Search Analysis for the Location of the AF447 Underwater Wreckage

A report by:

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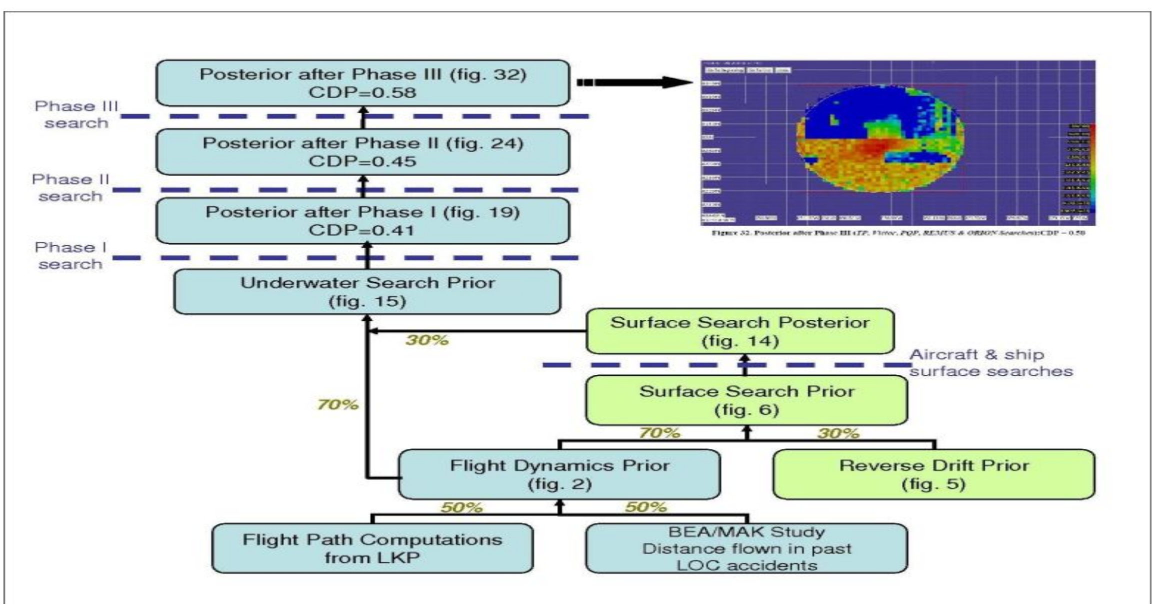
Short Intro about the mishap and the initial approach to chase the wreckage

On 1st June of 2009, an airbus named Air France Flight 447 was oddly declared missing over the South Atlantic during a night flight from Rio de Janeiro (Brazil) to Paris (France) with a total of 228 passengers and crew. It was certain that the plane had crashed somewhere as none of the two 'black boxes' were functional and hence the biggest challenge was to find the crash point over an infinite looking ocean whose about 1000 pieces and almost 50 bodies were recovered from random positions. The search initialized in three phases and it's evident to convey here in the beginning that none of them were successful.

1. **Phase 1:** In this phase, A French submarine as well as French and American research teams searched acoustically for the Underwater Locator Beacons (ULBs, or "pingers") on each of the two flight recorder's "black boxes" for 30 days with no results.
2. **Phase 2:** Here, the BEA (French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile) with Metron utilized side-looking sonar to scan the ocean bottom for the wreckage field. It was also unsuccessful.
3. **Phase 3:** Now, the phase 3 consisted of additional side looking sonar searches using REMUS AUVs operated by the Woods Hole Oceanographic Institute (WHOI) and using the ORION towed side-looking sonar operated by the US Navy 1 . The search also used a Triton ROV(Remotely Operated Vehicle) 2 still wasn't sufficient.

Using Bayesian Distribution for success



The chart above is the summary of the steps taken to obtain the circular probability distribution of the points where maximum wreckage can be restored along with the dead bodies. In the further report, we'll be explaining to you point by point the various data accumulated and how they are arranged together (using Bayes theorem) to scheme a meaningful plot, right from the bottom.

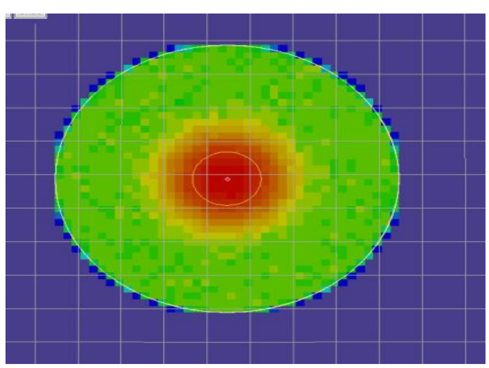
1. Flight Dynamics prior

a. Flight path computation from LKP:

This distribution was the initial step to determine the vague radius of maximum probable impact. Here, the position of the plane was analysed using ACARS (Aircraft Communications Addressing and Reporting System) which sends the coordinates of the flight every 10 minutes. The end of the flight occurred between 2 h 14 min 26 sec and 2 h 15 min 14 sec whose analysis was performed by the BEA which produced a uniform distribution over the disk of radius 40 NM centered at the LKP.

b. BEA/MAK Study Distance flown in past past LOC accidents: The second distribution is based on data from nine commercial aircraft accidents involving loss of control. This analysis was performed by the Russian Interstate Aviation Group and the BEA.The analysis shows that all impact points are contained within a 20-NM radius circle from the point at which the emergency situation began.

For Flight Dynamics Prior, 50-50% of the mixture was chosen between **a** and **b** for circular normal distribution truncated at 40 NM from the LKP (last known point) highlighted below.



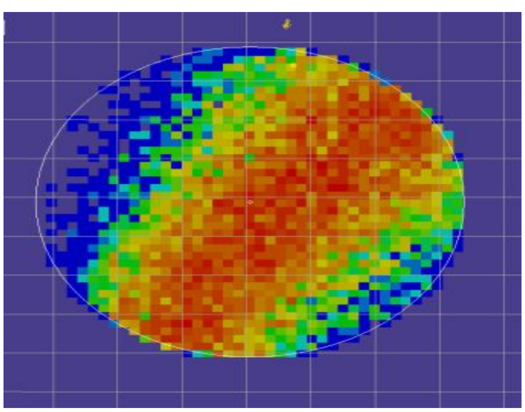
2. Reverse Drift Prior

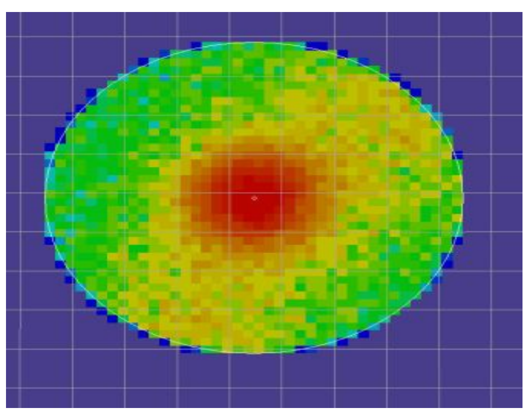
Here, backtracking of the debris found was the aim by looking over the ocean currents and the leeway (drift caused by the wind) and analyzing the path it could have followed. Because the area is near the equator and in the middle of the Atlantic, the currents were complex and difficult to estimate, So the BEA performed an experiment in which the French Navy dropped nine Self Locating Data Marker Buoys (SLDMBs) inside the 40 NM circle from the LKP on June 3 of 2010 and recorded their positions over the next several days, although all the trajectories were completely random. So for computation, Drift Group Report was used and a model was developed (based on empirical data) where maximum emphasis was given on leeway (as it was consistent) and a model was developed which produces a total drift speed of roughly 2.35% of wind speed and included a cross wind component as well.

D_{WL} = 1.17 $W_{10\,m}$ + 10.2 cm/s, C_{WL} = 0.04 $W_{10\,m}$ + 3.9 cm/s, where W_{10m} is in m/s and D_{WL} and C_{WL} are in cm/s.

Now **The prior distribution before surface search** by aircraft and ships is taken to be a mixture of **70%**

of the FD Prior and **30% of the RD Prior** found and the new modified distribution obtained is stated below.





By reverse drift analysis

By combining FD and RD prior

Accounting for unsuccessful search

If an unsuccessful search takes place, we compute the probability $p^1_d(n)$ that the search would have detected the search object if it were located where particle n is for n = 1, ... , N .

And the formula using Bayes Theorem is as follows:

$\mathbf{w_n^1 = (1-p^1_d(n))w_n / \Sigma_{n'=1}^{N}(1-p^1_d(n^1))w_{n1}}$ where n=1,2,3,4……N. Here, The n th particle has weight w n for n = 1, ... , N . Initially all weights are set equal so that w n = 1/ N for all n . The weight is the probability that the particle represents the search object's location or path. w^1_n is the posterior probability that particle n represents the object's location.

3. Surface Search Posterior:

Searches for debris by Brazilian and French aircraft were conducted from June 1st to June 26th 2009. These searches were unsuccessful until June 6 when debris and bodies from the aircraft were first recovered. Analysis of the unsuccessful air searches and ship searches prior to 6 June , provides negative search information that we use to decrease the probability on some particles and to increase it on others according to Bayes rule for computing posterior probability distributions.

To evaluate the effect of the unsuccessful air search effort, they started with the surface search prior distribution given in Figure 6. They allocated simulation particles in accordance with the probability density in each cell. Then they used SAROPS (software) to "drift" these particles forward in time from the time of impact though 6 June. In the process of doing this they accounted for the unsuccessful aircraft search and the search by the ship Douce France during that time. The search object was assumed to have the drift and detection characteristics of a four-person life raft. If the particles were predicted to pass through an area searched by aircraft or the Douce France, their weight was appropriately reduced. The result is a set of particles whose weights (probabilities) have been updated to incorporate the unsuccessful air and ship search effort during those days.From these reweighted particles, we calculated a new PDF for the impact point.

The result of this calculation is shown in the figure below.

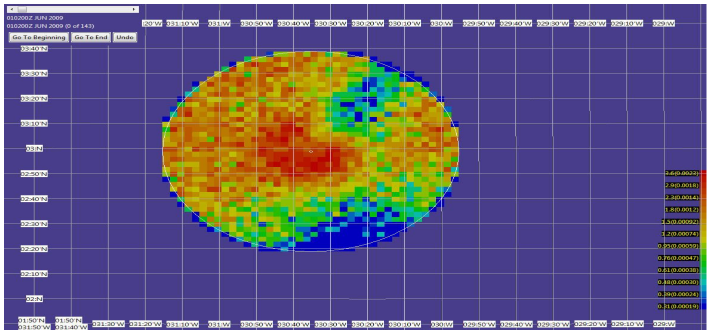


Figure 14. Surface Search Posterior PDF

4. Underwater Search Prior:

For the purpose of evaluating the underwater search, they formed a prior which is a mixture of 30% of the Surface Search Posterior in Figure 14 and 70% of the FD Prior in Figure 2. This PDF is shown in Figure 15. They have given the Surface Search Posterior a low weight in this PDF because it depends heavily on estimates of currents in the area of the crash during 1 – 10 June. Because the area is near the equator and in the middle of the Atlantic, the currents are complex and difficult to estimate. In addition the remote nature of the crash site means that there were few meteorological measurements to provide a basis for current estimates. Because of the complexity of the currents and the lack of data, there is substantial uncertainty to these estimates however, Here are the results based on these estimates a low weight in producing the prior and posterior distributions reported here because of the great uncertainty associated with the estimates.

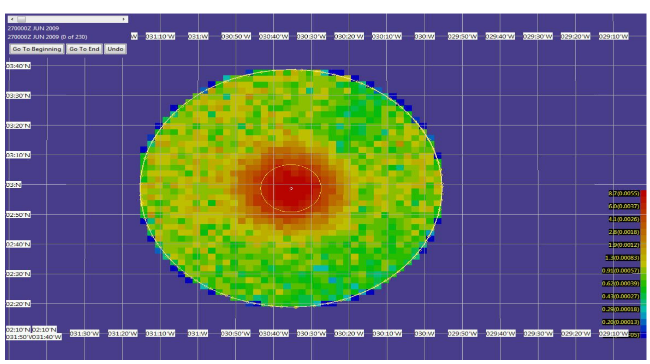


Figure 15. Underwater Search Prior

5. Posterior PDF after Phase I Search:

The posterior distribution after unsuccessful ULB searches by the Fairmount TPLs and the Victor ROV is shown in Figure 19 below. This is the posterior for location of the underwater wreckage after the Phase I searches. The Cumulative Detection Probability for the TPL and Victor searches is 0.41.

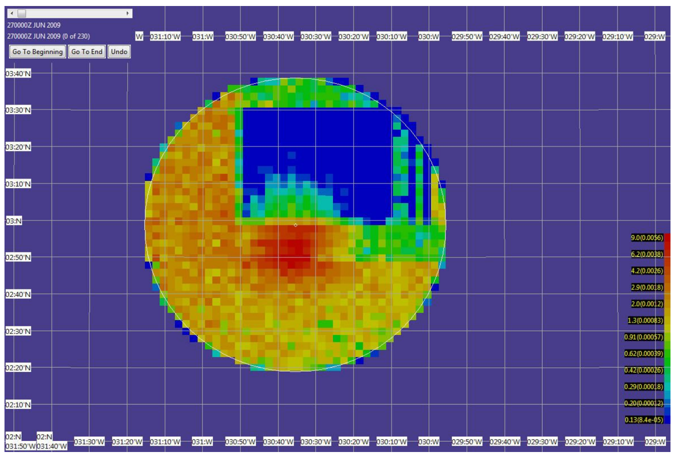


Figure 19. Posterior PDF of Impact Location after Unsuccessful ULB and Victor ROV Searches

CDP= 0.41

6. Posterior PDF after Phase II Search:

To continue the search after the pingers' extinction, the BEA decided to use the IFREMER towed sonar (called Sonar Acoustique Remorqué - SAR). The Pourquoi Pas? was equipped with this side scan sonar for the second phase during its port call in Dakar.

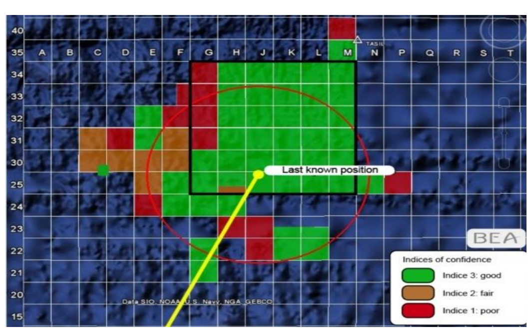


Fig. 20 Confidence Indices Attributed to Search Areas at the End of Phase I

Figure 20 shows the areas searched in Phase I along with indices of confidence attributed to cells by the BEA. Green denotes good, brown fair and red poor. One can see that cells J24 through M24 located inside the 40 NM radius circle had not been searched in Phase I. This was due to lack of time . After phase 1 it was estimated that the ship could cover three-to-four cells in the three weeks in which it would be on station at the accident site, achieving a 0.9 POD in those cells. Searching adjacent cells would allow the Pourquoi Pas? to maximize its search time by minimizing the “overhead” time spent turning at the end of each search leg (turns were estimated to take three hours to accomplish).But the Phase II search effort proved to be unsuccessful.

Figure 24 shows the posterior PDF and CDP after the Phase II searches were completed.

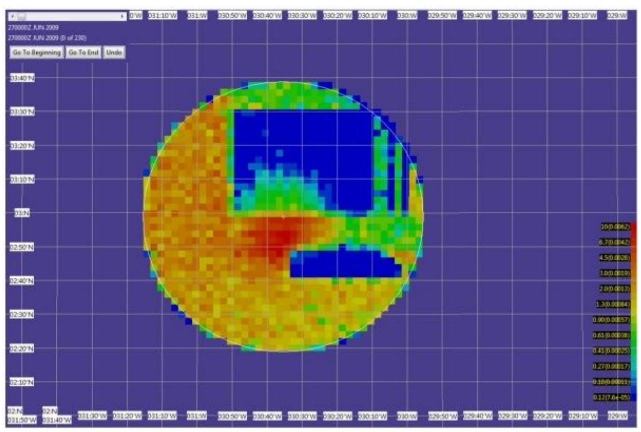


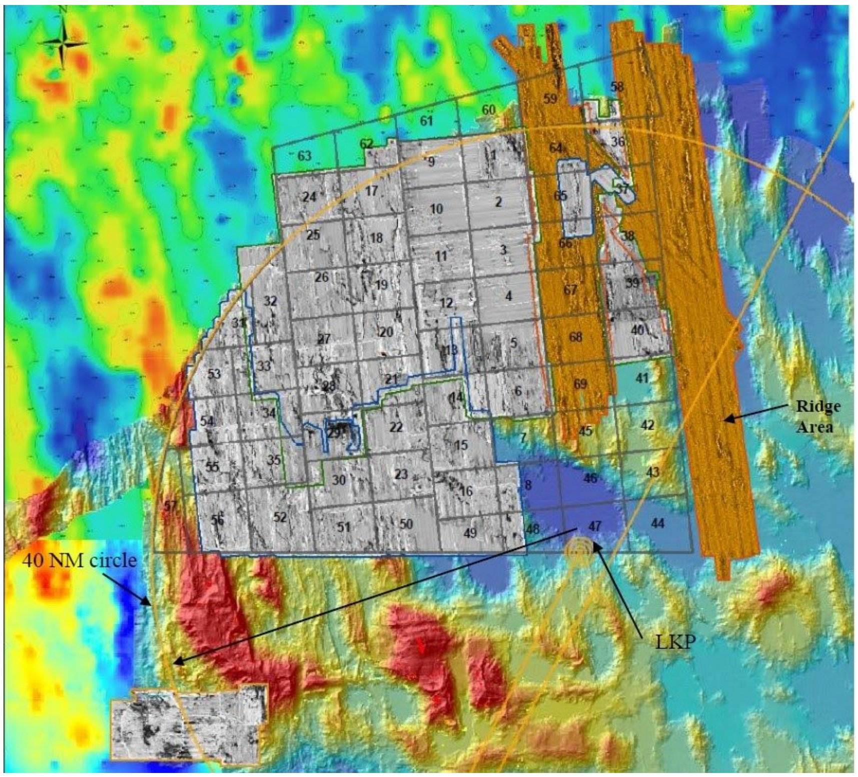
Figure 24. Posterior PDF After the Phase II Searches: CDP = 0.45

7. APhase III

In phase III two search efforts were made. Most of the area covered in this phase was recommended by drift group.

Search effort 1: US Navy/Phoenix International

The US Navy/Phoenix International search was performed using the USN ORION towed side-scan sonar system. The ORION covered the 1900 square kilometer area of orange swaths shown in Figure.



As a result, US Navy/Phoenix International operators/analysts evaluated the 1743 km^2 shown with cross hatching in Figure as having been covered with the highest degree of confidence and attributed a detection probability of 0.90 and for rest of the ORION search area we have set the detection probability equal to 0.50 with the exception of the ridge area shown in Figure. This area received a 0.10 detection probability.

A very small area of this possible debris field was photographed. Images of five individual, small, unidentified, manmade articles located, but the images obtained are not conclusive evidence of aircraft debris, further investigation of this site should be considered a priority.

Search effort: Woods Hole Oceanographic Institution

The Seabed Worker deployed to the search area with three REMUS 6000 AUVs which covered an area of 4,375 km^2.

We attributed a detection probability of 0.90 to all the areas shown in grey in Figure with the exception of the areas in the cells noted above. In these areas we set the detection probability to 0.10.

Posterior Distribution after Phase III searches.

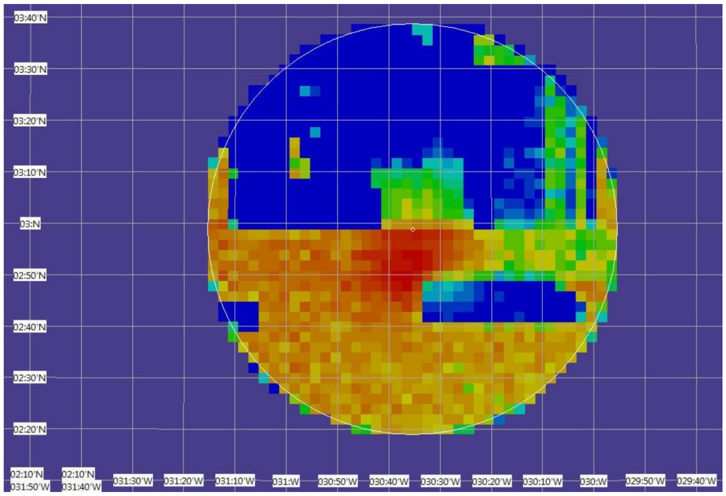
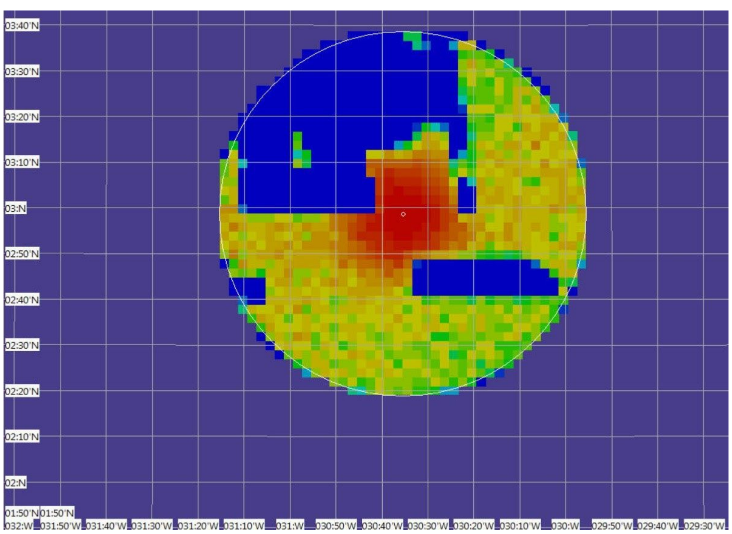


Figure shows the PDF after the unsuccessful searches from Phases I, II, and III. The resulting CDP, if either of the pinger is working, was calculated to be 0.58.

Posterior assuming the Pingers failed



If both pingers failed to activate, the ULB search would have no chance of detecting the wreckage and search will not contribute in computing the posterior. The resulting CDP was calculated to be 0.29.

Conclusion

The approach used methodical consideration of all data available, with associated uncertainties, to form an analytic assessment of the highest likelihood areas for future search efforts. The careful analysis of the detection effectiveness of each component of the search and the resulting accounting for this search by calculating the Bayesian posterior distribution on the impact location forms a solid basis for planning the next increment of search.