Lessons from Flight 447
Undersea Search Operations

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4th International Workshop on Technologies for Search and Rescue and Other Marine Operations

Le Quartz, Brest, France
10-12 May 2011
Airplane’s Flight Path

02h10 Last known position

Last radio contact
Difficult and Unknown Environment

02h10 Last known position
Surface Search

Operations coordinated by the Brazilians from 1 to 26 June 2009
Satellite Imagery

COSMO SkyMed (2 June 2009 – 08h16Z)
Data Exchange Coordination and Processing (June 2009)

Ships → CROSS → BEA Consolidation

French Navy → CECLANT → BEA Consolidation

Brazilian Navy → Recife RCC → BEA Consolidation

BEA Consolidation → Investigation groups

BEA Consolidation → Drift group

Investigation groups → BEA Consolidation

Drift group → BEA Consolidation
Drift group

- **Computations and Participation from different organizations**
  - Météo France (MOTHY model)
  - USCG
  - US Navy
  - Brazil Hydrographical Service
  - SHOM
  - CROSS
  - IFREMER

- **Model validation with different sets of buoys**
  - AOML
  - Argo floaters
  - French Navy
  - Brazilian navy
  - Quikscat observations
## Wind and Sea Current Models

<table>
<thead>
<tr>
<th>Sea current</th>
<th>MOHY</th>
<th>USCG</th>
<th>US Navy</th>
<th>Brazil</th>
<th>(SHOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERCATOR</td>
<td></td>
<td></td>
<td></td>
<td>NCOM</td>
<td>(HYCOM + dérives de stokes)</td>
</tr>
<tr>
<td>G-NCOM</td>
<td></td>
<td></td>
<td></td>
<td>NCOM</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wind model</th>
<th>ECMWF</th>
<th>NOGAPS</th>
<th>NOGAPS</th>
<th>GFS-10</th>
<th>(ECMWF)</th>
</tr>
</thead>
</table>

### Diagram:
- **20 Nm** scale
- Points labeled with various locations like **Point Météo France**, **Point USCG dérive**, **Point USCG corps**, **Point US NAVY dérive**
- Last reported position: 02:30:00
Search and Recovery Phases

- **Phase 1: 10 June to 10 July 2009**
  Acoustic search for Underwater Locator Beacons

- **Phase 2: 27 July to 17 August 2009**
  Search for the wreckage using a Side Scan Sonar

- **Phase 3: 2 to 25 April 2010 and 3 to 24 May 2010**
  Search using REMUS and ORION side-scan sonars

- **Phase 4: 25 March 2011 to 12 April 2011**
  Search using REMUS side-scan sonars and Electronic Still Camera

- **Phase 5: 26 April 2011 to 13 May 2011 and 20 May to 4 June 2011 (estimation)**
  Recovery operation using Phoenix’s REMORA

(On site)
Phase 1: Two Towed Pinger Locators (TPLs) operated by US Navy/Phoenix

✓ Fairmount Expedition & Fairmount Glacier

TPL 20

TPL 40
Phase 1: Means Used According to Depth

Divers

Diving suit

Standard ROV

ROV - specialized submarine

Continental shelf

Max. range of beacons

Abyssal plateau

LL: Lower Frequency Beacons

approx 2 km
Phase 1: The *Pourquoi Pas?*

Research vessel involved in phases 1 and 2

**Means onboard:**
- ROV Victor (Remotely Operated Vehicle)
- Submarine Nautile
- AUV (Autonomous Underwater Vehicle)
- Towed Hydrophone
- Hull-mounted Multibeam Sonar
- Side Scan Sonar (phase 2)
Phase 2: Sonar Detection

- IFREMER SAR Sonar search (Deep towed Side Scan Sonar)
- Completion of the bathymetry chart
Phase 2: Combining back-scattered data

**SSS 180 kHz Multibeam 12 kHz**

**Multibeam 24 kHz Rocky formation**

*LL: Development of a new methodology extensively used during phase 3*
Preparation of Phase 3

- Determination of a new search zone
  - Widening data collection
  - Work on current models
  - New reverse-drift simulations
  - Cross-checking with other sources
    - Work with French Air Force on AWACS data

- Search means
Determination of the search zone

An international synergy

• State Oceanographic Institute
• National Oceanography Center
• Woods Hole Oceanographic Institution

• IFREMER
• CNRS
• SHOM
• Mercator Ocean
• Météo France
• Etc.

Example of reverse-drift simulation
Setting up the 3rd Phase

International call for tender
- BIMCO (TIME CHARTER PARTY FOR OFFSHORE SERVICE VESSELS –Supplytime 2005)
- FMS (Foreign Military Sales)

Exclusive Economic Zone (EEZ) of Brazil

Prior authorization

Seabed Worker
BIMCO
Anne Candies (PHOENIX)

Woods Hole Oceanographic Institution

REMUS 6000 AUV TRITON ROV ORION SSS CURV21 ROV
B-52 Guam Accident (July 2008)

ORION 56 kHz –900 m scale
Example of detections (REMUS)

Anomalies (size approx 300 meters)

Other anomalies
ROV dive (TRITON)
ROV dive

LL: Field of small sea shells!
Preparation of Phase 4

• More in-situ data in the accident zone
  – Dropping SLDMB early June 2009

• METRON Study
  – Integration of BEA-MAK study on previous accidents occurring in cruise
  – Used results of drift group
  – New leeway coefficient of 2.35% on PIW
Dropping drift-measurement buoys (June 2010)

Self-Locating Data Making Buoys (SLDMB)

CEPPOL
Anti-pollution centre
(French Navy)
First results after two weeks (June 2010)

Data disseminated to the International community for scientific purposes (CORIOLIS central database)

**LL: Confirmation of the difficulties to model currents**
## BEA-MAK study on previous accidents in cruise

<table>
<thead>
<tr>
<th>Date of accident</th>
<th>Location (near)</th>
<th>Aircraft type</th>
<th>Registration</th>
<th>Operator</th>
<th>Upset Duration</th>
<th>Altitude loss (*)</th>
<th>Average vertical speed</th>
<th>Max distance from beginning of upset</th>
<th>Accident descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 March 1994</td>
<td>Near Mezhduretshensk (Russia)</td>
<td>A-310</td>
<td>F-OGQS</td>
<td>Aeroflot</td>
<td>~ 2 min 36 s</td>
<td>~ 31,000 ft</td>
<td>~12000 ft/min</td>
<td>~ 3 NM</td>
<td>Roll upset, spiral, spin</td>
</tr>
<tr>
<td>7 December 1995</td>
<td>Near Grossevichi (Russia)</td>
<td>TU-154B</td>
<td>RA-85164</td>
<td>Aeroflot</td>
<td>~ 57 s</td>
<td>~ 31,000 ft</td>
<td>~32000 ft/min</td>
<td>~ 8 NM</td>
<td>Roll upset, spiral (fuel imbalance)</td>
</tr>
<tr>
<td>19 December 1997</td>
<td>Musi river, near Palembang (Indonesia)</td>
<td>B737-9V-TRF</td>
<td>9V-TRF</td>
<td>Silk Air</td>
<td>~ 1 min 15 s</td>
<td>~ 35000 ft</td>
<td>~29000ft/min</td>
<td>~ 5 NM</td>
<td>Unknown</td>
</tr>
<tr>
<td>19 November 2001</td>
<td>Near Kalyazin (Russia)</td>
<td>IL-18V</td>
<td>RA-75840</td>
<td>IRS Aero</td>
<td>~ 59s</td>
<td>~ 26,000 ft</td>
<td>~26000 ft/min</td>
<td>~ 4 NM</td>
<td>Diving from cruise flight, spiral</td>
</tr>
<tr>
<td>21 December 2002</td>
<td>Off Penghu Islands (Taiwan, China)</td>
<td>ATR 72</td>
<td>B22708</td>
<td>Trans Asia</td>
<td>~ 40 s</td>
<td>~ 18000 ft</td>
<td>~27000 ft/min</td>
<td>~ 2 NM</td>
<td>In-flight icing, stall</td>
</tr>
<tr>
<td>16 August 2005</td>
<td>Near Machiques (Venezuela)</td>
<td>MD-82</td>
<td>HK-4374X</td>
<td>West Caribbean</td>
<td>~ 3 min 30 s</td>
<td>~ 31000 ft</td>
<td>~12000ft/min</td>
<td>~ 17 NM</td>
<td>Stall during cruise</td>
</tr>
<tr>
<td>22 August 2006</td>
<td>Near Donetsk (Ukraine)</td>
<td>TU-154M</td>
<td>RA-85185</td>
<td>Pulkovo</td>
<td>~ 2 min 46 s</td>
<td>~ 39,000 ft</td>
<td>~14000 ft/min</td>
<td>~ 3 NM</td>
<td>Stall during cruise flight, spin</td>
</tr>
<tr>
<td>1 January 2007</td>
<td>Makassar Strait, Sulawesi (Indonesia)</td>
<td>B737-700</td>
<td>PK-KKW</td>
<td>Adam Air</td>
<td>~ 1 min 45 s</td>
<td>~ 35000 ft</td>
<td>~20000 ft/min</td>
<td>~ 9 NM</td>
<td>IRS malfunction, PA disengagement, roll upset</td>
</tr>
<tr>
<td>15 July 2009</td>
<td>Near Qazvin (Iran)</td>
<td>TU-154M</td>
<td>EP-CPG</td>
<td>Caspian Airlines</td>
<td>~ 1 min 30s</td>
<td>~ 24,000 ft</td>
<td>~16000 ft/min</td>
<td>~ 5 NM</td>
<td>Loss of control, roll upset, spiral</td>
</tr>
</tbody>
</table>
Cumulative Distribution of Distance Traveled from Beginning of Emergency to Impact Location

Pro-rated to FL350
Methodology (SAROPS)

• METRON uses a modified version of SAROPS (Search and Rescue Optimal Planning System) of the US Coast Guards in order to model distributions of particles.

• Each particle (up to 10,000) is assigned a path and a “weight” coefficient, which give a probability figure to each one of them.

• SAROPS includes simulation modules (SIM) and planning modules (Planner) designed for the search of persons lost at sea.

**SIM** can represent particle distributions:
- red = high
- blue = low

**Planner** can produce optimized search zones and patterns.
Summary of the Methodology

Phase III search
- Posterior after Phase III (fig. 32)
  CDP=0.58

Phase II search
- Posterior after Phase II (fig. 24)
  CDP=0.45
- Posterior after Phase I (fig. 19)
  CDP=0.41
- Underwater Search Prior (fig. 15)

- Surface Search Posterior (fig. 14)

- Flight Dynamics Prior (fig. 2)

- Reverse Drift Prior (fig. 5)

Flight Path Computations from LKP
- BEA/MAK Study Distance flown in past LOC accidents
More details in the report available on the BEA website

Based on data
Rational approach
Used all unsuccessful searches

Main conclusion: **Systematic search** beginning within the North of the 20 NM circle

[Report link](http://www.bea.aero/fr/enquetes/vol.af.447/metron.search.analysis.pdf)
Zones covered by acoustic imagery

Priority Search Area (inside 20 NM circle)
Synthesis map: side scan sonar high-resolution survey coverage
Phases II 2009 and III Legs 1&2 2010

Seafloor mapping conducted in 2009 and 2010 including the high-resolution side scan sonar surveys
Phase 4 – AUV Search

✓ Chartered ship:

M/V Alucia (Deep Ocean)

AUV (x3)
Former Oceanographic Vessel: NADIR (IFREMER)
Side scan SONAR image of the accident site

Saturday 2 April 2011: Detection of possible underwater debris

• Slide presented to the families on 4 April 2011
Facts on the accident site

✓ Area to be searched during the various phases:
  ✓ 17 000 km²

✓ Wreckage site area
  ✓ 0.12 km² (like a needle in a haystack)
  ✓ Flat terrain (for once, we were lucky!)
  ✓ Depth: approx 3 900 meters

The deepest area of the zone (apart for the South-West Canyons)
Sunday 3 April 2011: Positive identification of the accident site
Landing gear

*Slide presented to the families on 4 April 2011*
Fuselage part / wing

• Slide presented to the families on 4 April 2011
Bathymetry of the Search Zone

Accident site (in the area of the Abyssal plain)

• Slide presented to the families on 4 April 2011
Phase 5: Search and Recovery of the recorders
Phase 5: FDR & CVR Recoveries

1 May 2011: identification of the memory unit from the FDR, lifted on board the “Ile de Sein” by the Remora 6000 ROV

2 May 2011: identification of the CVR, lifted on board the “Ile de Sein” on 3 May by the Remora 6000 ROV
Transfer of the two flight recorders
Transfer of the two flight recorders
On-going Transport

- ETA Cayenne: today
- ETA Paris (BEA): tomorrow morning
Some Lessons Learned

✓ The transmission time of underwater locator beacons must be increased from 30 to 90 days. Their effectiveness is, however, somewhat uncertain.

✓ Lower frequency beacons (8.8 kHz) should be installed onboard commercial airliners. A submarine is not appropriate to search for 37.5 kHz ULBs.

✓ More frequent position reporting by airplanes (flight AF447: every 10 minutes only)

✓ Drift buoys to be dropped as soon as possible after an accident to follow the drift currents

✓ Need to record all search data

✓ Development of new methodologies and improvement of tools for SSS searches
Conclusions

✓ The successful recovery of both flight recorders was a huge challenge.

✓ It represents the culmination of vast collective efforts in which the oceanographic community has actively participated

✓ We need to capitalize on this extensive work!
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