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AF447 Underwater Search and Recovery Operations
A Shared Government-Industry Process

by

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Author Biographies:

Olivier Ferrante joined the BEA in 2000 as the head of the safety analysis division. In early 2004, he was responsible for coordinating the underwater recovery operation off Sharm el-Sheikh (Egypt) after the Flash Airlines B737 accident. He was detailed to the FAA in 2006 and 2007 to work on data-sharing and risk-modeling under a BEA-FAA cooperation agreement. He also worked with the Commercial Aviation Safety Team (CAST) in the JIMDAT sub-team. Olivier holds a Master's in aviation engineering from the French National Civil Aviation School (ENAC). He is also a pilot and a certified diver. He coordinated the AF447 search and recovery operations from the 1st of June 2009 to the 16th of June 2011. He is currently the Secretary of the European Network of Civil Aviation Safety Investigation Authorities (ENCASIA) for technical aspects.

Michael K. Kutzleb has over 30 years experience in the location and recovery of objects lost in the ocean. Following graduation from college, Mike went to work full time with Seaward, Inc., which then held the US Navy's search and recovery contract. He has participated in over 120 search and recovery projects in all water depths. Nearly 100 of these search and recovery tasks involved searching for lost aircraft in order to assist air safety investigators in determining the cause of the crash. He has hands-on operational experience with all types of search systems as well as ROV systems for recovery operations ranging from small, shallow water inspection ROVs to large work class ROVs capable of operating in water depths to 6000 meters (20,000 feet). In 1997, Mr. Kutzleb started a new marine services company, Phoenix International, Inc., and now serves as its President. Phoenix worked for the BEA in the first three phases of the mission to locate the wreckage from Air France Flight 447 lost off Brazil in 2009, and was hired to recover the flight data and cockpit data recorders, human remains, and other pieces of the aircraft as requested by the onsite investigation team.

Michael Purcell is a Senior Research Engineer in the Oceanographic Systems Lab at the Woods Hole Oceanographic Institution. He has a B.S. from Florida Atlantic University and an M.S. from Massachusetts Institute of Technology, both in Ocean Engineering. Research interests include design, development and testing of underwater vehicles, instruments and systems; ROV handling systems and AUV launch and recovery systems; and material applications in underwater systems. Design accomplishments include the first underwater docking system for REMUS 100, vertical profilers for the LEO-15 underwater observatory, the Martha's Vineyard Coastal Observatory underwater node, the REMUS 6000 AUV and many components of other REMUS AUVs, multiple AUV launch and recovery systems and multiple ROVs. Currently, he also manages the REMUS AUV operations group and led the recent successful search for Air France Flight 447 wreckage in the equatorial Atlantic.

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Abstract

On 1 June 2009, Air France flight AF447, an Airbus A330-203 registered F-GZCP, disappeared over the ocean while flying en route between Rio de Janeiro (Brazil) and Paris-Charles de Gaulle (France). Twelve crew members (3 flight crew, 9 cabin crew) and 216 passengers were on board.

The estimated area of the accident was over the Mid-Atlantic Ridge close to the Equator and more than 500 NM from the coastline. The search efforts had to proceed in an unfavorable environment due to the depth and the topography of the seabed. The bathymetry and currents of this area were little known at the time of the accident. The absence of any trace of the accident in the first days and the absence of an emergency distress message and radar data complicated the search efforts. This was the first time the aviation world and oceanographic specialists had to face such a difficult and challenging search. The wreckage was ultimately discovered at a depth of 3,900 m, 6.5 NM north-north-east of last position transmitted by the airplane, on 3 April 2011 during the fourth search campaign after considerable search efforts .

This paper summarizes the four undersea search campaigns and the recovery campaign undertaken between 1 June 2009 and 16 June 2011. They eventually enabled the recovery of both flight recorders, numerous aircraft parts and human remains (HR). The total cost of the underwater search operations is evaluated at 34.6 million Euros.

The successful recovery of both flight recorders was a major step for the BEA safety investigation. These search efforts to find the wreckage and solve the enigma of the Rio-Paris flight required wide-ranging international government-industry cooperation in which:

- The Woods Hole Oceanographic Institution played a key role in the successful location of the wreckage and
- Phoenix International was instrumental in the search and recovery of the two flight recorders.

It is hoped that the lessons learned by teaming investigators with Industry and the safety recommendations released by the BEA during that process will first prevent the recurrence of the AF447 accident, and in case of accidents at sea, prevent future similar complex and challenging sea search operations.

Introduction

On 1 June 2009, Air France flight AF447, an Airbus A330-203 registered F-GZCP, disappeared over the ocean while flying en route between Rio de Janeiro (Brazil) and Paris-Charles de Gaulle (France).

Beyond radar coverage, the only available indications of the airplane's position were the reporting points transmitted automatically via satellite by the Aircraft Communications Addressing and Reporting System (ACARS). The last known position (LKP) was transmitted at 02 h 10 min UTC. From ACARS messages, it was determined that the airplane flew for a maximum of five additional minutes, which meant that the wreckage had to be within a circle with a radius of 40 NM (75 km) centered on last known position. This area extends over more than 17,000 km² and is situated more than 500 NM from the coastline.

Considerable international air and naval forces were mobilized to search for signs of the airplane and any possible survivors. The first floating debris was identified and recovered on 6 June 2009 within the circle, approximately 70 km to the north of LKP. Floating debris, continuously drifting northward, was found over the next week.

Four undersea search campaigns and one recovery campaign were undertaken which eventually enabled recovery of both flight recorders, numerous aircraft parts and human remains (HR). The operations officially ended on 16 June 2011 when the cable vessel C/V *Ile de Sein* unloaded its containers in Bayonne, France. This was slightly more than two years after the accident.

This paper summarizes the methods and the means used during the five phases of the underwater operations.

I) Summary of Phases 1 through 3 and Preparation of Phase 4

The acoustic searches (known as phase 1) aimed at detecting the acoustic signals transmitted by the Underwater Locator Beacons (ULB) on the recorders. As a priority, a vast zone was swept by Towed Pinger Locator (TPL)[4] along the airplane's projected trajectory as well as the greatest possible area within the Circle. On 22 and 23 June 2009, within the 30 day certified transmission period of the ULBs, the hydrophones were operating in close proximity to the debris field. However, no acoustic signal was detected. The post-recovery examination of the CVR's ULB showed that it was damaged on impact. The other ULB was separated from the FDR and never found. Extensive tests on the recovered beacon showed that it could not transmit with a new battery. There is a strong probability that both pingers were not transmitting when the hydrophones were towed near their location. However, the range and propagation conditions for the acoustic signals at the wreckage site are not known and could have been the reason that no signal was received. The BEA has been studying this issue since the accident.

At the end of the ULB transmission period, the only possible means for locating the wreckage was through the use of sonar detection. A first attempt was made from 27 July to 17 August 2009 (Phase 2) with the IFREMER deep towed side-scan sonar called SAR (operating on 180 kHz). Although this search turned out to be unsuccessful, this phase enabled the BEA to carry out a complete bathymetric survey of the circle (figure 1) thanks to the multibeam echo sounder mounted on the hull of the Research Vessel *Pourquoi Pas?*. This hull-mounted sonar also acquired 12 kHz and 24 kHz acoustic images. The IFREMER team onboard the R/V *Pourquoi Pas?* developed a methodology based on the analysis of the various acoustic images, which was subsequently used during the next search phase.

After Phase 2, it was estimated that covering all of the remaining of the 17,000 km^2 circle would take at least six months. In order to reduce this time, a smaller search zone was defined by evaluating the drift of the debris between the time of impact and the time the floating debris was recovered. To do this, the BEA called upon a group of experts from international oceanographic institutes. The proximity to the equator affects the modeling of the currents in the estimated accident zone. The lack of available in-situ data and the complex

[4] The US Navy's TPLs are the two only towed hydrophones in the world that can operate at up to a depth of 6,000 meters.

oceanic dynamics (notably due to the seasonal start of the north-equatorial counter-current during the month of June) also made it difficult to model the marine currents. These factors contributed to making the reverse-drift computations complex. However, the group was able to define a reduced area of 2,000 km², located to the north-west of LKP which had a high degree of probability of including the site of the impact.

Phase 3 consisted of two search periods onsite: from 2 to 25 April 2010 and from 3 to 24 May 2010. The ORION deep towed sonar and the three REMUS[5] 6000 autonomous underwater vehicles (AUV) operated by the American Woods Hole Oceanographic Institution (WHOI) explored an area of nearly 6,300 km². This search turned out to be unsuccessful as well.

The lack of success during the first three search phases led the BEA to undertake a complete review of both the means used and the zones explored. In particular, to check the predictive ability of the reverse-drift computations, the BEA asked the French navy to drop nine drift buoys in the area of the accident site at the beginning of June 2010. These SLDMB[6] buoys were tracked by satellite to follow the evolutions of surface currents. Their trajectories demonstrated the turbulent nature of the currents in this region and thus the difficulty of predictions.

The BEA also contracted Metron to review the results from the previous searches and to produce a probability map for the location of the underwater wreckage. To accomplish this Metron used SAROPS[7] and a prior distribution based on studies by the BEA and the Russian Interstate Aviation Group (MAK) dealing with nine previous accidents that had occurred while the airplanes were in cruise.

Metron analyzed the effectiveness of Phase 3 side-looking sonar searches and computed an updated probability distribution for the location of the wreckage using the new prior distribution and incorporating the unsuccessful phase 1 and 2 searches, as well as the photos and ROV searches. The unsuccessful aerial and ship searches performed between 1 June and 6 June 2009 were also taken into account.

Analysis of all the results from the previous searches indicated that the zones that had previously been searched using sonar did not need to be explored again. This was why phase 4 was based on the strategy of a systematic search of all of the zones not explored up to then during phase 2 by the IFREMER deep tow sonar and during phase 3 by the REMUS and ORION sonars.

The Metron study[8], published on the BEA website on 20 January 2011, indicated a strong possibility for discovery of the wreckage near the centre of the circle. It was in this area that

[5] Two REMUS 6000 AUV belonged to the Waitt Institute for Discovery (WID) and one to IFM GEOMAR, the German oceanographic institute. All three vehicles were manufactured by Hydroid, a wholly-owned subsidiary of Kongsberg Maritime.
[6] The SLDMB (Self Locating Data Marking Buoy) buoy developed by METOCEAN (Canada) is equipped with lateral fabric panels that act as a floating anchor. It transmits its GPS position via the ARGOS system that transfers the data by satellite.
[7] Metron was involved in the development of the US Coast Guard's SAROPS (Search and Rescue Optimal Planning System) software, which has been successfully employed to plan and execute searches for ships and personnel lost at sea. For the AF447 search, Metron used a modified version of SAROPS in order to model distribution of particles. Each particle (up to 10,000) was assigned a path and a "weight" coefficient, which gave a probability figure to each one of them.
[8] Search Analysis for the Location of the AF447 Underwater Wreckage, at http://www.bea.aero/fr/enquetes/vol.af.447/metron.search.analysis.pdf

it was in fact discovered after one week of exploration, at a depth of 3,900 m, 6.5 NM north-north-east of LKP (figure1).

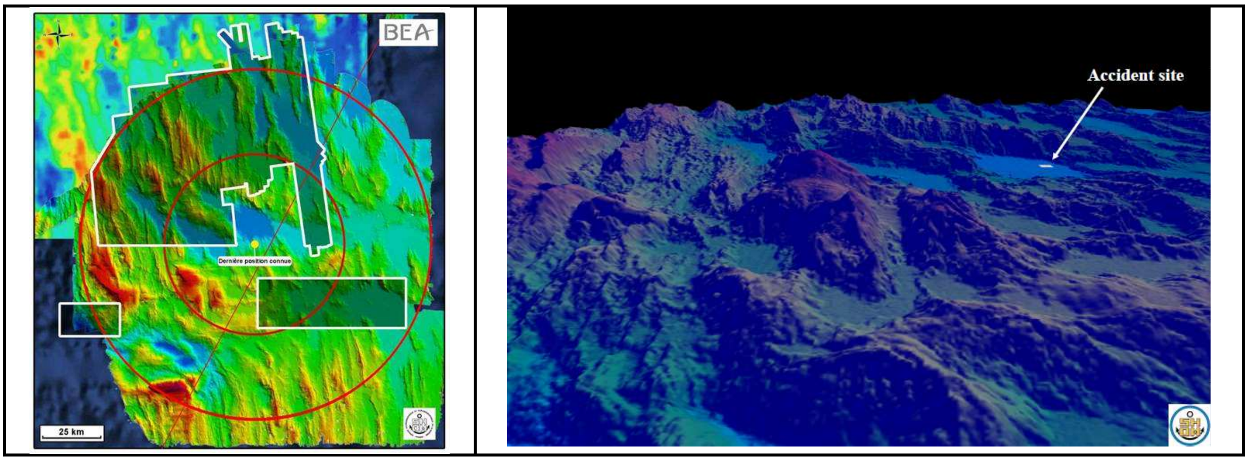
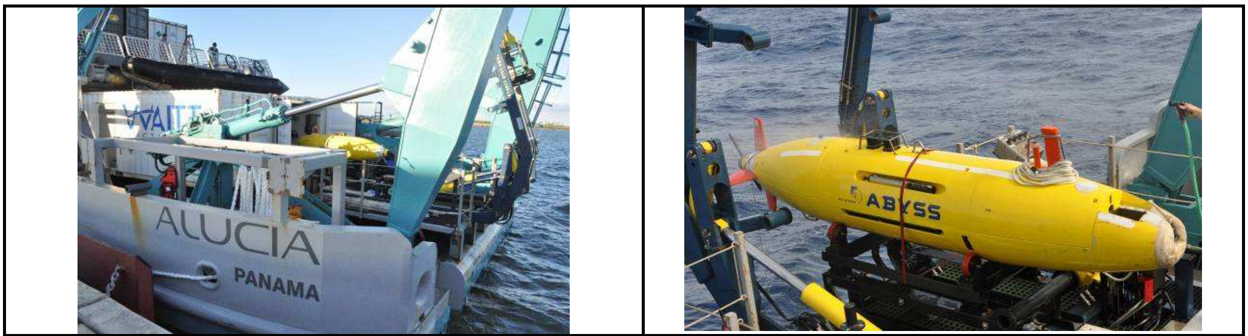


Figure 1:Bathymetry and accident site

II) Description of Phase 4 AUV Operations

Phase 4 lasted on site from March 25 to April 9, 2011. During that phase, the REMUS 6000 AUVs were again used for the search. They were operated by WHOI from the Merchant Vessel *Alucia*, which was owned by Deep Ocean Expeditions.



M/V Alucia | *AUV REMUS 6000*

Figure 2: Phase 4 ship and equipment

The REMUS 6000 AUV

The REMUS 6000 AUV has a length of approximately 4 meters and a weight of approximately 880 kg. Each vehicle is deployed with a lithium-ion battery capacity of 11 kW-hours, which means that the mission time is between 20 and 24 hours. The normal operational speed in search mode is 3.5 knots (1.8 m/s). At this speed the vehicle can swim approximately 125 km. The primary search sensor is an Edgetech 120/410 dual frequency non-simultaneous side scan sonar. During a wide area search the low frequency is operated at range settings of up to 700 meters. In areas of rough terrain the range is often reduced to 400 to 500 meters in order to improve resolution.

The REMUS navigates using a combination of transponder-supported long baseline navigation and an ADCP[9] Doppler Velocity Log (DVL) enhanced inertial navigation. The

[9] ADCP (Acoustic Doppler Current Profiler): Device to measure underwater current and vehicle speed over the seafloor.

long baseline is constituted of transponders with a frequency range of 8 to 12 kHz to provide position fixes when the REMUS are operating near the seabed. Thanks to coded signals, multiple vehicles can navigate with a single pair of transponders. During operations, the REMUS is also acoustically tracked from the support vessel by using an acoustic ranging/ communication system, which also provides REMUS status messages and allows redirection of a vehicle mission.

The REMUS is also equipped with an Electronic Still Camera (ESC). This camera was extensively used at the accident site during phase 4 as the conditions for photos were favorable with flat terrain and good underwater visibility. The photos were primarily taken from a distance of 9 to 11 meters. During the initial ESC mission, the picture resolution was 1024 pixels by 1024 pixels. Based on lighting performance the resolution was increased to 2048 pixels by 2048 pixels on subsequent missions. For the camera runs, the vehicle was slowed to 1.5 m/s and pictures were taken every 4.5 meters of travel over the sea floor.

Based on the experience gained during phase 3, the REMUS 6000 AUVs were upgraded to improve terrain following thanks to enhanced capabilities. The new software version enabled climb/dive angles up to 40 degrees and a new 300 kHz DVL increased altitude tracking from 90 m to 170 m above the seabed.

Discovery of the accident site

On April 2, the eighteenth AUV mission was recovered and the subsequent analysis of the side scan data included a bottom feature showing a concentration of backscattered data over an area of 600 by 200 meters (see figure 3).

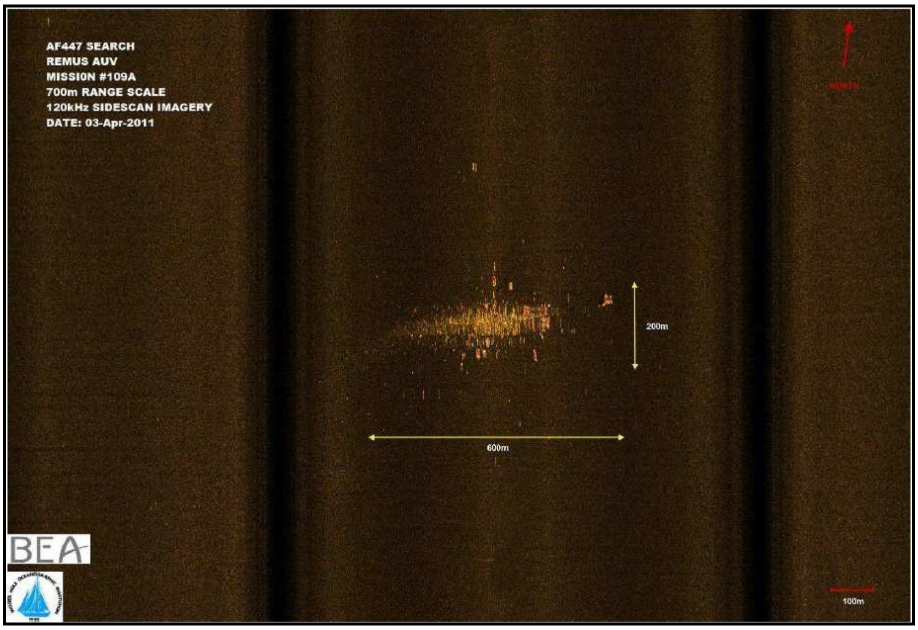


Figure 3: Sonar image of the bottom feature that was confirmed to be the wreckage area

A mission was programmed to obtain high frequency sonar images and ESC pictures of the feature. This mission was completed on April 3 and the pictures confirmed the feature was the plane wreckage. Some of these pictures (see figure 4) were published on the BEA website the next day.

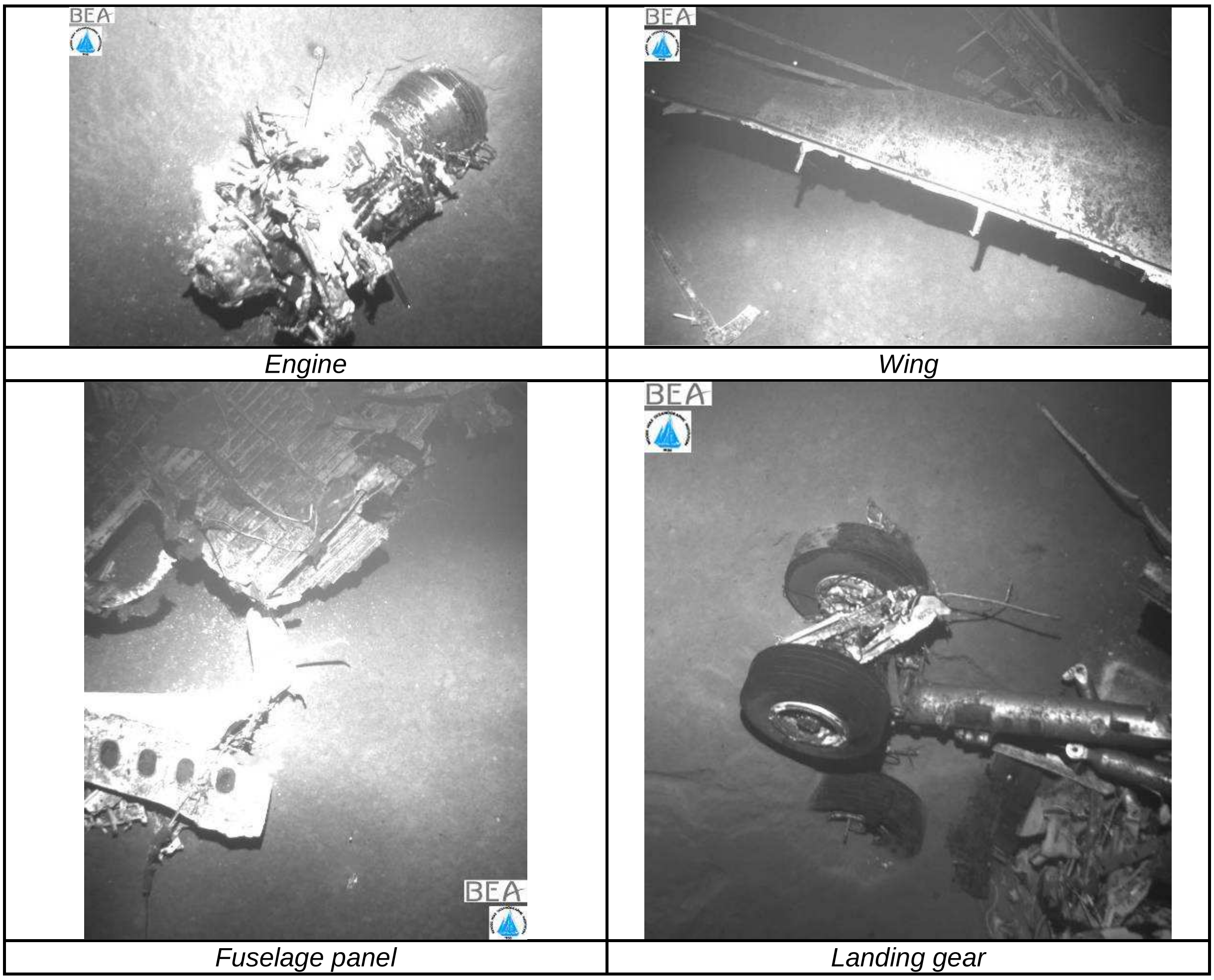


Figure 4 : Selection of pictures taken by the REMUS on 3 April 2011

The location was approximately 6.5 NM north-north-east from the last known position. Over the next six days, additional AUV missions were conducted to identify the extent of the wreckage field and obtain a complete photo record of the primary wreckage area.

This exploration made it possible to locate a fuselage panel approximately two kilometers away from the central zone as well as other man-made objects, such as oil drums probably thrown over board by vessels in transit (figure 5). The initial imagery was subsequently enhanced by high-resolution 410 kHz sonar images at various range scales.

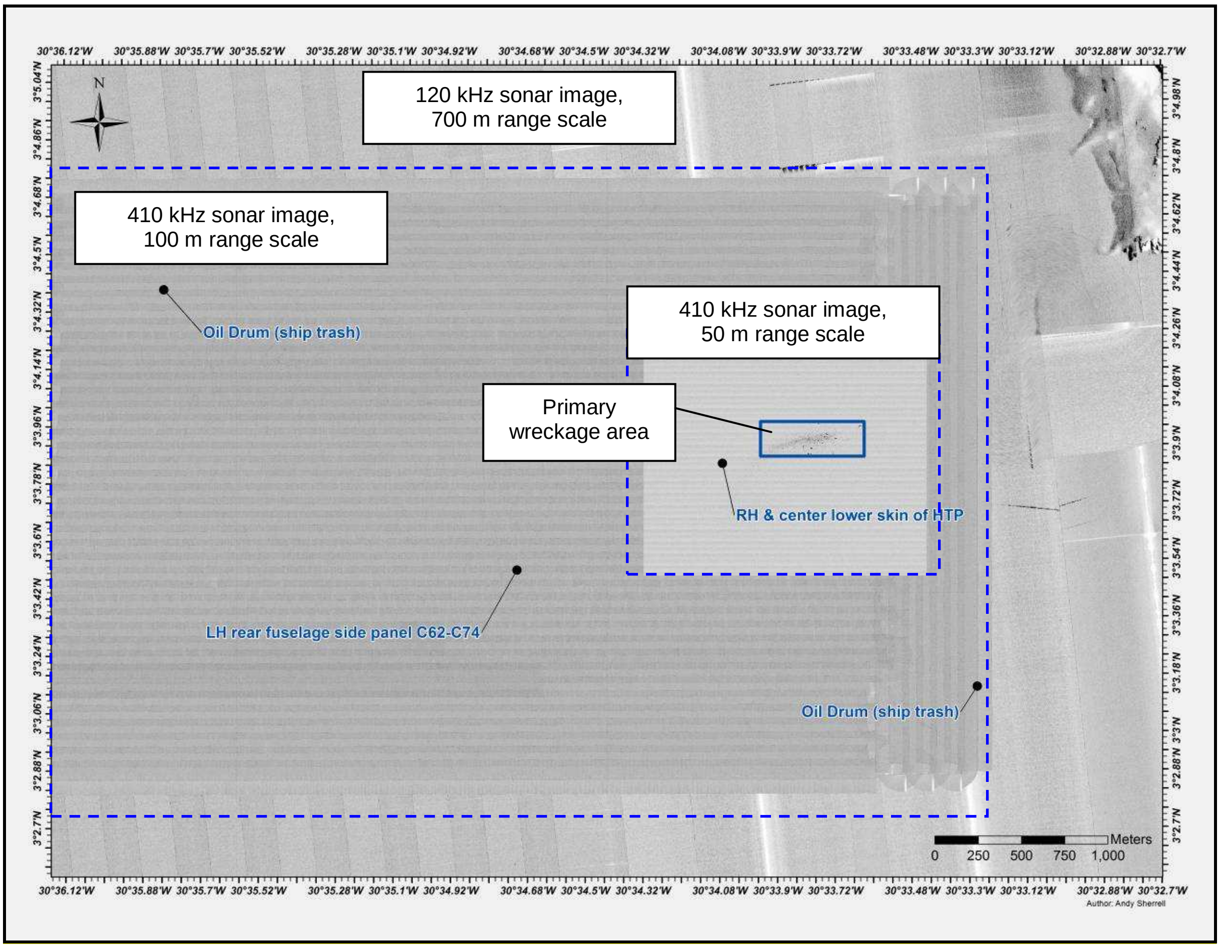


Figure 5: Superposition of sonar images obtained with various settings

This sonar mapping of the accident area was completed by the REMUS during the same missions the ESC pictures were taken. The debris field was overflown several times along North-South and East-West search patterns. More than 85,000 pictures were taken to create a photo mosaic of the accident site (see figure 6).

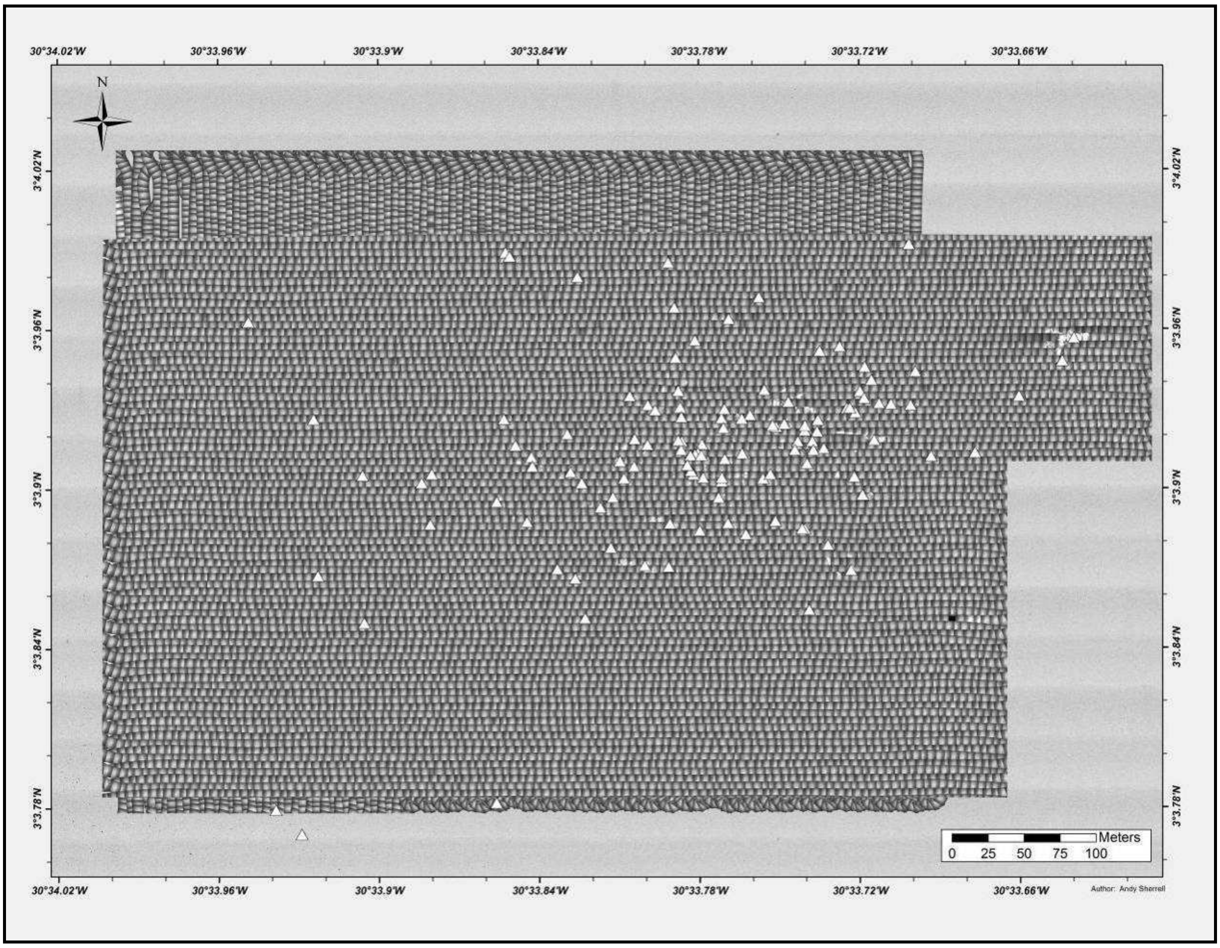


Figure 6: Photo mosaic obtained with REMUS ESC images and airplane parts identified by using the REMORA III ROV

The data produced during phase 4, especially, the photo mosaic of the accident site, helped the BEA to save a considerable amount of time for the following phase. It was the first time that investigators had a complete two dimensional representation of the crash site based on high resolution side scan sonar images and photos before the onsite intervention of an ROV. These aerial pictures were very useful both for preparing phase 5 and conducting the survey of the site. Color imagery could have provided significant additional information and possibly identified the flight recorder components on the seafloor.

Fusion of ESC images

WHOI and the Waitt Institute have developed techniques using commercially available software programs to enable analysts to semi-automatically stitch and merge photos from the mosaic. The following example (figure 7) displays this fusion process on one of the largest debris field components. This type of image provided operators and investigators an accurate overview of the debris field and facilitated ROV mission preparation.

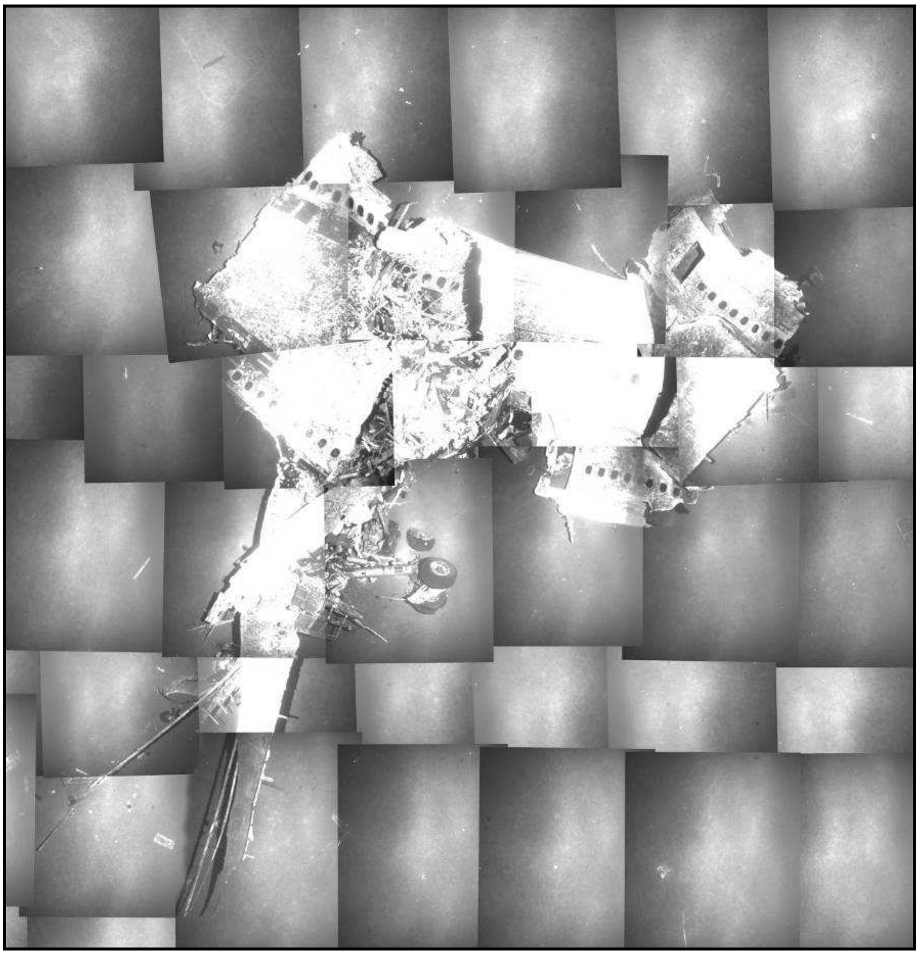


Figure 7: Example of the fusion process results

III) Preparation of Phase 5

Phase 5 was the recovery phase. Its preparation took place at the same time as the preparation of phase 4, as the M/V *Alucia* had only search equipment onboard and no recovery equipment. Phase 5 of course was dependant on the success of phase 4. As soon as the wreckage was found, it was crucial to mobilize a support vessel with recovery equipment to be on site as quickly as possible. To do this, the BEA published an international call for tenders in the format of a Framework Agreement. The deadline for submissions was March 15th 2011. The contractor had to provide the following services: *Sea search operations, localization and recovery of the aircraft recorders at a depth that may reach 6000 meters, submarine observation of the wreckage, charting the distribution of the debris that was identified as being relevant, recovering, preserving and transporting pieces of the aircraft wreckage, collecting any human remains (HR) according to the possibilities provided by the handling instruments and the state of preservation of the remains.*

Before the start of phase 4, the BEA preselected three offers that met its technical criteria. They took into consideration the difficult environment and the remoteness of the accident site and were mainly based on ship storage capacity, ship and ROV lifting capacity, ROV maximum operating depth as well as ROV maneuvering capabilities. It was also essential to anticipate having onboard all the necessary equipment and procedures to decently deal with human remains in case they were any and they had to be recovered. The psychological preparation of the operators dealing with HR recovery was another requirement specified by the BEA.

When the wreckage was found, the BEA just had to select one of the three preselected vessels, mainly on the criteria of proximity to the accident site. That was done after a short consultation period with a deadline of April 7th 2011.

To undertake the fifth phase of maritime operations, the BEA ultimately selected the cable vessel C/V *Ile de Sein* operated by Alcatel-Lucent and Louis-Dreyfus Armateurs (LDA), equipped with the REMORA III Remotely Operated Vehicle (ROV) from Phoenix International that can operate at maximum depth of 6000 meters.

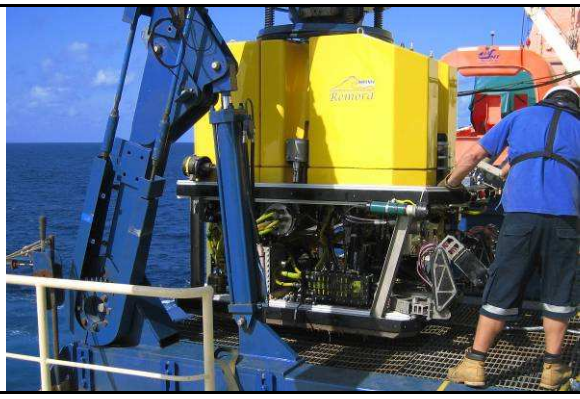
	
C/V Ile de Sein	***ROV REMORA III***

Figure 8: Phase 5 ship and equipment

IV) Organization of Phase 5 operations

Phase 5 was organized in two parts:

- The first part dealt with the search and the recovery of the two flight recorders as well as the recovery of airplane parts. It took place onsite from 26 April to 13 May 2011.
- The second part dealt with submarine observation of the wreckage, charting the distribution of the debris and the recovery of human remains. These operations lasted on site from 21 May to 3 June 2011.

The REMORA III ROV

The complete system is comprised of a vehicle, fiber optic cable and winch, a launch/recovery system, and operations and maintenance vans. The REMORA's design strikes a balance between power and capability, meets a wide range of operational requirements, and is sized for air transport and rapid mobilization on vessels of opportunity anywhere in the world. This small and powerful vehicle has axial lateral thruster geometry that allows precisely controlled maneuvers in the tightest of spaces and minimizes the probability of entrapment or entanglement. Given the REMORA's size and weight, added benefits include lower transportation and support vessel costs. The REMORA was installed on the C/V *Ile de Sein* in Las Palmas, Canary Islands.

The Cable Vessel *Ile de Sein*

The C/V *Ile de Sein* is about 140 meters long and designed to carry a heavy ROV on its deck with its support equipment. It has an advanced dynamic positioning (DP II) system that allows it to precisely maintain position, even with unfavorable meteorological and sea conditions. This ship having been designed to lay cables on the seabed with a one-meter precision, its system for cable tension and run-out speed proved to be very useful for bringing to the surface large and heavy plane parts. It is the sister ship of the C/V *Ile de Batz* that was used in 2004 for the successful recovery operation off Sharm el-Sheikh (Egypt) in the aftermath of the Flash Airlines B737 accident.

The onboard facilities such as meeting rooms, cabins and a restaurant made the C/V *Ile de Sein* a very effective vessel for a long mission on a remote site. The "test room" was set up to facilitate work onboard for the investigative teams who were working in close coordination with the ROV pilots through several video screens and the co-located Phoenix survey center. Being a large vessel, it could easily accommodate the installation of extra containers. The C/V *Ile de Sein* embarked with two 40-foot containers for parts on the lower deck (near the 50 ton A-frame) and three 20-foot refrigerated containers for storing HR on the upper deck. This included a spare in case of malfunction of one refrigerated container (figure 9).

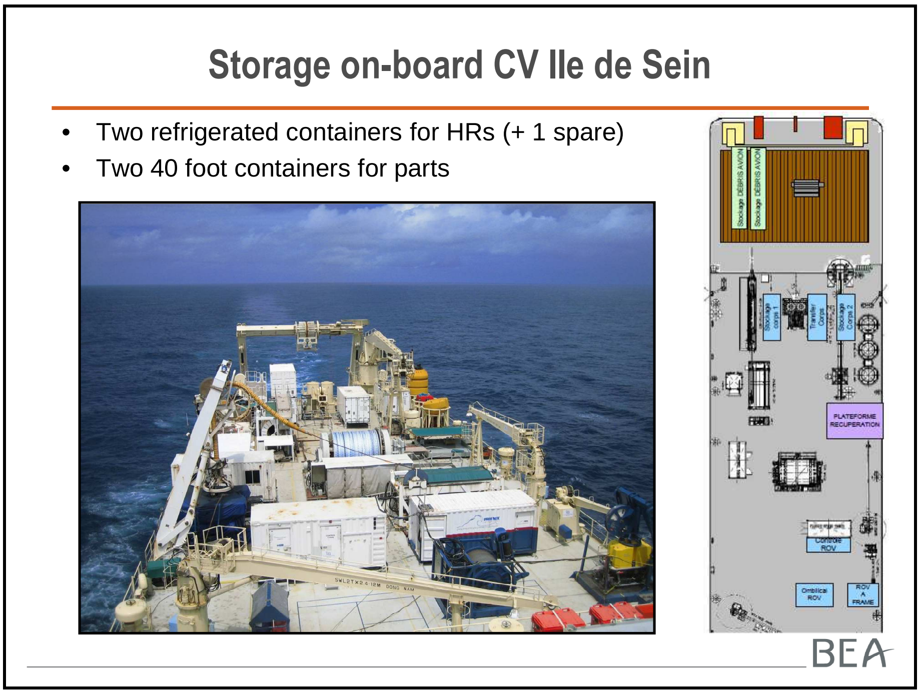


Figure 9: View of the upper deck (left) and layout of both decks (right)

The C/V *Ile de Sein* was thus the support ship for the REMORA III ROV. The movements of the ROV and the ship were coordinated by the survey that was located on the *Ile de Sein*'s bridge and the Phoenix survey center located in the test room.

USBL positioning system

Before the onsite mission, a new Ultra-Short BaseLine (USBL) acoustic positioning system was installed in Las Palmas on the Ile de Sein's through-hull deployment pole. The Sonardyne Ranger 2 USBL system was designed for deep water, long range tracking of underwater targets and position referencing for dynamically positioned (DP) vessels. The system calculates the position of a subsea target by measuring the range and bearing from the vessel-mounted transceiver to acoustic transponders fitted to the ROV, the recovery baskets and the lift lines. This system was integrated with the ROV REMORA III survey system. It made it possible to reach system accuracy of 0.1% of slant range under the best sea conditions. Having accurate underwater positioning has always been a challenge and subject to the sea environment. Indeed, acoustic waves are used for USBL systems in liquid environments and their propagation depends on various linked parameters such as salinity, water temperature and depth.

Underwater navigation performance

The operation of the new positioning system used in combination with Phase 4 data proved to be extremely helpful. The side-scan sonar maps and the photo mosaic were geo-referenced on the ROV's navigation system. When acoustic transmissions were perturbed, the ROV pilots could still navigate with high accuracy as they had at their disposal the REMUS 2D pictures. Thus, Phoenix International used the frog-leaping technique to visually navigate from one debris component to the next. A range and bearing were given by the survey to the ROV operators so that they could find with a precision of one meter each debris component or HR displayed by the REMUS images.

The survey center could also display the 2D photo of the target to the ROV pilots as they had the third dimension in real time through their ROV cameras. All sizeable items of debris were thus systematically searched for and identified during the mapping of the wreckage site.

Discovery and recovery of the flight recorders

When the accident site was discovered, it was observed that, apart for some large debris, the airplane was very fragmented. The small size of the flight recorders represented a challenge to overcome given the shear number of items of debris scattered on the sea floor, as shown in the following picture (figure 10).

Figure 10: Debris scattered on the seafloor

During the first ROV dive, the chassis of the airplane's Flight Data Recorder (FDR) was found, though without the Crash Survivable Memory Unit (CSMU) that contains the data. It was surrounded by debris from other parts of the airplane. The forward and aft parts of the airplane were broken apart and mixed up, which meant that a time-consuming systematic search was required.

On 1 May 2011, the investigation team localized and identified the memory unit from the Flight Data Recorder (FDR). It was raised and lifted on board the C/V *Ile de Sein* by the Remora 6000 ROV the same day. The next day, the Cockpit Voice Recorder (CVR) was localized and identified. It was raised and lifted on board the *Ile de Sein* on Tuesday 3rd May, 2011. The flight recorders were first transferred to the port of Cayenne by the French Navy patrol boat *La Capricieuse* and then transported to the BEA by plane on 12 May 2011. During that period, the recovery of airplane parts continued, with one engine and the avionics bay, containing onboard computers, being raised.

Wreckage mapping

The REMORA capabilities and the lifting equipment from the C/V Ile de Sein were jointly used to move and recover airplane debris. The REMORA « PAN & TILT » camera and especially the skills of the Phoenix operators enabled investigators to read most part number references of numerous items of debris in order to precisely identify the debris scattered at the bottom of the ocean. A geo-referenced database was created and a complete mapping of the wreckage site was achieved. Figure 11 illustrates the main wreckage parts that were identified.

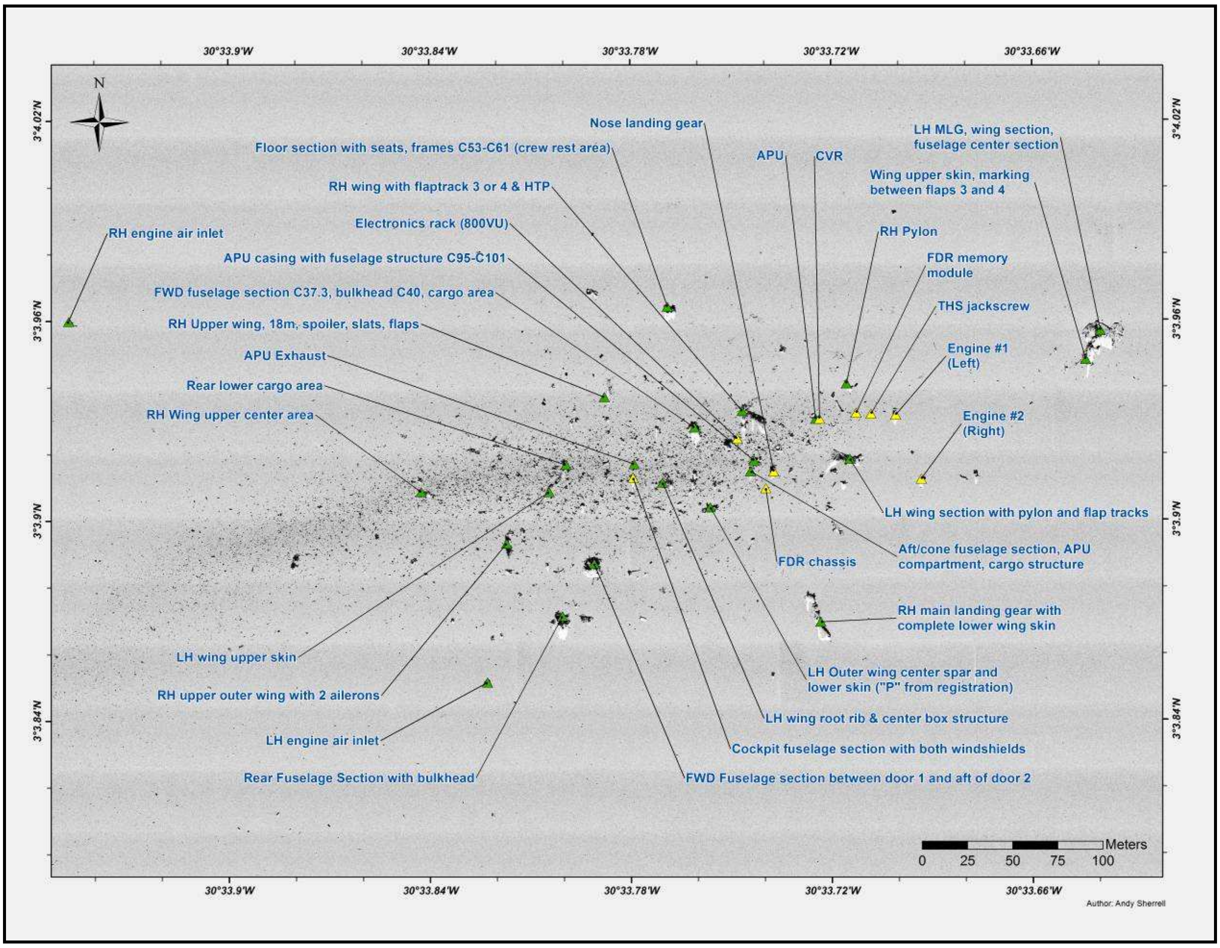


Figure 11: Mapping of the main airplane parts

HR and psychological aspects

The second part of phase 5 mainly dealt with HR recovery. The retrieval of any bodies and personal effects was placed under the responsibility of the representatives of the judicial authorities. A dual sweep of the accident site had thus been undertaken by both teams to comprehensively map the wreckage distribution and at the same time ensure that all HR were recovered.

The recovery of HR is an operation that cannot be improvised. Material preparation and space to process it in good conditions are crucial. The crew of the C/V *Ile de Sein* provided all the necessary logistical assistance to the forensic team who had space and a secured work station to perform their tasks with serenity, decency and discretion. The ROV operators managed to unbuckle seatbelts and extract bodies from the wreckage with outstanding skills.

A psychiatrist and a psychologist were also onboard the C/V *Ile de Sein*. Their presence was greatly appreciated by all those on board. It also demonstrated a strong involvement of management for the performance of that unusual job, which was to recover HR non-stop for two weeks. The medico-psychological support was adapted to each stage of the mission through preparatory briefings during the transit to site, possibilities of having defusing moments during or just after basket recoveries, and debriefing during the return transit.

The lessons learned from previous operations were implemented in that delicate mission, which went very well. The initial survey showed that nobody suffered any post traumatic syndrome disorder (PTSD) after that mission. Psychological follow-up has been offered to all persons onboard the C/V *Ile de Sein*.

V) Summary - Lessons Learned

Financial summary

The following table (figure 12) summarizes the AF447 search and recovery costs and the number of days spent onsite until each phase. The costs of the search and rescue (SAR) operation were borne by the Brazilian and French armed forces. Other States also participated in these SAR missions. Although it is difficult to estimate the costs of these surface searches that lasted until 26 June 2009, roughly 80 million Euros is a reasonable assessment made by specialists.

Surface search	June 2009	26 days	€80 million (estimated for information)
Phase 1	June/July 2009	30 days	10 M €
Phase 2	August 2009	22 days	
Phase 3	April/May 2010	52 days	11.6 M €
Phase 4	March/April 2011	15 days	7 M €
Phase 5	April-May 2011	31 days	6 M €
TOTAL phases 1-5 (on site)		**176 days**	**€ 34.6 million (estimate)**

Figure 12: Costs and duration of the sea search operations

On the other hand, the costs encountered for the underwater operations are better known. The first two phases cost the BEA 10 million Euros. The Phase 3 budget was estimated at 13 million Euros for the two parts. For that phase, a special common fund was created by the BEA. Airbus and Air France contributed equally to that fund. At the end of Phase 3, 1.4 million Euros was returned to the contributors. It is worth noting that sea search operation costs are dependent on fuel prices and the Euro/US Dollar exchange rate which are two difficult to predict variables. Phase 4 was directly paid for by Industry under the framework of a Memorandum of Understanding between Airbus, Air France, the BEA and WHOI. Phase 5 was directly financed by the BEA.

Lessons Learned and Recommendations

The initial negative search results triggered some lessons learned in order to facilitate the localisation of wreckage lost at sea. The BEA's Interim Report No.2 on the AF447 accident included two safety recommendations addressed to ICAO and EASA on ULBs:

- The first one recommended that ULB transmission time should be increased to 90 days, which would have made it possible to prolong the search for the ULB beacons in this vast zone.
- The second one pointed out that the current 37.5 kHz ULB beacons have a limited range, which means that specific equipment, not very widely available, must be used for depths greater than 1,500 metres, The use of beacons transmitting at lower frequencies (for example between 8.5 and 9.5 kHz) would have made it much easier to detect the wreckage, because they carry further. In addition most Navies in the world are equipped to detect these low-frequency signals.

Regarding the acoustic searches undertaken during Phase 1, it is worth noting that although the TPL position data were recorded, this was not the case for acoustic raw data. The use in deferred time of post-treatment software could have been helpful to check whether ULB signals were audible in the surrounding noise. For future passive acoustic search systems, it would be worth:

- recording this type of search data. Some of this feedback and other BEA safety recommendations have already been taken on board by Regulators and Industry in order to ultimately improve safety through improving the effectiveness of investigations.

Flight AF447 reported its position every 10 minutes. In the absence of any radar data, this proved to be useful, but the search Circle represented a vast area of 17,000 km^2.

- More frequent position reporting by airplanes is an easy modification to implement in the short term to avoid long and expensive searches.

Based on the results of a BEA-led international working group (the "Triggered Transmission of Flight Data" WG[10]), the BEA published two additional recommendations in its Interim Report No.3. They suggest making it mandatory for airplanes performing public transport flight on long haul flights over water to trigger the transmission of flight parameters to help the localization of the wreckage or to activate the Emergency Locator Transmitter (ELT) in case an emergency situation is detected in flight.

In addition, the work performed on reverse-drift simulations showed that:

- The dropping of drift-measurement buoys by the first aircraft to arrive over the zone would have made it possible to understand the drift better from the earliest hours.

[10] See http://www.bea.aero/en/enquetes/flight.af.447/triggered.transmission.of.flight.data.pdf

Conclusions

The successful recovery of both flight recorders was a major step for the BEA safety investigation. These search efforts to find the wreckage and solve the enigma of the Rio-Paris flight have required wide-ranging international cooperation in which:

- WHOI played a key role in the successful location of the wreckage and
- Phoenix International was instrumental in the search and recovery of the two flight recorders.

It was first a race against time to operate the acoustic detection devices (TPLs) while the beacons were still transmitting. It then became a very complex operation for the preparation of the subsequent phases when time was less of a factor. The BEA has been fortunate to benefit from the assistance of international partners coming from specialized fields that go beyond the domain of aviation (such as space, oceanography, marine, mathematics). The scientific tools provided by Metron enabled assessment of all previous search results with a rational approach based on probability maps. The Metron study indicated a strong possibility for discovery of the wreckage near the centre of the circle, which is where it was actually discovered one week after the beginning of phase 4.

The financial commitment of the BEA, Air France and Airbus to keep searching for the missing airplane illustrated the strong desire of the aviation sector to explain all accidents as completely as possible in order to prevent their recurrence.

Finally, the numerous lessons learned after these search efforts that involved governments and industry will lead to the development of new methodologies and improvement of tools for acoustic searches in both passive (towed pinger locators) and active (side-scan sonars) modes. It is hoped that the lessons learned and the safety recommendations released by the BEA during that process will first prevent the recurrence of the AF447 accident, and in case of accidents at sea, prevent future similar complex and challenging sea search operations.