies in particular to disciplinary or legal actions. Annex 13 explains the reasons for this as follows: "If such information is distributed, it may, in the future, no longer be openly disclosed to investigators. Lack of access to such information would impede the investigation process and seriously affect flight safety".

EU regulation 996/2010 increases protection for the CVR (Cockpit Voice Recorder), which can only be used for the safety investigation following any accident, unlike the FDR (Flight Data Recorder) which, if rendered anonymous, can be exploited for airworthiness and maintenance monitoring (article 14-2).

In any event, exemptions from these principles may be made, and the use of recordings can be authorised for legal purposes when the benefits involved "outweigh the adverse domestic and international impact that such action may have on that or any future safety investigation" (article 14-3).

Finally the European Regulation requires that relations between the safety investigation and the criminal investigation be governed by a memorandum of understanding (MoU), in order to ensure proper coordination. In France, such an MoU has recently been agreed between the ministry for justice and the BEA.

ANNEX 9: THE FLOW AND VOLUME OF DATA TO BE TRANSMITTED BEFORE THE ACCIDENT

This question arises if one wishes to transmit relevant data in order to understand the cause of an accident in cases when an abnormal situation has been detected before the crash. One can find information on the flows and volumes of recorded data on the Internet:

- *FDR: new aircraft can record 256 words of 12 bits per second, i.e. 3072 bits a second; over two hours, this represents 2*3600*3072 = 22.118 Mbits; over 24 hours (12 times more), 265 Mbits;*
- *CVR: the recorders are able to process four sources of vocal information. If the analogical band-width of each source is limited to 4 Khz (telephone band-width) it should be sampled at twice the frequency, i.e. 8 Khz; if each sample is coded onto 8 bits, the flow per channel is 64 Kbits/s; by compressing the data, each channel can be reduced to 9.6 kbps without any significant loss of quality, or to 4.8 kbps if a loss of quality is acceptable; 9.6 kbps per channel corresponds to 38.4 kbps for four channels which, over 2 hours, represents 276 Mbits.*

The transmission time necessary to transmit all this digital data by satellite depends on the bandwidth available on the satellite, which itself depends on the frequency band: Inmarsat, in band L (1.6 GHz)[32], proposes a maximum of four times 64 kbps (Swift Broadband), i.e. 256 kbps; 24 hours of FDR would thus require 1,035 seconds (17 minutes), with 2 hours of CVR taking 1,078 s (18 minutes).

It is also possible to restrict connections to real-time data transmission: in this case, 3 kbps would be enough for data, and 38.4 kbps for voice, compatible overall with the Inmarsat's Swift Broadband standard, on a single channel with 64 kbps. If the aircraft is equipped only with one Classic Aero standard H+ terminal, it is possible to transmit 9.6 kbps, in other words either data or vocal information.

Satellite transmission in emergency conditions raises several other problems:

- *the time to establish the connection: this should be kept to a minimum by giving top priority to this connection, but it is not immediate; the connection protocol does not guarantee a swift answer and it would be difficult to change*

32 Non-standardised denomination commonly used for radar and satellite systems.

this protocol, except with the new Ka band satellites with ultrafast connections.

- *the use of either mechanically or electronically pointed antennas: these antennas are set to the aircraft flying in a straight line and at a constant level but if the plane is turning, the connection can be lost momentarily, especially if the turn is a very steep one. Idem in the case of a pitch attitude greater than a few degrees in either direction.*

ANNEX 10: LIST OF AIRCRAFT MISSING AT SEA

Accident Date	Aircraft type	Operator	Location	Description	Depth (m)	CVR Days	FDR Days	Means	Approx Cost MUSD
19/05/2016	A320	Egyptair	Mediterranean Sea	Investigation in progress				Various	
28/12/2014	A320	Air Asia Indonesia	Java sea	Loss of control	30	15	14	Various	
08/03/2014	B777	Malaysia Airlines #370	Indian Ocean	Diverted from course and flew south over Indian ocean					
03/03/2014	Falcon 20	EP-FIC	Off Kish island airport						
19/11/2013	Learjet 35A	XA-USD	Gulf of Mexico	Engine problem	30	4		Various	
16/10/2013	ATR72	Lao Airlines	Mekong Pakse	Loss of control during go-around	12	13	14	Various	
13/04/2013	B737	Lion Air	Off Bali, Indonesia	Undershoot - floating airplane	0			Various	
10/04/2013	Beech 1900	ZS-PHL	Off Sao Tome and Principe						
26/11/2012	Emb 120	Inter Iles Air	Off Moroni, Comoros Islands	Engine failure and fuel leak?					
28/07/2011	B747-48F	Asiana Airlines	Off Jeju, South Korea	Fire on-board	87			ROV (remotely operated under-water vehicle	13.2

Accident Date	Aircraft type	Operator	Location	Description	Depth (m)	CVR Days	FDR Days	Means	Approx Cost MUSD
25/01/2010	B737	Ethiopian Airlines #4062	Off Beirut, Lebanon	Loss of control	45	20	13	Various	
18/11/2009	IAI 1124A West-wind	Pel-Air Aviation	Off Norfolk Islands, Australia	Ditch with low fuel	50				
30/06/2009	A310	Yemenia #626	Off Moroni, Comoros Islands	Loss of control	1,200	60	60	ROV	2.5
01/06/2009	A330	Air France #447	Atlantic Ocean	Loss of control	3,900	701	700	ROV	32
15/01/2009	A320	US Airways #1549	Hudson river, New York, USA	Birdstrike - Engine ingestions	20	3	3	Rigged	0.1
27/11/2008	A320	XL Airways	Off Perpignan, France	Loss of control	40	2	3	Various	0.5
09/04/2008	Metro III	Avtex Air Services	Off Sydney, Australia	Loss of control	109	90	91	ROV	0.45
04/01/2008	LET L410UVP	Transaven	Off Los Roques, Venezuela	Possible dual engine failure					
09/08/2007	DHC6	Air Moorea #1121	Off Moorea, French Polynesia	Control cable failure	670	21		ROV	2
01/01/2007	B737	Adam Air #574	Off Pare Pare, Indonesia	In-flight break-up	1,800	240	240	ROV	4
02/05/2006	A320	Armavia Air #967	Off Sochi, Russia	Loss of control	505	20	22	ROV	
06/08/2005	ATR72	Tuninter #1153	Off Palermo, Italy	Engine Failure	1,440	23	24	ROV	1
03/01/2004	B737	Flash Airlines #504	Off Sharm el-Sheikh, Egypt	Loss of control	1,030	13	12	ROV	1
21/12/2002	ATR72	Trans Asia #791	Off Pengu Island, Taiwan	Loss of control	60	23	22	ROV	2.5
25/05/2002	B747	China Airlines #611	Off Pengu Island, Taiwan	In-flight break-up	20	24	25	Various/ ROV	11.8

Accident Date	Aircraft type	Operator	Location	Description	Depth (m)	CVR Days	FDR Days	Means	Approx Cost MUSD
07/05/2002	MD-82	China Northern #6163	Off Dalian, China	Fire	10	7	14	Various	
23/08/2000	A320	Gulf Air #72	Off Muharraq, Bahrain	CFIT	3	1	1	Various	
02/02/2000	B707	Trans Arabian Air Transport	Lake Victoria, Tanzania	Undershoot - floating airplane	0				
31/01/2000	MD-83	Alaska Airlines #261	Off Los Angeles, USA	Mechanical Failure	200	2	3	ROV	2.5
30/01/2000	A310	Kenya Airways #431	Off Abidjan, Ivory Coast	CFIT (controlled flight into terrain)	50	26	6	Various	0.06
13/01/2000	Short 360	Avisto	Off Marsa Brega, Libya	Icing, power loss, ditching	38	9	9	Various	
31/10/1999	B767	Egypt Air #990	Off Nantucket, USA	Pitch down control inputs	75	13	9	ROV	3.5
17/10/1999	MD-11	FedEx	Subic Bay	Runway excursion	10	2	2	Various	
02/09/1998	MD-11	Swiss Air #111	Off Halifax, Canada	Fire	55	9	4	Various	25
18/03/1998	Saab 340	Formosa Airlines	Off Hsinchu, Taiwan	Loss of control					
19/12/1997	B737	Silk Air #185	Palembang, Indonesia	Undeter-mined	8	20	5	Various	
23/11/1996	B767	Ethiopian Airline #961	Off Moroni, Comoros Islands	Hijacking - Ditch with low fuel					
02/10/1996	B757	AeroPeru #603	Off Pasamaya, Peru	Obstructed static ports - Loss of control	230	17	17	ROV	

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Accident Date	Aircraft type	Operator	Location	Description	Depth (m)	CVR Days	FDR Days	Means	Approx Cost MUSD
17/07/1996	B747	TWA #800	Off Long-Island, New York, USA	Explosion	40	7	7	Various	10
11/05/1996	DC9	ValueJet #592	Everglades, Florida USA	In-flight fire	2	15	2	Various	1
06/02/1996	B757	Birgenair #301	Off Puerto Plata, Dominican Republic	Obstructed pitot tube - Loss of control	2,200	22	22	ROV	1.5
02/04/1993	DC9	LAV	Off Isla de la Margarita, Venezuela		30				
11/09/1990	B727	Faucett Airlines	Off Newfoundland, Canada	Ditch with low fuel					
08/09/1989	Convair 340/ 580	Partnair #394	Off Hirtshals, Denmark	In-flight break-up	90			SSS (Side Scan Sonar) ROV	
03/07/1988	B747	Korean Airline	Pacific Ocean	Shot down					
28/11/1987	B747	South African Airways #295	Off Mauritus	In-flight fire and Break-up	4,400	840		ROV	4
10/10/1985	IAI 1124 west-wind	Pel-Air Aviation	Off Sydney, Australia	Loss of control	92	135	135	Various	
23/06/1985	B747	Air India #182	Off Cork, Ireland	Explosion	3,250	17	18	ROV	
01/09/1983	A300	Iran Air #655	Off Bandar Abbas, Iran	Shot down					
09/02/1982	DC8	JAL	Off Tokyo, Japan		20	10	10	Various	
27/06/1980	DC9	Itavia #870	Off Ustica, Italy	Explosion	3,500	2,555	3,650	ROV	

Accident Date	Aircraft type	Operator	Location	Description	Depth (m)	CVR Days	FDR Days	Means	Approx Cost MUSD
30/01/1979	B707	Varig	Off Tokyo, Pacific Ocean	Missing 30 minutes after departure					
18/12/1977	Cara-velle	SATA #730	Off Funchal, Madeira	Possible spatial diso-rientation	110			Various	
22/07/1973	B707	Pan Am #816	Off Papeete, Tahiti	Possible spatial diso-rientation	700				
05/03/1973	Cara-velle	JAT	Off Funchal, Madeira	No informa-tion	100				
22/01/1971	Cara-velle	China Airlines	Off Pengu Island, Taiwan	Explosion?					
04/12/1969	B707	Air France #212	Off Caracas, Venezuela	Loss of control after takeoff	50			Various	

ANNEX 11: GLOSSARY

Acronyme *Acronym*	Signification *Meaning*	Explication (français)	*Explanation (English)*
ACARS	Aircraft Communications Addressing and Reporting System	Acronyme initial déployé par ARINC puis SITA pour les liaisons AOC	*Acronym used by ARINC then SITA for AOC links*
ACAS	Airborne Collision Avoidance System	Nom générique du TCAS (Traffic Collision Avoidance System)	*Generic name for TCAS (Traffic Collision Avoidance System*
ADS-B	Automatic Dependent Surveillance-Broadcast	L'avion diffuse sa position et son identité toutes les 10 secondes sans être sollicité ni connecté	*Aircraft spontaneously broadcast position and identity every 10 seconds without connection*
ADS-C	Automatic Dependent Surveillance-Contract	Mode connecté : il faut d'abord établir une connexion entre l'avion et la station sol ; est générale-ment utilisé dans les zones océaniques en utilisant des liaisons par satellite.	*Connected mode: connection must first be established between the aircraft and the ground station; generally used in oceanic zones by means of satellite link*
AFTN	Aeronautical Fixed Telecommunication Network	Réseau du service fixe des télécommunications aéro-nautiques (RSFTA)	
ANSP	Air Navigation Services Provider	Organisme de contrôle du trafic aérien	
AOC	Airline Operational Communications	Communications opération-nelles des compagnies	
APC	Aeronautical Passengers Communications	Communications des passagers	
ATC	Air Traffic Control	Contrôle de la circulation aérienne	
ATTF	Aircraft Tracking Task Force	Groupe de travail industriel sur le suivi	

Acronyme *Acronym*	**Signification** *Meaning*	**Explication (français)**	***Explanation (English)***
CAOC	Combined Air Operations Center	Organisme militaire de coordination des opérations	
CVR	Cockpit Voice Recorder	Enregistreur des voix du cockpit	
COSPAS-SARSAT		Organisation internationale (40 États membres) fondée en 1979 par les États-Unis, la France, le Canada et l'ex-URSS pour la détection et la localisation des émissions de balises de détresse aéronautiques ou maritimes à l'aide de satellites	*International organisation (40 member states) founded in 1979 by the US, France, Canada and the former Soviet Union for detecting and locating aeronautical or maritime distress signals by means of satellites*
ETOPS	Extended-range Twin-engine Operation Performance Standards	Règlement de l'OACI permettant aux avions commerciaux équipés de deux moteurs d'utiliser des routes aériennes comportant des secteurs à plus d'une heure d'un aéroport de secours donc, en particulier, les parcours océaniques	*ICAO regulation enabling commercial two-engine airliners to use air routes comprising sectors more than an hour away from a relief airport, i.e. oceanic routes in particular*
ELT	Emergency Locator Transmitter	Radiobalise de localisation des sinistres	
FDR	Flight Data Recorder	Enregistreur des données de vol	
GNSS	Global Navigation Satellite System	Nom général des systèmes de navigation satellitaires fournissant une couverture globale de géo positionnement à usage civil	*Generic name for satellite navigation systems providing global cover for civil geopositioning*
HF	High Frequencies	Hautes fréquences (3-30 MHz)	*(3-30 MHz)*
NPA	Notice of Proposed Amendment	Proposition de règlement émis par l'AESA	*Regulation proposal issued by EASA*
NPRM	Notice of Proposed RuleMaking	Proposition de règlement émis par la FAA	*Regulation proposal issued by FAA*
NTSB	National Transportation Safety Board	Bureau d'enquêtes américain multi modes de transport	
QRA	Quick Reaction Alert	Un ou plusieurs avions militaires en alerte permanente	*One or more military aircraft on permanent alert*

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Acronyme *Acronym*	Signification *Meaning*	Explication (français)	*Explanation (English)*
SAR	Search and Rescue	Recherche et sauvetage	
SATCOM	SATellite COMmunications	Système mondial de communications par satellite à large bande	*Global broadband satellite communications system*
TCAS	Traffic Collision Avoidance System	Système embarqué d'anti-collision	
UHF	Ultra High Frequencies	Ultra hautes fréquences (300 - 3000 MHz)	*(300-3000 MHz)*
VHF	Very High Frequency	Très hautes fréquences (30 – 300 MHz)	*(30-300 MHz)*

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On 8 March 2014, a Boeing 777 disappeared in flight with 239 people on board. So began the saga of Malaysia Airlines MH370 and its host of attendant questions. Three years on, no explanation has been found for this disappearance.

The Air and Space Academy (AAE) could not remain indifferent to such a dramatic event.

But what should be done? It was not the role of AAE to involve itself in the investigation, nor did it have the means. It could however take a systemic approach to examining the circumstances behind the plane's disappearance in order to suggest ways of enhancing air safety.

Dossier 41 presents the findings of a working group set up to look into questions concerning both the technical means enabling reliable positioning of aircraft in flight and the definition of air-ground communication, with the aim of preventing any further cases of missing aircraft, seen as more and more unacceptable by society as a whole.

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