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Emergency management:
Seismology to minimise aircraft crash location search time

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Abstract

The location of the wreckage of a missing aircraft is always a great challenge for emergency teams. In the immediate aftermath of an aircraft accident the chances of someone surviving the occurrence are considered to be low by some people. In fact, the survival probability for a passenger or a crew member of an aircraft crash depends on the search and rescue teams' rapidity and ability to locate the wreckage of the missing aircraft.

However, techniques in the hands of the aeronautical rescue coordination centre staff could sometimes lead to unsuccessful searches. Aeronautical search techniques are restricted to favourable weather conditions. Cospas-sarsat satellites won't give the precise latitude and longitude of the distress beacon carried by the missing aircraft. Emergency locator transmitters have shown their technical limits.

A solution worth considering for this issue is to approach seismology as a possible tool in detecting and locating aircraft accident sites. Ground motion waves generated by different events such as volcano eruptions, earthquakes, aircraft sonic booms, tornadoes and hurricanes are recorded by various seismographs all over the planet. By triangulating the records of three seismic stations the location of the events can be determined precisely and rapidly.

In this thesis the different aeronautical means of searches are assessed, namely the aeronautical search techniques, the cospas-sarsat satellites system and the emergency locator transmitter. Subsequently, twelve aircraft accidents with search operations are analysed. Finally, seismology is introduced as a new tool that emergency managers could use to minimize the search duration of the location of a missing aircraft. An overview of seismology is given followed by a description of the preliminary results of an experiment conducted at Prestwick international airport in Scotland. Finally, one aircraft accident of the past is used as an example to illustrate the possibilities offered by seismology.

Acknowledgements

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Fiona Longford, Prestwick airport airfield operations manager and Steve Thomson, Prestwick airport engineering manager, gave the authorization to conduct the experiment, dedicated a lot of their time towards its accomplishment and provided all the necessary data and equipment. This experiment would not have been possible without the work of Andy, Prestwick airport operations supervisor, Mathew, Prestwick airport engineering duty manager, and Prestwick airport engineering staff members. Tony Smedley and Ian Scouller, University of Glasgow, have been a great help for the logistics.

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DECLARATION

I hereby declare that this thesis is entirely my own work.

Nadine Alavès

Glasgow, March 2012

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1 Introduction

1.1 Background

Air Inter flight 148 departed Lyon-Satolas airport in the afternoon of January 20 1992. On board ninety passengers and six crew members were planning to arrive at Strasbourg-Entzheim airport less than an hour later (Bureau d'Enquêtes et d'Analyses 1993).

Air Inter Airbus A320 never reached its final destination. It hit the Mount "La Bloss" in the Vosges Mountains in France at an altitude of 2620 feet on its final approach and only 10NM from the airport (Bureau d'Enquêtes et d'Analyses 1993).

Amongst the ninety six occupants of the aircraft nine survived the aircraft accident. According to the aircraft accident investigation report four more occupants, who were alive after the impact, could have survived if the rescue teams had found them within the thirty minutes following the aircraft accident. The same report underlines as well that two others occupants also alive at the time of the occurrence died while being carrying to hospital and that they could have survived if the rescue teams had found them within the first two hours following the event (Bureau d'Enquêtes et d'Analyses 1993).

The facts are that four hours after the aircraft accident the search operations were still not successful. The emergency locator transmitter on board of the Airbus A320 was damaged and consequently wasn't able to transmit any distress signals to the Cospas-sarsat satellites system dedicated to search and rescue operations. Between one hour and a half and three hours were necessary to extract and analyse the radar data concerning that flight. The emergency teams conducted the search operations on foot, in a mountainous area covered by snow and forest, in the dark as it was already night time in winter. And even the helicopters aerial searches using night vision goggles gave no results (Bureau d'Enquêtes et d'Analyses 1993).

Last but not least, the emergency teams in charge of the search for the missing aircraft never found the wreckage. While other survivors were waiting for help one of them left the site to search for assistance. He came across a search and rescue team (Bureau d'Enquêtes et d'Analyses 1993).

1.2 Aims of the thesis

Twenty years after Air Inter flight 148 aircraft accident two questions need to be asked: can someone guarantee that lessons have been learned from the past? Can someone guarantee that nowadays a missing aircraft can be found instantaneously whatever the causes and the circumstances surrounding the aircraft accident are?

The aims of the thesis are to demonstrate:

- Firstly, that the aeronautical tools in hands of the emergency managers aren't sufficiently efficient.
- Secondly, that the aeronautical searches for a missing aircraft are too lengthy.
- Lastly, that the science of seismology should be taken into consideration.

1.3 Structure of the thesis

The first part of this thesis:

- First gives an overview of the international aeronautical search regulations followed by an overview of the United Kingdom aeronautical search and rescue organization.
- Then, the different tools that can be used by the emergency teams are assessed, respectively the aeronautical search techniques, the Cospas-sarsat satellites system and the emergency locator transmitter.
- Further, an historical examination of the different aircraft accidents where search and rescue was needed during the past thirty years is given.
- Finally, the search durations of those aircraft accidents are analysed.

The second part of this thesis:

- First give a brief overview of the science of seismology.
- Then, the experiment using seismographs conducted at Prestwick international airport is explained.
- Finally, an overview of a past aircraft accident seismological data is given as an example.

1.4 Literature review

Seismology and aeronautics are two sciences generally studied separately. Aeronautics concentrates on the design of new aircraft or new engines. Seismology analyses ground motions generated by earthquakes which in turn provoke tsunamis or volcano eruptions.

Aspinall and Morgan (1983) first evoked the possibility of using seismology to detect an aircraft accident. These authors suggested that owing to the very low probability of a geological event at the same time, the seismogram of the seismic station located on top of the Soufriere volcano in St Vincent Island in the West Indies, could only be the record of a Britten-Norman aircraft crash in that volcano. But first they weren't able to correlate the energy released by the aircraft impact to the magnitude computed using the seismogram. Secondly, the insufficiency of other seismic stations records prevented them from doing any triangulation and therefore the location of the aircraft crash site wasn't possible.

More recently, McCormack (2003) suggested the use of seismology for aircraft accident investigation. This author underlined that seismic data can rapidly give the vital information needed by aeronautical search and rescue operations. Quoting Lockerbie aircraft accident event time determined by the British Geological Survey, he concluded that the worldwide development of seismic stations could be a new tool for investigators.

Lately, Cetin (2005) in his paper noted that Turkish Airlines B737 crash time near Adana in Turkey in 1999 was like Lockerbie determined using seismology. This author only suggested that this technology could supplement the lack of distress beacons signals.

Some researchers have also explored and are still exploring different ways in using seismology for different reasons. Tornadoes, hurricanes and typhoons, sonic booms and underwater explosions are the fields that have been the most searched.

<u>Tornadoes</u>:

Kisslinger (1960) first started to analyse tornadoes from the past records of St Louis University seismographs network. He examined in particular the 1927 and 1959 tornado paths within St Louis that were recorded by the seismographs within a distance of less than one kilometer.

Later Tatom and Vitton (cited in Vincent et al. 2002, p. 2353) underlined that tornadoes can be recorded within a range of 41 kilometers. Vincent et al. (2002) researches on different events within Ohio showed that tornadoes were recorded by different seismographs as far as 172 kilometers. According to Tatom and Vitton (cited in Vincent et al. 2002, p. 2360) large tornadoes are normally recorded within the 4.5 and the 15 Hz range frequencies. Their work aim was to demonstrate that a "tornado fence" using seismographs could be set up around one town to protect it from tornado by giving early advanced warnings.

Hurricanes and typhoons:

In 1944 USA started to analyse microseisms created by hurricanes and typhoons. The aim of the project was to save lives by detecting and tracking those storms before they reached a continent or an island. Gilmoret and Hubert (1948) demonstrated that typhoons and hurricanes can be detected as far as 1600 miles from a station. During the non event period, low amplitudes of 5 mm were recorded, as an average. The amplitudes increased up to 55 mm sometimes when the hurricanes and typhoons formed. The tracking of those severe storms was possible by calculating their bearings from three different seismic stations located on three different continents or islands.

Further, in their short note Ebeling and Stein (2011) demonstrated, that Hurricane Andrew that hit the USA in August 1992 was recorded by the Massachusetts seismic station located at Harvard, before the storm hit the land and from a distance of 2000 kilometers. The maximum amplitude recorded was within the 143 MHz and the 200 MHz range frequencies.

Aircraft sonic booms:

In the 60s, with the arrival of the first supersonic commercial aircraft, NASA decided to study the impact of sonic booms. McDonald and Goforth (1969) explained in their paper that four military aircraft, namely "an operational fighter F104, an operational bomber B58, an experimental reconnaissance SR71 and an experimental supersonic XB70", were used for different experiments. Their task was to generate sonic booms during flights above Edwards US Air Force Base in California, for one of the experiments. Different seismographs were buried either under the flight path of the aircraft or at a distance of 4700 metres. McDonald and Goforth (1969) noted the display of the sonic booms on the various seismograms, demonstrating that a sonic boom can be recorded by a seismometer. One of their conclusions was that the seismic signatures of the different aircraft varied depending on their sizes and shapes.

Kanamori et al. (1992) pursued the research by studying the return flights of three American space shuttles to Edwards Air Force Base in California. The seismometers of three different stations, located within a range of 100 kilometers and 300 kilometers from Edwards Base, recorded the flights of the three space shuttles Columbia in August 1989, Atlantis in April 1991 and Discovery in September 1991.

Further, Cates and Sturtevant (2002) demonstrated in their work using Caltech's seismic network as well as the University of California Los Angeles seismic network that a supersonic SR-71 aircraft flight over California could be tracked. The seismic stations were located either at the vertical of the flight path or on the side within a distance of 50 kilometers.

<u>Under water explosions</u>:

In the summer of 1961, the US government conducted some underwater experiments using some explosives in the ocean nearby Californian coasts. Willis (1963) explained in his paper that the same quantity of explosive was used at different depths. Different seismographs located within a range of 123 kilometers and 518 kilometers recorded the occurrences. He noted that a nearby earthquake that happened during one of the experiments had the same P-waves but not the same S-waves and surface waves than the underwater explosion.

Gitterman, Ben-Avraham and Ginzburg (1998) studied the same type of explosions but this time in the Dead Sea using ocean-bottom seismographs. The equipments recorded the explosions from different distances up to 200 kilometers. Some of the explosions generated a release of energy of 2 or 3 magnitude.

Recently, Savage and Helmberger (2001) studied a special underwater event the “Kursk explosion”. Two explosions on board the Russian nuclear submarine Kursk happened when it was immersed in the Barents Sea area. These were recorded as far as 1000 kilometers away and generated a release of energy of the magnitude of 3.5.

All these different topics have a common point with the present thesis: they aim to demonstrate that seismology could be used to locate a special event. Whether the occurrences happen on land or in the sea the researches explain that seismographs can record them from different distances and regardless of the magnitude of energy released.

All these works will be of value and worthy of investigation in the future because they indicate the need to discriminate between an aircraft crash and other events, as well as the necessity to extract background noise. Such study could be beneficial in assessing the value of using seismology to locate crashed aircraft quickly and save lives.

2 International aeronautical search and rescue regulations

2.1 International aeronautical regulations

The document called Chicago Convention on Civil Aviation (2006) governs the worldwide air transportation regulations since the end of World War II. Its objectives are to promote "the safe and orderly growth of international aviation throughout the world."

The technical regulatory agency, the International Civil Aviation Organization (ICAO), develops standards and recommended practices - Annexes in accordance with the Chicago Convention principles that each contracting state is responsible for adhering to. ICAO Annex 12 search and rescue (2004) defines international search and rescue regulations.

Figure 1: International aeronautical regulations

The signatory states of the "Chicago Convention" must take the necessary steps to ensure that aircraft in an emergency situation can be assisted by search and rescue (SAR) services (International Civil Aviation Organization 2006).

To fulfil this commitment, each contracting states under ICAO regulations (2004) defines at least one SAR area within the limits of its territory. Each SAR area needs an adequate number of SAR units equipped with an appropriate number of fixed-wing aircraft and/or helicopters capable to cover the entire surface of the area. Then, an Aeronautical Rescue Coordination Centre (ARCC) is established within each SAR area to initiate and coordinate SAR units.

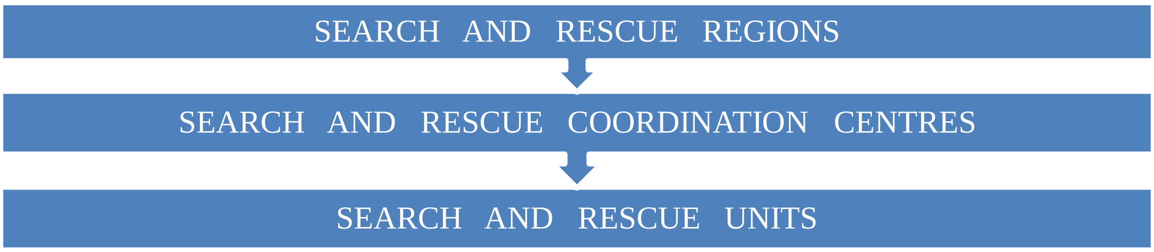

Figure 2: International aeronautical search and rescue organization

2.2 International aeronautical search and rescue procedures

The International Civil Aviation Organization (2004) defines three levels of emergency:

- Uncertainty phase: "A situation wherein uncertainty exists as to the safety of an aircraft and its occupants"
- Alert phase: "A situation wherein apprehension exists as to the safety of an aircraft and its occupants"
- Distress phase: "A situation wherein there is a reasonable certainty that an aircraft and its occupants are threatened by grave and imminent danger and require immediate assistance"

When the ARCC is notified by an air traffic control centre of an occurrence, it uses one of the following procedures, dependently on the emergency level of the occurrence:

- At the uncertainty level, it rapidly assesses all the information available concerning the occurrence.
- At the alert level, it put on standby the search and rescue units.
- At the distress level, it activates the search and rescue units.

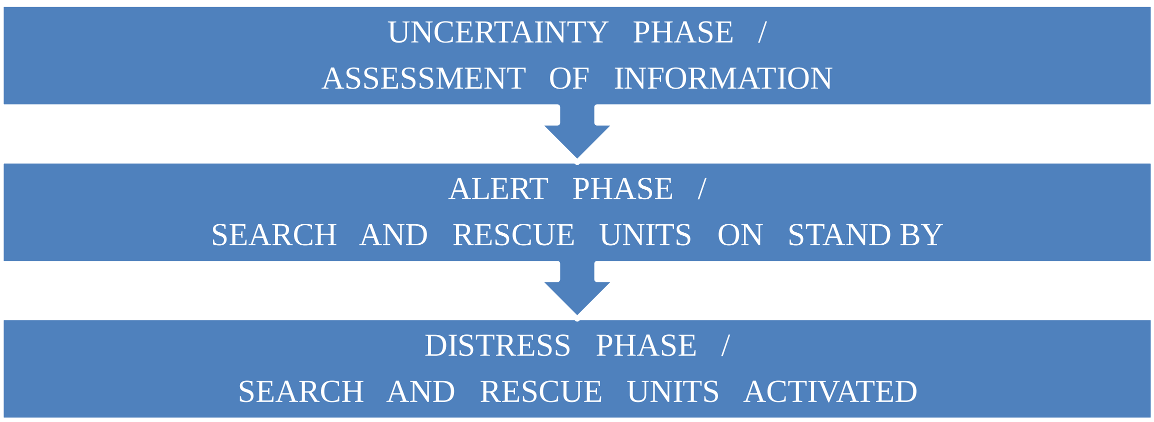

Figure 3: International aeronautical search and rescue procedures

3 United Kingdom aeronautical search and rescue organisation

The United Kingdom is a signatory state of the "Chicago Convention" and consequently must comply with the International Civil Aviation Organization regulation – annex 12 Search and rescue.

The Ministry of Defence is in charge of the civil aeronautical SAR in UK under the supervision of the department of transport. Only one search and rescue region has been defined in UK covering land and UK territorial waters. One ARCC is based at Royal Air Force (RAF) Kinloss Scotland (Maritime and coastguard 2008).

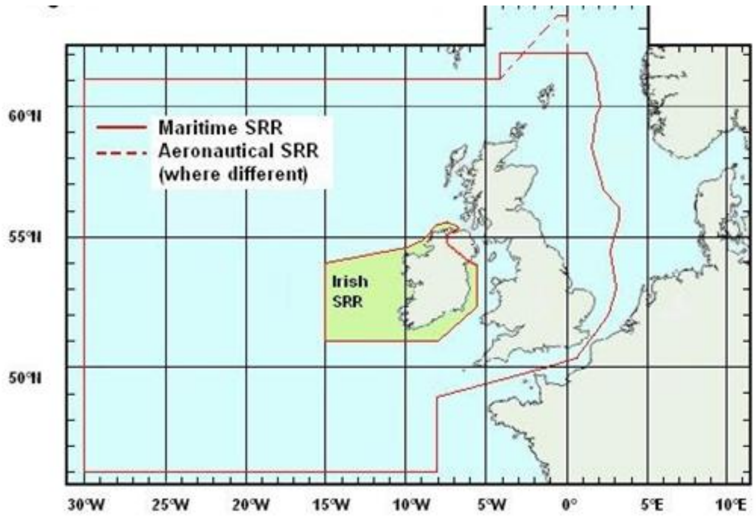

Figure 4: the UK SAR region
(*Source: Taylor 2011*)

3.1 SAR units

The British government fulfil its commitment to ensure that aeronautical search and rescue is provided over its territory by delegating the SAR services to three government entities: the Royal Air Force, the Royal Navy and the Maritime and Coastguard agency.

3.1.1 Royal Air Force units

The Royal Air Force operates two squadrons in charge of SAR operations within Great Britain. Both are composed of three flights each. All flights are equipped with two Agusta Westland Sea King HAR3 helicopters.

Squadron Nr. 22 operates three flights: Flight A at RAF Chivenor, Flight B at RAF Wattisham and Flight C at RAF Valley.

Squadron Nr. 202 operates three flights: Flight A at RAF Boulmer, Flight D at RAF Lossiemouth and Flight E at RAF Leconfield.

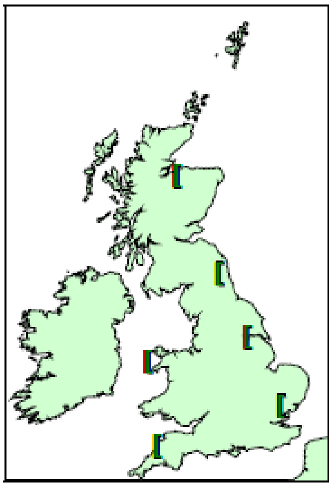

Figure 5: Royal Air Force units

(*Source: Maritime and Coastguard Agency 2001)*

3.1.2 Royal Navy units

The Royal Navy has established two Search and Rescue units within Great Britain: HMS Gannet and HMS Culdrose. Both units are manned by military and civilian staff all year around on a 24hrs basis.

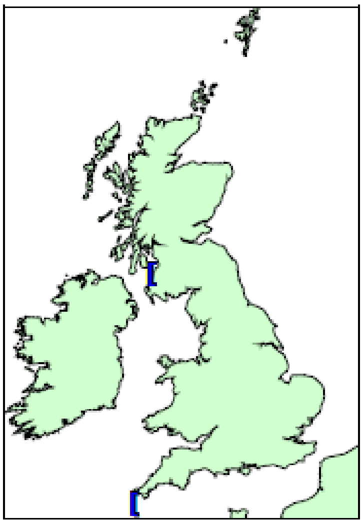

Figure 6: Royal navy units

(*Source: Maritime and Coastguard Agency 2001)*

HMS Gannet is located at Royal Navy air station Prestwick at Prestwick airport in Scotland. It operates three Agusta Westland Sea King MK5 helicopters. The area of coverage of this air station is of 98,000 square miles.

Royal Navy air station Culdrose is located near Helston in Cornwall. It operates six Agusta Westland Sea King MK5 helicopters. It covers a vast area of the South West of England.

3.1.3 Maritime and Coastguard Agency

The MCA provides SAR services under a civilian contract with CHC Scotia Company. Four different air bases are used in UK.

Stornoway, North West of Scotland and Sumburgh, in the Shetlands islands operate two Sikorsky S92 helicopters each.

Both Lee-on-Solent and Portland located on the English Channel border operate respectively two Agusta Westland AW139 and one Agusta Westland AW139 helicopters.

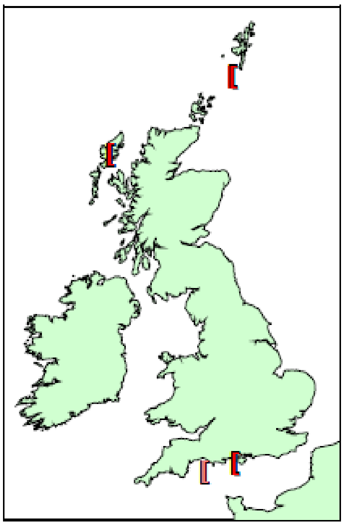

Figure 7: Maritime and Coastguard units

(*Source: Maritime and Coastguard Agency 2001)*

3.2 United Kingdom aeronautical search and rescue organisation conclusion

Three government agencies have the responsibility to conduct the search and rescue operations all over the United Kingdom: the Royal Air Force, the Royal Navy and the Maritime and Coastguard agency. Each of them operates respectively the following numbers of SAR units: six for the Royal Air Force, two for the Royal Navy and four for the Maritime and Coastguard Agency.

These different units operate only helicopters. The Royal Air Force used to have some BAE Nimrod long range maritime patrol aircraft until they were withdrawn from service during the year 2011.

Consequently, the British government can rely only on the SAR units' helicopters to conduct the searches for a missing aircraft. Those equipments don't have the same technical capability that is the endurance than the Nimrod aircraft. It means that the helicopters will need an accessible refuelling point from the meteorology point of view in the case of long searches, more than four hours.

Furthermore, an aircraft is able to fly faster than a helicopter. In the case of a long straight leg to be searched along the path of the missing aircraft it will take longer for a helicopter to fly it than for an aircraft.

Therefore, the only option that the British government would have at the moment being would be to use one of his long range aircraft, such as a Lockheed Hercules from the Royal Air Force, if available, to join the search and rescue operations for some long and quick operations.

4 Aeronautical search techniques

When an aircraft fails to report at a compulsory navigation point or when a flight disappears from the radar screen of an air traffic controller and when radio communication is not maintained, search and rescue operations are initiated. They must be planned and executed with accuracy.

4.1 Determination of search areas

It is the responsibility of the aeronautical rescue coordination centre to calculate the search areas. They must be defined with taking into consideration all the different factors that could be of influence, such as wind or drift.

4.1.1 Possibility area

That is the first area that needs to be delineated. It is the area where there is a possibility of the missing aircraft being located in. A circle is drawn using the last known position of the aircraft as its centre and the endurance of the aircraft expressed in Nautical Miles as its radius. Then from this point another circle is drawn where a wind factor is applied. For example, in the following figure A is the last known position of the aircraft, B represents the centre of the search area after the wind factor has been applied and 150 NM is the endurance of the aircraft.

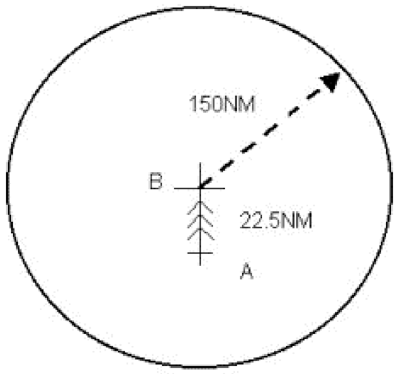

Figure 8: Possibility area

(*Source: National Search and Rescue Council 2011)*

4.1.2 Probability area

The possibility area is usually not used as it represents a zone too large to be searched. Consequently, a probability area must be delineated. This is the zone where the likelihood to find the aircraft is the most important. All the different factors such as the wind, the navigation error or others should be taken into consideration. For a missing aircraft an average of 10 NM on each side of the normal path of the missing aircraft is used to determine the search area. Depending on each flight particularities the area could include a turning point or not.

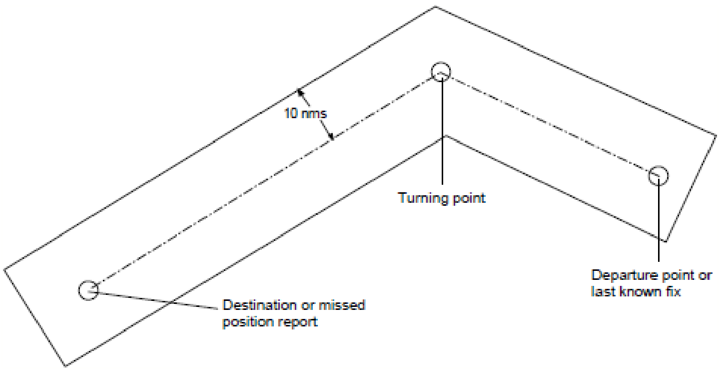

Figure 9: Probability area

(*Source: National Search and Rescue Council 2011)*

4.2 Aeronautical search patterns

When a "probability area" has been defined SAR helicopters and aircraft can start searching for the location of the distressed aircraft using different standard aeronautical search patterns jointly recommended by the International Maritime Organization and ICAO (2007).

4.2.1 Visual search patterns

Six visual search patterns are usually used by aircraft and helicopters to ensure a complete search is carried out with the objective of finding the missing aircraft as fast as possible: track line, parallel track, creeping line, square, sector and contour.

4.2.1.1 Track line search pattern

This is the first pattern used when no data is available concerning the aircraft. A search aircraft flies along the missing aircraft track between its last reported position and the position where the next report was due. It starts its flight at the last reported position and flies the same track than the missing aircraft until it reaches the destination point. Then, the SAR aircraft flies another leg parallel and on one side of its previous path, back to the departure point. It finally flies exactly the same leg on the opposite side of the flight path, back to the destination point. It can be said that this method is used when it is assumed that the aircraft hasn't diverted from its track and that it is expected to have fallen nearby its actual flight path.

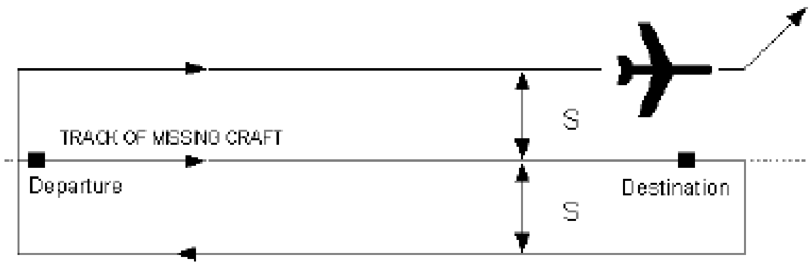

Figure 10: Track line search pattern

(*Source: National Search and Rescue Council 2011)*

4.2.1.2 Parallel track search pattern

A track line pattern is initiated when the previous search has been unsuccessful. The area to be searched becomes larger and different legs parallel to the missing aircraft track are flown. This pattern will be flown by an aircraft as the legs are long and the search needs to be conducted quickly. It is ideal for searches over big inland lakes.

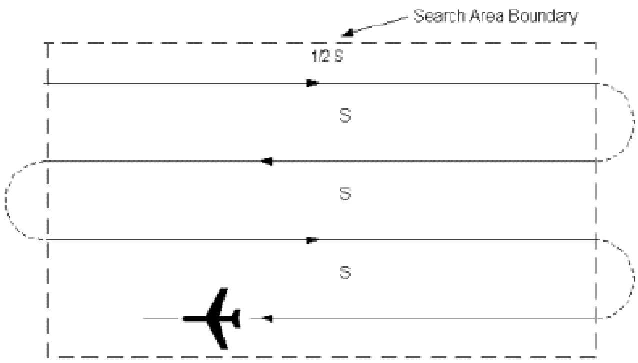

Figure 11: Parallel track search pattern

(*Source: National Search and Rescue Council 2011)*

4.2.1.3 Creeping line search pattern

A creeping line pattern consists of search legs perpendicular to the missing aircraft path. The area to be searched has the same size than the parallel track search. This pattern should be flown by a helicopter as the legs are short. It can be used for a narrow area, such as a valley.

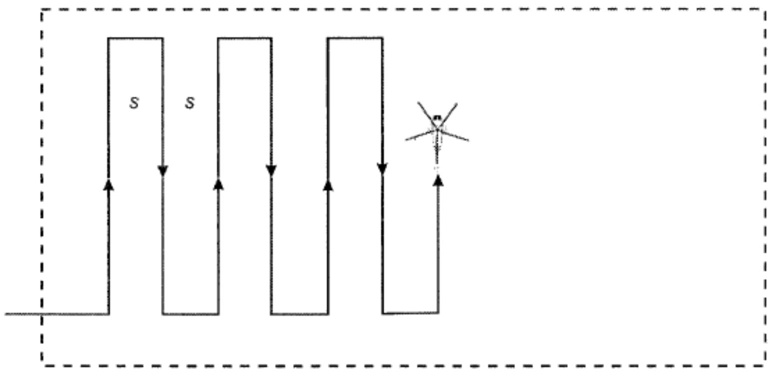

Figure 12: Creeping line search pattern
(*Source: International Maritime Organization & International Civil Aviation Organization* 2007)

4.2.1.4 Square search pattern

A square search is initiated when a possible location of the aircraft is known to be within a small area. The first search leg starts at the most probable position of the aircraft. Expanding concentric square legs are flown after. This pattern can be flown either by a helicopter or a very manoeuvrable aircraft.

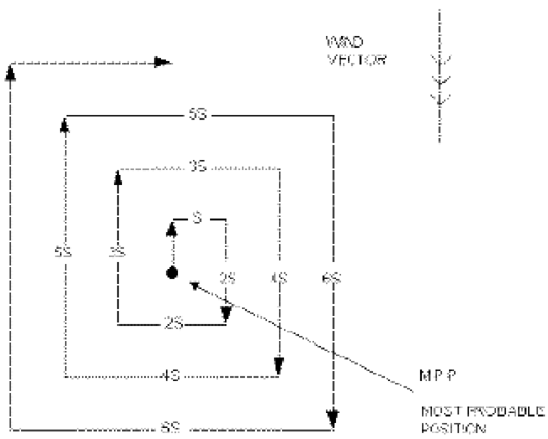

Figure 13: Square search pattern
(*Source: National Search and Rescue Council 2011)*

4.2.1.5 Sector search pattern

The sector pattern is used when the location of the aircraft is known to be within a very small area. It consists to fly sectors of a circle that represents the search area. Each sector has a triangle shape and the three sides of the triangle are the legs flown by the SAR aircraft. This pattern is not similar to the square pattern as the most probable position of the missing aircraft isn't known but only the narrow probable area.

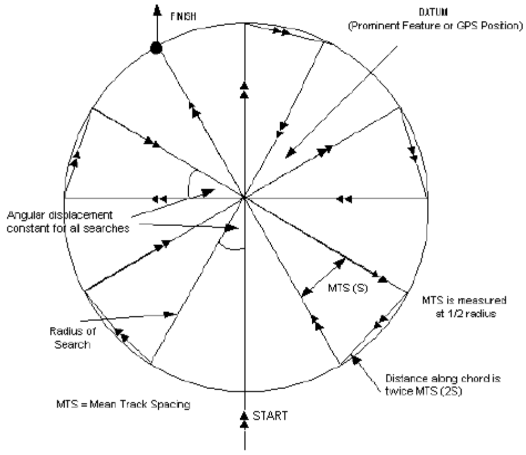

Figure 14: Sector search pattern

(*Source: National Search and Rescue Council 2011)*

4.2.1.6 Contour search pattern

A contour pattern consists of circles flown by an aircraft around a mountain at different levels. The flight starts from the top of the mountain and ends at its bottom. This is very dangerous and only very well trained crewmembers should perform it.

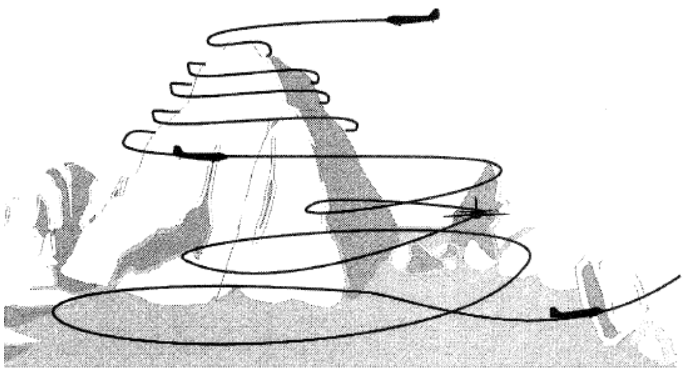

Figure 15: Contour search pattern

(*Source: International Maritime Organization & International Civil Aviation Organization* 2007)

4.2.2 Night search patterns

Three major night search patterns are available: flare, infra-red devices and night vision goggles.

4.2.2.1 Flare search pattern

This pattern is applied when survivors are known to be equipped with distress signal flares.

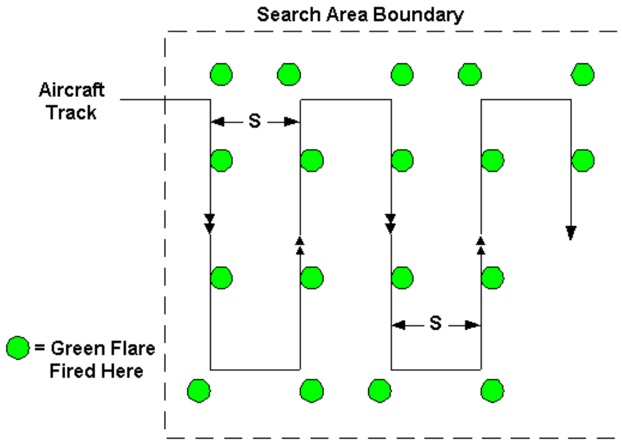

Figure 16: Flare search pattern

(*Source: National Search and Rescue Council 2011)*

The first green flare is fired by the search and rescue aircraft crew members at the start of the search. At the same time interval another flare is fired as well as at each turn. Each time a green flare is fired the survivors need to answer by firing a red flare. This pattern has the same shape than the visual creeping line search pattern.

4.2.2.2 Infra-red devices search pattern

These devices (whether radar or camera) generate pictures which show temperature differences. The objective is to detect survivors' body heat. This pattern must be flown very low.

4.2.2.3 Night vision goggles search pattern

Night vision goggles are binoculars mounted that allow to see in total darkness. They are usually mounted on the helmets worn by the helicopter pilots. But, pilots can see only a small area at the same time as when binoculars are used during the day.

4.3 Aeronautical search techniques conclusion

The only weaknesses of theses aeronautical search techniques are that they rely on different factors: aircraft or helicopter pilots, aircraft or helicopter observers and meteorology.

Firstly, the aircraft or helicopter pilots need to have some experience in the search and rescue operations. They also must have undergone the appropriate training dedicated to such emergencies. Part of the search depends of the pilots navigation skills. As they are human being they will become tired at some point and another crew should be available.

Secondly, the same comments could apply as well as to the aircraft or helicopter observers. An observer usually uses his eyes or some binoculars to try to find a missing aircraft. It is very easy to understand what is asked to be done by those persons is very difficult. The missing aircraft can be covered by the vegetation or by snow, or cannot be seen clearly because it is located in the shade. The main difficulty is that a wreckage looks like a small item from a search and rescue aircraft.

Lastly, the meteorology is crucial during the search operations. Low level clouds or fog reduce the visibility and will prevent the crew members to fly an aeronautical search pattern. On the other hand, high winds could endanger or slow the operations. Also, usually search operations are stopped at sunset as it becomes too dangerous due to the lack of visibility.

Therefore, it can be said owing to those elements that no one can say at the beginning of a search operation if such aeronautical search patterns are going to be successful or not.

5 Cospas-Sarsat satellites system

5.1 History of Cospas-Sarsat

In the early seventies, the French government decided to send into orbit a satellite called EOLE using the NASA facilities. It had the mission of locating meteorological balloons launched from different sites in Argentina and that were drifting around the Earth during several weeks. The mission was successful as EOLE satellite managed to track the different balloons (Levesque 2010).

During the seventies the USA and Canada examined the feasibility of using satellites for search and rescue purposes in addition to aircraft and helicopters. At that time a distress beacon called Emergency Locator Transmitter (ELT) was starting to be used by general aviation aircraft in USA. Helicopters and aircraft that were responsible for search and rescue operations could only rely on the chance to receive a distress signal from the missing aircraft if they were searching the proper area (Levesque 2010).

In the late seventies following EOLE success, the French government decided to set up a new programme called ARGOS. The French government owned space agency called Centre National d'études Spatiales (CNES) still runs that program nowadays. It cooperates with the United States meteorology agency called National Oceanic and Atmospheric Administration (NOAA) and the United States space agency called National Aeronautics and Space Administration (NASA). The NOAA polar-orbiting satellites system tracks any station in motion that carries an ARGOS distress beacon. But, this system is more a tracking system than an emergency system. The beacon needs to be activated manually in case of distress situations such as those encountered by yacht racers.

This was the inception of the Search and Rescue Satellite Aided Tracking (SARSAT) system jointly established by France, Canada and the United States. At the same time, the USSR started a new program called "Cosmicheskaya Sistema Poiska Avariynyh Sudov" (COSPAS) literally, "Space system for the search of vessels in distress". Its objective was to investigate the use of satellites for search and rescue operations and to set up a new satellites system for that purpose. In 1980, France, Canada, USA and URSS decided to cooperate to establish a new satellites system dedicated to search and rescue operations, the COSPAS-SARSAT (Levesque 2010).

5.2 System operations

5.2.1 System organisation

The constellation of satellites comprises six Low Earth Orbit SAR (LEOSAR) satellites in polar orbit and five Geostationary SAR (GEOSAR) satellites. The NOAA provides five LEOSAR satellites. The other one is provided by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Two GEOSAR satellites (GOES) are operated by the United States National Environmental Satellite, Data and Information service, two others (MSG) are operated by EUMETSAT and the last one (INSAT) is operated by the Indian Space Research Organisation (ISRO).

5.2.2 Satellites on board search and rescue equipment

The Cospas-Sarsat satellites system is dedicated to search and rescue operations but not its own satellites. Each satellite has a main mission not related to SAR but carries on its board SAR instrumentation.

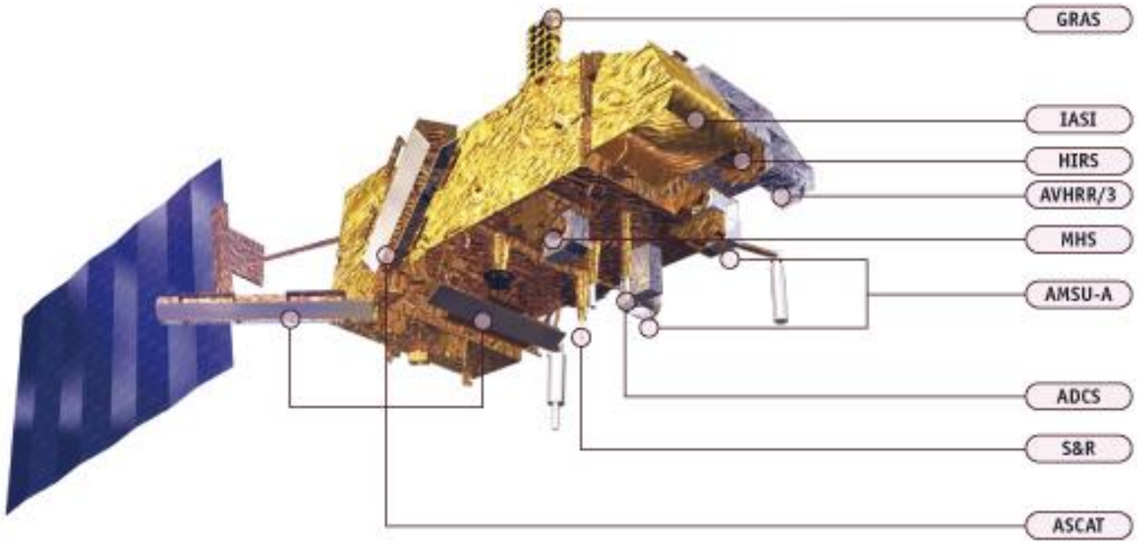

Figure 17: EUMETSAT METOP-A geostationary satellite with SAR instrumentation (Source: *EUMETSAT 2011)*

The on-board satellite SAR equipment is composed of a repeater unit (SARR) as well as a receiver-processor and memory unit (SARP). The SARR is the instrument that receives the distress signal. It converts the signal from the 406 MHz frequency to the 1544.5 MHz frequency that is used to transmit the signal back to Earth. An additional instrument is carried only by the LEO satellites, the SARP. Its task is to measure the frequency and to add a time to that measurement. It also memorises the data until the satellite can download it back to a station on Earth (Cospas-Sarsat 2009).

5.2.3 System operations principles

Each satellite uses its on-board SAR equipment to detect and transmit Emergency Locator Transmitter distress signals. Ground receiving stations, called Local User Terminal (LUT), transmit distress signals received by SAR satellites to Mission Control Centres (MCC) that process it to ARCC (Cospas-Sarsat 2011).

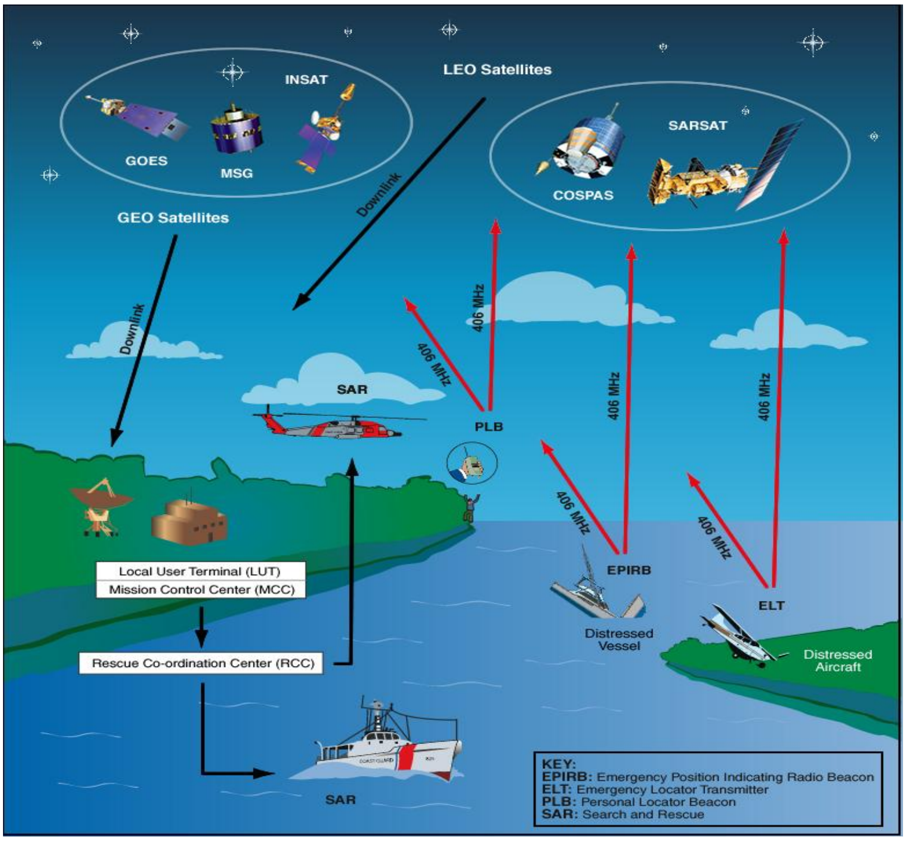

Figure 18: COSPAS - SARSAT satellites system
(*Source : Cospas-Sarsat 2011)*

5.3 LEOSAR satellites

5.3.1 LEOSAR satellites coverage time

The LEOSAR satellites don’t cover Earth continuously due to their polar orbital paths. Instead, they have a field of view of a continent size, around 6,000 kilometres wide (Cospas-Sarsat 2011).

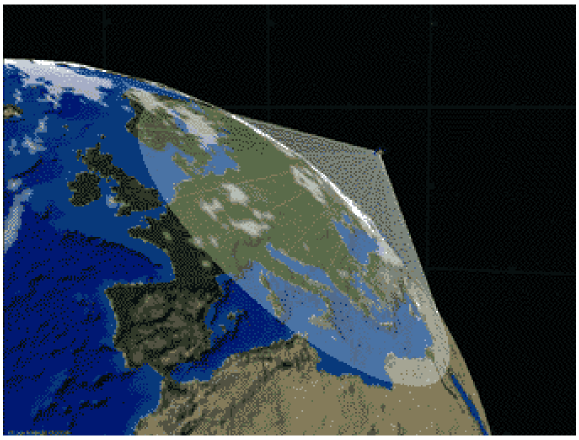

Figure 19: Illustration of a LEOSAR field of view
(*Source: Cospas-Sarsat 2011)*

According to the fact that the Earth rotates at the same time that the satellite travels around it, a maximum of 12 hours is necessary for the satellite to ensure an entire coverage of the Earth. Using two satellites the coverage time will be divided by two reaching a maximum waiting time of 6 hours. The LEOSAR satellites system was originally conceived to ensure a maximum waiting time of 1 hour using 4 satellites. Nowadays with 6 LEOSAR satellites a maximum of fifty minutes is normally necessary for an entire Earth coverage (Cospas-Sarsat 2011).

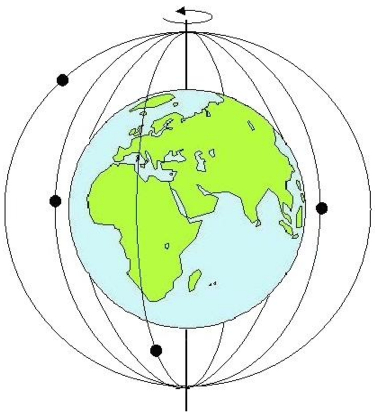

Figure 20: Earth coverage using 4 LEOSAR satellites
(*Source: Cospas-sarsat 2009)*

5.3.2 LEOSAR satellites principles

Firstly, the distress beacon must "be seen" by a satellite to be processed. Secondly, the satellite also needs to overfly a LEOLUT to retransmit the distress signal. If not, the signal is stored on its board before to be downloaded to the nearest LUT (Cospas-Sarsat 2011).

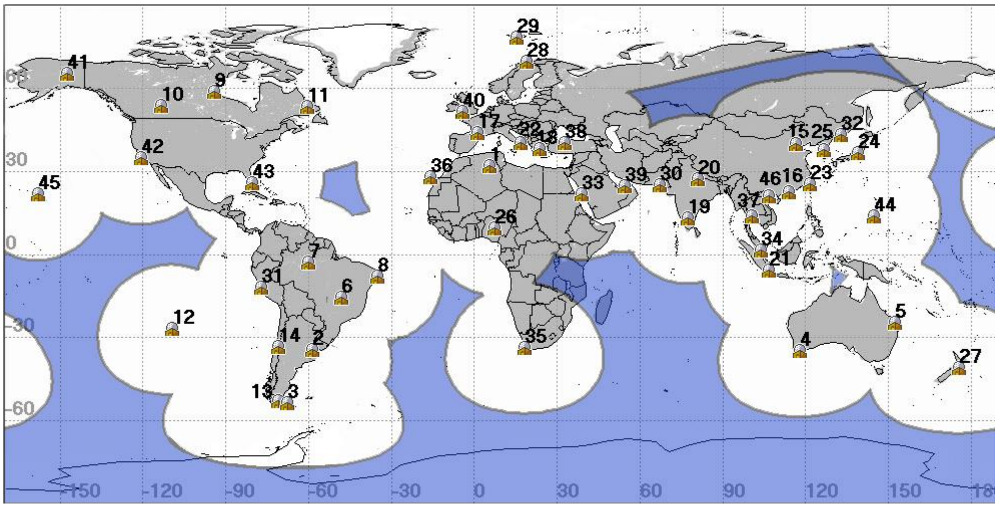

Figure 21: LEOSAR satellites retransmission regions (in white colour) and LEOLUT stations (numbered)
(*Source: Cospas-Sarsat 2011)*

But, before to retransmit the distress signal the SAR' on board equipment of the satellite needs to calculate the location of the beacon. This is done by using the Doppler technique: a beacon signal frequency increases when its distance from the satellite reduces and on the other hand its frequency decreases when its distance from the satellite increases.

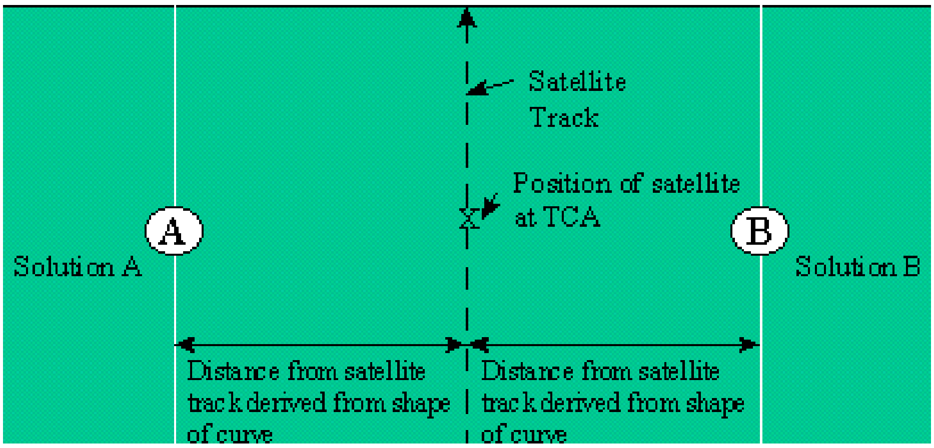

Figure 22: ELT two possible locations determined by a LEOSAR satellite
(*Source: Cospas-sarsat 2011)*

Finally, two possible locations of the distress beacon are found after the distress beacon signal frequency has been measured by the SARP instrument: the actual location and its "mirror". The pass of another satellite on a different track is usually used to solve that problem (Cospas-Sarsat 2011).

5.4 GEOSAR satellites

5.4.1 GEOSAR satellites coverage

GEOSAR satellites have a geostationary orbit around the Equator. They cover the regions located from the Equator up to an average of Latitude 70° (Cospas-Sarsat 2009).

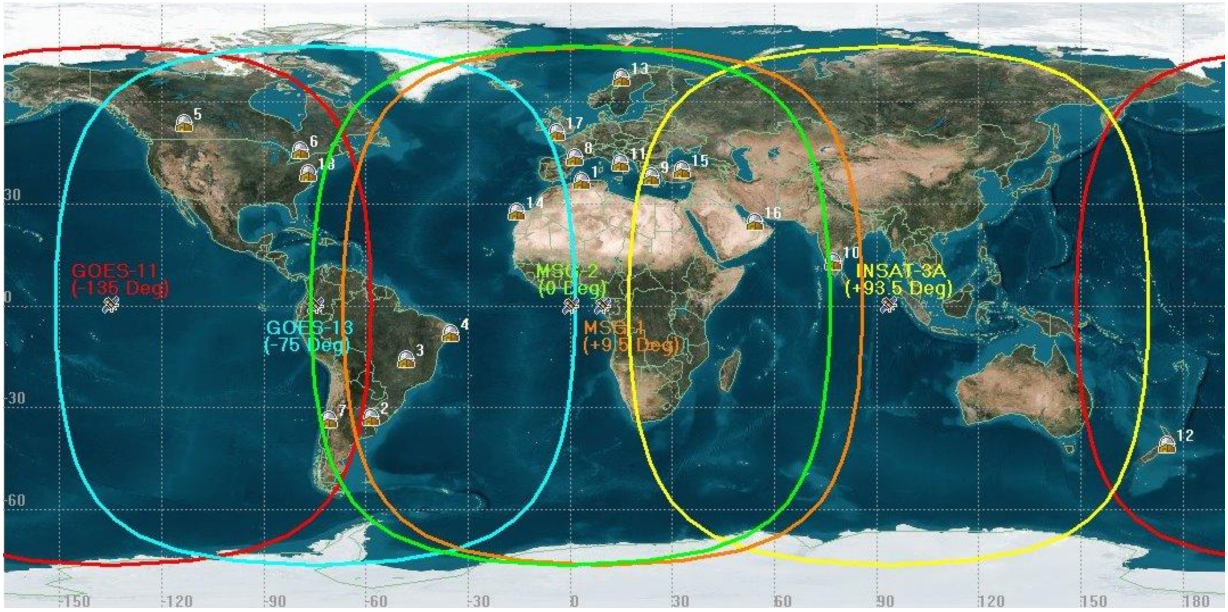

Figure 23: GEOSAR satellites coverage and GEOSAR stations (numbered)
(*Source : Cospas-Sarsat 2011)*

5.4.2 GEOSAR satellites principles

GEOSAR satellites need the same amount of time to travel around the Earth than Earth needs to complete an entire rotation. Therefore, the Doppler's effect based on motion between two objects cannot be used to locate a distress beacon. Instead, the beacon must be equipped with a navigation system, such as the Global Positioning System (GPS). If not, the LEOSAR satellites will need to be used (Cospas-Sarsat 2011).

5.5 Complementarity of the two satellite types

The two types of satellites are necessary to provide a complete coverage of the Earth. In fact, the LEOSAR satellites cannot provide a continuous coverage of the Earth resulting in a delay of the information transmission. On the other hand, the GEOSAR satellites can provide immediate information but they don't cover the Polar areas (Cospas-Sarsat 2011).

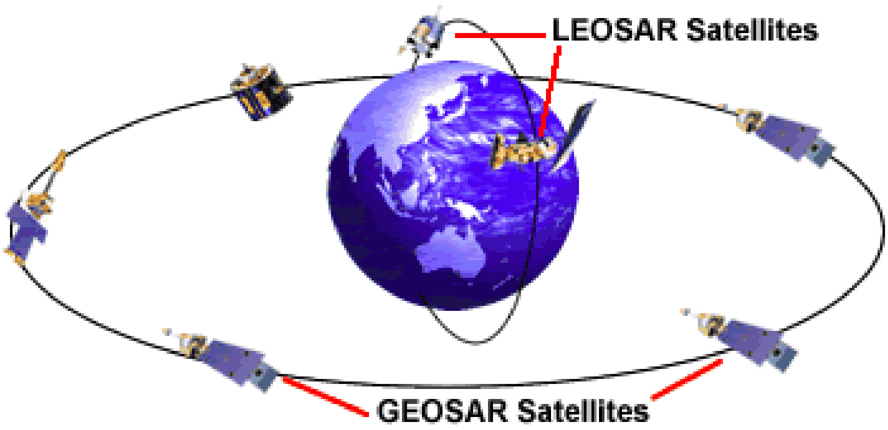

Figure 24: GEOSAR and LEOSAR satellites complementarity

(*Source : Cospas-Sarsat 2011)*

5.6 Cospas-Sarsat satellites processing

Until recently the satellites used to process all the emergency signals received on the 121.5 MHz, the 243 MHz and the 406 MHz frequencies. Starting the 1st February 2009, only the 406 MHz frequency is processed by the Cospas-Sarsat satellites.

5.7 Cospas-Sarsat satellites system conclusion

LEOLUT are not located everywhere on Earth. For example, the former URSS, Greenland and Mongolia don't have any LEOSAR satellites ground receiving stations. Therefore, some regions are not able to process distress signals.

Moreover, the waiting time for the ELT detection by the LEOSAR satellites as well as the retransmission of the information to Earth can sometimes be very long. It is even longer if an occurrence happened nearby the Equator regions.

Finally, because of its geostationary positions GEOSAR satellites are sensitive to line of sight. That is if there is an obstruction, such as a mountain between the satellite and the emergency beacon, the satellite won't be able to detect the ELT signal.

Last but not least, some airlines in the world still have their aircraft equipped with the old generation of emergency locator transmitter. These equipments cannot transmit on the 406 MHz frequency. Hence, the Cospas-Sarsat satellites will never be able to detect them. Only, a SAR aircraft or helicopter overflying the area where the wreckage is located will perhaps have the chance to receive the signal.

6 Emergency locator transmitter

6.1 History

The first Emergency Locator Transmitter beacons (ELT) were developed in the late 60s. They become mandatory on general aviation aircraft in the USA in the early 70s. The purpose of this equipment is to shorten the search time necessary to locate a missing aircraft by sending distress signals to the Cospas-Sarsat satellites system.

6.2 Description

The ELT is mainly composed of the following parts: a remote control unit, a main unit and an outside antenna. The remote control unit is located in the aft overhead panel of the cockpit.

Figure 25: ELT remote control unit in a Boeing B737 cockpit panel (*Source: courtesy Elta France*)

The main unit is found inside the rear top fuselage. It is connected to the outside antenna by a large cable. It is also connected to the main unit into the cockpit by a wire.

The antenna is located outside on the top rear fuselage of the aircraft.

Figure 26: an ELT main unit (orange) linked by a large cable (bottom left of main unit) to an antenna backside unit inside the fuselage (green rectangle, top left of the picture)
(Source: c*ourtesy Elta France*)

6.3 Principles

The Emergency Locator Transmitter operates only if a certain amount of G-forces versus the time is recorded (ELTA 2011): a short time impact with a high value of G-forces or a long time impact with a low value of G-forces.

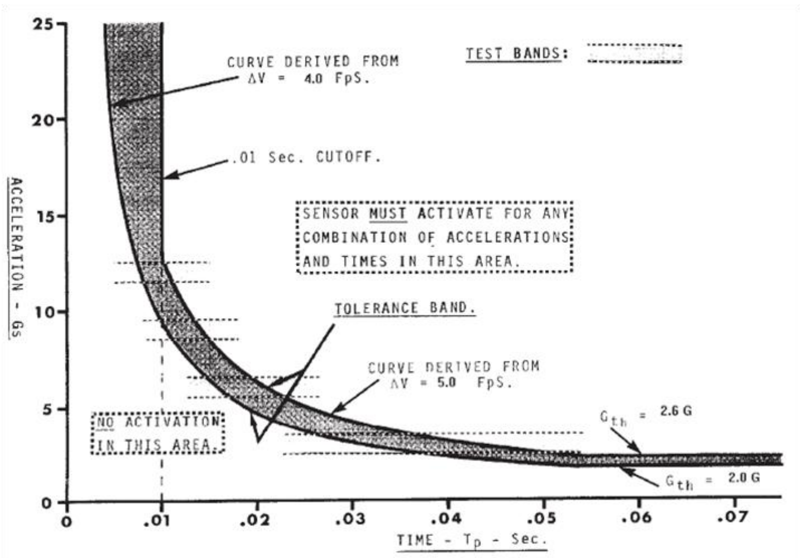

Figure 27: Emergency Locator Transmitter curve
(*Source: Elta 2011*)

6.4 Types

ICAO (2001) defined four types of ELT: automatic fixed, automatic portable, automatic deployable and survival.

6.4.1 Automatic fixed ELT

ICAO (2001) describes an automatic fixed emergency locator transmitter as "an automatically activated ELT which is permanently attached to an aircraft".

Figure 28: Automatic fixed ELT
(*Source: Elta 2011*)

6.4.2 Automatic portable ELT

ICAO (2001) describes an automatic portable emergency locator transmitter as "an automatically activated ELT which is rigidly attached to an aircraft but readily removable from the aircraft".

Figure 29: Automatic portable ELT
(*Source: Elta 2011*)

6.4.3 Automatic deployable ELT

ICAO (2001) describes an automatic deployable emergency locator transmitter as "an ELT which is rigidly attached to an aircraft and which is automatically deployed and activated by impact, and, in some cases, also by hydrostatic sensors. Manual deployment is also provided".

6.4.4 Survival ELT

ICAO (2001) describes a survivable emergency locator transmitter as "an ELT which is removable from an aircraft, stowed so as to facilitate its ready use in an emergency, and manually activated by survivors".

Figure 30: Survival ELT
(*Source: Elta 2011*)

The main difference between the four categories of ELTs is between the automatic and the survival types. As the name tells it by itself the automatic ELT is automatically activated upon an aircraft crash, where the survival ELT is manually activated.

Within the automatic category the automatic deployable ELT is the most sophisticated and the most reliable as it separates from the aircraft upon impact and then activates automatically. This reduces the chances of the equipment being destroyed during the crash.

On the other hand the automatic portable ELT gives a second chance to survivors of an aircraft accident as it can also be manually activated alike the automatic deployable ELT but not like the automatic fixed ELT.

6.5 Performances

Two different models of ELT exist the old generation capable to transmit signals on the 121.5 MHz frequency and the new generation ELT capable to transmit on the 406 MHz frequency.

The new generation of 406 MHz ELT performs better than the older one 121.5 MHz ELT. The area to be searched is 100 times less than for a 121.5 MHz ELT where a 406 MHz ELT is carried by an aircraft - from 1260 sq. km to 13 sq. km. It gives a search radius circle ten times smaller than for an ELT 121.5 MHz - from 20 km to 2 km (Defence Research and Development Canada 2009).

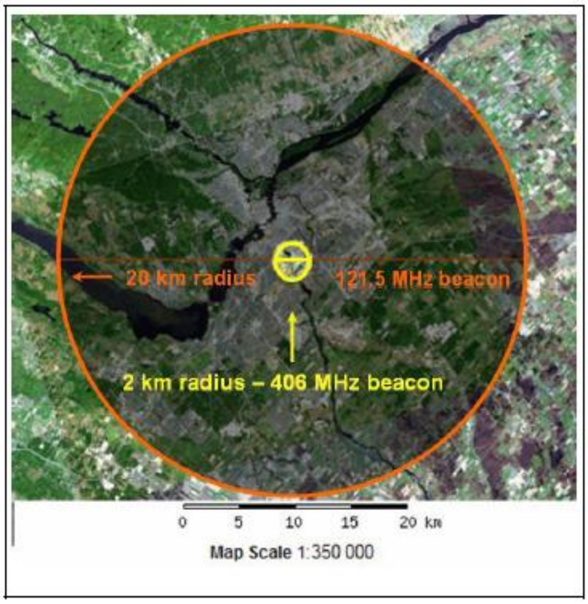

Figure 31: 121.5 MHz and 406 MHz ELT search radius difference
(*Source: defense research and development Canada 2009*)

6.6 Regulations

6.6.1 ICAO

ICAO (2001) states that all aircraft “overflying water” (at least 30 minutes away from land) on long range flight operations must carry two ELTs including one automatic.

ICAO (2001) also states that all aircraft “overflying designated land areas” (where search and rescue operations could be difficult) must carry one automatic ELT.

6.6.2 Joint Aviation Authorities

The Joint Aviation Authorities (2007) states that all aircraft with a certificate of airworthiness issued before 1st January 2002 must carry any type of ELT that transmits on 121.5 MHz and 406 MHz.

The Joint Aviation Authorities (2007) also states that all aircraft with a certificate of airworthiness issued after 1st January 2002 must carry an automatic ELT that transmits on 121.5 MHz and 406 MHz.

6.6.3 UK Civil Aviation Authority

The UK Civil Aviation Authority (2008) states that all aircraft with a certificate of airworthiness issued before 1st January 2002 must carry either an automatic ELT or a survival ELT.

The UK Civil Aviation Authority (2008) also states that all aircraft with a certificate of airworthiness issued after 1st January 2002 must carry an automatic ELT.

6.7 Emergency locator transmitter conclusion

Firstly, of the three main components two are fragile: the main unit and the antenna. The main unit is made to resist to any kind of shocks. It also needs to be water and fire resistant. If one of these components is damaged the ELT cannot transmit a signal. Moreover, even if all the components aren't damaged, the antenna may relay an intermittent signal.

Secondly, if the time versus the G-forces doesn't fit within the tolerance band then no signal is emitted. Also, even if it represents a narrower area, 13 sq. km is still a large zone to search especially where it includes mountains, hills and forest.

Thirdly, the JAA and the UK CAA gives the option of using only a simple survival type ELT that is manually activated to the airlines for their aircraft with a certificate of airworthiness issued before 1st January 2002. Can the airlines guarantee that in case of an emergency the crew members will survive the aircraft accident and be able to activate the emergency beacon? Can they also guarantee that in the case of no crew members have survived to the crash a passenger will know that there is an emergency beacon on board of the aircraft, where to find it and how to use it?

Finally, despite knowing that the 121.5 MHz ELT processing by the COSPAS-SARSAT system ended on February 1st 2009, neither the ICAO nor the UK CAA mentioned the requirement for an ELT capable of transmitting on the 406 MHz frequency to be carried by all commercial aircraft. As a result, some aircraft may still carry the old ELT device that will never be detected by the satellites system.

7 History of commercial aircraft accidents with search operations

7.1 Introduction

The following aircraft history is a review of the past aircraft accidents during the past thirty years where aeronautical search operations were needed. It starts in 1979 with Air New Zealand crash and ends in 2009 with Airlines of Papua New Guinea aircraft accident.

Only twelve aircraft accidents have been kept for that history where actually more have happened during that period of time. The main reason is that for some of them the aircraft accident investigation report wasn’t and still isn’t available. Some others have a published investigation report available but not written in an understandable language by the author.

Moreover, only commercial aircraft accidents have been chosen. The definition of a commercial aircraft for the purpose of this research is an aircraft involved in regular or charter flight but not in a business flight.

Finally, the choice between all those flights has been narrowed to the aircraft that can at least carry 19 passengers or more.

Last but not least, all the information provided in the following history has been extracted from the different aircraft accident investigation reports whose list can be found in the bibliography.

7.2 Air New Zealand TE 901,

Mount “Erebus”, Ross Island, Antarctica (1979)

7.2.1 History of flight

On November 27, 1979 Air New Zealand flight TE 901 departed from Auckland international airport in New Zealand at 1917 hours (All times in GMT, New-Zealand time is GMT + 13 hours). It was expected to overfly McMurdo station in Antarctica at 0100 hours. Then, the flight was planned to return to Auckland international airport in New Zealand after a first stop at Christchurch airport in New Zealand.

After flying over South island (New Zealand), Auckland islands, Balleny islands, Cape Hallett, Air New Zealand DC 10-30 entered in contact with McMurdo air traffic control, 140 miles away from the airport. The aircraft started its descent to 10000 feet at 0035 hours.

During its descent to the Wright and Taylor Valleys for sightseeing Air New Zealand TE 901 crashed into mount “Erebus” in Antarctica at 0050 hours.

7.2.2 Injuries to persons

The McDonnell Douglas DC 13-30 was carrying 1 captain, 2 first officers, 2 flight engineers, 15 cabin crew members and 237 passengers. None of the 257 persons on board of the aircraft survived to the crash.

7.2.3 Search timing and organization

- 0045 / This is the last contact of the aircraft with the air traffic control
- 0050 / Air New Zealand flight TE 901 accident occurred
- 0050 / Mac Centre tries to get in touch with the aircraft. Mac Centre asks other aircraft to get in touch with the aircraft
- 0200 / Mac Centre informs Air New Zealand of the aircraft no radio communication
- 0343 / Mac Centre activates the search operations: 1 Lockheed C130 aircraft and two UH-IN helicopters are on stand-by
- 0416 / Six aircraft start the search operations from McMurdo station (the search begins from the last known aircraft position)
- 0428 / One USAF Lockheed C141 starts the search operations from McMurdo station (the search is conducted along the missing aircraft flight track back to New Zealand)
- 0830 / This is the estimated time of the aircraft running out of fuel

- 1255 / One Lockheed C130 discovers the aircraft crash site

7.2.4 Rescue operations

The aircraft that discovered the aircraft wreckage was unable to land due to poor meteorological conditions. It had to fly back to McMurdo station. A Lockheed C130 circling over the wreckage coordinated the rescue operations.

At 0125 hours, thirty minutes after the discovery of the missing aircraft, a rescue helicopter was at the accident site. But, it encountered the same meteorological conditions than the first rescue aircraft and couldn’t land. It also had to fly back to McMurdo station.

7.2.5 Radar information

The US Navy operated a radar facility at McMurdo airport. The aircraft accident investigation report underlines that the radar could track the aircraft only where it was located within a 40 miles range from the airport.

7.2.6 Weather information

It was snowing during the search and rescue operations.

7.2.7 Accident location

The accident occurred at an altitude of 1467 feet and at 27 NM from the nearest airport.

7.2.8 Accident site

The wreckage was found on Mount Erebus volcano slope. It is covered by ice and snow all year round.

7.2.9 Emergency locator transmitter

The aircraft wasn’t equipped with an ELT. It wasn’t required at the time of the accident, according to the aircraft accident investigation report.

7.3 Dan air services DA 1008,

Mount “Pico Del Chiriguel”, Tenerife, Canary Islands, Spain (1980)

7.3.1 History of flight

On April 25, 1980 Dan Air Services flight DA 1008 departed Manchester airport in England at 0922 hours (all times in GMT, Spain time is GMT + 2 hours). The flight was expected to arrive at Tenerife Norte airport in the Canary Islands three hours after its departure from Manchester.

After flying through the United Kingdom airspace and France airspace Dan Air Services Boeing 727-100 entered the Canary Islands airspace. Its first radio contact was with Las Palmas control centre and then with Tenerife Norte airport approach at 1314 hours which cleared it to descend from FL 110 to FL 60 about one minute later.

During its descent Dan Air Services flight DA 1008 crashed into mount “Pico Del Chiriguel” in the Canary Islands at 1321 hours.

7.3.2 Injuries to persons

The Boeing 727-100 was carrying 1 captain, 1 first officer, 1 flight engineer, 5 cabin crew members and 138 passengers. None of the 146 persons on board of the aircraft survived the crash.

7.3.3 Search timing and organization

- 1321 / This is the last control with the air traffic controllers
- 1321 / Dan Air Services flight DA 1008 accident time
- xxxx / There is no more contact with the aircraft. The search operations start
- xxxx / La Guardia Civil, the Spanish aerial rescue service conduct the search operations
- 1800 / La Guardia Civil locates the aircraft

7.3.4 Rescue operations

The rescue operations started immediately after the discovery of the missing aircraft. They were conducted by the Police, the Army, the Guardia Civil, the Spanish Red Cross and some mountaineering groups. The rescue operations stopped at night and also because of the location of the aircraft accident site. At that time just a few bodies were found. The rescue operations re-started the next morning and lasted for two days.

7.3.5 Radar information

There was no approach control radar at Tenerife Norte airport.

7.3.6 Weather information

Fog was encountered by the emergency teams during the search and rescue operations.

7.3.7 Accident location

The accident occurred at an altitude of 5450 feet and 6.2 NM from the airport.

7.3.8 Accident site

The aircraft impacted the ground in a remote mountainous area. It is composed of mountain peaks of an altitude of 4800 feet up to 5748 feet, a valley at an altitude of 4,300 feet and a forest.

7.3.9 Emergency locator transmitter

The aircraft wasn’t equipped with an ELT.

7.4 Inex Adria Aviopromet JP 1308,

Mount "San Pietro", Corsica Island, France (1981)

7.4.1 History of flight

On December 1, 1981 Inex Adria Aviopromet flight JP 1308 departed Ljubljana international airport in Slovenia at about 0637 hours (All times in GMT, France time is GMT + 2 hours). The flight was expected to arrive at Ajaccio airport in Corsica Island around 0800 hrs.

After flying through the Slovenia airspace and the Italia airspace, Inex Adria Aviopromet JP 1308 DC 9-82 was cleared to start its descent at 0731 hrs. Then, it entered the French airspace and was in contact with Ajaccio airport approach at 0747 hours.

During its initial approach Inex Adria Aviopromet flight JP 1308 crashed into Mount "San Pietro" in Corsica Island at 0753 hours.

7.4.2 Injuries to persons

The Mac Donnell Douglas DC 9-82 was carrying 1 captain, 1 first officer, 1 flight engineer, 4 cabin crew members and 173 passengers. None of the 180 persons on board of the aircraft survived the crash.

7.4.3 Search timing and organization

- 0753 / This is the last contact with the air traffic controller
- 0753 / Inex Adria Aviopromet flight JP 1308 accident time
- 0754 / The search operations start
- xxxx / Three aircraft, five helicopters search the aircraft
- xxxx / The Gendarmerie (military Police), the fire fighting services and some rangers conduct the ground search
- xxxx / No distress signals are received by the search aircraft
- xxxx / A radar record and some witnesses' reports help to narrow the search area
- 1240 / Two helicopters and the rangers discover the aircraft crash site

7.4.4 Rescue operations

At 1300 hours, twenty minutes after the discovery of the missing aircraft the fire-fighter chief doctor arrived at the site. The rescue operations were terminated thirty minutes later, as there were no survivors.

7.4.5 Radar information

There was no approach control radar at Ajaccio airport. The radar information used for the discovery of the missing aircraft was provided by Marseille control centre.

7.4.6 Weather information

The mountains around the aircraft accident site were generally covered by clouds.

7.4.7 Accident location

The accident occurred at an elevation of 4478 feet and 13 NM from the airport.

7.4.8 Accident site

The aircraft impacted the ground in a mountainous area covered by copses and shrubs.

7.4.9 Emergency locator transmitter

The aircraft wasn’t equipped with an ELT.

7.5 Air Inter 148,

Mount “La Bloss”, France (1992)

7.5.1 History of flight

On January 20, 1992 Air Inter flight 148 departed Lyon Satolas airport in France at 1720 hours (All times in GMT, France is GMT + 1 hour). The flight was expected to arrive at Strasbourg - Entzheim airport in France after half an hour flight.

During its cruise part of the flight the aircraft was in contact with Reims area control centre. The latter cleared Air Inter 148 Airbus 320-100 to start its descent to flight level FL70. Then, it was in contact with Strasbourg approach control, at 1809 hours. It was then cleared to descent to flight level FL50.

During its initial approach Air Inter flight 148 crashed into Mount “La Bloss” in France at 1820 hours.

7.5.2 Injuries to persons

The airbus A320-100 was carrying 1 captain, 1 first officer, 4 cabin crew members and 90 passengers. Nine persons, amongst a total of 96 persons on board of the aircraft, survived the crash.

According to the aircraft accident investigation report, six more occupants of the aircraft, who survived to the crash, could have lived if the rescue had been at the aircraft accident site earlier.

7.5.3 Search timing and organization

- 1819 / This is the last contact with the air traffic controller
- 1820 / Air Inter 148 aircraft accident time
- 1831 / Strasbourg approach control alerts Drachenbronn Aeronautical Rescue Coordination Centre
- 1834 / The search starts
- 1839 / The Civil security is activated
- 1841 / Drachenbronn and Reims area control centre radar records are asked
- 1843 / The Gendarmerie (military Police) is activated
- 1856 / Nonprofessional radios are asked to listen for ELT signal
- 1909 / The first search area is defined by ARCC

- 1913 / An Alouette helicopter starts some visual search
- 1930 / A new enlarged search area is defined by ARCC
- 1940 / The Gendarmerie starts search patrols
- 1940 / One Puma helicopter starts some search with night vision goggles
- 2000 / Some nearby cities rescue centres start to search
- 2010 / Drachenbronn radar records are available to the ARCC
- 2015 / The ARCC confirmed first search area instead of the second one
- 2045 / The ARCC defined three new search areas with a side of 3kms each following two Air Inter ground staff information concerning the last aircraft expected position
- 2100 / The first search area is searched by the Gendarmerie
- 2125 / The ARCC asks to narrow search on an axe crossing Mount "La Bloss"
- 2132 / A second Puma helicopter starts some search with night vision goggles
- 2135 / The first search area search is stopped
- 2204 / Reims area control centre radar records available to the ARCC
- 2204 / The ARCC asks to concentrate search on a position close to Mount "La Bloss" estimated by Reims control
- 2204 / The Army starts (200 persons) to search the area n°2
- 2220 / The Army mission is cancelled following new information
- 2235 / A survivor crosses a search team and indicates the aircraft wreckage location

7.5.4 Rescue operations

The first rescuers on site were the Gendarmerie staff followed by three military doctors. Four survivors were evacuated by the Gendarmerie staff, either on their backs or using stretchers made out of wood. Seven other persons were evacuated between 2320 hours and 0015 hours using the same manner.

The survivors were transferred to the ambulances positioned on a parking near a main road. Two survivors died during their evacuation between the aircraft accident site to the ambulances.

All aircraft accident survivors were found before 2300 hours. The evacuation of the survivors to the hospitals started at 0130.

7.5.5 Radar information

One military radar facility was available at Drachenbronn 30 NM north of Strasbourg Entzheim airport.

7.5.6 Weather information

There was some fog, a visibility of less than 500 meters and some snow on the ground during the search and rescue operations.

7.5.7 Accident location

The aircraft accident occurred at an altitude of 2620 feet and 10 NM from the airport.

7.5.8 Accident site

The accident site is on a mountain slope of the Vosges range covered by a forest and also by snow at the moment of the accident.

7.5.9 Emergency locator transmitter

The aircraft was equipped with an ELT. It didn’t activate because it was destroyed during the aircraft crash.

7.6 Ansett New Zealand 703,

Palmerston North, New Zealand (1995)

7.6.1 History of flight

On June 9, 1995 Ansett New Zealand flight 703 departed Auckland international airport in New Zealand at 2017 hours (All times in GMT, New-Zealand time is GMT +12 hours). The flight was expected to arrive at Palmerston North airport in New Zealand at 2130 hours.

After flying over North Island in New Zealand and south towards its destination Ansett New Zealand De Havilland DHC - 8 was cleared to start its descent by area control Ohake at 2057 hours. It was asked to contact Palmerston airport tower, at 2119 hours.

During its final approach Ansett New Zealand flight 703 crashed into a hill nearby Palmerston North airport in New Zealand at 2122 hours.

7.6.2 Injuries to persons

The De Havilland DHC-8 was carrying 1 captain, 1 first officer, 1 cabin crew member and 18 passengers. Three passengers and the cabin crew member were killed during the crash.

According to the aircraft accident investigation report the crash was survivable. One of the passengers, who survived to the crash and was caught by the aircraft fire while waiting outside of the aircraft for the rescue, died at hospital twelve days after the aircraft crash.

7.6.3 Search timing and organization

- 2121 / This is the last contact with the air traffic controller
- 2122 / Ansett New Zealand 703 accident
- 2123 / Palmerston North airport tower and Ohakea control try to contact the missing aircraft
- 2123 / Confirmation of the aircraft missing on the radar screen by Ohakea control
- 2126 / The airport rescue fire fighting services, the New Zealand fire service, the Police and the rescue helicopters notified by Palmerston North airport tower of the aircraft accident
- 2127 / The ground search starts at a point located 4 nm from runway 25 where the aircraft was believed to be by the Ohakea air traffic controller
- xxxx / One passenger calls the Police saying the aircraft in on top of a hill in clouds
- xxxx / Some farmers help to find a road access to the area

- xxxx / The passenger reports the sound of helicopter helping to narrow the search area
- 2129 / One helicopter from Palmerston North starts the search
- 2200 / One helicopter from Hastings starts the search
- xxxx / Both helicopters conduct visual and electronic searches on Manawatu Gorge Ashhurst and Woodville sides
- xxxx / One helicopter conducts the search below the cloud base and can’t find the aircraft as it is located higher on a hill
- xxxx / One helicopter conducts the search in and above the clouds at altitude
- xxxx / Both helicopters track the weak ELT signal
- 2219 / The aircraft wreckage is located by one helicopter

The air traffic control radar recording wasn’t used for the search of the missing aircraft. Between one hour and two hours were necessary in order to study it.

7.6.4 Rescue operations

The rescue staffs on board of the helicopters were immediately disembarked at the aircraft crash site. While the two helicopters returned to Palmerston North hospital to get more rescue staff, four other rescue helicopters arrived at the aircraft crash site. The ground rescue team arrived just after. At 1039 hours a command post was established nearby the aircraft accident. All survivors were evacuated between 1100 hours and 1207 hours. At 1500 hours all the dead persons were evacuated.

7.6.5 Radar information

Radar information was available through three radars facilities: one primary surveillance radar nearby Ohakea town (14 nm from Palmerston North airport), one secondary surveillance radar nearby Balance town (7 nm from Palmerston North airport) and one secondary surveillance radar nearby Hawkins Hill (73 nm from Palmerston North airport).

The instrument approach procedure for Palmerston North airport stated that the aircraft should remain with Ohakea control until it reported to be visual of Palmerston North airport. Then, the latter should take control of the aircraft. But, Palmerston North airport tower wasn’t equipped with any radar.

7.6.6 Weather information

Fog was encountered by the emergency teams during the search and rescue operations.

7.6.7 Accident location

The aircraft accident occurred at an altitude of 1272 feet and 8 NM from the airport.

7.6.8 Accident site

The wreckage of the aircraft was found on the slope of a hill.

7.6.9 Emergency locator transmitter

The aircraft was equipped with an ELT. Only a weak signal was received by one helicopter.

7.7 American Airlines 965,

Mount “El Deluvio”, Cali, Columbia (1995)

7.7.1 History of flight

On December 20, 1995, American Airlines flight 965 departed Miami international airport in Florida in the United States at 2335 hours after 1 hour 55 minutes of ground delay (All times in GMT, Columbia is GMT – 5 hours). The flight was expected to arrive at Alfonso Bonilla Aragon international airport in Cali in Columbia three hours after its departure from Miami.

After flying through the Cuban airspace and the Jamaican airspace America Airlines Boeing 757 - 200 entered the Colombian airspace. I started its descent at 0226 hours and was in contact with Cali airport approach at 0234 hours.

During its final descent and approach American airlines flight 965 crashed into Mount “El Deluvio” in Columbia at 0242 hours.

7.7.2 Injuries to persons

The Boeing 757-200 was carrying 1 captain, 1 first officer, 6 cabin crew members and 155 passengers. Five passengers, amongst a total of 163 persons on board of the aircraft, survived the crash.

One of the passengers, who survived to the accident, died of its injuries while being at the hospital. According to the aircraft accident investigation, nobody should have survived the crash.

7.7.3 Search timing and organization

- 0241 / This is the last contact with the air traffic controller
- 0242 / American airlines 965 accident time
- 0250 / Notification time of the missing flight to the search team located nearby Cali and Buga
- 0330 / Activation of the Police, the Army, the Red Cross and the Civil Defense in the Buga area
- 1130 / Discovery of the aircraft accident site by an helicopter

7.7.4 Rescue operations

The rescue teams arrived at the aircraft crash site, using helicopters, just after the discovery of the missing aircraft location.

7.7.5 Radar information

There was no approach control radar at Alfonso Bonilla Aragon airport.

7.7.6 Weather information

The visibility was more than 10 kilometres during the search and rescue operations.

7.7.7 Accident location

The aircraft accident occurred at an elevation of 8900 feet and 28 NM from the airport.

7.7.8 Accident site

The aircraft impacted the slope of a mountain covered by forest.

7.7.9 Emergency locator transmitter

The aircraft wasn’t equipped with an ELT.

7.8 Vnukovo airlines VKO 2801,

Operafjellet Mountain, Svalbard, Norway (1996)

7.8.1 History of flight

On August 29 1996, Vnukovo airlines flight VKO 2801 departed Vnukovo airport in Moscow in Russia at 0444 hours. The flight was expected to arrive at Longyear airport in Svalbard in Norway at 0814 hours (All times in GMT, Norway time is GMT + 2 hours).

After flying west of Murmansk, Russia, Vnukovo airlines Tupolev 154 M flew over the Barents Sea. The crew wasn't able to contact Bodo air traffic control centre in Norway in order to get its descent clearance at 0755 hours. The flight started its descent, after contacting Longyear airport AFIS officer at 0756 hours.

During its final approach Vnukovo airlines flight 2801 crashed into Operafjellet Mountain in Svalbard in Norway at 0822 hours.

7.8.2 Injuries to persons

The Tupolev TU-154M was carrying 1 captain, 1 first officer, 1 navigator, 1 flight engineer, 7 cabin crew members and 130 passengers. None of the 141 persons on board of the aircraft survived the crash.

7.8.3 Search timing and organization

- 0817 / This the last contact with the air traffic controller
- 0822 / Vnukovo airlines 2801 accident time
- 1006 / Discovery of the aircraft crash site by an helicopter

7.8.4 Rescue operations

The rescue operations details aren't provided by the aircraft accident investigation report.

7.8.5 Radar information

The airport wasn't equipped with a radar facility.

7.8.6 Weather information

The search and rescue operations were conducted under low level clouds meteorological conditions.

7.8.7 Accident location

The aircraft accident occurred at an altitude of 2975 feet and 8 NM from the airport.

7.8.8 Accident site

The aircraft hit the slope of a mountain covered by snow.

7.8.9 Emergency locator transmitter

The aircraft was not equipped with an ELT.

7.9 TANS Peru 204,

La Florida, Pucallpa, Ucayali, Peru (2005)

7.9.1 History of flight

On August 23 2005, TANS Peru flight 204 departed Lima, Peru, at 1924 hours (All times in GMT, Peru time is GMT – 5hours). The flight was expected to arrive at Pucallpa, Peru.

TANS Peru Boeing 737-200 reached its cruise level of FL 330, at 1941 hours. Then, it started its descent, at 1952 hours.

During its final approach to Pucallpa TANS flight 204 crashed nearby Pucallpa airport in Peru at 2009 hours.

7.9.2 Injuries to persons

The Boeing 737-200 was carrying 1 captain, 2 first officers, 4 cabin crew members and 91 passengers. Fifty eight persons, amongst a total of 98 persons on board of the aircraft, survived the crash.

7.9.3 Search timing and organization

- 2009 / TANS 204 accident
- 2014 / Pucallpa Air traffic controllers informs the rescue services that they have lost contact with the aircraft
- 2055 / Confirmation is received that the aircraft has made an emergency landing 7 kilometres away from the runway

7.9.4 Rescue operations

After giving the confirmation of the aircraft wreckage site the security services informed the air traffic control that the aircraft was in fire at around 2120UTC. Following this the rescue services went to the aircraft accident site.

7.9.5 Radar information

Pucallpa air traffic control tower wasn't equipped with radar facilities.

7.9.6 Weather information

According to the aircraft accident investigation report, there were some thunderstorms and cumulonimbus clouds.

7.9.7 Accident location

The aircraft accident occurred at sea level 4 NM from the airport.

7.9.8 Accident site

The aircraft impacted the ground in a flat area covered by tropical forest.

7.9.9 Emergency locator transmitter

The aircraft was equipped with an ELT. The aircraft accident investigation report doesn’t give any explanations concerning the non transmission of signals by the equipment.

7.10 Gol transportes aereos 1907,

Peixoto de Azevedo, Mato Grosso state, Brazil (2006)

7.10.1 History of flight

On September 29 2006, Gol transportes aereos flight 1907 departed Eduardo Gomes international airport in Manaus in Mato Grosso state in Brazil at 1835 hours (All times in GMT, Brazil Mato Grosso state time is GMT – 3 hours). The flight was expected to arrive at Rio de Janeiro international airport in Rio de Janeiro state in Brazil after a technical stop at Brasilia international airport in Brazil capital.

During its cruise Gol transportes aereos Boeing 737-300 collided with another aircraft flying in an opposite direction at flight level FL370 over Mato Grosso Brazil state, at 1956 hours.

7.10.2 Injuries to persons

The Boeing 737-800 was carrying 6 crew members and 148 passengers. None of them survived the crash.

7.10.3 Search timing and organization

According to the aircraft accident investigation report the Boeing 737 missing aircraft was found September 30, one day after the crash.

7.10.4 Rescue operations

The aircraft accident investigation report doesn't provide any information concerning the rescue operations.

7.10.5 Radar information

Brazil provides radar coverage for its entire aerospace. It is not clear why the air traffic controllers weren't able to provide data concerning the missing aircraft to the emergency services, according the aircraft accident investigation report.

7.10.6 Weather information

According to the aircraft accident report, there was a clear sky at the time of the accident.

7.10.7 Accident location

The aircraft accident occurred at sea level and at more than 100 kilometres away from the nearest airport.

7.10.8 Accident site

The wreckage was located in a dense rain forest zone of the Amazonian region of Brazil.

7.10.9 Emergency locator transmitter

The aircraft was equipped with an ELT. The equipment didn’t emit any signals because the G- forces received were too low.

7.11 Kenya Airways 507,

Mbanga Pongo, Douala, Cameroon (2007)

7.11.1 History of flight

On May 4 2007, Kenya Airways flight KQA 507 departed Douala international airport in Cameroon towards Jomo Kenyatta airport Nairobi Kenya at 2306 hours (All times in GMT, Cameroon time is GMT + 1 hour).

The aircraft crashed during its initial climb on May 5 nearby Douala international airport in Cameroon at 2308 hours.

7.11.2 Injuries to persons

The Boeing 737-800 was carrying 9 crew members and 105 passengers. None of them survived crash.

7.11.3 Search timing and organization

- 1630 / On May 6 the aircraft wreckage is found

7.11.4 Rescue operation

The aircraft accident investigation report doesn’t give any information concerning the rescue operations.

7.11.5 Radar information

Douala airport wasn’t equipped with radar facilities at that time.

7.11.6 Weather information

The visibility was good during the search operations with some thunderstorms moving away from Douala airport vicinity.

7.11.7 Accident location

The aircraft accident occurred at sea level 3 NM from the airport.

7.11.8 Accident site

The aircraft wreckage was found in dense rain forest.

7.11.9 Emergency locator transmitter

The aircraft was equipped with the latest generation of emergency locator transmitter that transmits on 406 MHz. It was damaged during the accident.

7.12 Merpati Nusantara airline 9760,

Ambisil, Papua, Republic of Indonesia (2009)

7.12.1 History of flight

On August 2, 2009 Merpati Nusantara airlines flight 9760 departed Sentani airport in Papua in the Republic of Indonesia at 0115 hours (All times in GMT, East Indonesia time is GMT + 9 hours). The flight was expected to arrive at Oksibil airport in Papua in the Republic of Indonesia, at 0205 hours.

During its final descent and approach Merpati Nusantara airline De Havilland DHC-6 crashed into a mountain near Ambisil in Papua in the Republic of Indonesia.

7.12.2 Injuries to persons

The De Havilland DHC-6 was carrying 1 captain, 1 first officer, 1 engineer and 12 passengers. None of them survived the crash.

7.12.3 Search timing and organization

- 0150 / This is the last contact of the missing aircraft with an Indonesian Air Force aircraft
- xxxx / Merpati Nusantara airline 9760 accident time
- 0405 / Estimated time of aircraft running out of fuel
- 0405 / the search starts
- 0630 / The search postponed to August 3 due to bad weather
- xxxx / August 3 / Search resumed
- xxxx / August 3 / Search starts for an ELT signal, but no return
- xxxx /August 3 / The missing aircraft has been seen flying by villagers, helping to narrow the search area.
- 2120 / August 4 / The aircraft wreckage is located

7.12.4 Rescue operations

The aircraft accident investigation report doesn't provide any information concerning the rescue operations.

7.12.5 Radar information

Oksibil airport wasn't equipped with an air traffic control tower and consequently with no radar facilities.

7.12.6 Weather information

There were clouds on the mountains.

7.12.7 Accident location

The accident occurred at an elevation of 9300 feet and 6 NM from the airport.

7.12.8 Accident site

The aircraft impacted the mountain in a remote high altitude mountainous area surrounded by jungle.

7.12.9 Emergency locator transmitter

The aircraft was equipped with a 243 MHz / 121.5 MHz ELT. But, no signal was received by the search aircraft even if the ELT wasn't damaged during the accident. The equipment wasn't serviceable due to a lack of inspection.

7.13 Airlines of Papua New Guinea 4684,

Kokoda, Papua New Guinea (2009)

7.13.1 History of flight

On August 11, 2009 Airlines of PNG, flight 4684, departed Jackson international airport in Port Moresby in Papua New Guinea, at 0052 hours (All times in GMT, Papua New Guinea time is GMT + 10 hours). The flight was expected to arrive at Kokoda airstrip in Papua New Guinea, at 0120 hours.

The De Havilland DHC-6 of Airlines of PNG crashed during its descent into a mountain in the vicinity of Kokoda airstrip in Papua New Guinea at 0113 hours.

7.13.2 Injuries to persons

The De Havilland DHC-6 was carrying 1 captain, 1 first officer and 11 passengers. None of them survived the crash.

7.13.3 Search timing and organization

- 0111 / This is the last contact with the air traffic control
- 0113 / Airlines of PNG 4684 accident time
- 0114 / Port Moresby air traffic control tries to contact the missing aircraft
- 0135 / Confirmation by another aircraft of the company that the aircraft hasn't arrived to Kokoda
- 0136 / The search and rescue alert phase is activated
- 0225 / The search and rescue distress phase is activated
- xxxx / Two private helicopters start some search
- xxxx / A SAR aircraft Dornier 328 flies from Cairns Australia to Papua New Guinea late in the afternoon
- xxxx / The Dornier 328 aircraft overflies Kokoda while en route to Port Moresby from Australia. The missing aircraft is not found during the evening. The search is stopped until the next morning.
- 2147 / The search is resumed and the Dornier receives an ELT signal
- 2210 / The aircraft accident location is found by a SAR helicopter

7.13.4 Rescue operations

The aircraft accident investigation report doesn’t provide any information concerning the rescue operations.

7.13.5 Radar information

Kokoda airstrip had no air traffic control. There was only a flight service area, but not located at Kokoda airstrip.

7.13.6 Weather information

There were clouds on the mountain.

7.13.7 Accident location

The accident occurred at an altitude of 5,780 feet and 5.9 NM from the airport.

7.13.8 Accident site

The aircraft impacted the mountain in a remote high altitude mountainous area surrounded by jungle.

7.13.9 Emergency locator transmitter

The aircraft was equipped with an ELT. The signal was weak due to the damaged antenna.

8 Search operations duration analysis

It is never known in advance how long the search operations for a missing aircraft will last for after an aircraft accident. The duration depends mainly on the same following factors: radar availability at arrival or nearest airport, emergency locator transmitter operations, altitude of occurrence, weather during search operations, wreckage location, phase of flight, distance from nearest airport and time of occurrence.

8.1 Methodology

For this analysis the twelve aircraft accidents described in “the history of commercial accidents with search operations” have been chosen. They all have the same particularity: search operations were required to find the missing aircraft. The survey starts in 1979 with Air New Zealand aircraft accident in Antarctica and ends in 2009 with Airlines of Papua New Guinea aircraft accident in Papua New Guinea.

Table 1: Aircraft accidents

AIRLINES	DATE	LOCATION	FATALITIES SURVIVORS
Air New-Zealand	1979	Antarctica	257 NONE
Dan Air Services	1980	Canary Islands Spain	146 NONE
Inex Adria Aviopromet	1981	Corsica Island France	180 NONE
Air Inter	1992	France	87 9
Ansett New-Zealand	1995	New-Zealand	4 17
American Airlines	1995	Columbia	159 4
Vnukovo Airlines	1996	Svalbard Island Norway	141 NONE
Tans Peru	2005	Peru	40 58
Gol Transportes Aéreos	2006	Brazil	154 NONE
Kenya Airways	2007	Cameroon	154 NONE
Merpati Nusantara Airlines	2009	Papua Republic of Indonesia	15 NONE
Airlines of Papua New Guinea	2009	Papua New Guinea	13 NONE

Firstly it can be said that aircraft accidents with search and rescue operations have no particular preferred occurrence locations. They can happen everywhere: in very remote areas or on the contrary in very populated areas.

Secondly on the contrary to what someone could think passengers and crew members of an aircraft can survive an aircraft crash. It seems to be that there is no direct relation between the occurrence location and the probability of having survivors. It cannot be stated that an occurrence happening in a remote area gives less chance to survivors to survive than in a populated area.

Table 2: Search time

AIRLINES	SEARCH TIME	SEARCH TIME GROUP
Ansett New-Zealand	0.58	SHORT
Tans Peru	1	SHORT
Vnukovo Airlines	1.44	SHORT
Air Inter	4.16	SHORT
Dan Air Services	4.38	SHORT
Inex Adria Aviopromet	4.47	SHORT
American Airlines	8.49	MEDIUM
Air New-Zealand	12.1	MEDIUM
Airlines of Papua New Guinea	21	LONG
Gol Transportes Aéreos	24	LONG
Kenya Airways	33.3	VERY LONG
Merpati Nusantara Airlines	43.3	VERY LONG

The search time expressed in this table represents the time lapsed (hours & minutes) between the aircraft last contact with the air traffic control and the moment the wreckage was discovered.

Intriguing is the fact that there are no occurrences at all with a search time of less than thirty minutes. It means that on the contrary of what someone may think that is a missing aircraft can be found instantaneously it is not exactly what happens in reality.

Perhaps it could be stated that the occurrences part of the short search time group are those happening within populated areas. But, Vnukovo airlines aircraft accident is located in Svalbard Island, a remote island of Norway.

In the same vein the aircraft accidents part of the very long and long search time groups seems to all have happened in a remote area. But, it cannot be confirmed that it is always the case. Kenya Airways accident happened just nearby the international airport of Douala, Cameroon capital.

It also can be seen that there is a big gap between the shortest search time and the longest search time: more than forty hours. This difference comes from different factors that will be investigated in the following paragraphs.

8.2 Radar availability at arrival or nearest airport

Aircraft accidents can be located at airports, in the vicinity of airports, at some distances from an airport or very far from any airports. The first tool that emergency management teams can use to search a missing aircraft is the latest known information of the flight from the air traffic control.

Air traffic control towers at airports all over the world are normally equipped with radars. This equipment is able to track an aircraft during its entire flight: taxi, take off, climb, cruise, descent, approach and landing.

Radar displays the following main information concerning an aircraft: flight number, speed, flight level and heading.

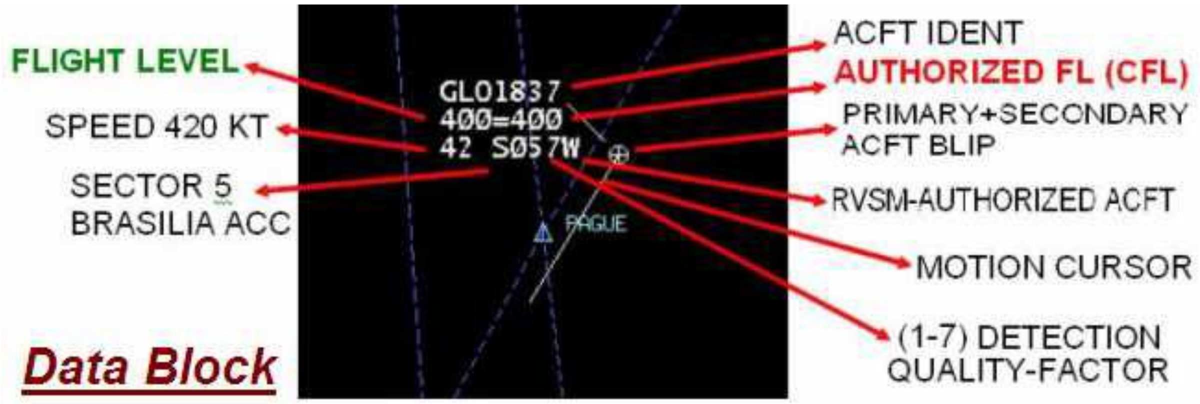

Figure 28: Radar display

(*Source: Centro de Investigação e Prevenção de Accidentes Aeronáuticos 2008*)

When an aircraft is missing the senior air traffic controllers in charge of emergency can provide the aeronautical search and rescue teams with the latest known information concerning the flight. Nowadays radar data are usually available within 15mn. But even so it will only allow delineating a search area but will never give the precise location of an aircraft accident. In the past a long time was sometimes necessary to extract and to analyse the data, sometimes between 40 minutes or even more (Bureau d'Enquêtes et d'Analyses 1993).

But, emergency management for a missing aircraft is not always as simple as it could be thought from the previous paragraph. In fact, the planet is covered by remote areas very difficult of access where people live in settlements. Sometimes small airports operate airstrips in such locations with no air traffic control services provided and consequently no radar coverage. No radars were available for Merpati Nusantara Airlines and Airlines of Papua of New Guinea aircraft accidents respectively in Papua, Republic of Indonesia and Papua. Consequently, the latest information concerning the aircraft was not available leading to very long or long searches (National Transportation Safety Committee 2010; Accident Investigation Commission of Papua New Guinea 2011).

Table 3: Radar availability at arrival or nearest airports

AIRLINES	RADAR AVAILABILITY	SEARCH TIME HOURS AND MINUTES
Air New-Zealand	YES	12.1
Air Inter	YES	4.16
Gol Transportes Aéreos	YES	24
Dan Air Services	NO	4.39
Inex Adria Aviopromet	NO	4.47
Airlines of Papua New Guinea	NO	21
Ansett New-Zealand	NO	0.58
American Airlines	NO	8.49
Vnukovo Airlines	NO	1.44
Tans Peru	NO	1
Kenya Airways	NO	33.3
Merpati Nusantara Airlines	NO	43.3

Airports with no radar facilities can also be located in non-remote areas. In 1980, Dan Air services aircraft accident happened in the Canary Islands that are not considered as a remote area. But, the airport wasn't equipped with radar at that time leading to several hours of search (Spanish Civil Aviation Accident Commission 1981)

Moreover, someone can expect that nowadays all international airports in the world are equipped with radar facilities, but it seems that it is not the case. In 2007, Kenya Airways aircraft accident occurred at the international airport of Douala, Cameroon capital. This airport wasn't apparently equipped with radar. This is one of the causes of the search lasting for almost two days (Cameroon Civil Aviation Authority 2010).

Finally, it should also be noted that there is a big disparity of search times between the aircraft accidents with radar available at airports. Different explanations can be provided. In the case of Air Inter around two hours were necessary to extract the data from the air traffic control tower computers (Bureau d'Enquêtes et d'Analyses 1993). The range of the radar available at McMurdo station was not sufficient to detect the aircraft in Antarctica for Air New-Zealand missing aircraft (Royal Commission 1981).

8.2.1 Radar availability at arrival airport conclusion

Even if non radar availability can be considered as one cause of the lengthy searches it cannot explain why in some cases, for example Merpati Nusantara Airlines the missing aircraft was found after two days of search where on the other hand only one hour was necessary, for example Tans Peru (National Transportation Safety Committee 2010; Comision de Investigacio de Accidentes Aviacion 2006).

In the same manner but on the contrary radar availability at airports doesn't seem to have been of help in shortening the search operations of missing aircraft in the past and even recently.

8.3 Emergency Locator Transmitter operations

In addition to the latest information known of the missing aircraft from the air traffic control radar, the emergency management teams should expect to narrow the search area using the ELT signal received by the Aeronautical Rescue Coordination Centre from one of the Cospas-Sarsat satellites.

Emergency locator transmitters are equipments that send a distress signal upon activation, as previously explained, to the Cospas-Sarsat satellites system dedicated to search and rescue operations. Every commercial aircraft are required to carry such equipment.

At first sight it seems that the carriage of an ELT on board of aircraft wasn't mandatory before the late 90s. In fact all the aircraft accidents that are part of the non carriage of an ELT group happened during that time. But, it also can be noted that different regulations applied as that time to different part of the world. In fact, Air Inter and Ansett New-Zealand aircraft accidents happened respectively in 1992 and 1995 and were equipped with the emergency beacon (Bureau d'Enquêtes et d'Analyses 1993; Transport Accident Investigation Commission 1997). Where on the other hand American Airlines occurrence happened the same year than Ansett New-Zealand but the aircraft was not equipped with an ELT (Aeronautica Civil de la Republica de Colombia 1996). The same comment applies to Vnukovo Airlines aircraft accidents that happened even later on in 1996 (Aircraft accident Investigation Board Norway 1999).

The first group of flights with no emergency locator transmitter shows some difference of search time between each aircraft accidents. It varies from around two hours for Vnukovo airlines (Aircraft accident Investigation Board Norway 1999) to up to twelve hours for Air New-Zealand (Royal Commission 1981).

Table 4: Emergency locator transmitter

AIRLINES	ELT	SEARCH TIME HOURS AND MINUTES
Air New-Zealand	NO	12.1
Dan Air Services	NO	4.39
Inex Adria Aviopromet	NO	4.47
American Airlines	NO	8.49
Vnukovo Airlines	NO	1.44
Air Inter	YES BROKEN	4.16
Tans Peru	YES BROKEN	1
Kenya Airways	YES BROKEN	33.3
Gol Transportes Aéreos	YES	24
Ansett New-Zealand	YES	0.58
Merpati Nusantara Airlines	YES	43.3
Airlines of Papua New Guinea	YES	21

The second group is composed of aircraft that carried an emergency locator transmitter at the time of the accident. But Air Inter and Kenya Airways emergency beacons were damaged during the impact of the aircraft with the ground (Bureau d'Enquêtes et d'Analyses 1993;

Cameroon Civil Aviation Authority 2010) where Tans Peru aircraft ELT didn't emit a signal for unknown reasons (Comision de Investigacio de Accidentes Aviacion 2006).

The four aircraft of the third group were equipped with an ELT. But, for one of them Gol Transportes Aéreos, the ELT didn't send a distress signal because the G forces received by the equipment were too low to activate the beacon (Centro de Investigação e Prevenção de Accidentes Aeronáuticos 2008).

Finally, Cospas-Sarsat satellites system doesn't process anymore the distress signals transmitted on the 121.5 MHz frequency since February 2009. But, there are still some aircraft in the world that carry such equipment. The result is that those aircraft cannot be located using the distress beacon unless if a SAR helicopter or aircraft overflies the area and receives the distress signal. In this case the signal is usually weak. This is exactly what happened to Airlines of Papua New Guinea aircraft and to Ansett New-Zealand aircraft (Accident Investigation Commission of Papua New Guinea 2011; Transport Accident Investigation Commission 1997).

8.3.1 Emergency locator transmitter operations conclusion

Amongst the twelve aircraft accidents seven aircraft were fitted with an emergency locator transmitter. For three of them the equipment was damaged. But, here there is a disparity between the search times: from one hour for Tans Peru (Comision de Investigacio de Accidentes Aviacion 2006) up to almost two days for Kenya Airways (Cameroon Civil Aviation Authority 2010). Consequently, it cannot be stated that the fact that the emergency locator transmitted didn't work was the main cause of the long search time of Kenya Airways (Cameroon Civil Aviation Authority 2010).

In the same vein Vnukovo Airlines aircraft had no ELT but the search lasted for a short time (Aircraft accident Investigation Board Norway 1999) where Air New-Zealand aircraft with also no ELT had its search lasting for much longer (US Navy 1979). Consequently, it can be said that having no ELT on board of an aircraft doesn't necessary mean long searches.

On the other hand, four aircraft had an ELT that was not destroyed during the aircraft accident. It seems that it was of help for Ansett New-Zealand as the search is the shortest of the analysis (Transport Accident Investigation Commission 1997). It also can be said that having an old generation ELT didn't help at all the search teams of Merpati Nusantara Airlines and of Airlines of Papua New Guinea. Both had some of the longest search time

(National Transportation Safety Committee 2010; Accident Investigation Commission of Papua New Guinea 2011).

8.4 Altitude of occurrence

When the emergency teams have delineated a probability area using the latest radar data and the ELT data, whether or not available, the SAR helicopters and aircraft start to search the missing aircraft. Different circumstances will have an impact on the search duration in addition to the two causes aforementioned: firstly the altitude of the occurrence.

Amongst the twelve aircraft accidents three happened at sea level, four at low altitude (under 3.000 feet), three at medium altitude (between 3.000 feet and 6.000 feet) and two at high altitude (more than 6.000 feet).

Table 5: Altitude of occurrence

AIRLINES	ALTITUDE FEET	ALTITUDE GROUP	SEARCH TIME HOURS AND MINUTES
Gol Transportes Aéreos	0	SEA LEVEL	24
Kenya Airways	0	SEA LEVEL	33.3
Tans Peru	0	SEA LEVEL	1
Air New-Zealand	1467	LOW ALTITUDE	12.1
Air Inter	2620	LOW ALTITUDE	44.16
Ansett New-Zealand	1272	LOW ALTITUDE	0.58
Vnukovo Airlines	2975	LOW ALTITUDE	1.44
Dan Air Services	5450	MEDIUM ALTITUDE	4.39
Inex Adria Aviopromet	4500	MEDIUM ALTITUDE	4.47
Airlines of Papua New Guinea	5774	MEDIUM ALTITUDE	21
American Airlines	8900	HIGH ALTITUDE	8.49
Merpati Nusantara Airlines	9300	HIGH ALTITUDE	43.3

It could be said that a search at sea level should be the easiest one and consequently the shortest. But amongst the three sea level accidents Kenya Airways has the second longest search time (Cameroon Civil Aviation Authority 2010) and another Gol Transportes Aéreos has the third longest search time (Centro de Investigação e Prevenção de Accidentes Aeronáuticos 2008).

On the other hand a search at high altitude is expected to last for a long time. This is true for the highest altitude occurrence that happened amongst the twelve aircraft accidents: Merpati Nusantara Airlines crashed at 9.300 feet and had the longest search with 33.30 hours (National Transportation Safety Committee 2010). But, this is not true for the other high altitude accident: American Airlines. It happened at 8.900 feet but had a medium length search time of 8.49 hours (Aeronautica Civil de la Republica de Colombia 1996).

It also should be underlined that three of the low altitude occurrences belong to the short search time group. Two of them have the shortest search time: Ansett New Zealand with 0.58 hours (Transport Accident Investigation Commission 1997) and Tans Peru with 1.00 hour (Comision de Investigacio de Accidentes Aviacion 2006).

Moreover two of the three medium altitude occurrences amongst the twelve aircraft accidents are related to the short search time group. But, within that group the third occurrence has the fourth longest search time: Airlines of Papua New Guinea. Its search lasted for 21.00 hours (Accident Investigation Commission of Papua New Guinea 2011).

8.4.1 Altitude of occurrence conclusion

According to the aforementioned analysis of the occurrence altitude of the twelve aircraft accidents it seems that there is no proportionality link between the altitude of an occurrence and its search time. It could be expected that because the aircraft accident happened at sea level everybody should be able to see it and consequently the search time will be short. But the previous examples have shown that it is incorrect. It cannot be demonstrated that at sea level aircraft accidents would have a short search time and that a high altitude aircraft accident would have a very long search time.

8.5 Weather during search operations

The second circumstance that impacts the search duration is the weather encountered by the search and rescue teams during the search operations, poor visibility being the most difficult consequence of harsh weather conditions to cope with.

Amongst the twelve aircraft accidents search operations two were carried out in clear sky conditions, two under thunderstorms conditions, four in cloudy conditions, three out in fog conditions and one in snow conditions.

Within the “Clear sky” group one could expect that those conditions should result in very short search operations. But, this is not what happened: American Airlines had a medium search of more than eight hours (Aeronautica Civil de la Republica de Colombia 1996) and Gol Transportes Aéreos had a long search of twenty four hours (Centro de Investigação e Prevenção de Accidentes Aeronáuticos 2008).

Intriguing is the second group “Thunderstorm” with a big difference of search time between Tans Peru occurrence and Kenya Airways occurrence: one hour only for the first aircraft accident and more than a day for Kenya Airways accident (Comision de Investigacio de Accidentes Aviacion 2006; Cameroon Civil Aviation Authority 2010).

Table 6: Weather during search operations

AIRLINES	WEATHER	SEARCH TIME HOURS AND MINUTES
Air New-Zealand	SNOW	12.1
Air Inter	FOG	4.16
Dan Air Services	FOG	4.39
Ansett New-Zealand	FOG	0.58
Inex Adria Aviopromet	CLOUDS	4.47
Airlines of Papua New Guinea	CLOUDS	21
Merpati Nusantara Airlines	CLOUDS	43.3
Vnukovo Airlines	CLOUDS	1.44
Tans Peru	THUNDERSTORM	1
Kenya Airways	THUNDERSTORM	33.3
Gol Transportes Aéreos	CLEAR SKY	24
American Airlines	CLEAR SKY	8.49

In the same manner than the “Thunderstorm” group there is a big difference of search time between the flights within the “Clouds” group: Merpati Nusantara Airlines had two days search (National Transportation Safety Committee 2010) but Vnukovo Airlines had only two hours (Aircraft accident Investigation Board Norway 1999). In this case the term “clouds” means low level clouds that are usually found in mountainous area and that prevent to see the terrain. They can stay in the same location for hours or days especially in tropical or equatorial regions. This could be one of the reasons of the lengthy searches of Airlines of Papua New guinea and Merpati Nusantara Airlines.

Moreover it is obvious that search operations will be more difficult where fog conditions are prevailing. But it can be noted that there is a difference of three hours within than group between the shortest and the longest search: Ansett New-Zealand lasted for only one hour (Transport Accident Investigation Commission 1997) where Dan Air Services search ended after more than four hours (Spanish Civil Aviation Accident Commission 1981).

Finally it is known that when it is snowing the visibility usually decreases at the same time making search operations more difficult. It can be said that it was one of the main circumstances of Air New-Zealand lengthy search: twelve hours (US Navy 1979).

8.5.1 Weather during search operations conclusion

It is logic to say that harsh weather conditions encountered during search operations could increase the length of the searches. But, it should be underlined that the best weather conditions didn’t lead to the shortest searches and that the worst didn’t lead to the longest searches. It cannot be stated that there is a direct connection between the search duration and the weather conditions encountered during the searches.

8.6 Wreckage location

The third circumstance that has an impact on the search duration is the location of the wreckage. Amongst the twelve aircraft accidents three happened in lowlands, one in a hill and eight in mountains.

Within the lowlands group two were located in rain forest. This could be the major circumstance of both aircraft accidents search length: respectively one day for Gol Transportes Aéreos and more than a day for Kenya Airways (Centro de Investigação e Prevenção de Accidentes Aeronáuticos 2008; Cameroon Civil Aviation Authority 2010). A wreckage within and under the cover of the rain forest must be difficult to see from a search and rescue aircraft. But on the other hand the tropical forest that is not as dense as the rain forest combined with the lowlands seems to not have had the same impact on the search time with only one hour for Tans Peru occurrence (Comision de Investigacio de Accidentes Aviacion 2006).

The third group "Mountain" shows a big disparity of search time within the group of aircraft accidents. It seems that the mountain and tropical forest together is the worst combination within that group. It could explain why the search of Merpati Nusantara Airlines and Airlines of Papua New Guinea aircraft lasted so long: respectively more than two days and almost a day (National Transportation Safety Committee 2010; Accident Investigation Commission of Papua New Guinea 2011).

Table 7: Wreckage location

AIRLINES	WRECKAGE LOCATION	WRECKAGE LOCATION CATEGORY	SEARCH TIME HOURS AND MINUTES
Tans Peru	TROPICAL FOREST	LOWLANDS	1
Kenya Airways	RAIN FOREST	LOWLANDS	33.3
Gol Transportes Aéreos	RAIN FOREST	LOWLANDS	24
Ansett New-Zealand	NO VEGETATION	HILL	0.58
Dan Air Services	FOREST	MOUNTAIN	4.39
American Airlines	FOREST	MOUNTAIN	8.49
Inex Adria Aviopromet	FOREST	MOUNTAIN	4.47
Vnukovo Airlines	SNOW NO VEGETATION	MOUNTAIN	1.44
Air New-Zealand	SNOW NO VEGETATION	MOUNTAIN	12.1
Air Inter	SNOW + FOREST	MOUNTAIN	4.16
Merpati Nusantara Airlines	TROPICAL FOREST	MOUNTAIN	43.3
Airlines of Papua New Guinea	TROPICAL FOREST	MOUNTAIN	21

Also it should be underlined the difference of search time between two aircraft accidents, Vnukovo Airlines and Air New-Zealand that have the same wreckage location: mountain covered by snow and no vegetation. It could be said that the 10 hours difference probably comes from the fact that Air New-Zealand crashed in a very remote area, Antarctica where Vnukovo Airlines crashed only in a remote area (Transport Accident Investigation Commission 1980; Aircraft accident Investigation Board Norway 1999).

Finally, still within the third group the combination of forest and mountain with or without snow seems to have had the same impact on the searches of Dan Air Services, Inex Adria Aviopromet and Air Inter wreckages with an average of 4 hours (Spanish Civil Aviation Accident Commission 1981; Bureau Enquêtes Accidents 1983; Bureau d'Enquêtes et d'Analyses 1993) except for American Airlines occurrence (Aeronautica Civil de la Republica de Colombia 1996).

8.6.1 Wreckage location conclusion

It appears from the analysis of the wreckage location that either the combination of the tropical forest and the mountain or the combination of the rain forest and the lowlands could have been the major circumstances of the long search duration. Whether it is easier to search in mountainous areas within tropical forest or in lowlands within rain forest it cannot be said. But, it should also be underlined that this cannot explain everything, as the search duration almost double from one aircraft accident to another one within both groups.

On the other hand it can be stated that the best circumstance for the wreckage location to be found quickly is when the occurrence happened on a hill not covered by some vegetation. But, the same could be said when the occurrence happened in lowlands covered by tropical forest.

Consequently, it is certain that the location of the wreckage has an impact on the search time. But it cannot be demonstrated that the search time increases proportionally with the increase of the level of difficulties of the terrain encountered during the search operations.

8.7 Phase of flight

The fourth circumstance that can have an impact on the search operations is within which phase of flight the aircraft accident happened. The phases of flight are directly linked with the distance from the departure and the arrival airport.

Boeing (2010) has defined nine phases of flight that it uses to produce statistics of aircraft accidents: taxi, take off, initial climb, climb, cruise, descent, initial approach, final approach and landing.

Amongst the twelve aircraft accidents one happened in initial climb, one in cruise, five in descent, two in initial approach and three in final approach.

Normally an aircraft wouldn't have travelled a long distance during its initial climb and consequently its wreckage would be located very close to the airport of departure. Therefore it should be easy to find it. Intriguing is the fact that the aircraft that crashed during its initial climb has the second longest search time: Kenya Airways search lasted for 33.30 hours. Even if the wreckage was located very close to the airport it wasn't found within minutes (Cameroon Civil Aviation Authority 2010).

The only aircraft accident that happened in cruise has the third longest search time: Gol Transportes Aéreos search lasted for 24.00 hours (Centro de Investigação e Prevenção de Acidentes Aeronáuticos 2008). That could be understandable as the search area that has been defined must has been of great size.

Table 8: Phase of flight

AIRLINES	PHASE OF FLIGHT GROUP	SEARCH TIME HOURS AND MINUTES
Kenya Airways	INITIAL CLIMB	33.3
Gol Transportes Aéreos	CRUISE	24
Air New-Zealand	DESCENT	12.1
Dan Air Services	DESCENT	4.39
American Airlines	DESCENT	8.49
Merpati Nusantara Airlines	DESCENT	43.3
Airlines of Papua New Guinea	DESCENT	21
Inex Adria Aviopromet	INITIAL APPROACH	4.47
Air Inter	INITIAL APPROACH	4.16
Ansett New-Zealand	FINAL APPROACH	0.58
Vnukovo Airlines	FINAL APPROACH	1.44
Tans Peru	FINAL APPROACH	1

Within the "Descent" group two accidents are related to the same search time group: medium with an average of 10 hours search time. Two others are linked to either the long search time group or even the very long search time group. It appears that there is no coherence between the search times within that group.

It is interesting to note that the two aircraft accidents during the initial approach phase are related to the short search time group. But, they have the highest search time within that group: 4.16 hours for Air Inter (Bureau d'Enquêtes et d'Analyses 1993) and 4.47 hours for Inex Airlines (Bureau Enquêtes Accidents 1983). One could have expected that because of the proximity of the arrival airport the searches would have been much shorter.

Logically the aircraft accidents during the final approach phase have the shortest search time: 0.58 hours for Ansett New-Zealand (Transport Accident Investigation Commission 1997), 1.00 hours for Tans Peru (Comision de Investigacio de Accidentes Aviacion 2006), and 1.44 hours for Vnukovo Airlines (Aircraft accident Investigation Board Norway 1999).

8.7.1 Phase of flight conclusion

Some logic appears in this analysis: the aircraft that crashed during their final approach have the shortest search time. The same logic seems to apply as well to the initial approach group that also has short search times. But, in this case the average search time is of 4 hours. One could expect than an aircraft in initial approach that is less than 25 NM from the arrival airport won't need such amount of time to be found. But what is not logical at all is the length of the search of the only aircraft that is part of the initial climb group.

8.8 Distance from nearest airport

The distance from the nearest airport is the fifth circumstance that may have an impact on the search operations. Amongst the twelve aircraft accidents five happened very close to the arrival or departure airport, four close to, two far from and one very far from.

Surprising is the fact that the three longest searches are found within the "Very close" group. Kenya Airways aircraft accident was located only 3 NM from the airport but its search lasted for more than one day (Cameroon Civil Aviation Authority 2010). One could expect that an occurrence happening so close to an international airport will need only a few minutes to locate the aircraft.

Perhaps someone who is not aware of the facts will say that the same logic should also apply to both Merpati Nusantara Airlines and Airlines of Papua New Guinea aircraft accidents that respectively had more than a day search and almost one day search. But, in these cases it is different as both occurrences happened in very remote areas (National Transportation Safety Committee 2010; Accident Investigation Commission of Papua New Guinea 2011).

It should also be underlined that there is only one aircraft in that group, Tans Peru that follows the logic of having a very short search: one hour. It was located only 6NM from the airport (Comision de Investigacio de Accidentes Aviacion 2006).

Within the second group of occurrences there is a difference of one hour between two aircraft accidents that happened at the same distance from the nearest airport. One explanation could be that Vnukovo Airlines occurrence happened in a remote area where Ansett New-Zealand didn’t (Aircraft accident Investigation Board Norway 1999; Transport Accident Investigation Commission 1997).

Table 9: Distance from nearest airport

AIRLINES	AIRPORT DISTANCE NAUTICAL MILES	AIRPORT DISTANCE GROUP	SEARCH TIME HOURS AND MINUTES
Kenya Airways	3	VERY CLOSE	33.3
Tans Peru	4	VERY CLOSE	1
Dan Air Services	6	VERY CLOSE	4.39
Merpati Nusantara Airlines	6	VERY CLOSE	43.3
Airlines of Papua New Guinea	6	VERY CLOSE	21
Vnukovo Airlines	8	CLOSE	1.44
Ansett New-Zealand	8	CLOSE	0.58
Air Inter	10	CLOSE	4.16
Inex Adria Aviopromet	13	CLOSE	4.47
Air New-Zealand	26	FAR	12.1
American Airlines	28	FAR	8.49
Gol Transportes Aéreos	> 100	VERY FAR	24

In the same group two aircraft accidents needed a double amount of search time compared to the two previous occurrences. But, they happened only just a few nautical miles farther than the other occurrences not even within a double distance from the airport. In the case of Air Inter flight the occurrence was close to a French major city called Strasbourg (Bureau d’Enquêtes et d’Analyses 1993).

It should be underlined that the aircraft accidents within the “Far” group have a shorter search time that most of the occurrences within the “Very close” group.

Within the twelve aircraft accidents only Gol Transportes Aéreos happened very far from an airport: more than 100 NM (Centro de Investigação e Prevenção de Acidentes Aeronáuticos 2008). But when compared to Merpati Nusantara Airlines and Kenya Airways its search was shorter (National Transportation Safety Committee 2010; Cameroon Civil Aviation Authority 2010).

8.8.1 Distance from nearest airport conclusion

It seems that in some cases the closest to an airport the aircraft accident happened to an aircraft the longest is the search. Also it can be said that far occurrences from an airport proportionally don't have a lengthy search. But, what appears is that there is no real coherence within each group and between the different groups. Consequently, it cannot be stated that there is direct connection between the distance of the nearest airport with an aircraft accident location and the time used to find the wreckage.

8.9 Time of the occurrence

The sixth and last circumstance that could impact an aircraft' accident search duration is the time of the day when the occurrence happened. Amongst the twelve aircraft accidents nine happened during the day and three during the night.

There are some big differences of duration between the search times during the day. Usually search operations are either stopped at sunset or slowed during the night. As a result search operations last longer.

Gol Transportes Aéreos aircraft accident happened just before sunset. This can explain why the search lasted so long, one day and why the aircraft was found only the next day (Centro de Investigação e Prevenção de Acidentes Aeronáuticos 2008).

Table 10: Time of occurrence

AIRLINES	TIME OF OCCURRENCE	SEARCH TIME HOURS AND MINUTES
Air New-Zealand	DAY	12.1
Dan Air Services	DAY	4.39
Ansett New-Zealand	DAY	0.58
Inex Adria Aviopromet	DAY	4.47
Airlines of Papua New Guinea	DAY	21
Merpati Nusantara Airlines	DAY	43.3
Vnukovo Airlines	DAY	1.44
Gol Transportes Aéreos	DAY	24
Tans Peru	DAY	1
Air Inter	NIGHT	4.16
Kenya Airways	NIGHT	33.3
American Airlines	NIGHT	8.49

On the other hand Merpati Nusantara Airlines didn't happen before sunset but around mid-day. Not only the aircraft wasn't found during the afternoon but also it wasn't found during the next day. Consequently the search included two nights but it doesn't explain why the wreckage couldn't be found during the first and the second day (National Transportation Safety Committee 2010).

Searches in night conditions are very difficult because of the decrease of visibility. Consequently additional time is needed compared to the searches during the day.

This could be one of the causes of Air Inter and American Airlines lengthy searches. Air Inter aircraft accident happened in late afternoon but because it was during winter it was already dark (Bureau d'Enquêtes et d'Analyses 1993) where in the case of American Airlines the accident happened during the night (Aeronautica Civil de la Republica de Colombia 1996).

On the other hand Kenya Airway happened just after midnight. The aircraft was found only on the next day. The fact that the aircraft accident happened during the night doesn't explain why it couldn't be found in daylight conditions (Cameroon Civil Aviation Authority 2010).

8.9.1 Time of occurrence conclusion

It is obvious that search operations conducted during a night will be more difficult than those conducted during the day because of the decrease of the visibility. It can be said that sometimes night conditions can have an important impact on the searches but not always. On the other hand it seems that daylight conditions aren't always synonymous of very short or short searches. Consequently, there is no apparent link between the length of the searches and the time of the occurrence.

8.10 Search operations duration analysis conclusion

The success of a search operation depends on the influence of different factors: radar availability at the airport, emergency locator transmitter operations, altitude of occurrence, weather during search operations, wreckage location, phase of flight, distance from nearest airport and time of occurrence.

Unfortunately radars aren't available at all airports all over the world: only three arrival or departure airports were equipped with radar facilities. Where available they haven't shown yet that their uses can shorten the search time. Even if radar data can be extracted quickly using modern technology nowadays that information won't show the exact latitude and longitude of the wreckage of a missing aircraft.

It must be underlined that only seven aircraft were fitted with an emergency locator transmitter, amongst which only four operated properly: thus, the emergency locator transmitter has shown its limits due to its weaknesses that are the high probability of the equipment being damaged during an aircraft accident with the consequences of no distress signals being emitting or the probability of the equipment not being able to record the G-forces having the same effect that the first weakness. Also, in the case of this equipment working properly the emergency transmitter won't give the precise location, in meters, of the occurrence and consequently. It can be said that this beacon isn't 100% reliable.

In addition to these two main causes of non successful search operations are some circumstances. The altitude of the occurrence is the first one. At an average half of the occurrences happened either at medium altitude or at high altitude. The proportionality between the altitude of an occurrence and the duration of a search hasn't been demonstrated: the highest doesn't mean the longest and vice versa the lowest doesn't lead to the shortest searches.

The weather encountered by the emergency teams during the search operations must certainly have had an impact on the duration of the searches: more than an half of the operations were conducted under bad meteorology conditions: snow, fog or low level clouds. But, again it hasn't be demonstrated that this was the direct circumstance leading to long searches.

Not only could the weather have had influenced the searches duration but also the wreckage location: many occurrences have happened in a mountain that was either covered by forest or by snow. But it has been demonstrated that this cannot be considered as a main circumstance all the time as where two aircraft accidents have happened within the same kind of location the same search duration didn’t apply.

Furthermore, it seems that most of the aircraft accidents where search operations were needed either happened during the descent or the approach phase of the flights. In this case coherence appears between the initial and the final approach phase of the aircraft accidents and the search durations: they are the shortest. But on the other hand no logic appears within the other groups. Consequently, it cannot be said that the phase of flight can determine the numbers of hours that will be needed to find one aircraft.

Moreover most occurrences have happened very close or close to an airport. But, it has been shown that there isn’t any apparent logic: an aircraft accident can happen very close to an airport and have a long search and vice versa an aircraft accident happening far from an airport can see its search duration not stand for too long.

Last but not least, most aircraft accidents have happened during the day. But, it appears that for those occurrences the search operations were stopped at sunset due the lack of visibility and consequently to the dangerousness of the operations. Again here there isn’t any logic between the time of the occurrence and the search duration: an accident that happened during the day doesn’t necessary mean short searches. Consequently, it cannot be said what the impact of this factor is on one search.

Finally, the different elements that could have an influence on the search operations duration have been explained. It can be said as for an aircraft accident that it is a long chain of causes and circumstances that will determine the length of a search operation. Also according to the analysis the technology available today seems not to be sufficiently efficient. But, even if some facts can be very well understood they cannot be given as excuses for why some missing aircraft are so long to be found.

Therefore, emergency managers responsible of search and rescue operations definitively need a new tool: seismology could perhaps be that one.

9 Seismology

9.1 Introduction

The science of seismology is used by scientists to explore the different elements that composed the Earth interior with the objective of having a better understanding of the constitution of the different internal layers of the Earth and their interactions. It also analyses the different vibrations recorded on the Earth surface or inside the Earth that may come from an earthquake, a volcano eruption, a mine blast or a sonic boom (Doyle 1995, p. 1).

9.2 History of seismology

Early manuscripts give an indication of the first earthquakes occurrences dated at least 4000 years ago. Early philosophers such as Aristotle wrote on those earth movements given some indications on the past history of the Earth to the scientific community. The inception of the science of seismology can be established in November 1755 during the Lisbon earthquake and it continued in 1889 with the design of the first modern seismology equipment (Ben-Menahem1995)

9.3 Seismology equipment

Seismologists used seismographs buried in the ground to record Earth's vibrations. Three elements composed that equipment: a seismometer that measures the ground motion, an amplifier that amplifies the signals received and a recorder that records the data (Udías 1999, pp. 404-410).

Different pendulums moving horizontally or vertically based on the motion detected by the instrument are located inside the seismometer. By convention the two horizontal components are named "East-West" and "North-South" where the vertical component is named "Z" (Bullen & Bolt 1985, pp. 201-205).

After being measured by the seismometers the ground motions called seismic waves in seismology are recorded on a document named seismogram.

9.4 Seismology principles

Three different types of seismic waves are displayed on a seismogram: first the waves that travel in the Earth namely the P-waves (Primary waves) and the S-waves (Secondary waves) and then the surface waves.

The P-waves travel faster than the S-waves which in turn travel faster than the surface waves. Consequently to their speeds of travel the P-waves are the first to arrive at a seismic station where a seismograph is buried followed very closely by the S-waves and after by the surface waves.

The P-waves and S-waves average speeds have been measured in the past by different seismologists and are recognised now as a standard in the world. The distance of an event from a seismograph is given by measuring on the seismogram the time difference between the P-waves and the S-waves and by multiplying the result by the average speed. The records of three different seismographs will allow by triangulation to determine the location of an occurrence (Davison 1921, p. 159).

9.5 Prestwick airport experiment

9.5.1 Introduction to Prestwick experiment

The next step should be to tell whether or not a seismograph can record an aircraft crash. But before this the following question comes to mind: can a normal aircraft landing at an airport be recorded by a seismograph?

Consequently to this an experiment was conducted at Prestwick international airport located west of Scotland during a day. Two main runways that intersect a right angle at their ends are operated at that airport.

Figure 32: Map of Prestwick airport showing the location of the seismographs

The National Environmental Research Council (NERC) in the UK loaned three GURALP CMG-6TDs seismographs that were buried at the following positions (Figure 32):

- seismograph n°1 on the left hand side of runway 03 touchdown marking zone and 90 meters away from the runway centreline,
- seismograph n°2 on the right hand side of runway 31 touchdown zone and 135 meters away from the runway centreline,
- seismograph n°3 on the left hand side of runway 13 touchdown zone and 123 meters away from the runway centreline.

9.5.2 Prestwick experiment preliminary results

Prestwick international airport air traffic control recorded Cargolux Boeing B747-400 landing on runway 31 at 19.18’ UTC. All the three components of the seismograph n°2 clearly show the aircraft landing around 19.17’.35’’ UTC (Figure 33).

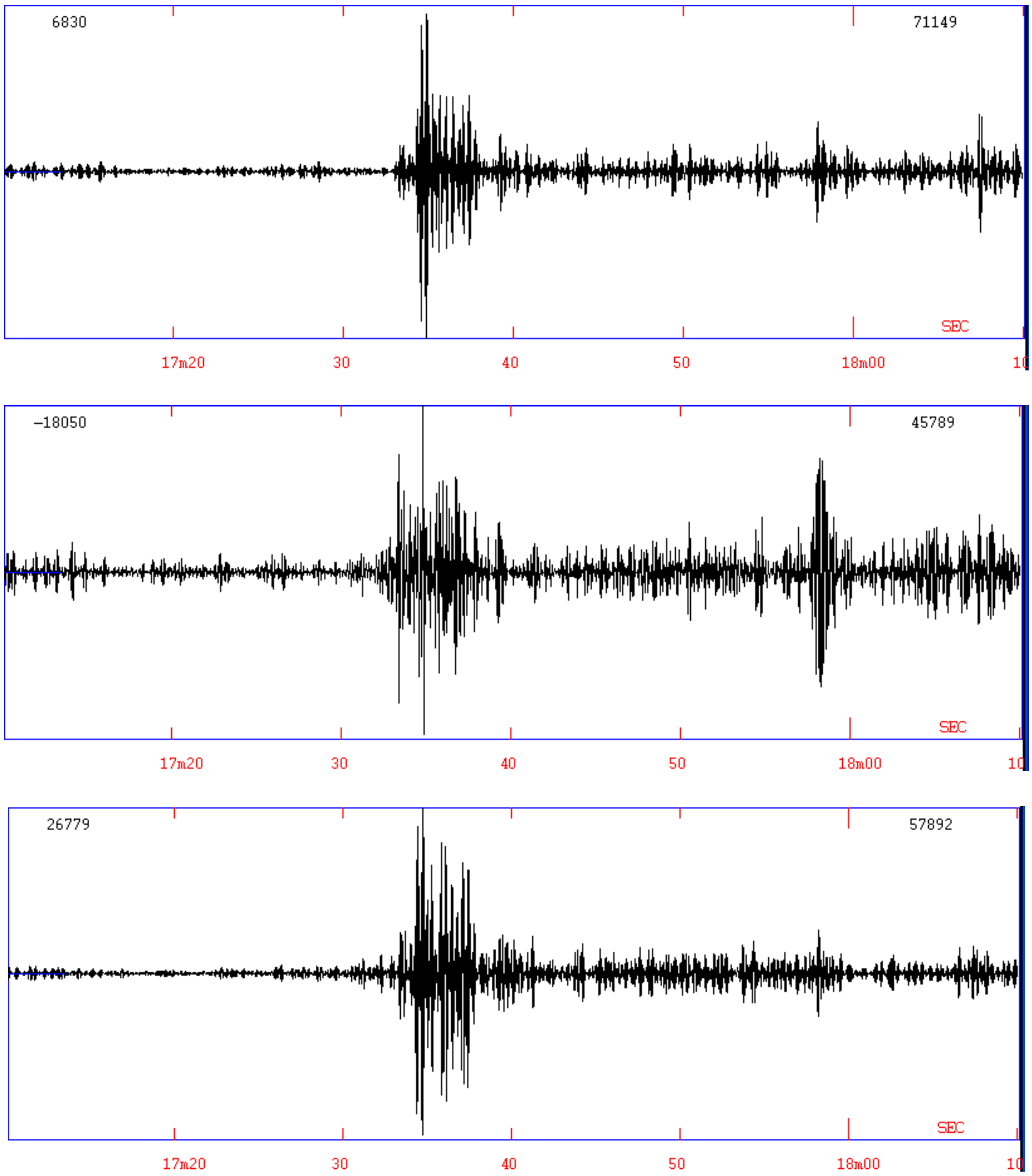

Figure 33: Seismograph n°2, from top to bottom East-West, North-South, and Vertical components, filtered to 10.000-15.000 Hz, time in seconds, displaying Cargolux Boeing B747-400 landing

Another illustration of the experiment is Ryanair Boeing B737-800 landing on runway 13 recorded by the seismograph n°3. The touchdown can be seen perfectly around 08.42’45’’ UTC on each component seismogram where on the other hand the air traffic control data gives the official landing time at 08.43’ UTC (Figure 34).

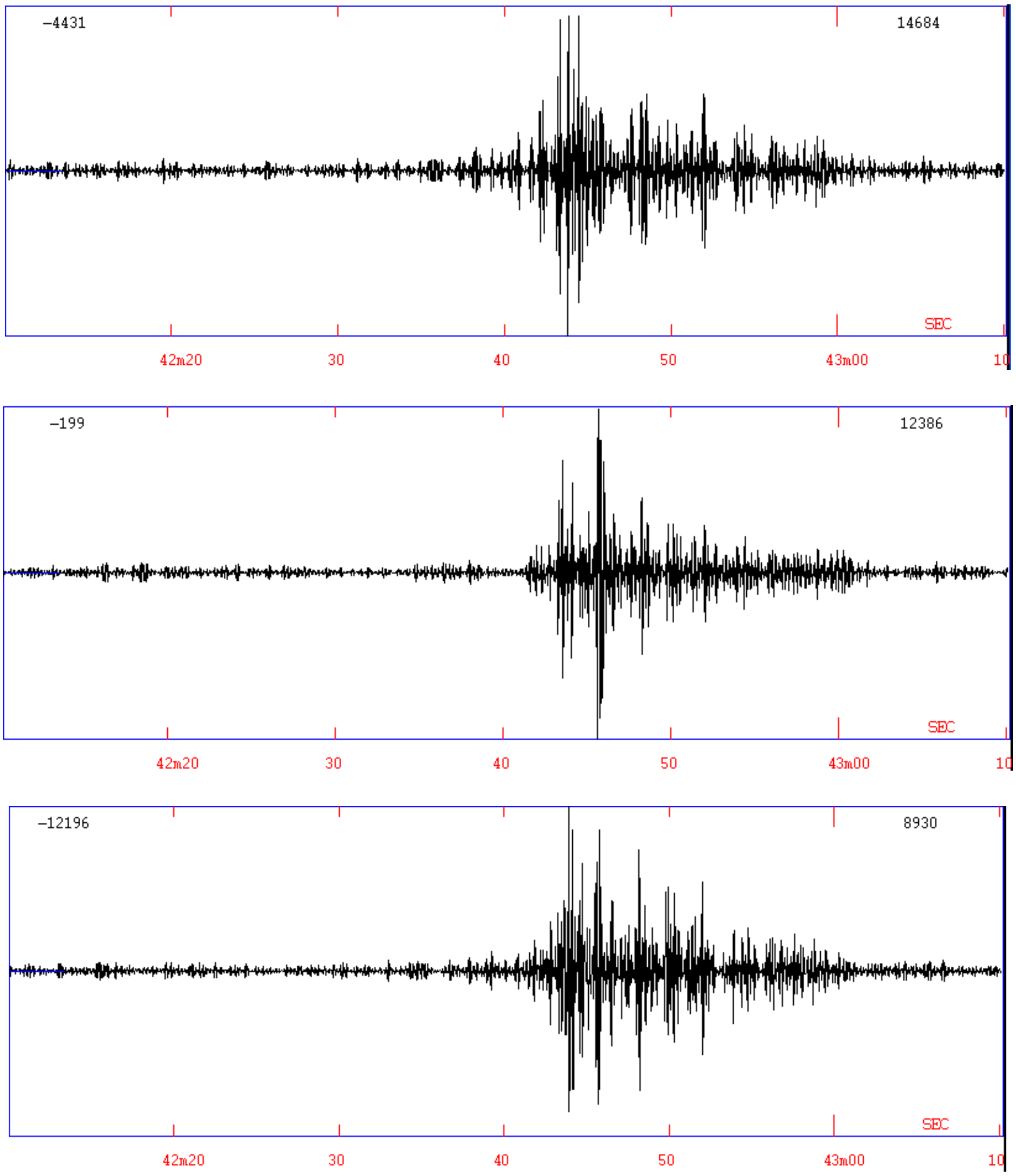

Figure 34: Seismograph n°3, from top to bottom East-West, North-South, and Vertical components, filtered to 10.000-15.000 Hz, time in seconds, displaying Ryanair Boeing B737-800 landing

9.6 Application to aircraft crashes

Following Prestwick experiment a preliminary answer to the question, can an aircraft accident be recorded by a seismograph, could be given by finding an example from the past.

Vnukovo airlines Tupolev TU-154M crashed into the Operafjellet Mountain near Longyear airport in Svalbard Island in Norway on the 29 August 1996. The time of the occurrence was determined by the aircraft investigation board using the seismic data at 08.22'.23'' (Aircraft Accident Investigation Board Norway 1999).

The aircraft accident was recorded by nine seismographs. The impact can be seen very clearly around 08.22'.24'' on each seismograms of the different seismographs vertical components (Figure 35). The investigation report accident time has been corrected by the distance between the event location and the different seismographs.

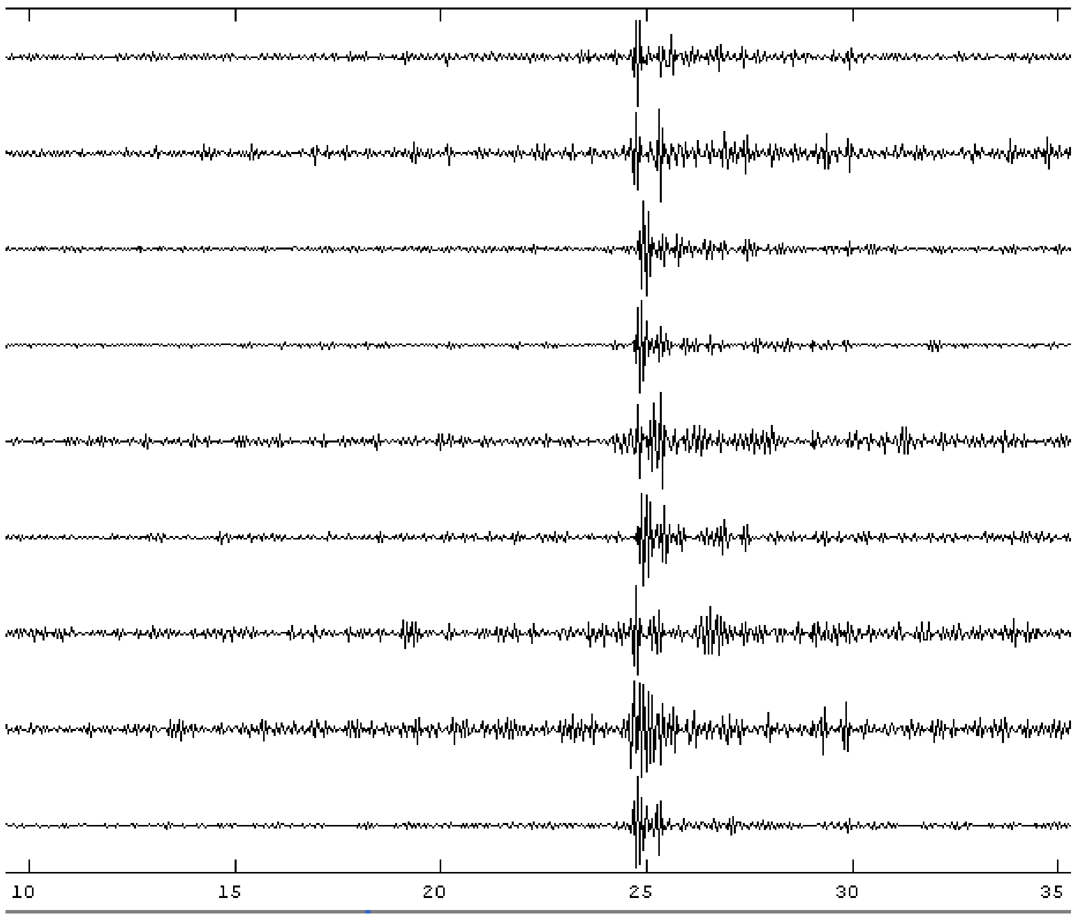

Figure 35: From top to bottom seismograms of seismographs SPA0, SPA1, SPA2, SPA3, SPB1, SPB2, SPB3, SPB4, SPB5, vertical component, filtered 10.000-15.000 Hz, time in seconds, displaying Vnukovo airlines Tupolev impact

9.7 Seismology conclusion

The preliminary results obtained from the experiment conducted at Prestwick international airport in Scotland clearly show some aircraft landing seismic signatures from two different types of aircraft. Consequently, it has been demonstrated that the landing of an aircraft under normal operational conditions can be recorded by a seismograph buried in the ground at an average distance of one hundred meters from the runway centreline.

A first and short investigation of the past aircraft accidents reveals that seismology was used for at least one of them not to locate its wreckage but to find the time of the occurrence. The seismic records from different seismographs display clearly the aircraft accident and a brief examination also gives the precise time of the event. This example demonstrates that an aircraft accident can be recorded using some seismological equipment a few kilometres from the location of the event.

10 Conclusion

Countries in the world signatories of the Chicago Convention are obliged to comply with the international regulations set up by the International Civil Aviation Organization. Amongst their commitments is the obligation to provide aeronautical search and rescue services over their territory. This comprises to delineate one or more aeronautical search and rescue within their country, to establish one aeronautical rescue coordination centre and to set up an appropriate number of aeronautical search and rescue units equipped with the adequate types of air assets.

Despite having set up the appropriate search and rescue services the United Kingdom has recently made the decision to withdrawn from services its long range search and rescue air asset limiting its dedicating task force to helicopters.

The assessment of the different tools available to the emergency managers responsible for the aeronautical search and rescue operations leads to the following conclusions:

- The traditional search techniques are in theory excellent but might be difficult to apply in reality. The meteorological conditions encountered during the searches and the terrain to be overflown will have an impact on the duration. Their successes also depend on the aircrews' skills, training and physical conditions.
- The Cospas-sarsat satellites system is composed of polar orbiting satellites and geostationary satellites. The first category needs to be in view of a ground station to retransmit a distress signal and rely on the Doppler system to find the source of a distress signal. This of course takes a certain amount of time. On the other hand the second category of satellites doesn't cover the polar areas and must rely on an onboard GPS system, if provided, to give the location of a distress beacon. It is also vulnerable to obstacles between its location and the location of an emergency transmitter. Both satellites types don't give the instantaneously and precise Latitude and Longitude of a distress beacon. Finally, the Cospas-sarsat satellites system has stopped to process the 121.5 MHz beacons where some aircraft in the world still carry them leading to a non detection possibility.
- The emergency locator transmitters have shown some weaknesses: it can be damaged or destroyed during an aircraft accident. A certain amount of energy must be released by the aircraft during a certain amount of time to be recorded by the equipment during the impact with the ground. Some of the regulations still don't

recommend the airlines to fit their aircraft with the new generation of emergency locator transmitter despite knowing the end of the processing of the old generation equipment. Finally, some regulations allow the airlines to use a survival beacon type instead of an automatic leading to these questions: how many passengers know that such equipment is on board an aircraft, do they know where it is located and will they know how to use it?

Consequently to the aforementioned conclusions it can be said that the emergency managers cannot rely entirely on those actual aeronautical search tools.

Furthermore, the analysis of twelve aircraft accidents that happened during the past thirty years with the common point of having had search operations leads to the following conclusions:

- Radars aren't always available at airports and even in the case where the airport is equipped with radar it can't give the location of the wreckage of an aircraft within meters but can only be of help to delineate a search area.
- The probabilities of having an emergency locator transmitter operating properly or being part of the new generation are medium. That equipment hasn't demonstrated that it can shorten the search time.
- Different circumstances have an impact on the search duration: the altitude of the occurrence, the weather encountered during the searches, the wreckage location, the phase of the flight, the distance from the nearest airport and the time of the occurrence. Taken separately these various circumstances will have a different impact and influence on the search duration.
- It should be highlighted that most aircraft accidents happened during their descent or approach phases of flight.

Consequently to the aforementioned conclusions it can be said that the success of the search of a missing aircraft will depend on different causes and circumstances. It cannot be demonstrated which circumstance has the most important impact on the search. But, what has been demonstrated is that it is always the same "cocktail" of cause and circumstances that will be encountered by the search and rescue teams.

From those different conclusions comes the following thought: very clever will be the person that at the start of the search operations can state its duration. In fact, searches can be very lengthy as it has been shown.

Consequently, another option, seismology should be taken into consideration. The science of seismology uses seismographs to detect ground motion generated by the release of energy of earthquakes or volcano eruptions, for example.

It has been demonstrated during an experiment conducted at Prestwick international airport that a seismograph can record an aircraft landing during its normal operations. It also has been shown from a past event that seismology can record an aircraft accident nearby the location of the event.

Therefore, according to the following facts:

- the aeronautical search tools aren't sufficiently efficient,
- various causes and factors can influence the search duration,
- all these points together leading to very lengthy searches sometimes
- none of the tools offered to the emergency managers can give an instantaneous and extremely precise location of an aircraft accident
- on the other hand most occurrences happened during the descent or the approach phase of flight that is not far from the destination airport,
- seismology can detect an aircraft accident

aeronautical search and rescue senior managers should take into consideration the science of seismology as an additional tool to minimise the search time of a missing aircraft enhancing the survival probability of aircraft crashes survivors.

11 Future work

Prestwick international airport experiment provided a lot of data. Only two samples of these have been used for this thesis. Interestingly, the seismographs also recorded the aircraft taking off that day. More surprising was the discovery that the helicopters movements including both take off and landing, were also on the seismic records.

Future work will be to analyse the entire data with the aim to demonstrate the following points:

- An aircraft landing can be recorded by a seismograph from different distances, from 100 meters up to 2900 meters representing the diagonal distance between the seismograph n°1 and the seismograph n°3
- An aircraft landing location can be found by triangulation using the data of the same aircraft from the three seismographs
- The difference between the landing seismic signatures of two different aircraft types can be made
- A similarity between the landing seismic signatures of the same aircraft type can be made
- A distinction between an aircraft landing and an aircraft taking off seismic signatures can be made
- A distinction between an aircraft landing and a helicopter landing or taking off seismic signatures can be made
- The comparison between the magnitude obtained with the seismic data and the release of energy obtained from the aeronautical data can be made

Future work also includes an investigation of the actual networks of seismographs country by country. The aim is to determine the best locations of the seismographs to shorten the searches time after an aircraft accident.

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