Links for a successful investigation
C-212 Robison Crusoe Island Accident Case

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Luis Gracia was born in Madrid (Spain) at 1958. Master degree (MSc) in Aeronautical Engineering by Madrid Polytechnic University and Master in Direction of Production, Technology and Operations by University Institute for Business & Administration ICADE of Pontifical University of Comillas. He started to work at 1983 for the former Spanish aeronautical company CASA, then EADS CASA, Airbus Military and finally Airbus Defence & Space, in the Flight Test Department. He is experimental Flight Test Engineer with more than 1.200 flight test hours. He acted as Head of Flight Test for 17 years, with a deep involvement in Eurofighter, A330 Tanker, A400M and Light Turboprops (C-212, CN-235, C-295) programs. In 2010 he was nominated as Head of Product and Flight Safety. He is also Associated Professor in Madrid Polytechnic University, teaching Flight Mechanics.

This paper introduces how a successful investigation on a complex accident can be made even when you don´t have any record from the Flight Data Recorder (FDR) or Cockpit Voice Recorder (CVR). Most of accident investigations are normally based on the in-flight recorded data during the accident, but what we can do if the crashed aircraft was not fitted with those recording means?. This paper shows the reader how it is possible to perform the investigation by linking information and data coming from other sources, and merging different technologies available in the aviation sciences to be able to determine the accident causes.

Message provided in this paper is to show that we should not be only dependent from the recorded data, and how evidences may be got from many different sources that, when used in smart manner, can allow to perform a successful investigation.

The study case presented is linked to the accident happened on September 2nd, 2011, with the C-212 Series 300, Model DF MSN 443, operated by the Chilean Air Force (FACH), where the aircraft was lost into the sea while performing a second approach to the Robison Crusoe Island airport (Juan Fernandez Archipelago - Chile) in high crosswind and bad weather conditions.

The aircraft is military twin turboprop transport aircraft, with a fixed landing gear, non-pressurized, equipped with a rear fuselage ventral door and ramp, able for passengers and cargo transport, with a Maximum Take-off weight of 8.100 kg. Aircraft is suitable for external underwing tanks for range increasing.

Figure 1

1. Investigation Overview

The fight of the accident was a logistic flight in supporting of humanitarian actions developed by a non-government organization (NGO) in favor of the local population after suffering a tsunami. The Juan Fernandez Archipelago is part of Chile territory and is located in the middle of Pacific Ocean at 410 NM from Santiago the Chile.

There were 21 people on board: 4 were the FACH crew and 15 were civil personnel from the NGO and a Chilean TV channel supported by 2 FACH Public relations representatives.

As part of civil personnel, there were on board the brother-in-law of Ministry of Defense, who was also the NGO chairman, and the most popular TV showman and his team to provide media coverage.

The accident had a huge repercussion on the Chilean population, and the Chile Republic´s President designated a civil judge (Ministro en Visita) as maximum authority for the investigation over any other civil or military Chilean organization.

For the investigation, the Ministro en Visita decided to designate two independent investigation teams: the FACH Official Investigation Board, and a second non official Investigation Board chaired by Airbus Military, as aircraft manufacturer. Both Boards were committed to prepare their own Investigation Report identifying the accident causes.

To provide independence and credibility to our work, Airbus Military decided to create a mix team under our leadership, with accredited investigators from: Dowty Rotor (UK), as Propeller manufacturer; Honeywell (USA), as Engine manufacturer; and Accident Investigation and Research (AIR – Canada), as General Advisors.

2. History of the Flight

Aircraft didn´t exhibit any relevant defect or malfunction prior to the flight, and a 1A maintenance inspection had been recently passed.

Aircraft was full refueled. No external fuel tanks were fitted. Endurance declared was 3:35 hours for an EET (Estimated Elapsed Time) of 2:40 in the Flight Plan.

Aircraft didn´t have enough fuel for a return flight, and landing in the destination airport was mandatory when the non-return point is overcome. This way to operate is accepted by the FACH policy, based on the actual distance between the Island and the Continent and in the absence of any alternative airport other than those located in the Continent.

Flight was properly planned by the crew with knowledge of weather information in both airports and in route. Weather forecast in route stated winds from northwest–west of 20 to 30 kts at 3.000 ft, increasing at higher altitude up to 50 kts at 11.000 ft. A cold front was expected in route with light to moderate ice formation at FL050 to 070. Weather forecast in the destination airport corresponded to a post front situation with instability, unlimited visibility, winds from south-southwest of 20 kts, cloudy to partial with cumulus based at 3.000 ft up to 15.000 ft.

The flight was delayed along the morning of September 2nd (Friday) expecting weather improvement but finally the aircraft took off at 16:51 UTC (13:51 Local). Aircraft should return to Santiago de Chile in the same day.

The two pilots were properly qualified for the flight, but only the captain had the experience of a previous flight to the Island.

The Take-off weight (TOW) was estimated to be 8.265 kg, which is slightly overweight on the maximum allowed (8.100 kg) but with no influence on the accident.

The route was partially covered by Santiago radar and aircraft was tracked up to 30 NM beyond MORSA reference point.

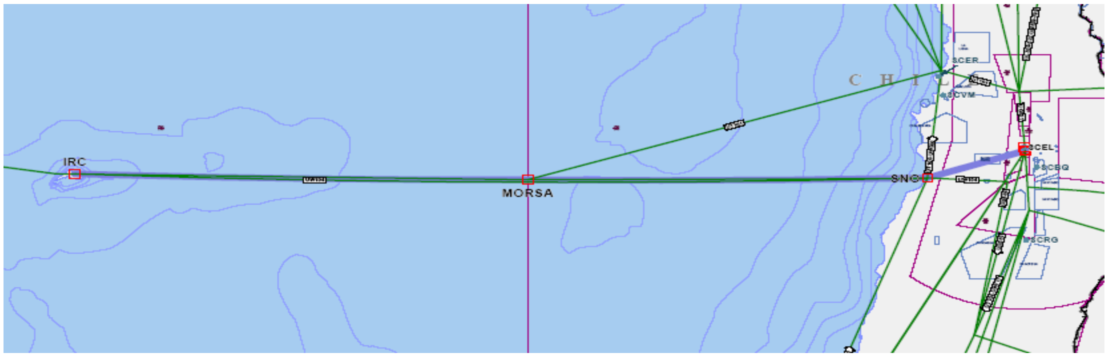

Figure 2

The flight in route was developed in adverse weather conditions: strong permanent headwind with varying intensity, numerous clouds and storms that forced major changes in heading and flight level, with the aircraft climbed up to FL150 versus FL090 authorized level.

Radio comms were hold in VHF with Santiago Control Center and with Robinson Crusoe Island (SCIR) Local Control. No comms held in HF with Oceanic Control Center on the second half of the route.

The aircraft arrived to the Island at 19:48 UTC, after 02:57 of flight.

A local representative was waiting on the airfield to welcome the aircraft and passangers. This witness was the only source to know what the aircraft did when arrived to the Island. He described the aircraft flight path as follows:

The aircraft flew-over the runway RWY 14 (North to South) and performed a teardrop maneuver to the right to invert heading for approaching to RWY 32, but this maneuver was performed at very low altitude, because the witness lost the aircraft view while performing it. Then, when the aircraft was on RWY 32 heading, a balked landing was experienced with high and gusty cross-wind, with the aircraft deviated at the right of the runway. When in the North, an open left turn for a new approach to RWY 32 was initiated through the channel between the airfield and Santa Clara Island but the aircraft disappeared below the hills around the airport and it was never seen again.

Figure 3

3. Robinson Crusoe Airfield (SCIR)

The Juan Fernandez archipelago consists of the islands of Robinson Crusoe (a single village), Santa Clara (inhabited) and the separate island of Alejandro Selkirk.

It is a sharp mountain area of volcanic origin with significant heights from up to 915 meters as well as sea cliffs over 100 meters high.

Figure 4

The airport is unattended, with no Tower, VFR (Visual Flight Rules), and no beacon. Meteo info and radio control is provided by an office located at town, at the opposite island side. Runway is a "carrier type", with a length of 3.304 ft., width of 59 ft. and elevation of 433 ft. The unique local help is a wind sock, and the AIP special advises are: - Cliff at both RWY heading & - Animal presence on RWY.

4. Wreckage Recovery

Aircraft wreckage was found on the seabed, at a depth of 50 m., in line with the direction set by the channel between the islands, some days later.

Only few parts like the ramp, a MLG wheel, and other light internal parts (cushions …) were found floating in the sea. Chilean Authorities used two sea robots for seabed screening and for supporting the work of the divers in the bodies and some aircraft light parts recovery (propellers, instrument cockpit panel …). Those sea robots took videos and GPS position from the different parts found in the bottom.

Two and a half months after the accident, a major rescue operation was performed to recover the wreckage from the sea floor. That wreckage was moved to a hangar, where it was laid out for airplane reconstruction.

Figure 5

5. Accident Investigation

5.1 Information available

Aircraft didn´t fit FDR or CVR and the on-board GPS didn´t have recording capability.

Information from inside the aircraft was only got from a broken but recovered VHS video tape from a TV camera. This information showed that Pilot In- Command was the 2nd Officer, in his first trip to the Island, while the Captain was seated on the right managing comms. A photograph was extracted from the video tape to show the Take-off and Landing (TOL) Card, where figures for the Take-off speed were used to confirm the Take-off weight based on the aircraft performance tables.

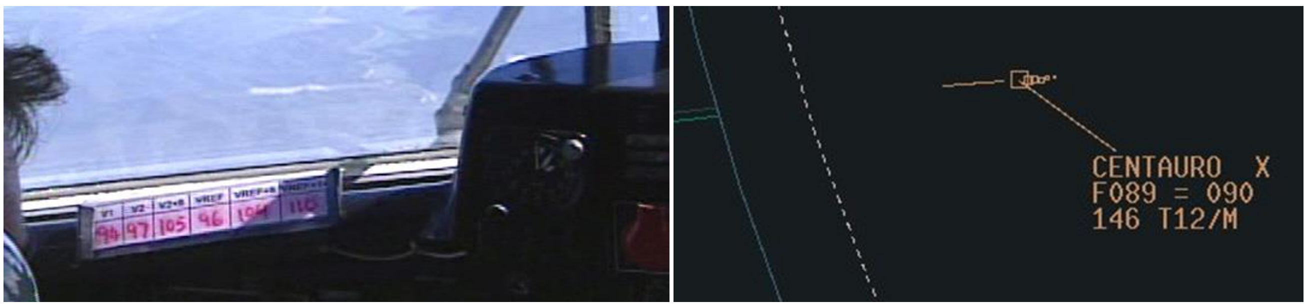

Figure 6

Flight radar tracking information was also available for the first half of the flight, due to the limitation in the radar coverage located in the Continent, providing information about time, position, altitude and ground speed.

VHF Audio records with Santiago Control and Robinson Crusoe Island were also available. No problems or emergency was declared at any time.

Meteorological conditions at the Island at the accident time were computed based on the on-ground local records and satellite information.

As a key element for the investigation, a precise and detailed testimony was provided by the unique witness.

Information about the landing conditions in the Island was provided by a previous commercial flight landed on the island in a second attempt after a balked landing caused by high and gusty crosswind.

Other source of information was the examination of the recovered wreckage parts, especially the engines and propellers, some cockpit instrument and the aircraft structure.

5.2 Route Performance

One of the hypotheses for the accident to be examined was that the aircraft fell into the sea by lack of fuel, or that shortage of fuel could stress the crew for wrong actions. A performance analysis was done to evaluate this hypothesis.

Total distance and time were matched for different power settings, and wind speed was calculated based on data provided by radar tracking or estimated where no radar data was available.

Analysis using Max Cruise Power showed that the remaining fuel in the tanks should be enough for a 110 minutes flight; and even if stronger headwind would be encountered (10 kts more) and Max Cont Power should be used, remained fuel should be enough for 90 minutes.

These amounts of fuel were in agreement with the marks found in the fuel tank content instruments.

So, it was concluded that the lack of or shortage of fuel was not a contributing factor to this accident.

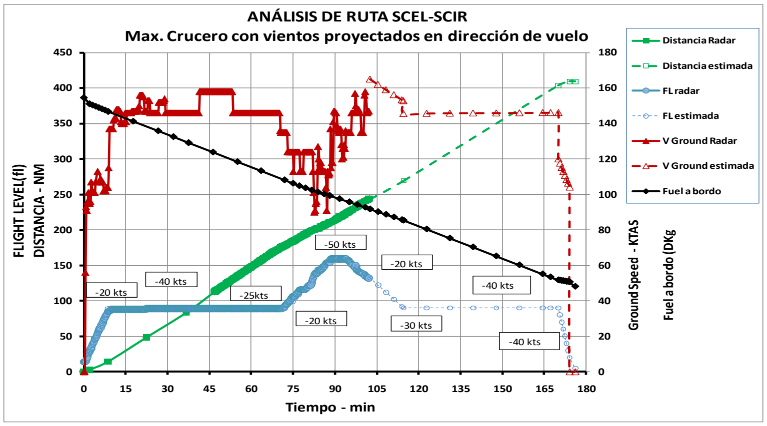

Figure 7

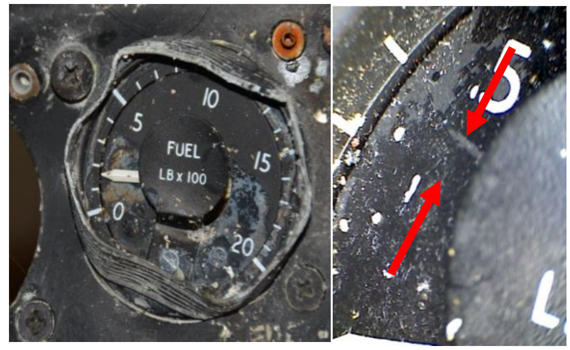

Figure 8

5.3 Witness Testimony – Flight Test

Witness located in the airfield was visually tracking the aircraft path after balked landing until the aircraft was hidden by the hills around.

Investigation teams were detached to the Island to perform real flight checks. It was used FACH aircraft (by the way the oldest Twin Otter in the world still in flight) to fly over the channel between the two island at different altitudes while the Investigation Boards were located in the same witness position observed if the plane was visible through the surrounding hills profile, and trying to match the aircraft altitude over the channel with the exact location where the aircraft was hidden by the surrounding hill according to witness declaration.

Tests showed that aircraft altitude in the channel should be **650 ft. or less**. It should be reminded that airfield elevation is 433 ft., and Santa Clara Island maximum height is 1.226 ft.

It was concluded that the aircraft was flying at a much lower altitude than the height of the Santa Clara Island and therefore the aircraft was exposed to the turbulence wake generated by the presence of that island in high wind conditions when the aircraft flew at the back of the island while flying through the channel between both islands.

Figure 9

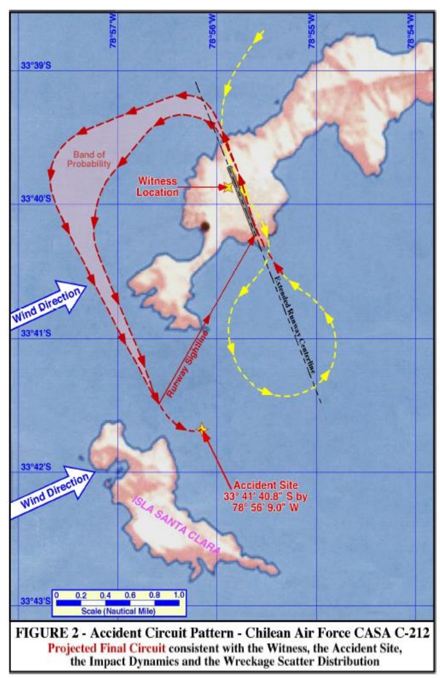

Figure 10

5.4 Meteorological Information

After the accident, the Chilean meteorological Institute determined the existing weather around the airfield using information taken from:

- Images provided by satellites to see cloud activity and storm cells.
- Local data from meteo station located close to the island´s village.
- Analytical models and meteorological data gathered in the Pacific south area.

Based on such information, it is stated:

- "the Juan Fernandez archipelago, around 19:00 and 20:00 UTC, was under strong instability post front , …, with significant development of cumulus near and west of the island
- the archipelago was affected by a region of strong winds (at least 30 or 35 knots) from 18:30 or 19:30 UTC, not ruling out that these conditions have persisted until after 20:000 UTC
- It indicates the occurrence of high variability in terms of wind intensity and horizontal and vertical variation
- It allows to conclude the presence of strong instability around the aerodrome of Robinson Crusoe around 19:00 to 20:00 UTC, with average winds over 25 knots and gusty, strong horizontal wind shear (more than 180 degrees in 2 minutes) and presence of upwind and downwind associated with proper circulation of vertical development clouds. This situation was generated by the activity of open cells (cumulus clouds).
- The presence and characteristics of open cell allows concluding that there was a strong instability, and therefore at least moderate turbulence in the sector, and the presence of downwind between Santa Clara and Robinson Crusoe islands.

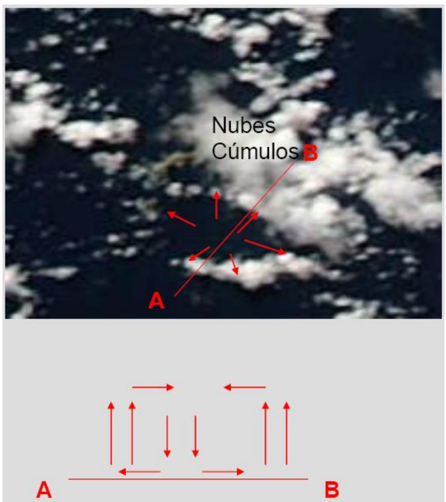

Figure 11

5.5 Engines & Propellers Examination

Both engines were partially disassembled for rotating parts examination. The damages exhibited were consistent with both engines operating at the time of impact. The damages observed in the curvics of the turbine impellers suggest medium /high power setting. The damage observed among the rotating parts was consistent with the turbine overdriving the compressor when the rotating propellers were slowed by the action of water.

For the propellers, it was concluded that both propellers were rotating at the time of impact. Based on the bending of the blades, the propellers were with power and were operating within their normal flight range. Initial propeller damage occurred at the time of impact with water and the secondary damage was consistent with a propeller under power entering into the water and being driven aggressively into reverse by the increase on torque caused by the density change from air to water.

So, it was also concluded that both engine were operating in the normal range at the time of the accident.

Figure 12

5.6 Cockpit Instrument Inspection

Not many instruments were recovered, and the most of them belong to the front central panel.

Both propellers RPM indicators showed marks around normal range. Flaps indication was around 14% where APP/TO (25%) was the recommended deflection for landing in high cross-winds condition.

The most relevant information was provided by the g´s indicator, where the needle was pointing to a negative vertical acceleration of -1.6 g´s. Aircraft flying in inverted position with a significant downwards acceleration.

Figure 13

5.7 Examination of the Structure

Aircraft structural integrity at the crash time was confirmed based on recovered parts and the examination of underwater videos. All control surfaces were found, as well as some of the wing parts and the stabilizers.

Aircraft recovered parts were laid out on a hangar for aircraft reconstruction. When all recovered parts were displayed in their position into the aircraft, the following findings were observed:

- No large sections of the outer left wing were recovered. Structure was scattered in many small pieces. A small leading edge part recovered was completely flattened. All these factors showed the left wing impacted on the water with high energy. Before that, the wingtip was ripped off when it touched the water.
- The outer right wing slammed into the water symmetrically along the leading edge. It is broken up into much larger sections than the left wing showing that impact occurred at a lower energy.
- Aircraft nose was destroyed but rotated 30º to the right as it could be observed in the lower fuselage beams.
- The ramp travelled forward.
- The upper fuselage skin was ripped off by water surface friction loads.
- The vertical fin had pulled away from the rear fuselage.

Figure 14 Figure 15

5.8 Impact Reconstruction and Accident Scenario

Based on the wreckage structural damaged and the already mentioned findings, the sequence for the water impact could be reconstructed.

It was concluded that the aircraft struck the ocean in an abnormal attitude with significantly past 90º left bank. Aircraft was inverted and still rolling to the left while side-slipping to the left. The break-up sequence shows the aircraft was flying forward (it had forward momentum), but it was also a quickly dropping (side-slipping) to the left.

The aircraft nose was also dropping, but, however, aircraft did not cartwheel. It rolled inverted while the outer portion of the left wing was slicing into the water and literally shattering from water forces.

At the same time, the aircraft nose and cockpit were destroyed when impacted the water and rotated some 30º to the right, while being crushed rearwards by water forces.

When the aircraft rolled totally inverted, the right wing slammed into the ocean and broke into three large sections. The top of the fuselage was rippled like accordion by water friction forces, and the rear fuselage and dorsal fin displayed hydraulic crushing on the right side.

The vertical fin was ripped away from the rear fuselage attachment, showing the aircraft had forward momentum throughout its destruction.

The horizontal stabilizers were the less damaged parts as most of the impact energy was already dissipated by the crushing of others parts. The right inverted horizontal stabilizer struck the water first (aircraft banked 15º "left") causing diagonal compression while the left stabilizer only showed inertial effects.

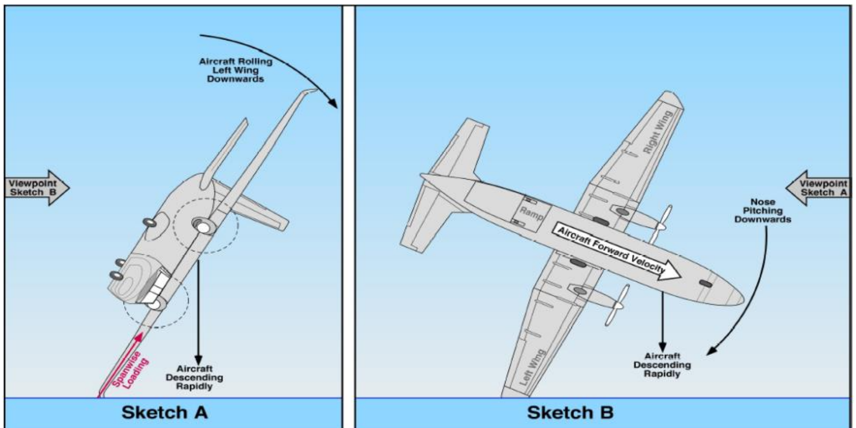

FIGURE 5 - Schematic of Aircraft's Orientation and Motion at the Moment of Initial Impact with the Sea

Figure 16

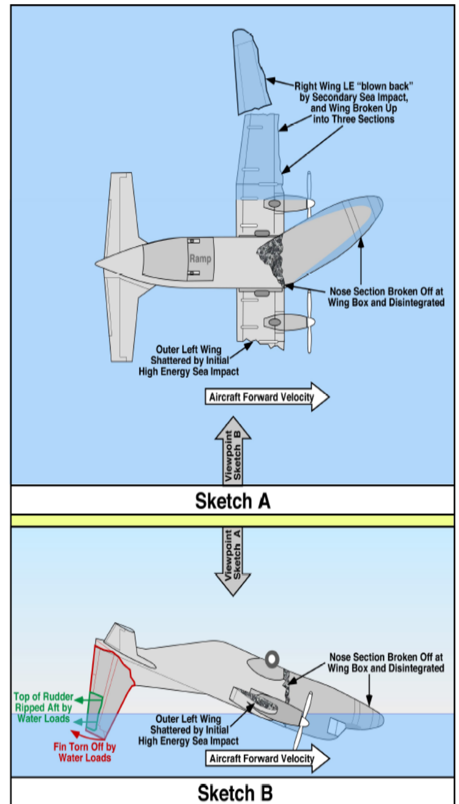

FIGURE 6 - Schematic of Aircraft's Orientation and Break-up at the Time of Secondary, Inverted Impact with the Sea

Figure 17

As a summary of Impact Reconstruction it was concluded that all findings were consistent with **a loss of control from a relatively high groundspeed and low altitude above the ocean surface.**

But the real question was: What caused the crew to lose control in flight of the aircraft in such circumstances?

As there were no failures on the aircraft systems, two main external contributors were identified:

- Instability caused by the meteorological condition as described in chapter 5.4
- Downwind instability generated by the presence of Santa Clara Island when flying in high winds at its wake at low altitude.

As both effect are not obvious and tangible and they could not be understood by the public opinion and, in addition, it is difficult to determine its intensity and if such intensity could be enough to force the aircraft loss of control, it was decided to measure the second effect through a wind tunnel tests campaign.

5.9 Local Airflows Determination – Wind Tunnel Test

To determine and quantify the airflows in the channel between the islands in the presence of strong winds from south-southwest, Airbus Military decided to build a wind tunnel model of the area that included the Santa Clara Island and the western tip of Robison Crusoe Island, where the airport is located.

The Aeronautical Engineering School from Madrid Polytechnic University manufactured the escalated model and tested in their wind tunnel facilities. The flow pressure and speed were measured in all affected area. Smoke was also use for flow visualization.

Airbus Military also performed an analytical study using CFD (Computer Fluid Dynamics) models about wind flows around the islands, which was tuned to wind tunnel results and used as graphical support mean for them.

Figure 18

Figure 19

Four wind directions were tested: 210º, 240º, 270º y 300º. The results showed that the rugged terrain and the sharp shape of Santa Clara Island, with dimensions of 3 km x 1,5 km and a maximum height of 1.226 ft., resulted in the appearance of two downwind vortexes, with high instability. These two vortex tubes are dragged along the wind direction towards Robinson Crusoe Island (see Fig. 20), resulted in a really instable wake for any aircraft crossing through.

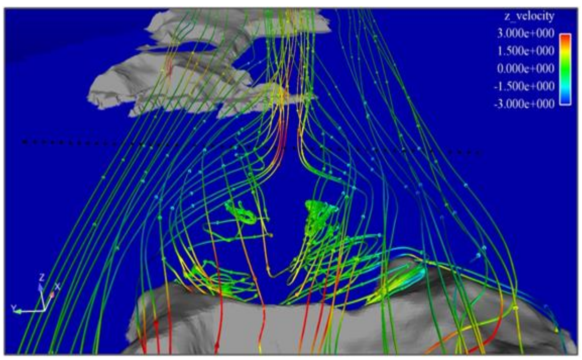

Figure 20

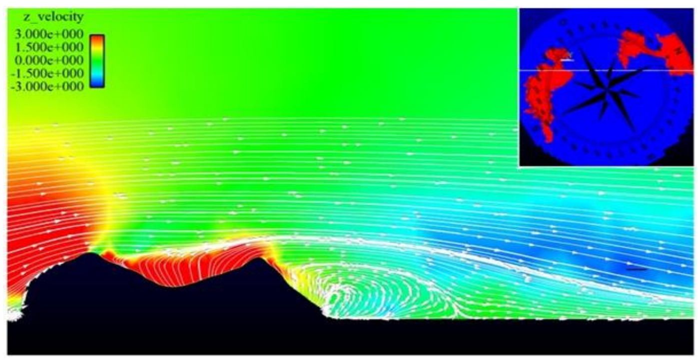

Figure 21

These vortexes caused rotational movements in the air mass, resulting in alternates upward and downward flows in a very short distance, resulting in changing strong gradients in airflow vertical speed and wind shear rates.

As it can be seen in Fig. 22, one aircraft flying at 500 ft. through the channel between both islands would find significant downwind (blue) followed by upwind flows (red) and finally stronger downwind (blue) when crossing through these counter rotating vortexes. It happens along less than 1.000 meters that means about 15 second for the normal aircraft airspeed.

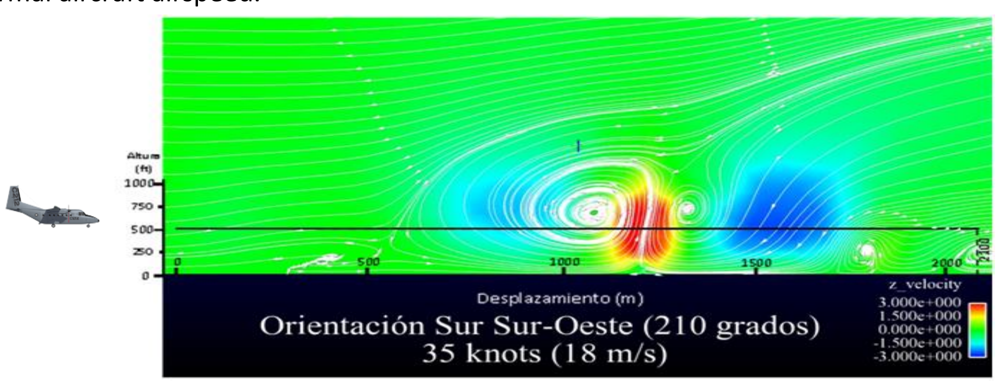

Figure 22

In such situation, the difficulty to maintain aircraft control become evident, especially when it is combined with the convective flow resulted from the meteorological situation.

5.10 Investigation Results

Accident was caused by the loss of control of the airplane while performing the tailwind leg through the channel between the islands of Robinson Crusoe and Santa Clara to an estimated height of 650 feet or less, during the circuit approach to runway 32, in a very low trajectory (with little height difference above the runway), where very adverse airflow conditions were found, including wind shear, which exposed the crew to extreme flight conditions.

Adverse airflow conditions were the results of a combination of different factors:

- Very unstable atmosphere, with strong turbulence and possibly eventually powerful down gusts, arising from the presence of open cell after a front passed.
- The presence of the two counter rotating vortexes in the Santa Clara Island downwind wake.
- The presence of strong and gusty cross winds very variable in strength and direction in a very short time.

These investigation results were well accepted by all parties involved in the accident and no one questioned the conclusions reached.

6. Conclusion

Accident occurred with the C-212 in the Robison Crusoe Island in 2011 has allowed to demonstrate how a successful investigation may be performed even when there are no recorded data from the flight.

The combination and links among different investigation technologies may provide the investigator the pieces for a puzzle to be smartly matched to create the scenario in which the accident occurred.

The result of this methodology may be as conclusive as the recorded data are, although it requires normally much effort and imagination than the recorded data interpretation.