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Bureau enquêtes accidents pour la sécurité de l'aéronautique d'État

Safety Investigation Report

I-2016-15-A

Date of event	**24 October 2016**
Place	**Malta International Airport**
Type of aircraft	**SA227 AT - MERLIN IV C**
Company	**CAE Aviation**

BEA-É

NOTICE

REPORT COMPOSITION

The first chapter of the report presents the facts relevant to understanding the accident. The second chapter analyzes the possible causes of the accident. The third chapter draws the conclusions of this analysis and presents the identified causes. Finally, safety recommendations are proposed in the final chapter.
Unless otherwise specified, the times specified in this report are expressed in Maltese legal time.

USE OF THE REPORT

The sole purpose of this safety report is to prevent accidents and serious incidents without apportioning blame or responsibilities. The identification of causes does not imply the determination of administrative, civil or criminal liability. Consequently, any use of the full or partial report for purposes other than its aim of improving safety is contrary to the spirit of the laws and regulations and is the responsibility of its user.

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GLOSSARY

ATPL	Airline Transport Pilot Licence
CAE Aviation	*Compagnie Anglo Européenne d'Aviation*
Cpt	Captain
CofA	Airworthiness Certificate
DGA EP	French Defence Procurement Agency – Propulsion Tests
DGA EV	French Defence Procurement Agency – Flight Tests
DGA TA	French Defence Procurement Agency – Aeronautical Systems
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
ft	foot (1 ft ≈ 0.30 m)
HF	High Frequency
ITAR	International Traffic in Arms Regulations
kt	knot (1 kt ≈ 1.852 km/h)
NTSB	National Transportation Safety Board (USA)
ICAO	International Civil Aviation Organization
OSAC	"Organisme de Surveillance de l'Aviation Civile" (Civil Aviation Safety Organizaton) – France
THS	Trimmable Horizontal Stabilizer
PNF	Pilot Non Flying
TR	Type rating
SAS	Stall Avoidance System
TCAS	Traffic Collision Avoidance System
TSB	Transport Safety Board (Canada)

SUMMARY

Date and time of event: 24 October 2016 at 07:20
Place of event: Malta International Airport
Company : CAE Aviation [1]
Aircraft: SA227 AT Merlin IVC, registration No. N577MX
Nature of flight: maritime patrol
Number of persons on board: 5

Summary of the incident, according to the initial findings

When taking off on Runway 13, during rotation, the aircraft seems adopting a normal pitch then the nose rose significantly very quickly followed by a roll to the right until it was three-quarters inverted at the top of its trajectory. During the descent, the aircraft began to tilt back to the left until it hit the ground 130 meters to the right of the runway center line and approximately half-way down the runway.
All those on board died. The aircraft was destroyed.

Composition of the safety investigation group

- An Investigator in charge from the French State aviation accident investigation Bureau ("Bureau Enquêtes Accidents pour la Sécurité de l'Aéronautique d'État"[2] – BEA-É);
- An assistant investigator from BEA-É;
- A technical expert from BEA-É;
- A test pilot with expertise in the flight tests applicable to this type of aircraft;
- A doctor qualified in aviation medicine.

Other experts consulted

- French Defence Procurement Agency – Aeronautical Systems (DGA TA);
- French Defence Procurement Agency – Propulsion Tests (DGA EP);
- French Defence Procurement Agency – Flight Tests (DGA EV);
- Eurocontrol.

Other accident investigation boards consulted

- National Transportation Safety Board (NTSB) – USA;
- Transport Safety Board (TSB) – Canada.

Manufacturers consulted

- M7 Aerospace (holder of the aircraft type certificate);
- Dowty Propellers;
- Honeywell;
- Woodward;
- SANDEL Avionics.

[1] The acronym "CAE" stands for "Compagnie Anglo Européenne".

[2] Pursuant to the terms of Decree No. 2018-346 dated 9 May 2018, the previous name for the French state aviation accident investigation bureau, "BEAD-Air", has been changed. The French State aviation accident investigation Bureau is now known in French as "Bureau Enquêtes Accidents pour la Sécurité de l'Aéronautique d'État" or by the acronym "BEA-É").

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1. FACTUAL INFORMATION

1.1. History of the flight

1.1.1. Mission

Type of flight: GAT IFR[3]
Type of mission: maritime patrol
Last point of departure: Malta International Airport
Departure time: 07:19
Planned landing point: Malta International Airport

1.1.2. Sequence of events

1.1.2.1. Flight preparation

The plane was fully refuelled on 21 October 2016.
The five crew members prepared for their mission on 23 October 2016 around 15:00.
The flight plan was received by the European Organization for the Safety of Air Navigation ("Eurocontrol") on Sunday 23 October 2016 at 18:29.

1.1.2.2. Description of the flight and of the factors that led to the event

The aircraft left its parking stand at 07:15 and stopped at the "Oscar Inner" holding point, waiting for its authorization to line up for takeoff on runway 13.
It was cleared to line up and then take off at 07:18 for a standard instrument departure[4] termed SUDIK 2B.

The engines were throttled to full power and the brakes released at 07:19.
Retraction of the landing gear was initiated shortly after lift-off.
The aircraft adopted very quickly a sharp nose-up attitude.
A few seconds after entering this pitch attitude, a sudden rightward rolling movement was noticed.
The plane was observed in a three-quarters inverted position at the apogee of its trajectory.
During its descent, the aircraft started an inverse roll to the left, until impact with the ground, 130 metres to the right of the takeoff axis and roughly at mid-runway level.
A total of approximately ten seconds elapsed between lift-off and impact.

1.1.2.3. Reconstitution of the significant part of the flight trajectory

A reconstitution of the flight path is presented in Figure 1.

[3] GAT IFR: General Air Traffic – Instrument Flight Rules.
[4] For IFR flights, standard instrument departures (SIDs) have a specific name.

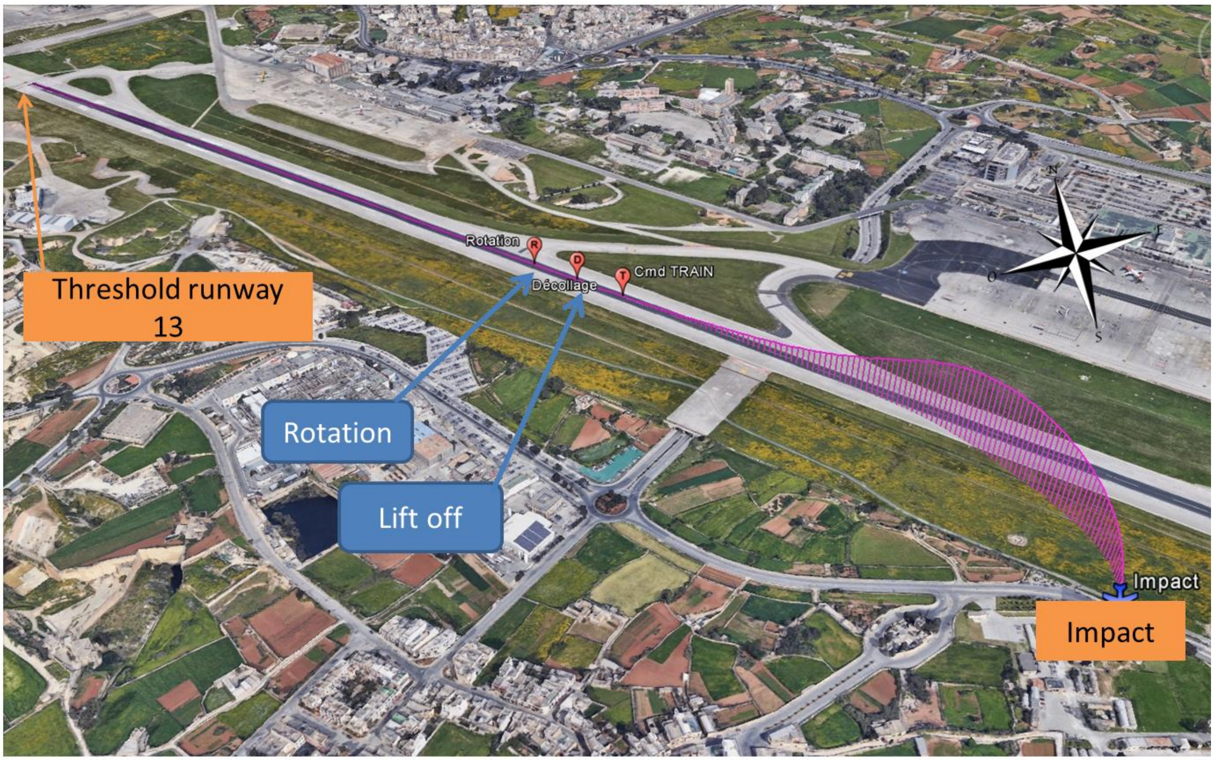

Figure 1: Reconstitution of the aircraft's trajectory

1.1.3. Location

- Place: Malta International Airport
  - Country: Malta
  - Town: Kirkop
  - Geographical coordinates: N 35°51'/ E 014°28'
  - Maximum height during the incident: 240 ft
- Time of day: day (dawn)

1.2. Injury to persons

The five persons on board died.

1.3. Damage to aircraft

The aircraft was destroyed.

1.4. Other damage

The impact zone was located at the perimeter wall of the airport. The perimeter wall and the associated fence were destroyed or damaged over a distance of approximately twenty metres. The exterior road and the wall on the other side of the road were damaged over a distance of at least about thirty metres. Three buildings located on the other side of the road were partly damaged or bear traces of the fire that broke out on the ground. Some of the surrounding trees were burned (see Figure 2).

Figure 2: Damage to the perimeter wall, road and surrounding buildings

1.5. Personnal information

1.5.1. Flight crew

1.5.1.1. Captain

The initial training of the Captain (Cpt) was carried out in the French Air Force, he obtained the 2nd level military pilot licence - Transport option - in 2009. He also obtained a European CPL (A) commercial pilot licence in 2009.
He left the French Air Force in 2011.
Aged 30, he had been employed by the company CAE Aviation since 2012. He held an American licence issued in August 2014 with the following notes in the "Ratings" section:

- ATPL (airline transport pilot licence);
- multi-engine aeroplane, land[5] ;
- Type rating (TR) on SA227.

- Flight hours as pilot:

	Total		During the previous 6 months		During the previous 30 days	
	on all types	including SA227	on all types	including SA227	on all types	including SA227
Total (h)	3,511	1,229	99	99	31	31

- Date of previous flight as pilot: 20 October 2016 on the same aircraft as for the flight on 24 October 2016.

[5] The notice " *LAND*" on the licence provides a differentiation from pilots qualified on amphibian aircraft or hydroplanes, and whose licence bears the notice "*SEA*".

1.5.1.2. Monitoring Pilot

According to the company's manual, the monitoring pilot must be a pilot holding an up-to-date license and medical certificate. The monitoring pilot does not necessarily have to be qualified on the aircraft and can be seated in the right-hand seat for a certified single-pilot aeroplane, as is the case of the Merlin IV. The role of the monitoring pilot is to provide an extra level of safety during complex or long flights. The monitoring pilot is officially designated as Pilot Non Flying (PNF).
On this flight, the monitoring pilot, aged 70, was employed by CAE Aviation. He held an American licence (ATPL) delivered in February 2013, and a TR for the Dassault Falcon 10.

- Flight hours as pilot and monitoring pilot:

	Total		During the previous 6 months		During the previous 30 days	
	on all types	including SA227	on all types	including SA227	on all types	including SA227
Total (h) as pilot	21,806	2,304	0	0	0	0
Total (h) as monitoring pilot	75	75	75	75	37	37

- Date of previous flight as monitoring pilot: 20 October 2016 on the same aircraft as for the flight on 24 October 2016.

1.5.2. Operators of the on-board systems

- Tactical coordinator: 39 years old;
- Operator No. 1: 33 years old;
- Operator No. 2: 52 years old.

1.6. Aircraft Information

- Company: CAE Aviation;
- Type of aircraft: Swearingen SA227 AT (description in Annex 1).

Before being sold to CAE Aviation and after a period without airworthiness certificate (CofA) between 2005 and 2011, the aircraft's history is as follows:
- a technical inspection and aircraft appraisal report of the aeroplane was drawn up by Worldwide Aircraft Services on 13 July 2011;
- the aircraft has been modified by Worldwide Aircraft Services between 13 July and 28 July 2011 (avionics, sensors, extra fuel tank);
- a "recertification" was issued, resulting in a CofA in the "*special*" category, "*restricted*" sub-category on 28 July 2011;
- a new "*normal*" category CofA was issued by the FAA on 11 August 2011 (see Annex 1);
- the plane was sold to CAE Aviation in September 2011.

According to the aircraft's maintenance records, the major components installed on the aircraft and their respective operating times are as follows:

	Type - Series	Number	Total flight hours	Flight hours since	Flight hours since
Airframe	SA227 AT	AT-577B	9,261	Check A+B: 174	Check C+D : 74
Engine No. 1	TPE 331-11U-611G	P44498C	17,922	OH[6]: 2,276	-
Engine No. 2	TPE 331-11U-611G	P44269	7,191	OH: 3,606	HSI[7]: 1,145
Propeller No. 1	DOWTY R321/4-82F/B	DRI/DRG/4008/85	14,770	OH: 1,616	-
Propeller No. 2	DOWTY R321/4-82F/B	DRI/DRG/313/86	25,090	OH: 1,026	-

1.6.1. Maintenance

Maintenance of the SA227 AT aircraft is based on the completion of four regular scheduled inspections termed "Checks A, B, C and D", each of different content. The maintenance programme of the aircraft involved in the accident conformed to the following maintenance schedule:

- Checks A + B;
- then Checks C + D after 100 flight hours;
- then Checks A + B after a further 100 flight hours;
- etc.

During the modification works on the aircraft from March 2015 to March 2016, the aircraft was submitted to four simultaneous inspections, due to the long period of immobilization (Checks A, B, C and D after 9,006 hours). During this visit, the flight control cables were changed. This operation was performed in the absence of appropriate documentation concerning the modifications to the flight controls carried out in 1985. Any maintenance operations concerning the additional components of the flight control system (pulleys, guides, turnbuckles etc.) were not tracked on this occasion.

The aircraft was subsequently maintained as follows:

- Checks A + B were carried out in July 2016, together with various additional tasks;
- Checks C + D and additional tasks were carried out in September 2016.

Examination of the maintenance documentation shows that Service Bulletin[8] SB 227-27-020 concerning the improvement of the operating reliability of the Stall Avoidance System (SAS) was not implemented on the aircraft.

[6] OH: overhaul.
[7] HSI: Hot Section Inspection.
[8] This service bulletin recommends replacing the components of the SAS with improved versions (servo controls and control units), a new electrical wiring system and increasing the fuse capacity from 3 to 5 amps.

The aircraft has been fitted with a high-frequency (HF) antenna since 2011. This installation was approved by the FAA. The aircraft had registered 3,503 cycles on the date of the accident. The first inspection of the antenna was scheduled for 12,850 cycles.

1.6.2. Performance

According to the aircraft flight manual, under the conditions at the time of the event (mass at takeoff 16,000 pounds[9], temperature 25 °C, airfield elevation 300 ft, no wind, use of water-methanol injection, de-icing off), the takeoff distance is less than 1,000 metres, and the accelerate/stop distance is less than 1,700 metres.
Under the same conditions, the net climb gradient[10] with one engine inoperative is greater than 3%.
For these calculations, the crews are provided with a flight preparation software program described in the operations manual of CAE Aviation.

1.6.3. Mass and centre of gravity

The aeroplane left the modification workshop on 8 March 2016. Its load sheet on this date stipulated an empty weight of 10,470 pounds. Equipment was added to the aircraft during 2016. The weight and balance form was not updated, but, the empty weight was increased by 116 pounds, its total mass can be calculated at 10,586.

Taking this new figure for the empty weight and adding the mass of the fuel, the water-methanol and the actual weights of the members of the crew, the aircraft's ramp weight is evaluated at 16,082 lb. Between the moment of starting the engines and the application of full throttle for takeoff, a period of approximately twenty minutes elapsed, resulting in fuel consumption of approximately 80 lbs. The takeoff mass at the time of the accident corresponded essentially to its authorized maximum takeoff weight.

The estimated centre of gravity on the apron was in the middle of the authorized envelope for this mass.

1.6.4. Fuel

- Type of fuel used: JET A1

The quantity at takeoff has been estimated at 4,320 lb, in the absence of any value indicated in the on-board documents:

- fully fuelled on the airport apron: 4,400 lb (tanks filled, according to witness reports);
- consumption for start-up and taxiing estimated at 80 lbs.

1.6.5. Other fluids

The aircraft was fitted with a power enhancement system that operates by injection of a mixture of water and methanol. The quantities below have been estimated, in the absence of values specified in the on-board documents:

- water-methanol at takeoff: 16 US gallons[11] (tank filled, according to witness reports);
- water-methanol at time of incident: 12 US gallons (4 US gallons since engine power-up at the runway threshold).

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[9] One pound (lb) corresponds to approximately 0.453 kilogrammes.
[10] Net climb gradient: gross climb gradient (achieved during flight tests) reduced by 0.8%.
[11] One US gallon corresponds to approximately 3.78 litres.

1.7. Meteorological information

The data below are the internationally available data and were supplied to BEA-É by Météo-France:

- observation at 07:15: wind varying from sector 060° to 130°, wind speed 11 kt, visibility 7 km, broken cloud cover at 600 ft, temperature 23 °C / dew point 22 °C and pressure at sea level 1018 hPa;
- observation at 07:45: wind from 080°, wind speed 10 kt, visibility 8 km, broken cloud cover at 600 ft, temperature 23 °C / dew point 22 °C and pressure at sea level 1019 hPa;

During the transmission of the takeoff clearance, the controller indicated a wind direction of 080° with a wind speed of 17 knots.

1.8. Navigation aids

Not applicable.

1.9. Communications

The crew was in communication with the airport control tower via VHF[12].

1.10. Airfield Information

The information below is the internationally accessible information. It has not been possible to determine whether an ATIS[13] message was available at the time of the accident. The data recorded by the approach radar have not been supplied.

Malta International Airport (LMML) is an airport open to public air traffic (map in Annex 2). It has two runways:

- one measuring 3540 metres long by 60 metres wide, orientation 13/31;
- one measuring 2376 metres long by 45 metres wide, orientation 05/23;

The day of the event:

- the ILS DME precision approach system of runway 31 was out of order due to maintenance;
- taxiways E (Echo) and F (Foxtrot) were closed;
- crews were asked to taxi carefully when using taxiways K, L, Q, R and Z and taxi lane O (Oscar).

The airport is equipped with a video surveillance system, which recorded the event.

1.11. Flight recorders

The aircraft was not equipped with a flight data recorder.

[12] VHF: Very High Frequency

[13] ATIS: Automatic Terminal Information Service.

1.12. Wreckage and impact information

1.12.1. Examination of the area

The aircraft was removed from the accident zone before the arrival of the BEA-É investigation team. The map below was produced by the Maltese authorities. The supplementary information added to the initial map by BEA-É is in colour (see Figure 3).

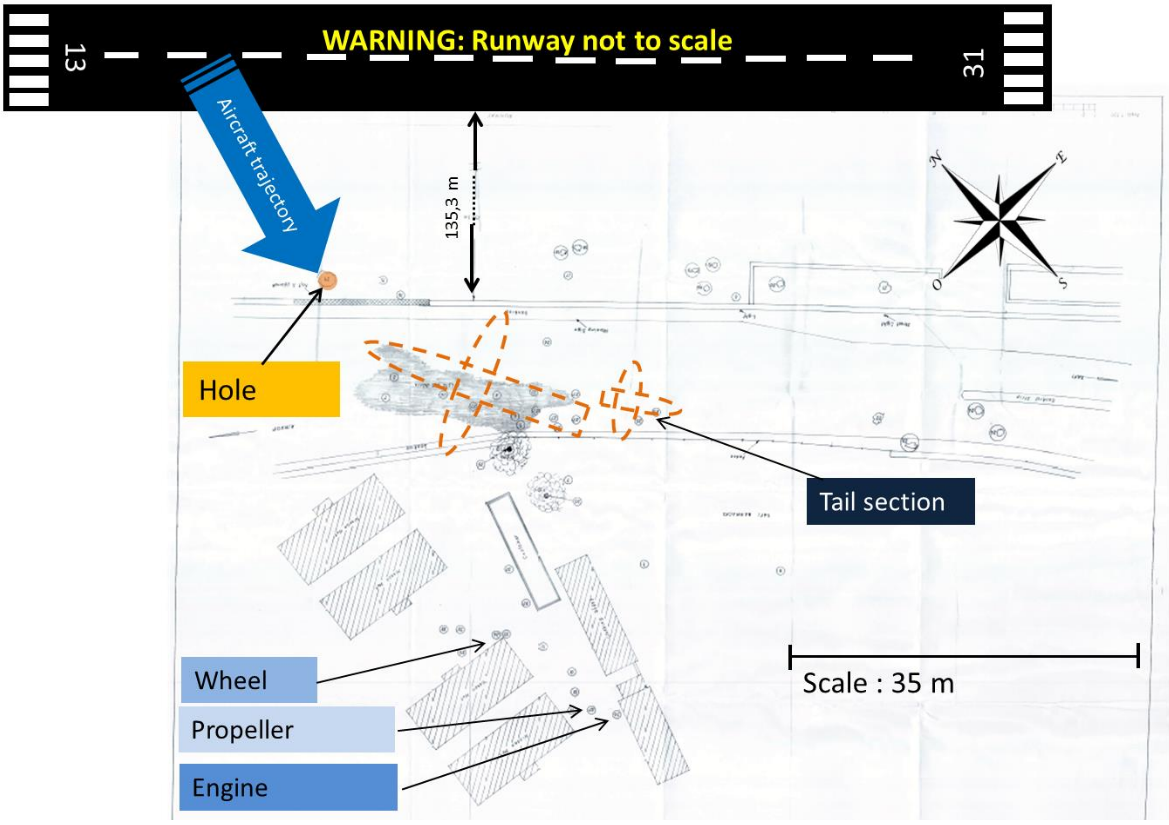

Figure 3: Map of the accident zone

The main part of the wreckage was on the road alongside the airport fence. It was oriented at 350°.
The tail was separated from the rest of the airframe but was still connected by the flight control cables.
The heaviest components (one of the two engines and one wheel of the main landing gear) were found approximately 30 metres away from the airframe.
A hole 1.5 metres in diameter was identified close to the fence (runway side).

1.12.2. Examination of the wreckage

The examination of the wreckage began in a storage hangar in the town of Mosta on 2 November 2016.
The aircraft was severely damaged by both the impact and the fire on the ground.

Concerning the fuselage, only the lower part behind the wing spar remains in one piece.

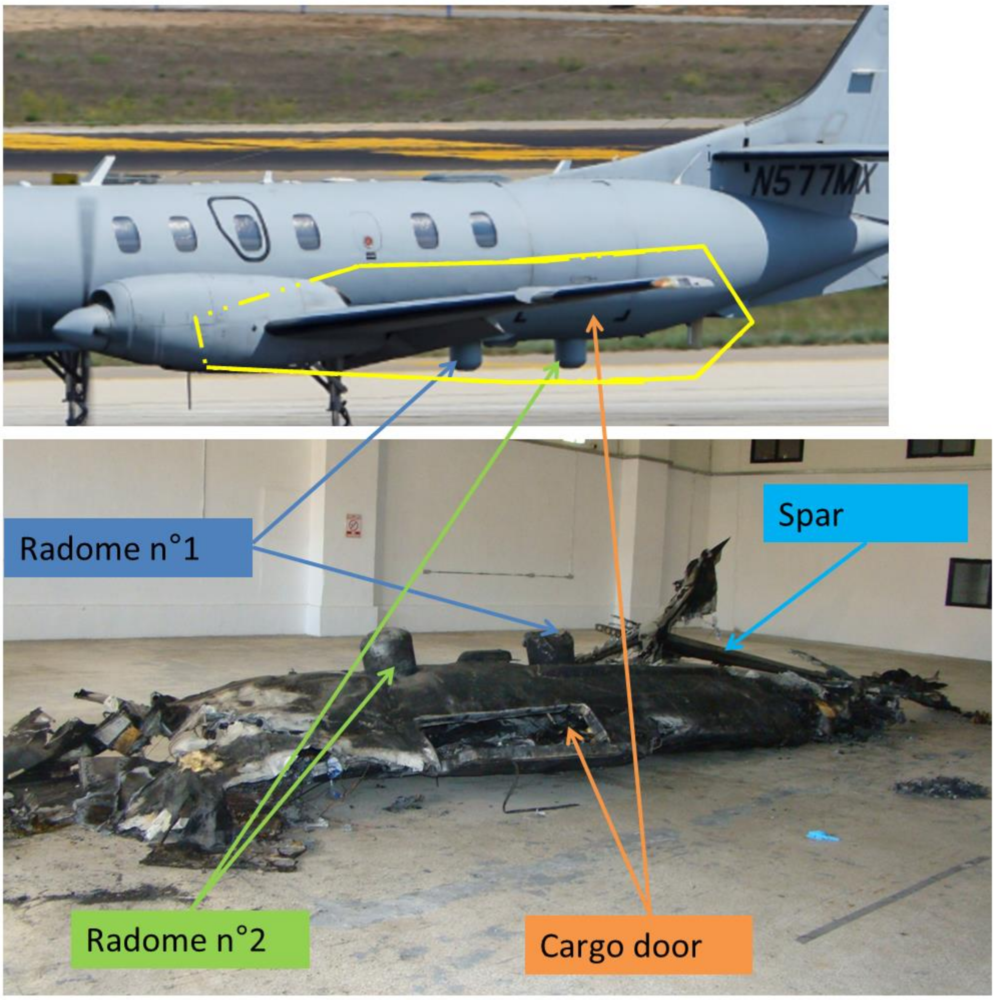

Figure 4: Remaining part of the fuselage

In the accident area, the empennage was still connected to the fuselage by the flight control cables. For the requirements of transportation, it was separated from the fuselage after cutting the cables. The empennage was damaged by fire.

Figure 5: Empennage (lying upside down)

The two engines were separated from the airframe.

Left engine Right engine

Figure 6: Engines

The eight blades of the two 4-blade propellers were found separated.

Figure 7: Blades of the 4-blades propellers

The lightest components (pilot control sticks, seats, flight instruments, electronic control units, landing gear etc.) were collected in the storage zone.

1.13. Medical and pathological information

1.13.1. Flight crew

1.13.1.1. Captain

- Last medical examination:
  - type: first class airman medical certificate (conforming to US regulations FAR Part 67)
  - date: 23 September 2016
  - result: eligible
  - validity: 1 year
- Biological examinations: carried out
- Injuries: fatal

1.13.1.2. Monitoring Pilot

- Last medical examination:
  - type: first class airman medical certificate (conforming to US regulations FAR Part 67)
  - date: 11 May 2016
  - result: eligible, with corrective lenses
  - validity: 6 months
- Biological examinations: carried out
- Injuries: fatal

1.13.2. Others

- Biological examinations: carried out
- Injuries: fatal

1.14. Fire

The information below comes from viewing the videos.

On impact with the ground, the aircraft caught fire.
The firefighters (three trucks) arrived close to the scene of the accident 2 min 40 s after impact, spreading a mixture of water/extinguisher with their fire hose.
The fire was effectively extinguished 45 seconds later, i.e. 3 min 25 s after impact.
The use of the extinguisher product continued for 30 more seconds in order to cool the area.

1.15. Survival aspects

The detailed description of the alarm and response chain provided below comes from viewing the videos and listening to the radio exchanges between the control tower and the fire service.
The alarm was triggered by the crew of the airliner waiting at the Delta holding point, which had just been cleared by ATC to enter the runway; the alarm was then relayed by the control tower to the fire service.
The firefighters observed that the five occupants had died.

The reasons why the air traffic controller has not been the first to report the event are unknown.

1.16. Tests and research

The following elements have been exploited or examined:

- the airport surveillance videos, exploited by the DGA EP Department for analysing crash recorders (RESEDA);
- the seats, examined by DGA TA;
- the warning lights and certain flight instruments, examined by DGA EP;
- the propulsion components (engines and propellers), examined by DGA EP;
- the other flight instruments, examined by DGA EP, including:
  - one navigation system that recorded the flight and required the intervention of the Californian manufacturer (SANDEL Avionics) to recover its data,
  - a satellite data transmission unit, which required the assistance of the Canadian Transport Safety Board,
- the center pedestal (see illustration below), examined by DGA EP;
- the remainder of the airframe (fuselage, empennage, landing gears and flight controls), examined by DGA TA.

The low-speed flight characteristics of the aircraft were evaluated in September 2017 at DGA EV.

Some of the on-board documents were recovered from the wreckage. They were damaged by the effects of the impact and fire. They were restored by a laboratory working for the Maltese authorities.
The validity of the captain's licence was verified with the assistance of the NTSB.

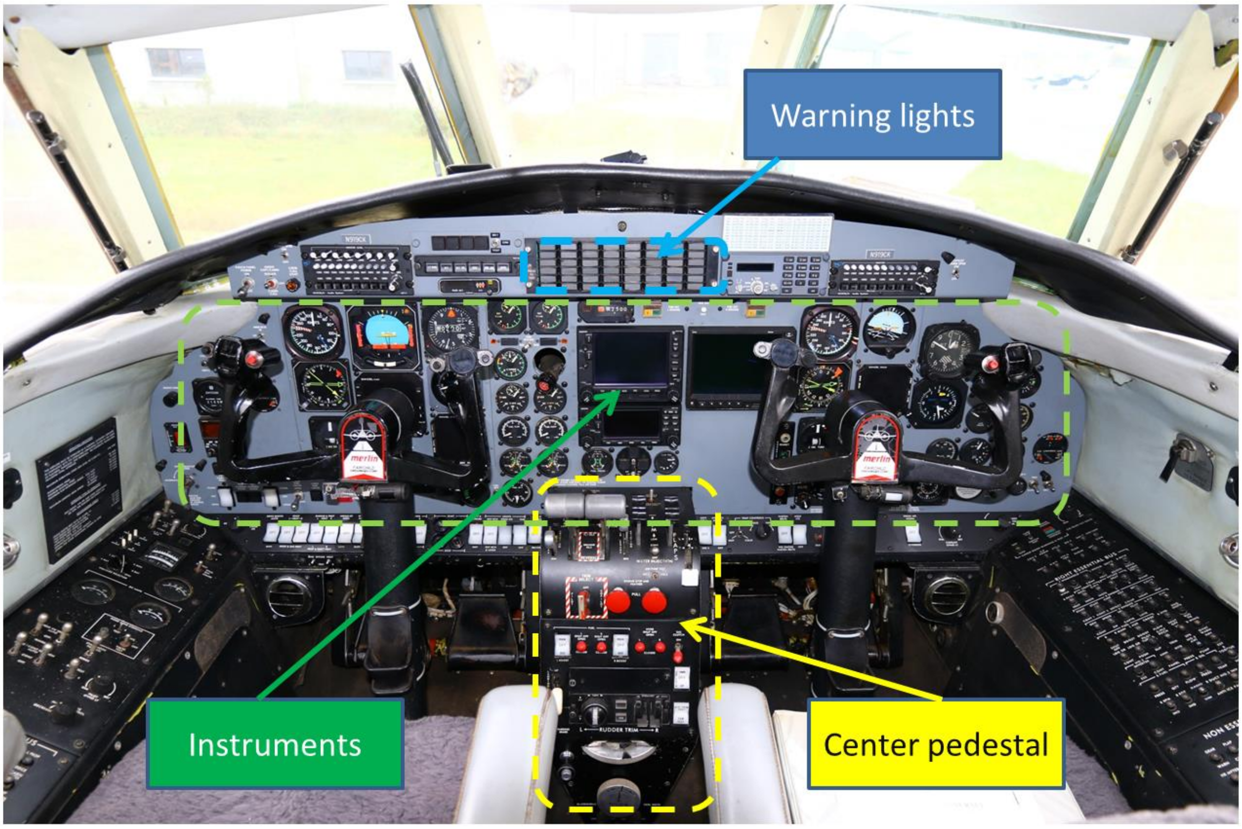

Figure 8: Illustration of the locations of the various cockpit elements submitted to examination

1.17. Organizational and Management information

1.17.1. Aviation company

The plane was operated by the company CAE Aviation based in Luxembourg. This company carries out air operations of the type:
- parachuting;
- ground surveillance and reconnaissance;
- aerial surveillance.

On 7 September 2016, the civil aviation authority of the Grand Duchy of Luxembourg issued a certificate of competence to CAE Aviation for the aerial working activities listed above.

The simplified organization chart of the company is provided below.

Figure 9: Simplified organization chart of CAE Aviation

The company's fleet comprises:
- one Piper PA18 registered in the USA;
- eight Cessna C208 aircraft registered in Germany;
- one Beechcraft A100 registered in the USA;
- two Beechcraft BE300 aircraft registered in the USA;
- two Beechcraft BE350 aircraft registered in the USA;
- one SA226 A registered in France;
- three SA227 TT aircraft registered in the USA;
- two SA227 AT aircraft registered in the USA.

1.17.2. Maintenance company

The accident aircraft was maintained by CAVOK, a subsidiary of CAE since 2010, based in France. This company notably holds EASA[14] certificates of approval as maintenance organization (Part 145[15]) and continuing airworthiness management organization (Part M[16], subpart G). The scopes of approval of these certificates cover the SA226 and SA227 aircraft registered in Europe.
For the aircraft registered in the USA, the company holds a certificate issued by the FAA on 26 March 2015 designating it as an approved "Repair Station". The American regulations have no equivalent to Part M. The corresponding approval is the responsibility of the operator or owner CAE Aviation (14 CFR Part 91, section 91.403).

Concerning the modifications made to the aircraft registered in Europe, CAVOK holds a certificate of approval as production organization (Part 21G) for the products of category C1 ("equipment") and C2 ("parts"), covering the production of "electric cables, electronic control units, miscellaneous supports and racks and cabin fittings and structure assembly".
In the case of the modifications to the aircraft registered in the USA, the company submits application documentation that is approved by the FAA by means of "Form337".

The company also holds a certificate of approval as training organization for maintenance and inspection (Part 147), limited to the Cessna C208 aircraft.

The organization chart of CAVOK is provided below.

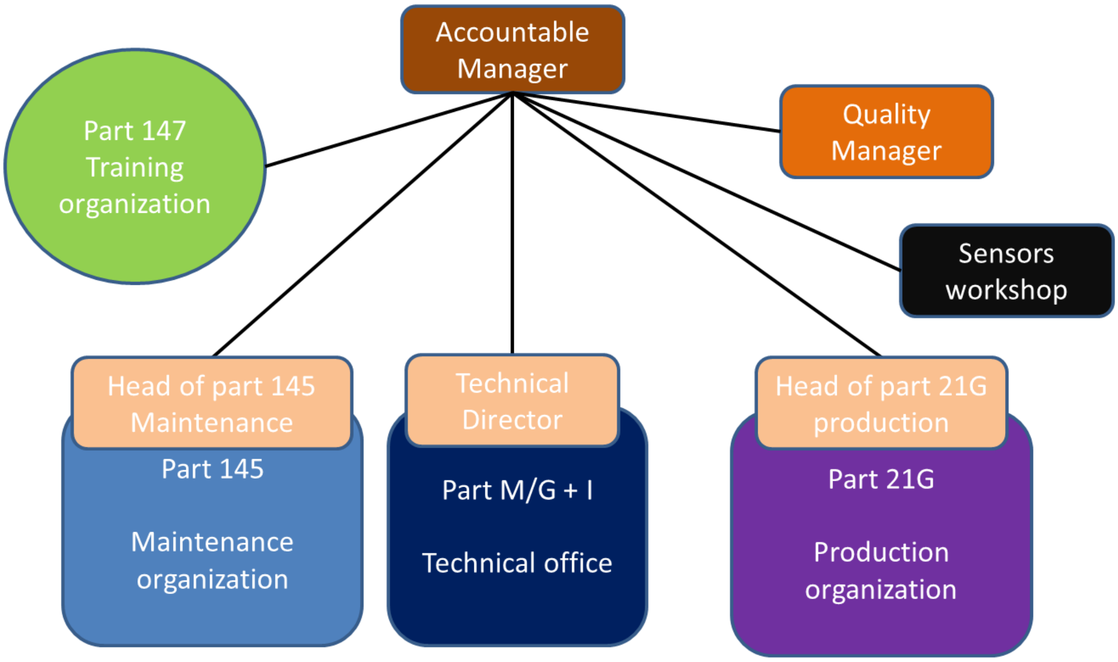

Figure 10: Simplified organization chart of CAVOK

[14] EASA: European Aviation Safety Agency.
[15] A Part 145 maintenance organization is an organization that complies with requirements in terms of premises, personnel (qualifications, licences etc.), tools (verified) and maintenance data (up-to-date) and that has a quality policy and system (monitoring).
[16] A Part M continuing airworthiness management organization is an organization that ensures application of the airworthiness requirements (and other imperative application data), controls the maintenance of the aircraft in conformity with the appropriate maintenance programme and ensures the validity of the airworthiness documents.

2. ANALYSIS

The analysis below is structured into three parts. The first part presents the results of the various examinations. The second details the chain of events of the accident, and the third attempts to identify the causes of the accident.

2.1. Results of the examinations

This chapter presents the results of the following examinations:
- video recordings and data from the equipment containing memories;
- flight test campaigns;
- examination of the wreckage, including seats, visual alarm indicators, flight instruments, propulsion systems (engines and propellers), center pedestal and airframe;
- environmental analyses;
- restored on-board documents;
- validity of the captain’s licence.

2.1.1. Analysis of recordings

Three sources of information were usable. They concern:
- the videos from the airport surveillance cameras, some of which also have audio tracks;
- the data extracted from the navigation instrument manufactured by SANDEL Avionics;
- the data recorded by the satellite transmission unit and extracted by the TSB.

Despite the absence of an on-board flight recorder, the trajectory of the aircraft could be reconstituted. Some of the video recordings have an audio track. Spectral analysis of the audio bands was used to verify the operation of the engines. Since the images are of low definition, they could not be used to determine the position of the flaps or to view the parts of smaller dimensions (antennas, flight controls etc.).

The data extracted from the instruments or control units enabled the investigators to refine the results obtained from studying the videos (see Annex 3) and to establish a more precise time line.
The data presented below are derived from the compilation and cross-referencing of these three sources.

2.1.1.1. Data analysis

To reconstitute the flight path, the basic elements (latitude and longitude of the aircraft, height of the aircraft relative to the runway, pitch, roll and yaw; direction and position of the landing gear) were extracted from the three sources of information, and then certain parameters were calculated. The air speed was calculated on the basis of a wind direction of 080° and wind speed of 17 kt.

The final part of the flight path below integrates calculated parameters. The position of the aircraft is presented second by second.

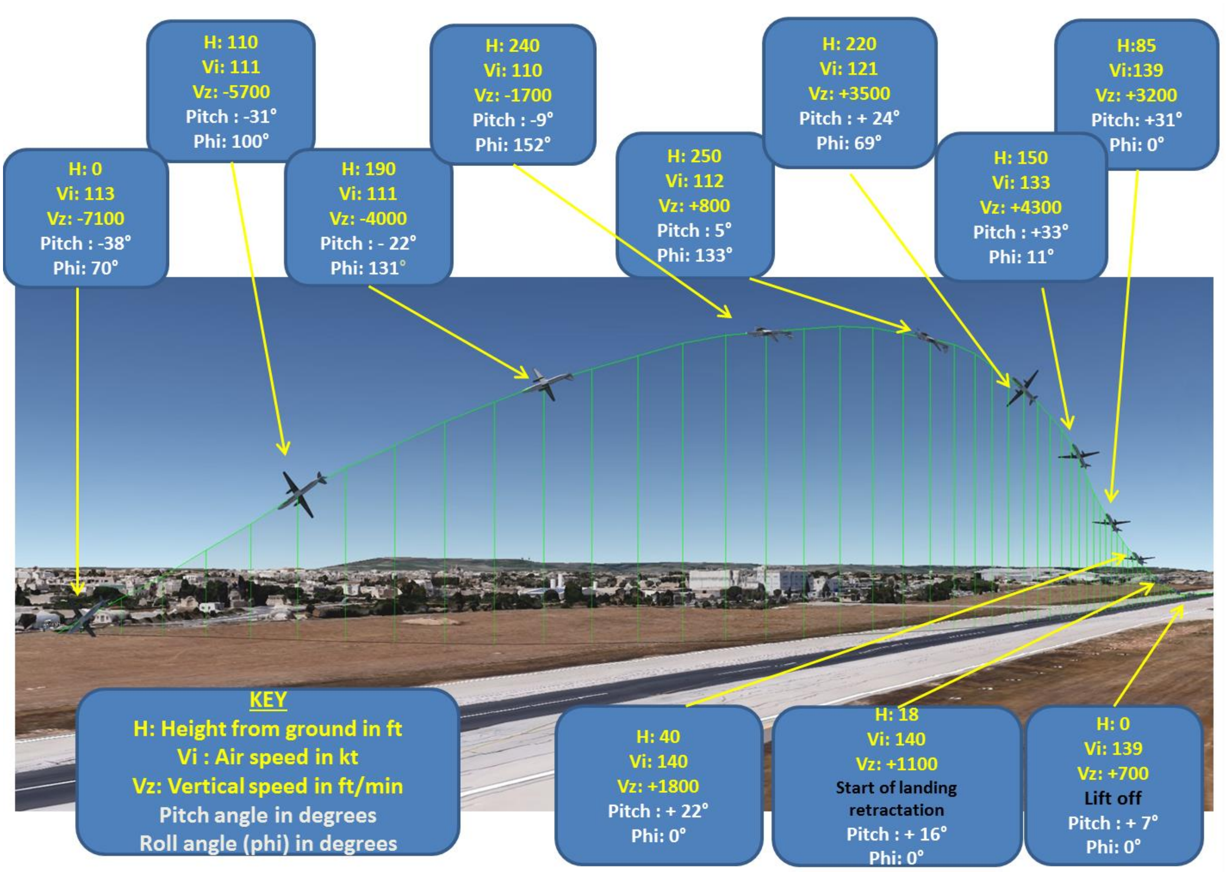

Figure 11: Final reconstituted trajectory

Analysis of the plane's attitude shows that the pitch angle increased continuously from the moment of rotation (see Figure 12). The pitch attitude before lift-off was normal, but then it continued to increase constantly until the start of the roll. A deviation can already be observed less than one second after lift-off, or soon after the pilot manoeuvred the elevator control to set the attitude.

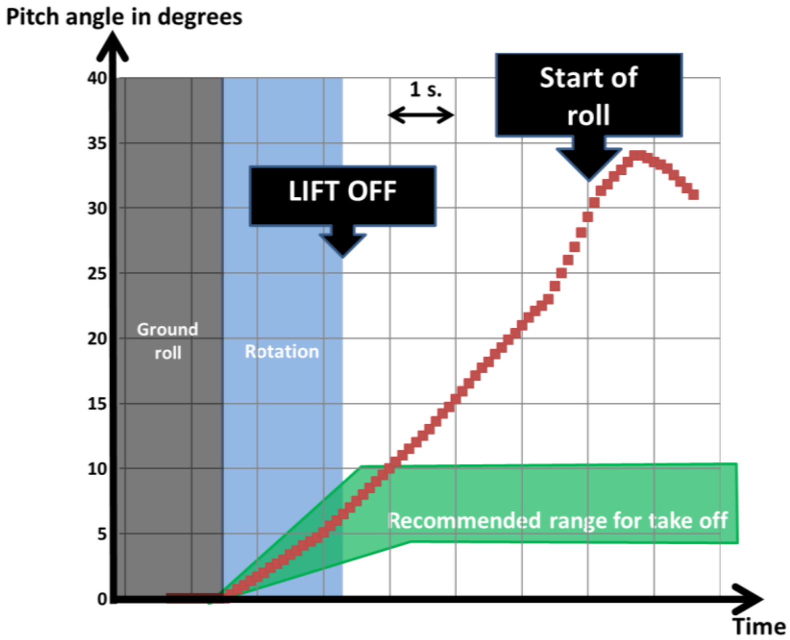

Figure 12: Change in pitch attitude between rotation and the start of the roll (attitude calculated image by image)

Analysis of the data shows that:
- the rotation was carried out at a speed of 130 kt;
- lift-off occurred at an air speed of approximately 139 kt and a pitch attitude of 7°, increasing rapidly;
- the maximum speed attained during the incident was 140 kt;
- the maximum height attained was 260 ft;
- on impact, the plane was banking 70° to the right, with a 38° nose-down attitude;
- between rotation and roll, the attitude increased continuously;
- less than one second after lift-off, a pitch angle deviation is already present compared to the pilot action on the elevator.

2.1.1.2. Analysis of the audio recordings of the videos

A spectral representation of the sound recorded by one of the video cameras is reproduced below. On filtering out the Doppler effect[17] caused by the movement of the aircraft, the measurements taken show a frequency of between 101 and 109 Hz for the main line.

A four-blade propeller rotating at 1591 revolutions per minute normally generates a sound spectrum with a main frequency line of approximately 106 Hz and harmonics that are multiples of this frequency.

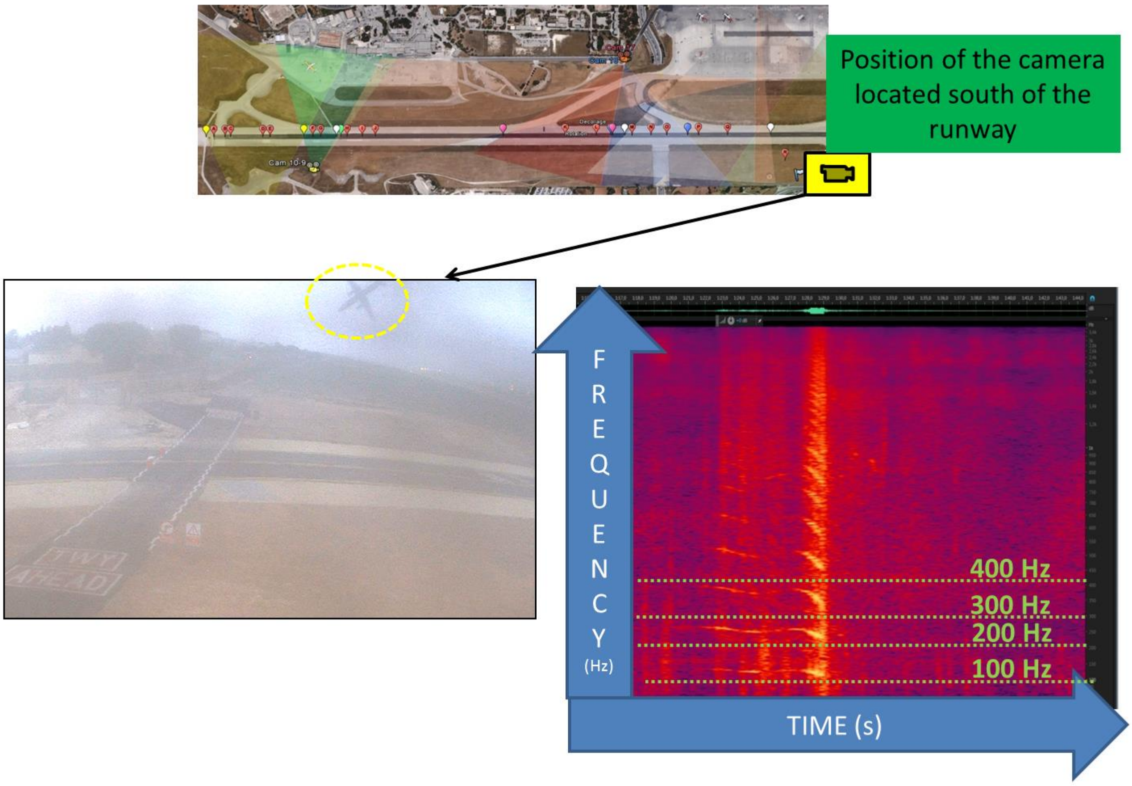

Figure 13: Spectral representation of the sound recorded by a surveillance camera

[17] Doppler effect: effect occurring when the sound source is moving in relation to the observer. The perceived sound differs according to whether the source is approaching (perceived frequency increasing) or moving away from the observer (perceived frequency decreasing).

Only a single main line (and its harmonics) can be distinguished for the two propellers. In normal operation, since the two propellers are synchronized, their spectra are combined.

Spectral analysis shows that:
- during the phase of taxiing to takeoff, the rotation speeds of the two engines are identical;
- in flight, at least one of the two propellers was turning at nominal speed until impact.

2.1.2. Flight test campaign

The flight test campaign comprised three phases:
- evaluation of the pilot's field of vision;
- evaluation of the flight characteristics of the sistership [18] owned by CAE Aviation;
- approximation of the aircraft's flight path with an aerobatic plane.

2.1.2.1. Evaluation of the pilot's field of vision

On the basis of the pilot's seat adjustments that could be identified and the characteristics of the cockpit, the pilot's front field of view is as follows:

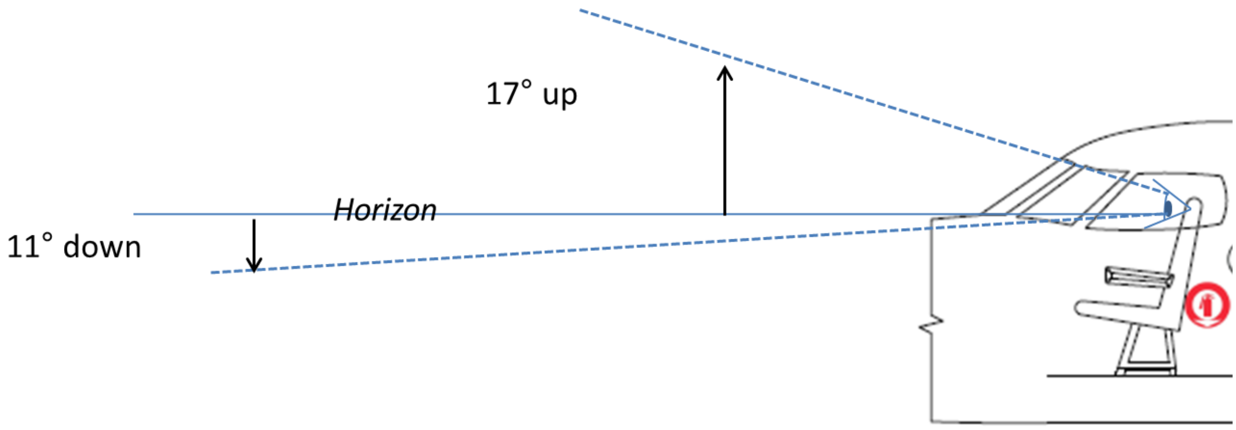

Figure 14: Field of vision of the pilot in the vertical plane

[18] The sistership is the second SA227 AT owned by the CAE Aviation company. It has been modified in a similar way.

With a pitch attitude greater than 11°, the horizon is no longer visible to the pilot. The normal takeoff attitude is in the range from 5° to 7°.

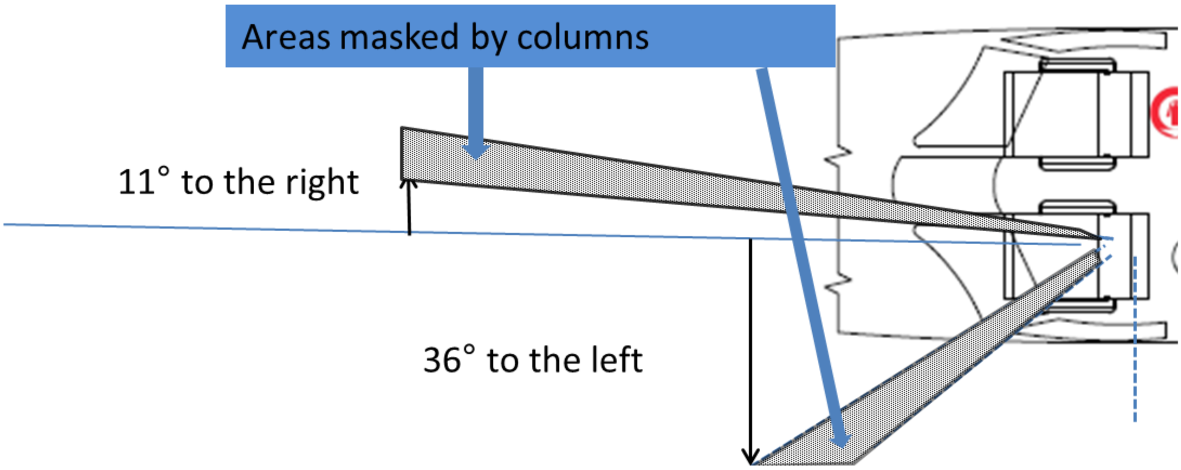

Figure 15: Field of vision of the pilot in the horizontal plane

The zones masked by the uprights do not impede to piloting the aircraft or to detecting obstacles on the takeoff trajectory.

The characteristics of the cockpit do not cause any visual obstruction for normal takeoff.

2.1.2.2. Evaluation of the flight characteristics of the sistership

The accident aircraft, like its sistership, had been significantly modified and had numerous appendages. A flight test was carried out to determine if the flight properties of the modified aeroplane were degraded compared to a standard (unmodified) SA227 AT, in particular at low speeds.

The test was conducted under conditions of mass and balance close to those of the accident and at air speeds around 120 kt[19] with and without power. Stall tests were also conducted.
The tests showed that the flight characteristics of the modified aeroplane are similar to those of a standard aeroplane even on opening the camera hatches.
At low speed and with 100% installed power on both engines, the plane banks naturally and suddenly to the right. This is due to a power-on stall (see Annex 5) that can be countered by a "stick pusher". Depending on the dynamic effects, a stick pusher can attenuate or suppress the stall conditions.

The modified aeroplane has the same flight characteristics as a standard SA227 AT. The phenomenon encountered during the accident is a "power-on stall".

[19] Speed identified as the speed at the start of the roll in Figure 11.

2.1.2.3. Approximation of the aircraft's trajectory with an aerobatic plane

Several attempts to reproduce the trajectory were carried out using an instrument-equipped plane of type Pilatus PC7 owned by DGA EV, with an initial speed of 140 kt and altitude of 5,000 ft. The bank angles adopted were those identified from the recordings.

The condition that yielded the most faithful approximation of the flight path of the accident consists in maintaining and fixing the same stick position on the pitch axis (rear sector or nose-up sector), yielding a pitch attitude variation of 30° in 3 seconds at the beginning of the flight path. Despite different aerodynamics on the PC7, the characteristic points of the flight path were situated at essentially the same times. On repositioning the displacements of the PC7 with this condition in the environment of the accident, the comparative result is presented below:

Figure 16: Comparison of the flight path of the PC7 (red) with that of the accident (magenta)

Analysis of the flight path of the SA227 AT shows that it recovered the effectiveness of the controls after reaching the three-quarter turned position, as revealed by an inversion of the rate of roll. The descent path reveals that the nose-up elevator control was maintained in the same position.

Only a constant "nose-up" stick position can approximate the trajectory of the accident.

2.1.3. Examination of the wreckage

The wreckage was examined in the following chronological order:
- examination of the seats;
- examination of the warning lights and flight instruments;
- examination of the propulsion systems (engines and propellers);
- examination of the center pedestal;
- examination of the flight instruments and of the control unit containing data;
- examination of the airframe (including flight controls).

2.1.3.1. Examination of the seats

The aircraft had been modified and had 6 seats, including 4 identical pilot seats. Seats D and E are passenger seats. They were installed as indicated below.

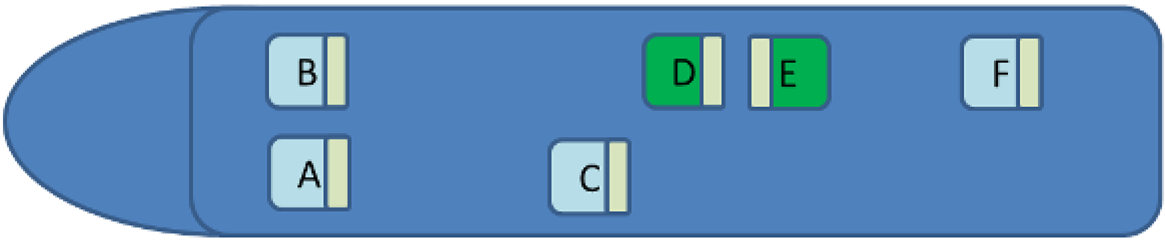

Figure 17: Arrangement of the seats in the aircraft

The conducted investigations established that on impact all the seats (especially the pilot's seat A and co-pilot's seat B) were locked in their two adjustment axis (longitudinal and height).

The pilot's and co-pilot's seats were locked in position during the accident.

2.1.3.2. Examination of the warning lights

The alarm panel consists of 48 indicator lights (some not used); after the accident, 8 were missing and 6 no longer labelled. The holder of the aircraft's type certificate (*M7 Aerospace*) was contacted to identify the missing labels. They are shown in brackets in Figure 18.

The examination conducted in the laboratory was able to determine the status of most of the warning lights on impact: 23 unlit, 9 lit and 8 undetermined.

A summary presentation of the results obtained is proposed in the table below, using the following colour code:
- indicators not lit: black;
- indicators lit: colour of the warning light (green, amber or red);
- indicators status not determined: white.

The indicators not found in the wreckage following impact are identified by the darker shaded boxes.

L ENG FIRE (1)	R ENG FIRE (7)	(13)	L BETA (19)	[R BETA] (25)	(31)	(37)	(43)
L WING OVHT (2)	R WING OVHT (8)	BATTERY FAULT (14)	L CHIP DET (20)	R CHIP DET (26)	CABIN ALTITUDE (31)	[LH W/S HT] (38)	[RH W/S HT] (44)
L OIL PRESSURE (3)	R OIL PRESSURE (9)	SAS FAULT (15)	L XFER PUMP (21)	R XFER PUMP (27)	GPU PLUG IN (33)	----- (39) -----	(45)
L HYDR PRESS (4)	R HYDR PRESS (10)	CARGO DOOR (16)	L BAT DISC (22)	R BAT DISC (28)	LH SRL OFF (34)	[SAS ARM] (40)	SAS DE-ICE (46)
----- (5) -----	----- (11) -----	[YAW DAMPER] (17)	L AC BUS (23)	R AC BUS (29)	RH SRL OFF (35)	NOSE STEERING (41)	--- (47) ---
----- (6) -----	(12)	(18)	(24)	R GENERATOR FAIL (30)	NOSE STEER FAIL (36)	AWI #1 PUMP ON (42)	[AWI #2 PUMP ON] (48)

FAULT : RED | FAULT: AMBER | INDICATOR: GREEN

Figure 18: Representation of the results of annunciator panel investigation

The following green lights signalling normal system operation were lit:
- right and left-hand windshield heating (RH W/S HT and LH W/S HT);
- SAS de-icing (SAS DE-ICE);
- nose steering power assist (NOSE STEERING);
- water-methanol injection pumps Nos. 1 and 2 (AWI #1 and #2 PUMP ON).

The delay required for an indicator to heat up and be considered lit is approximately 50 milliseconds.
Consequently, the fact that the “R BETA” light is lit is attributed to the fact that the right-hand propeller touched the ground before the alarm panel, given the attitude of the plane on impact (the estimated delay between the impact of the propeller and that of the alarm panel is approximately 70 milliseconds).
The lit status of the “R AC BUS” indicator is also attributed to the attitude of the plane on impact. In support of this conclusion, no AC power supply fault was identified by the SANDEL[20] control unit up to the end of the data recording less than 3 seconds before impact (see Annex 3).

[20] The SANDEL control unit is powered by the two electric power sources of the aircraft (direct and alternating current). In the event of power failure, an internal parameter indicates this fault.

The red warning light of the Stall Avoidance System, marked "*SAS FAULT*" was lit (see Annex 4). Concerning this system, the angle-of-attack vane located in the nose of the aircraft is the component that touched the ground first. The hypothesis that this transducer might have been able to transmit an erroneous signal on impact and thereby activate the "*SAS FAULT*" light was investigated. Given the distance between the vane and the alarm panel and the speed of the aircraft on impact, it would appear that the "*SAS FAULT*" light was already lit before impact.

The red "*SAS FAULT*" light was lit before impact.

2.1.3.3. Examination of the flight instruments

It was possible to extract the following information from the approximately sixty identifiable and potentially usable flight instruments and equipment components:
- cockpit clock: hands stationary at 05:29;
- pilot's artificial horizon: approximately 65° bank to the right;
- direction indicator No. 1: direction fixed at approximately 220;
- direction indicator No. 2: direction fixed at approximately 240;
- right-hand engine torquemeter: approximately 110%;
- elevator trim position indicator: middle of green range (takeoff range) ;
- the primary navigation equipment - make: SANDEL Avionics, type: SN3500 – contains non-volatile memories that were retrieved by the manufacturer (see Annex 3).

The stall warning computer of the stall avoidance system was the original unit installed on the aeroplane when new. It was severely damaged by the accident, preventing identification of any potential damage pre-existing the impact.

The information extracted from the flight instruments is consistent with the attitude of the aeroplane on impact.

2.1.3.4. Examination of the propulsion systems

The two turboprop engines and their respective propellers were analyzed by experts at DGA EP with the assistance of the engine manufacturer (Honeywell) and the propeller manufacturer (DOWTY Propellers). The Woodward engine and propeller governors were tested and examined at the premises of the American company in Illinois.

The results for both propulsion systems are as follows:
- the two engines were running on impact;
- the two propellers were receiving power;
- the tests and dismantling of the governors show that the operating deviations identified on the test bench occurred after impact.

The respective settings of the two propellers were similar and in the "flight" range. The estimated power developed by each engine was approximately 85% on impact.

The two engines were delivering symmetrical power, and the two propellers had a similar setting on impact.

2.1.3.5. Examination of the center pedestal

Examination of the center pedestal provided information on the status of the following controls on impact:

- flap position selector: estimated between 1/4 and fully "*UP*";
- landing gear control UP;
- fuel shut-off valves open (normal position);
- *"SAS Clutch*" [21] set to "*ON*";
- the "gust lock" lever for locking the aircraft control surfaces when the aircraft is parked was disengaged ("OFF"), as expected.

The positions of the controls and selectors were as expected for takeoff.

2.1.3.6. Examination of the airframe

The airframe could only be partially reconstituted, due to the destruction of certain structural elements by impact or fire.

In the case of the wings, only the biggest parts, such as the spars, are present.
In the case of the three landing gears, their position (up or down) could not be defined.
In the case of the fuselage, the parts or surfaces completely or partially missing are identified in orange in Figure 19.

[21] The " *SAS CLUTCH*" switch is used to activate or deactivate the SAS stall avoidance system.

Figure 19: Illustration on the sistership of the missing parts or surfaces of the fuselage (marked in orange)

From this partial reconstitution, it was possible to establish that:

- the configuration of the aircraft on impact was as follows:
  - the value identified at the flap position selector in the cockpit was found to be between “UP” and 1/4, as expected. Examination of the hydraulic actuators, which may have changed in position on impact, indicates a left/right symmetrical position of between 1/3 and 1/2. This deviation alone cannot have any major consequence on the accident;
  - cargo and passenger doors closed and locked;
- no movement of the equipments in the hold liable to modify the centre of gravity of the aircraft was identified before impact;
- the angle of the angle-of-attack vane on impact was between 15° and 19°.

Concerning the flight control system, the observations are as follows:

- the flight control system is equipped with a device for locking the control surfaces of the three axes (pitch, yaw and roll), termed a “gust lock”. The gust lock can only be used when the aircraft is parked and is designed to prevent the effects of wind gusts on an airport apron or parking area. This mechanism was found to be set to the “disengaged” position at the center pedestal, as expected;
- pitch axis (elevator control system):

- the orange zone in Figure 20 (starting behind the elevator walking beam and extending to station 347 of the aircraft) designates the missing section that could not be reconstituted. This section corresponds to a zone that was modified to fit the on-board systems;

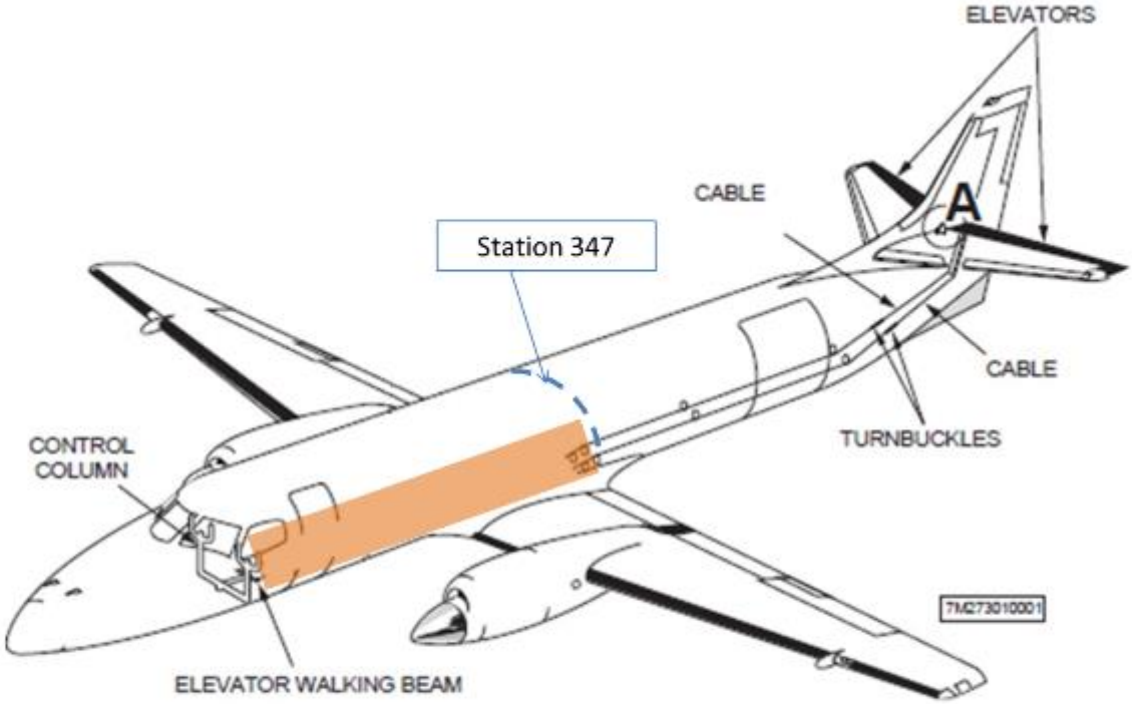

Figure 20: Illustration of the missing and unreconstituted zone of the elevator control (orange)

- main control: no damage pre-existing the impact was identified on the parts examined (from the pilot's control column to the walking beam and from station 347 to the elevators). The gust lock was not engaged. No indication of the position of the control surface on impact could be identified;
- SAS: only the cable drum of the servo control was found. The damage incurred prevented any determination of its condition before impact;
- trim adjustment position: the position of the trimmable horizontal stabilizer was defined on the basis of the trim actuator and corresponded to -3.4°. Given the balance of the aircraft in the middle of the authorized range for the aircraft, this setting induces a "nose up" tendency at low speed (see Figure 21). The variation in attitude observed during a takeoff under the same conditions but without adjusting the elevator after rotation was approximately 10° pitch angle in 3 seconds. This attitude variation is easily controlled by operating the nose-down control.

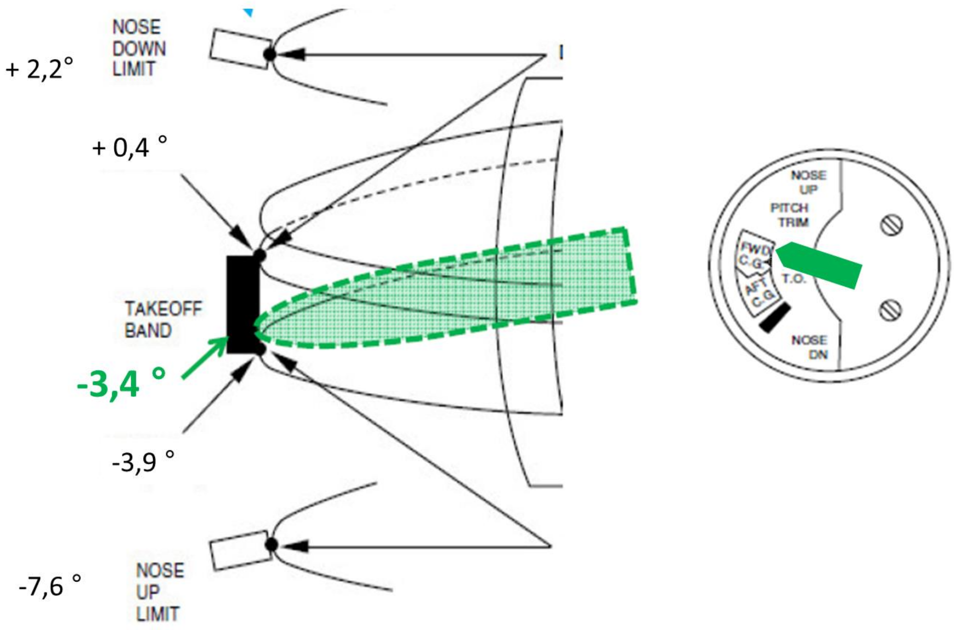

Figure 21: Illustration of the trimmable horizontal stabilizer and its assumed representation on the indicator in the cockpit

- yaw axis (direction control):
  - main control: no damage pre-existing the impact was identified on the parts examined. The gust lock was not engaged;
  - trim adjustment position: the trim position could not be identified.
- roll axis (bank control):
  - main control: no damage pre-existing the impact was identified on the parts examined. On impact, the position of the two sticks in the cockpit was to the left. Given the damage resulting from the accident, it was not possible to determine if the gust lock was engaged. This locking mechanism is operated in common with the locks on the other two axes (pitch and yaw), which were found to be disengaged, and so it can be assumed that the gust lock was also disengaged on this axis. In the video, during the descent, the aircraft starts an inverse rolling movement consistent with the leftward position of the two sticks, indicating that the gust lock was not engaged;
  - trim adjustment position: the trim position could not be identified.

With the exception of the flaps that were more extended than recommended and the elevator trim setting, which induced a “nose up” tendency insufficient to explain the sharp nose-up observed during the accident, the configuration of the aircraft is as expected during the takeoff phase.
The damage identified on the examined parts of the flight controls is due to the accident.
No trace of any movement of the equipment in the hold has been identified.
A significant section of the flight control system cannot be reconstituted.
This non-reconstituted section corresponds to the zone of the aircraft modified to fit the on-board systems.

2.1.4. Environmental analyses

In the environmental domain, the following hypotheses were investigated.

2.1.4.1. Wake turbulence[22]

Concerning wake turbulence, the mass of the SA227 AT places the aircraft in the "light" category. Before takeoff of the SA227 AT, the last aircraft to use runway 13 was a Boeing 757, classed as "heavy", which had landed on the runway.

The SA 227 AT started its takeoff more than 3 minutes after the Boeing 757 had left the runway via the taxiway Golf: this period of time is amply sufficient to dissipate its wake turbulence. Moreover the moderate-force side wind accelerated the evacuation of the vortices generated by the heavy aeroplane.

The hypothesis that wake turbulence caused the accident is rejected.

2.1.4.2. Obstacle turbulence[23]

The wind conditions on the day (maximum 17 knots) and the absence of high infrastructure close to the runway means that this hypothesis can be discounted.

The hypothesis that obstacle turbulence caused the accident is rejected.

2.1.4.3. Bird strike

Examination of the videos did not reveal the presence of any bird in the vicinity of the aircraft before, during or after takeoff.
The witness reports collected from the crews of the aeroplanes that had landed previously or were close to the aircraft during the accident do not mention the presence of birds or the loss of any aircraft part that could be caused by bird strike.
Inspection of the runway after the accident did not identify any feathers or any mechanical components belonging to the SA227.

The hypothesis that a bird strike might have caused the accident has not been retained.

2.1.4.4. Position of the sun

The takeoff took place at dawn. Sunrise on the day of the accident was effective at 07:17. The azimuth at sunrise is 104 degrees. The position of the sun in the cockpit before rotation is represented in Figure 22. The representation of the meteorological conditions has been enhanced to show the sun.

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[22] Wake turbulence: aerodynamic disturbance generated in the wake of an aircraft in flight after it has flown past.

[23] Obstacle turbulence: aerodynamic disturbance generated in the wake of a building or other object on the ground due to strong wind.

Figure 22: Position of the sun before rotation (on left seat)

The hypothesis that the position of the sun hampered the pilot is rejected.

2.1.4.5. Proximity of other aircraft on the ground

During takeoff, a Boeing 737 was at the Delta holding point, and an Airbus A320 was taxiing out the commercial aviation apron to the same holding point.
A reconstruction of the view from the cockpit of the accident aircraft before rotation (based on the video recordings in the case of the A320 and the flight recorder of the B737) enables the distance between the aircraft to be measured (see figure 23).

Figure 23: Relative position of the aircrafts at the moment of rotation

Also, the SANDEL Avionics control unit (see Annex 3) recorded the transmission of at least one traffic information message during the takeoff phase. The proximity of these aircraft could have triggered a visual and aural warning message generated by the TCAS of the aircraft involved in the accident.
The InCAS® software developed by Eurocontrol was used to create a scenario including the paths or positions of the B737 and A320 and of the SA227 AT involved in the accident.
Simulation of the scenario indicates the possibility of two TA (Traffic Alert) messages in the SA227 AT on takeoff.

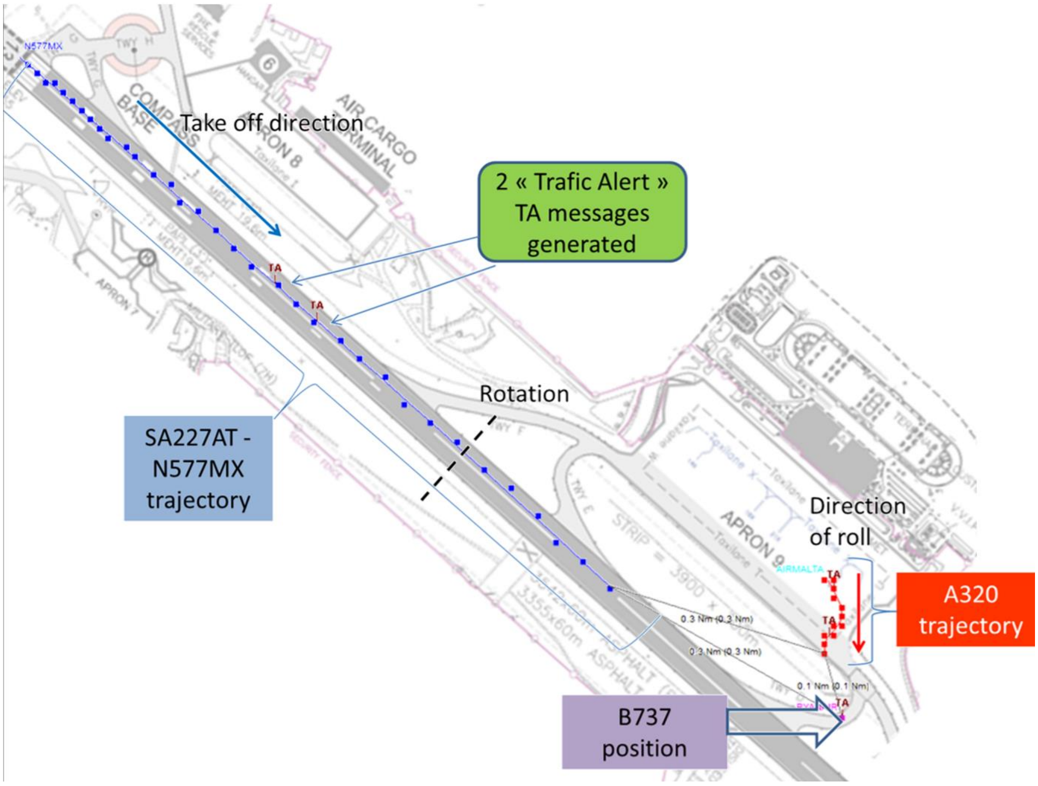

Figure 24: Positioning of the two TA messages generated by the TCAS of the B737 and A320 (source: Eurocontrol InCAS® software)

Unlike a RA message ("Resolution Advisory"), which requires the crew to take specific action by means of an aural announcement, the generation of a TA message only provides information to the crew.

Transmission of a TA alone is not sufficient to distract or disturb the crew.

On the aircraft involved in the accident, the TCAS was not coupled to the autopilot and therefore could not transmit any signal to the controls.

The hypothesis that the accident was caused by a message generated by the TCAS is rejected.

2.1.5. Examination of the aircraft's airworthiness certificate (CofA)

The classification definitions of airworthiness certificates differ between France (DGAC) and the USA (FAA).

France draws the distinction between the normal CofA, special CofA and restricted CofA.

The normal CofA implies use and maintenance in conformity with the regulations of the ICAO.

The special CofA applies to modified aircraft and implies specially adapted use and maintenance.

The restricted CofA applies to aircraft without a type certificate holder and permits less stringent maintenance. By contrast, use of the aircraft is restricted (flight abroad prohibited, etc.).

Besides that, the FAA classifies aircraft into two types of CofA, namely "normal" or "special". The "normal" CofA is identical to the normal CofA applied in France. By contrast, the "special" CofA is limited to American airspace and includes the "restricted" subcategory. This "restricted" subcategory covers aircraft developed for aerial work, including "aerial surveying", and it implies lighter maintenance compared to a "normal" CofA but also requires compliance with the FAA requirements, which are much stricter than for a restricted CofA in France.

Following its recertification in 2011, the aircraft involved in the accident was issued a US "normal" CofA. The FAA conducted a documentary investigation of the aircraft involved in the accident and concluded:

- that the computerized data held by the FAA concerning the history of this aircraft started in 2011;
- that the absence of digital data prior to 2011 can be explained by the use of the aeroplane for military purposes outside the scope of civil aviation,
- that since the aeroplane had an STC SA1518SO applied in 1985, it should have been used in the "Restricted category".

The absence of digital data recorded between 1985 and 2011 led the FAA to issue an inappropriate CofA.

2.1.6. Examination of the restored on-board documents

Some documents on board the accident aircraft have been restored and analyzed.
None of the restored documents are complete. Due to the fire generated by the impact, the first and last pages are often missing. These documents notably concern:

- flight preparation documents (aviation maps, meteorological maps, navigation logs, letters for fuelling, aircraft load sheet);
- aircraft logbooks, check-lists and aircraft flight manual;
- captain's flight log.

Analysis of the aircraft logbooks, check-lists and flight manual did not yield any particular observation, except for the lack of information concerning the quantities of fuel on refuelling. Of the flight preparation documents, only the outdated 2011 balance form was found.

Analysis of the documents on-board the aircraft did not yield any significant information concerning the causes of the accident.

2.1.7. Validity of the captain’s licence

To operate as first pilot (captain) of an SA227 AT registered in the USA, the pilot must hold an American licence and an up-to-date TR for the SA227, in addition to the medical certificate.

The captain’s initial TR was issued on 22 August 2014 by an FAA examiner following a proficiency check flight. Since the SA227 is certified as a single-pilot aircraft not propelled by turbojets, the validity of the TR requires a flight review with an FAA instructor every 24 months. On 24 January 2016, the captain conducted a flight on an SA227 AT with the training officer of the CAE Aviation company who is qualified as an FAA instructor.

The captain’s American licence was valid.

2.1.8. Summary of examinations

The combined analyses and investigations of the recorded data and videos show that:

- no mechanical malfunction was identified in the propulsion systems, airframe components or the reconstituted part of the flight controls;
- a significant section of the flight control system was destroyed by impact and could not be reconstituted. This section of the system corresponds to a zone that was modified in 1985 to house the additional on-board systems;
- no movement of the pilots’ seats or equipment in the hold was identified;
- no particular environmental phenomenon was identified;
- although modified, the aircraft had the same low-speed flight properties as a standard SA227 AT;
- the aircraft configuration conformed to expectations for the first phase of takeoff, except for the flaps that were further out than recommended and the elevator trim setting, which induces a nose-up tendency;
- less than one second after lift-off, a pitch angle deviation is already present compared to the pilot action on the elevator;
- the red “ *SAS FAULT*” light was lit before impact;
- the aircraft’s flight path is identical to that of an aircraft with its elevator control surface held firmly in a “nose-up” position up to the moment of impact.

2.2. Accident time line

In view of the results obtained (technical analyses and flight tests), the following sequence of events has been established:

7h19min30s: brakes released;

7h20min01s: rotation is started by the pilot at an air speed of approximately 130 kt, by adjusting the elevator control surface as normal into the "nose up" sector (corresponding to an aft position of the control stick);

7h20min03s: the wheels of the main gear leave the ground, with a pitch attitude of 7° at a speed of 139 kt. The elevator control surface in the empennage is still in "nose up" position;

7h20min04s: the gear retraction lever is activated. Pitch angle is continuing to increase;

7h20min04s to 7h20min08s: the "nose up" position of the elevator causes a continuous rise in pitch angle, increasing from 10° to approximately 32°, an increase in the aircraft's angle of attack from 8° to approximately 18° and a reduction in speed from 139 to 121 kt. The power maintained in the two engines then brings the aircraft into the conditions of a power-on stall (Annex 5);

7h20min08s: pitch angle approximately 32° with an angle of attack approximately 18°. The aircraft stalls and begins banking to the right. This banking movement leads progressively to masking of the satellite antennas located on the aircraft's dorsal fin.
The position of the elevator control surface remains "nose up";

7h20min11s: the maximum altitude and bank angle are attained. Reduction of the bank angle is initiated, accompanied by a loss of altitude.
The position of the elevator control surface remains "nose up";

7h20min12s: the SANDEL Avionics equipment stops recording data.
The position of the elevator control surface remains "nose up";

7h20min14s: with the elevator control surface still in the "nose up" position, the aircraft hits the ground at a bank angle of 70°, a negative pitch angle of 32° and an air speed of approximately 113 kt.

2.3. Investigation of the causes of the accident

In view of the results of the examinations and in the absence of the complete aircraft and of a flight recorder, BEA-É has envisaged five scenarios that might explain why the elevator control surface remained in the "nose up" position. However, it is not possible to totally exclude the hypothesis of other scenarios.

The five scenarios investigated are as follows:
- possible high-risk behaviour;
- physical incapacitation of one of the pilots;
- rupture of the HF antenna, which subsequently became wrapped round the elevator control surface;
- technical malfunction of the SAS stall avoidance system;
- technical malfunction of a component of the flight controls.

2.3.1. High-risk behavior

2.3.1.1. Sensation-seeking

The adoption of a high-gradient takeoff path does not correspond to any operational necessity at Malta airport. However, the pilot may have chosen a flight path of this nature for “thrills” or to impress the other members of the crew.

However, the witness reports collected during the enquiry do not describe the pilot as a risk-taker. Moreover, for this aircraft and under the conditions on the day, the maximum-gradient flight path was obtained at an indicated air speed of 129 kt and an attitude of approximately 10°. Any increase in pitch attitude beyond this limit would have reduced the speed after takeoff and therefore neutralized any desired sensational effect by forcing the crew to reduce the pitch in the seconds that followed.

Also, for a transport pilot, an attempt to achieve a spectacular takeoff with an aircraft at maximum mass and a pitch angle exceeding 30° is simply inconceivable. Whatever the case, the maintaining of nose-up after the power-on stall is sufficient to invalidate this hypothesis.

2.3.1.2. Suicidal intent

The hypothesis of suicidal intent of one of the crew members has also been envisaged. However, the absence of any identified struggle at the controls during the flight path means that this hypothesis too can be rejected.

No factual element found by the investigation team supports the hypothesis of deliberate high-risk behaviour as an explanation for the accident.

The hypothesis that the crew engaged in high-risk behaviour on takeoff is rejected.

2.3.2. Physical incapacitation of one of the pilots

2.3.2.1. Incapacitation of the captain

The captain had been prescribed medication in July 2016. Taking the medication as prescribed was compatible with eligibility to fly. Given the hypnotic effect of the medication, if it was taken without adhering to the prescription, it could have altered the captain’s cognitive and physical abilities. His post-mortem examination was unable to verify whether he had taken the medication or conformed to its prescribed use.
Analysis of the conversations of the captain with the control tower do not reveal the slightest sign of diminished cognitive abilities. Moreover, in this hypothesis, the diminished capacities of the captain cannot explain why nose-up was maintained nor the absence of any corrective action by the monitoring pilot.

2.3.2.2. Incapacitation of the monitoring pilot

The monitoring pilot, aged 70, had several proven cardiovascular risk factors, as identified by the CEMPN (medical centre for flight crew personnel) in 2013.

From 2013 onwards, there is no trace of any visits to a CEMPN in France nor of regular medical monitoring of these cardiovascular risks. His last medical examination in 2016 was by a doctor approved by the FAA in France. This is because only an FAA-approved doctor can issue a medical certificate compliant with an American licence.
The post-mortem examination was unable to support or invalidate the hypothesis of a heart attack. However, it is highly unlikely that a heart attack would lead to the permanent blockage of the controls by the monitoring pilot. This conclusion is based on the fact that during this phase of the flight, according to the company manual, the hands of the monitoring pilot must not be on any of the flight controls. Also, any possible catching of the stick due to a sudden stiffening or collapse of the co-pilot could not in any way lead to a blockage of the flight controls without the captain being able to react. A heart attack cannot therefore explain the flight path of the aircraft.

The hypothesis that physical incapacitation of one of the pilots during takeoff was the cause of the accident is rejected.

2.3.3. Technical scenarios

2.3.3.1. Rupture of the HF antenna, which subsequently became wrapped around the elevator control surface

Description of the scenario

The HF antenna (consisting of a cable installed above the fuselage) could have broken during rotation and caused the elevator control to jam in the "nose up" sector by becoming wrapped around the control surface.

Figure 25: Position of the HF cable on the aircraft

The cable would probably have been more likely to wind itself along the right-hand side, due to the direction of rotation of the propellers. This scenario can be illustrated by the accident report issued by the BEA concerning the accident that occurred on 7 August 1998 in Royan (see Annex 7), except that in this case jamming in the "nose-down" position would have to be replaced by jamming in "nose-up" position.

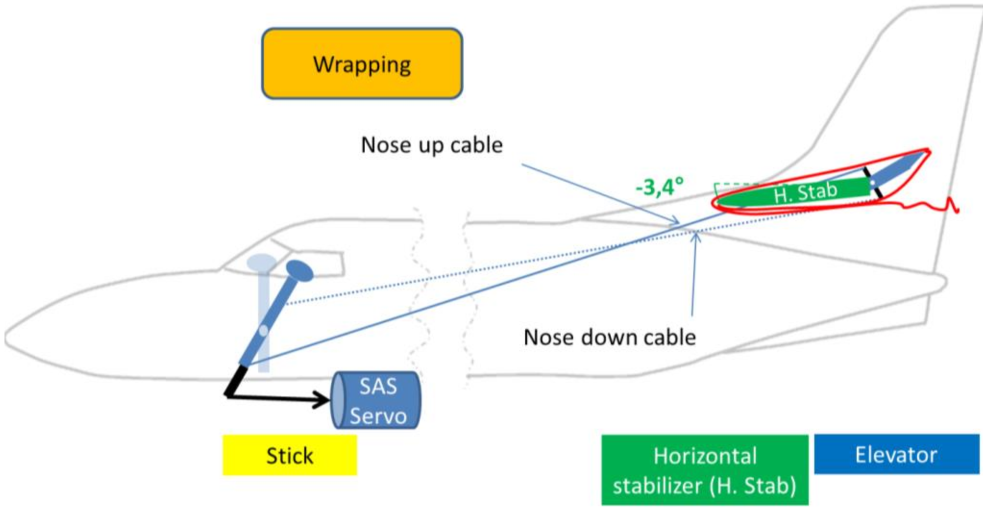

Figure 26: Schematic diagram of the antenna cable becoming wrapped around the elevator control surface

This jamming of the elevator control surface could not have been countered by the control stick. Any action of the control stick would have had no effect, and the pitch angle of the aircraft would have continued to increase.
On approaching the stall, the SAS would have been triggered and would have activated the stick pusher system, which firstly would have had no effect, because it uses the same control cable system as the pilot, and secondly would then have been disengaged, because the value of force required would be greater than the declutching force of the SAS, which would have caused the "*SAS FAULT*" indicator to be lit.

In this situation, one solution to recover control of the aircraft is to act rapidly on the elevator trim to bring it into the "nose down" sector. According to the data in the maintenance manual, the shortest time necessary to attain this sector is approximately 8 seconds.
However, control of the aircraft cannot be recovered once it has stalled, which means less than 4 seconds after lift-off.

Analysis of the scenario

In this scenario, the following factors tend to support the hypothesis of rupturing of the HF antenna:

- cases of HF antenna cables breaking have been reported in aircraft fitted with external HF antennas;
- the cable's tensile breaking strength is 204 kg, which is sufficient to cause jamming of the control surface;
- this resistance force applied at the control surface permits the hypothesis of a torque greater than the SAS declutching torque (approximately 27 kg) applied at the control stick;
- the antenna had never been inspected since its installation in 2011. The antenna was not included in the software for monitoring the aircraft maintenance intervals provided by the Part M organization of the maintenance company;
- the red " SAS FAULT" light was lit before impact;
- between rotation and the start of banking, the aircraft's attitude increased continuously, which corresponds to an elevator control surface locked in the "nose up" sector.

However, the following factors tend to invalidate the hypothesis of a rupture of the HF antenna:

- inspection of the runway on the day of the accident did not identify any elements of the HF antenna belonging to the SA227 AT;
- the HF antenna, installed in 2011 following approval by the FAA, was scheduled for inspection every 12,850 cycles. However, the aircraft had only recorded 3,603 cycles;
- the kinematics necessary for the cable to wind itself around the right-hand control surface at the moment of rotation remain improbable.

The hypothesis that a rupture of the HF antenna caused the accident is improbable.

2.3.3.2. Malfunction of the Stall Avoidance System (SAS)

Description of the scenario

The SAS is designed to protect the aircraft from stalling. It is operative as soon as a combination of three conditions are met: speed lower than 140 kt, "SAS Clutch" switch set to ON, and weight-on-gear contactor released[24] (see Annex 4).
As soon as the SAS is engaged, if the angle of attack attains a calibrated value (estimated at approximately 15°), the stick pusher is activated. On the ground, this system is inhibited by the "weight-on-gear" condition. After lift-off, the system's third inhibiting condition - "weight on gear" is released.

According to this scenario, on lift-off, while the pitch angle was beginning to rise, malfunction of the SAS caused the transmission of an erroneous signal to be sent unexpectedly and without warning, to the stick pusher. The cause of this activation remains unexplained. Consequently, it is impossible to define whether the action of the stick pusher was progressive or sudden.

Given the low altitude, the Pilot Flying would have been surprised by this activation and would have attempted to counter the stick force in order to clear of ground.

This reaction would have had the effect of inducing an increase in pitch angle, enabling the pilot to gain altitude. The pilot's failure to understand the cause of the nose-down action would have caused him to maintain the nose-up attitude to clear of danger (proximity to the ground).

When the force on the controls became too great (theoretically 27 kg, but the manufacturer specifies that the maximum force can attain 66 kg), the SAS clutch would have been disengaged (see Annex 4), although it is impossible to tell at what moment.

Disengagement of the SAS would then have caused:

- the "*SAS FAULT*" indicator to be lit, without switchover of the "*SAS CLUTCH*" switch to off;
- reduction of the pushing force on the pilot's control stick.

The aircraft would then have entered the range of a power-on stall.
On stalling, it would have been impossible to regain control of the aircraft at this altitude.

[24] The release of the weight-on-gear contactor signals that the aircraft is no longer resting on its landing gear on the ground.

Analysis of the scenario

In this scenario, the following factors tend to support the hypothesis of SAS malfunction:

- approximately thirty cases of erroneous and inadvertent activation of the SAS stick pusher on SA226/227 aircraft had been reported by operators[25] in 1988 for the ten previous years, including at least one fatal case (see Annex 4). Given the high number of cases of erroneous and inadvertent activation, improvements to the SAS were implemented (SB 227-27-04, 27-019 and 27-020), and crews were informed in order to raise their awareness of a potential malfunction. In the case of the aircraft that crashed in Malta, service bulletin SB 227-27-020 dated March 1987, concerning improvement of the reliability and performance of the SAS, was not applied by the first owner of the aircraft nor by the subsequent owners. This SB is not mandatory. It is not subject to an airworthiness requirement;
- the red “SAS FAULT” light was lit before impact;
- due to a modification to the flight controls applied in 1985, the servo control of the SAS is no longer located in the same place as in the standard SA227 AT. It is now close to a fuselage-mounted water evacuation drain, and its electrical connection is not similar to the wiring configuration on the other SA227s. Infiltration of water or corrosion in the electric motor could explain the malfunction, but this component was not found. Maintenance of the SAS was identical to that of a standard system, despite the fact that the installation is different and in a more humid environment;
- the pilots at CAE Aviation with SA227 type rating declared that they had never encountered activation of the stick pusher during TR training or other flights. This could result in an effect of surprise in the event of activation, especially when close to the ground;
- according to flight instructors, during pilot training for the stick pusher(which the captain had not received), when a pilot is first confronted by activation of the stick pusher, the first reaction is frequently to struggle against this activation by immediately pulling the stick back, despite the explicit instruction not to resist the force (see page 10 of *Advisory Circular* FAA 120-109)[26];
- the surprised pilot could have been the victim of a state of consternation, causing a nose-up reaction for the full duration of the event. The short time between the malfunction and the stall did not allow him to regain his composure. This situation would explain why the “SAS CLUTCH” switch was “ON” and not “OFF”, despite the SAS malfunction (first action of the procedure for an SAS fault).

However, the following factors tend to invalidate the hypothesis of an SAS fault:

- between rotation and the start of the roll, the pitch attitude increased continuously, and the videos do not show the potential jolt that would be caused by the sudden relaxing of force on the controls when the clutch was disengaged before the stall;
- according to this scenario, the “nose up” action was maintained by the pilot, although a disengagement of the clutch before stalling should have enabled him to modify the flight path without resistance, which would have been perceptible on the videos.

[25] The current holder of the type certificate, M7 *Aerospace* is no longer systematically sent all cases of SAS malfunction. These malfunctions are resolved by the application of check-lists by the crew and by the troubleshooting maintenance directives.

[26] However, this document does not specify either the duration of the counteraction or whether it is excessive.

- the SAS malfunction could have generated an unexpected and intense force. Under these conditions, the reaction of the pilot could not have been immediate. However, no downward inflection of the flight path can be observed;
- in the absence of a flight recorder, the supposed actions of the crew necessary to construct this scenario cannot be confirmed.

The hypothesis that the accident was caused by malfunction of the stall avoidance system in combination with an inappropriate response by the pilot is possible.

2.3.3.3. Damage to a component of the flight controls.

Description of the scenario

During the rotation phase, the pilot pulls the stick back to raise the nose of the aircraft for lift-off. As soon as the desired pitch attitude is attained, the pilot stops applying “nose up” force to the stick.

For a cable-operated flight control system, these actions are only possible if the system (cables, pulleys and bellcranks) is intact and the cables remain tensioned (see illustration below). Any loss of tension or jamming (blockage) of a cable makes the actions of raising or lowering the nose impossible.

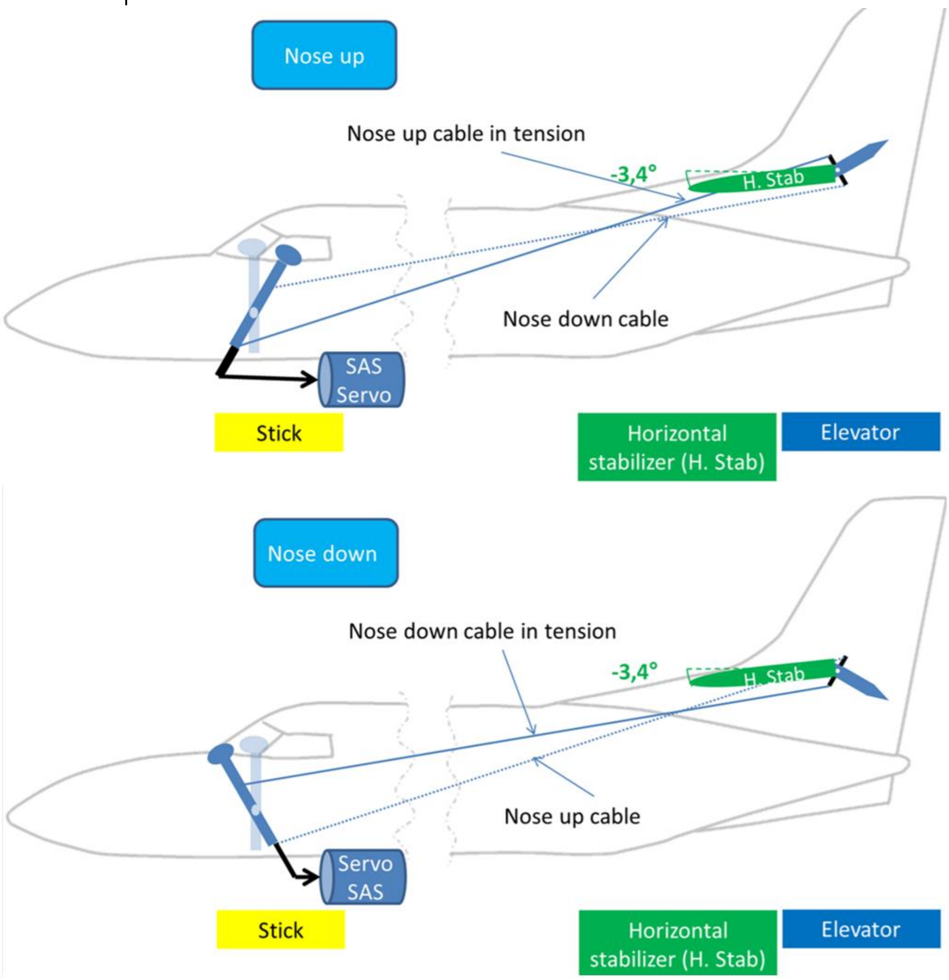

Figure 27: Diagram illustrating the cables actuated by moving the control stick

According to this scenario, the elevator control surface remained in the “nose up” range due to jamming of a component of one of the flight controls.

The cause of this fault would have been located in the part of the aircraft that could not be reconstituted.
The case of rupture or loss of tension of the “nose down” cable alone was envisaged by BEA-É. This configuration would have caused the elevator control surface to be positioned in the axis of the trimmable horizontal stabilizer (THS). In this case, given the adjustment of the THS in the “nose up” range and the centre of gravity of the aircraft in the middle of the envelope, a “nose up” tendency can be observed, but it remains insufficient to explain the high pitch angle observed during the incident.

In the case of jamming (or freezing) of the elevator line, the pilot flying would have been surprised and would have tried to counteract this situation at the control stick by pushing it back. Jamming of the control surface would not necessarily have caused the control stick to jam (cables slipped out of the pulleys or guides, or blocked in one direction but possibly moving freely in the other direction). The action of the control stick would have had no effect, and the pitch angle of the aircraft would have continued to increase.
On approaching stall conditions, the SAS would have engaged and would have activated the stick pusher system, which would have had no effect, because it uses the same system of cables as the pilot’s controls. The SAS, although fully functional, would have been neutralized by this damage. Disengagement of the SAS would then have caused the “SAS Fault” indicator to be lit.

In this situation, one solution for recovering control of the aircraft would be to act rapidly on the elevator trim to set the horizontal stabilizer into the “nose down” sector. According to the data in the maintenance manual, the shortest time necessary to attain this trim range is approximately 8 seconds from position -3.4°.
However, control of the aircraft cannot be recovered once it has stalled, which means less than 4 seconds after lift-off.

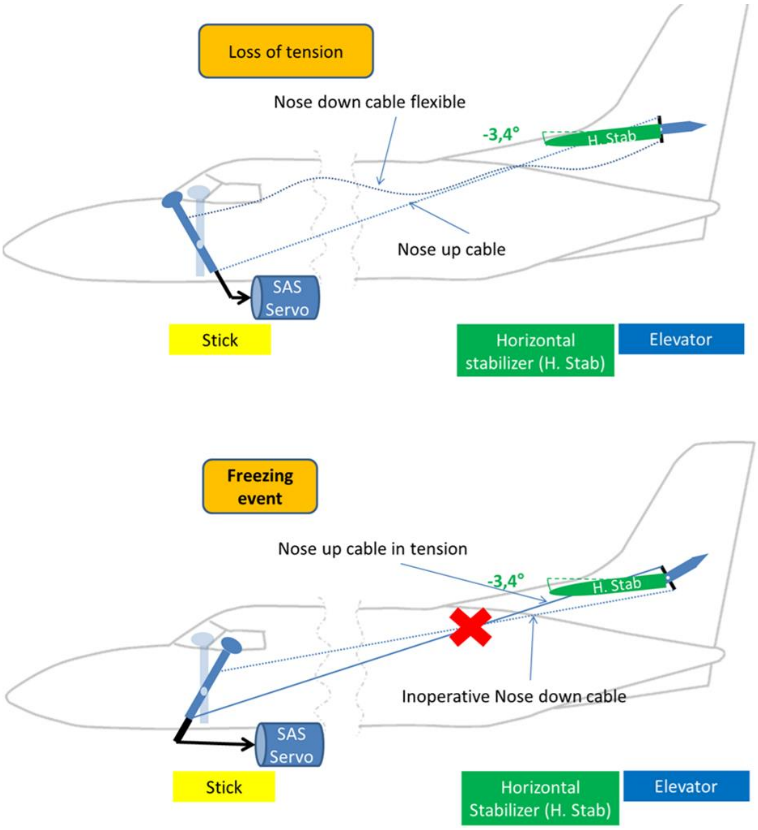

Figure 28: Diagram illustrating the two investigated fault scenarios

Analysis of the scenario

In this scenario, the following factors tend to support the hypothesis of a malfunction in one of the flight controls:

- some cases of damage to the flight controls have been reported by operators of SA226/227s (see Annex 8)
- the red "SAS FAULT" light was lit before impact;
- the modifications made to the aircraft in 1985 concerned the flight controls and were located in the zone of the aircraft that could not be reconstituted (parts destroyed or disappeared). These modifications required a more complex routing of the flight controls to avoid the locations of the installed equipment, such as the retractable cameras (see Annex 6). This routing requires, first, a higher number of pulleys, pulley supports, turnbuckles etc., and, second, the arrangement of cable routing zones in other parts of the aircraft close to components that are normally kept clear of the cables. The increased number of components increases the risk of malfunction;
- the documentation relating to the modification of the flight controls is legally protected by the American ITAR regulations[27]. Despite the submitted requests, the maintenance company was not authorized to receive the exact routing layout of the flight control cables. So, the cable replacement operations by the CAVOK company in March 2016 were carried out without the maintenance documentation that included the aircraft modifications;
- the maintenance operations carried out on the flight control components other than the cables themselves were not subject to particular monitoring in terms of frequency or maintenance level;
- aircraft registered in the USA are outside the scope of the French civil aviation safety organization (OSAC). To obtain the *Repair Station* certificate, the FAA recognizes EASA Part 145 approval "by equivalence". By contrast, there is no American equivalent of EASA Part M/G approval for "continuing airworthiness management organization". EASA Part M requires the provision of an appropriate maintenance programme for the use of the aircraft. In the absence of the maintenance programme, certain components may not have been inspected or replaced at sufficiently frequent intervals;
- between rotation and the start of banking, the aircraft's attitude increased continuously, which corresponds to an elevator control surface locked in the "nose up" sector.

Due to the incomplete reconstitution of the flight controls and the impossibility of determining the position of the elevator control surface on impact, it is impossible to identify the factors invalidating or supporting this hypothesis. No existing factor tends to invalidate this scenario.

The hypothesis that the accident was caused by malfunction of a flight control component of the elevator control line is plausible.

[27] ITAR: international Traffic in Arms Regulations– American regulations for the control of arms exports. These regulations govern arms exports to prevent proliferation. They impose various standards and requirements on users.

2.3.3.4. Summary of the technical scenarios

The scenarios investigated tend to indicate a technical malfunction.

This malfunction could be caused firstly by the specific modifications made to the aircraft and secondly by maintenance not suitably adapted to these modifications.

The aircraft modifications were all approved by the FAA. The ITAR classification of two of these modifications prevented the maintenance company from obtaining the special maintenance instructions (technical definition, maintenance intervals, specific work cards, supplementary checks etc.). These modifications, which in certain cases were major, did not result in any change to the “normal” category of the Certificate of Airworthiness of the SA227 AT registration number N577MX when it was recertified in 2011.

Concerning maintenance, the CAVOK company has EASA Part 145 approval. This approval enabled it to obtain an FAA “Repair Station” certificate. This certificate is issued by equivalence pursuant to the approval signed on 30 June 2008 between the United States and the European Community in the field of cooperation in civil aviation safety. Concerning the EASA approvals, the monitoring scope of the French civil aviation authority (OSAC) is limited to the aircrafts registered in a member state of the EASA. Since the aircraft involved in the accident was registered in the USA, it was not monitored by OSAC.

Concerning continuing airworthiness management, the CAVOK company has EASA Part M subpart G approval. No equivalent approval exists in the FAA. This responsibility is assigned to the operator or owner, CAE Aviation (14 CFR part 91, section 91.403). The various internal audits conducted in the maintenance company had already identified difficulties in ensuring the continuing airworthiness of the aircraft owned by CAE Aviation. This is due to the different countries of registration, the operation of aircraft of different manufacturers and the specific characteristics of each airframe (history, modifications applied etc.). This complexity is most acute in the case of the Merlin aircraft. In the absence of an FAA equivalent to an approval for the maintenance and monitoring of continuing airworthiness, the maintenance programme of the aircraft was not appropriate, since its technical definition, and therefore the conducted maintenance, did not take into account the specific characteristics of the aircraft. If the aircraft had been managed in accordance with European requirements, the EASA Part M organization would have had to elaborate and obtain official approval from the authority for the aircraft maintenance programme covering the specific characteristics of the aircraft.

For the scenarios involving a malfunction in the SAS stall avoidance system or the flight controls, in the absence of the specific documentation of this 1985 modification protected by ITAR, the analysis of BEA-É is based on visual inspection of the sistership owned by CAE Aviation. A request to view the documentation relating to this modification is still being processed, and so the analysis of the BEA-É may be supplemented at a later date following a review of this documentation.

Three scenarios remain envisaged:
- the hypothesis that the accident was caused by a rupture of the HF antenna is improbable;
- the hypothesis that the accident was caused by an SAS malfunction is possible;
- the hypothesis that the accident was caused by a malfunction in a flight control component of the elevator control line is plausible.

3. CONCLUSION

The accident began by a technical malfunction during rotation or on lift-off, leading to a loss of control.

3.1. Identified factors useful to understanding the accident

At Malta International Airport, the crew of a modified SA227 AT aircraft carried out a standard instrument departure at maximum takeoff weight.

On lift-off, the retraction of the landing gear was initiated, and the aircraft continued to increase its pitch attitude. When the pitch angle reached 34°, the aircraft entered a power-on stall and banked suddenly to the right until it was three-quarters inverted. The bank angle was reduced at the apogee of the flight path, and then the aircraft continued its flight nose down.

The aircraft hit the ground with a 38° nose-down attitude, a bank angle of approximately 70° to the right and a symmetrical installed power on the two engines.

The aircraft, which was registered in the USA, notably had modified flight controls, and its maintenance was performed in conformity with the maintenance programme by a French company in accordance with an FAA "Repair Station" approval. The maintenance company did not have the specific documentation for this modification, which is protected under ITAR.

3.2. Causes of the accident

Investigations show that a technical malfunction was the cause of the accident. This malfunction probably originated in the specific modifications of the aircraft and in the application of an inappropriate maintenance to these modifications.

Three scenarios can be envisaged:

- rupture of the HF antenna, which then wrapped around the elevator control surface;
- inadvertent activation of the SAS, countered by the pilot;
- jamming of the elevator due to a technical failure in the flight control line.

Given the condition of the wreckage and the absence of witness reports from the crew, only a flight data recorder could have enabled the BEA-É to confirm one of these hypotheses.
However, in consideration of the factors detailed in the analysis, the hypothesis of damage to a component of the elevator control line remains the most plausible explanation.

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4. SAFETY RECOMMENDATIONS

During the phase of launching the investigation, the BEA-É received information from the French Bureau of Investigation and Analysis for Civil Aviation Safety ("Bureau d'Enquêtes et d'Analyse pour la Sécurité de l'Aviation Civile" – BEA).

Consequently, BEA-É recommends:

> **to the authorities concerned, and more generally to all State representatives concerned, to consider the systematic introduction of a clause, in contracts of aircraft on charter used to carry out missions on behalf of the French State, stipulating that the competencies of the BEA-É must be systematically called upon in the event of an aviation accident.**
>
> R1 – [I-2016-15-A]

4.1. Preventive measures linked directly to the event

4.1.1. Appropriate maintenance

With a "normal" category Certificate of Airworthiness, in the absence of any special instructions or documentation, the maintenance company maintained the aircraft in accordance with a standard maintenance programme drawn up by the type certificate holder, even though the aircraft had undergone certain modifications that were classified under ITAR. This is notably the case of the modifications to the flight controls and SAS.

Consequently, BEA-É recommends:

> **to CAE Aviation that it conducts maintenance appropriate to the modified aircraft that are registered in the USA.**
>
> R2 – [I-2016-15-A]

4.1.2. Training of pilots of aircraft equipped with a "stick pusher"

The FAA has studied the reactions of pilots during activation of the stick pusher. It concluded (in *Advisory Circular* FAA 120-109 page 10) that, often, a pilot confronted for the first time by activation of the stick pusher will fight against this activation and immediately pull back on the stick, despite the received theoretical instruction not to counteract this force. Faced with a fault with no prior warning (alarm or increased angle of attack), this type of reaction is all the more probable.

Consequently, BEA-É recommends:

> **to the FAA and EASA to ensure that all operators using aircraft equipped with a "stick pusher" include in their pilot training syllabus a practical module concerning inadvertent activation of the stick pusher and the associated response. For this module, the use of a simulator shall be preferred.**
>
> R3 – [I-2016-15-A]

4.2. Preventive measures not directly linked to the event

4.2.1. Alarm triggering

During the investigation, due to limited access in situ, it was not possible to determine why the controller in the tower was not the first to trigger the alarm.

Consequently, BEA-É recommends:

> **to the Maltese authorities responsible for the airport to investigate the reasons why the controller in the control tower at the time of the accident was not the first person to detect the accident, in order to set-up improvement measures.**
>
> **R4 – [I-2016-15-A]**

4.2.2. Flight data recorders

The aircraft was not equipped with a flight data recorder.

Consequently, BEA-É recommends:

> **to the State authorities affreighting aircraft to stipulate the preferential use of aircraft equipped with flight recorders in the contracts of affreightment of aircraft used to carry out missions on behalf of the French State.**
>
> **R5 – [I-2016-15-A]**

ANNEXES

ANNEX 1

DESCRIPTION OF THE MERLIN IV SA227 AT AIRCRAFT, REGISTRATION NUMBER N577MX

The Merlin IV C SA227 AT is a single-pilot aircraft[28] designed by Fairchild in the 1980s. As an upgrade of the SA26 designed in the 1960s, it is a low-wing pressurized aircraft equipped with two turboprop engines and is designed to carry a maximum of 16 passengers.
The maximum authorized weights are as follows:

- maximum ramp weight 16,100 pounds;
- takeoff 16,000 pounds;
- landing 15,500 pounds.

Figure 29: SA227 AT

It is equipped with two Honeywell TPE 331-11U-611G engines driving DOWTY R321/4-82F/B propellers. The engine has a power of 1000 hp (1100 hp with water-methanol injection) and is a single-shaft turboprop engine with:

- a two-stage centrifugal compressor;
- a reverse annular-flow combustion chamber;
- a three-stage axial turbine, which drives a reduction gearbox linked to the propeller.

The engine is designed to run at constant speed (N1) and to drive the propeller at 1591 rpm. Variation of the propeller pitch enables the power to be varied, by regulating the engine and propeller, while maintaining a constant speed of rotation.
The authorized fuels are Jet A, Jet A1, JP4 and JP5. The authorized oils must comply with MIL-L-23699 (Type II).

The aircraft is fitted with an anti-stall system named SAS (Stall Avoidance System). The operation of this system is described in Annex 4.

The accident aircraft had been owned by several owners and had been modified at different times.
The table below summarizes the main history of these modifications.

[28] According to the aircraft flight manual, the minimum crew is one pilot, except when two pilots are required for the aerial operations.

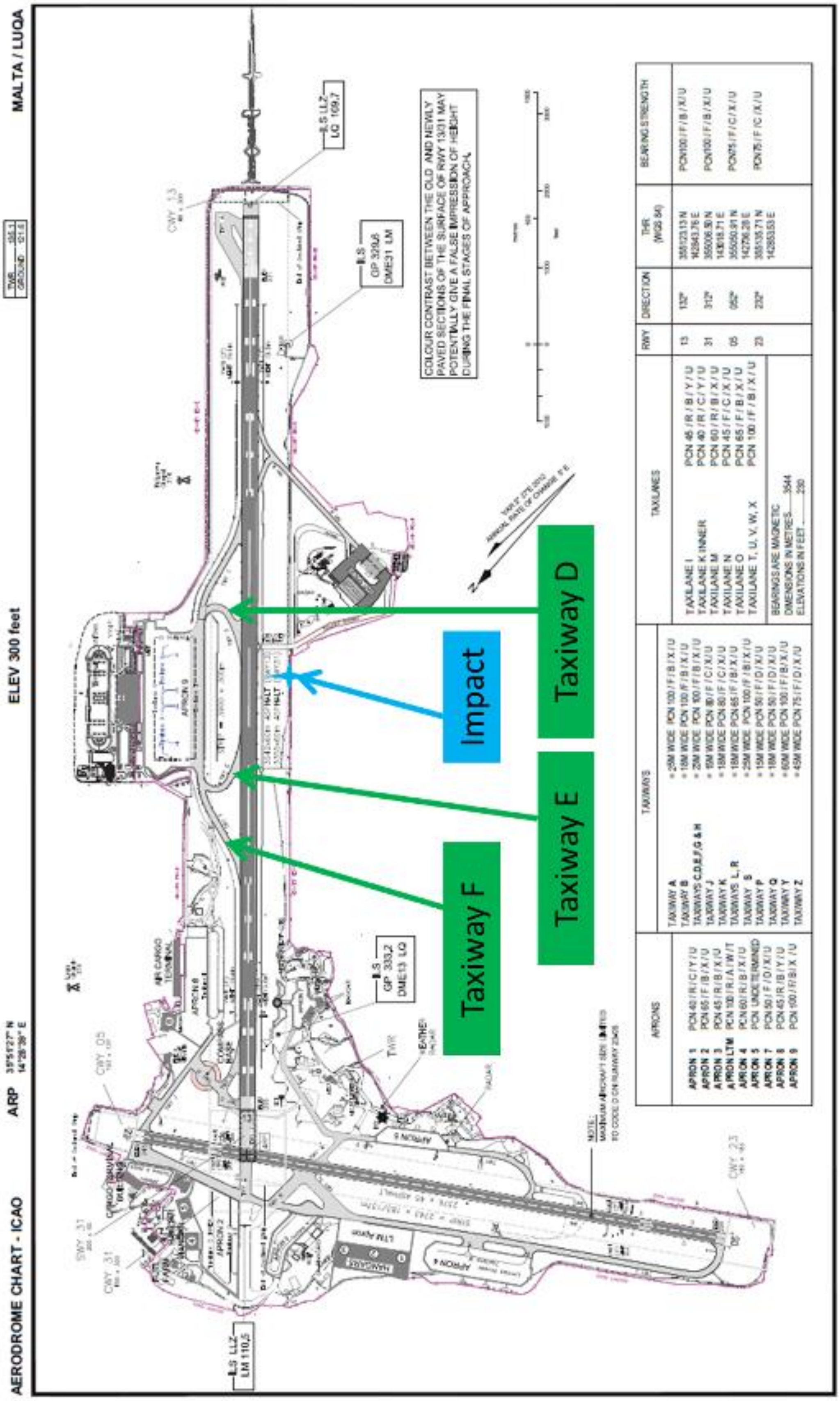
Date	Flight hours	Reg.	Situation	FAA Certificate of Airworthiness	Observations
26/11/1983	0	N31134	New		Leaves the factory
09/04/1985	10	N31134	Modification		MTOW[29] increased to 16,000 pounds, and installation of cameras and STCs[30]
01/05/1985	10	N31134		*Experimental*	
06/06/1985	27	N31134		*Special*	
28/08/1991	1,884	N31134	Inspection		Following a lightning strike during flight
27/03/1997	4,747	N120JM	-		Change of registration
11/04/1997	4,764	N120JM		*Restricted*	
07/05/2003		N120JM	Modification		Removal of RADAR and FLIR components
21/12/2005	?	N120JM	-	Fly permit	Fly Permit dated 19/12/2005
?	?	N120JM	No maintenance records between December 2005 and July 2011. Loss of certificate of airworthiness		
13/07/2011	6,325	N577MX	-	-	Change of owner and registration number
28/07/2011	6,328	N577MX	Modification		Installation of new sensors, TCAS[31], TAWS[32], extra fuel tanks and HF/UHF antennas
28/07/2011	6,328	N577MX	-	*Restricted*	Recertification by FAA
11/08/2011	6,331	N577MX	-	*Normal*	Certification by FAA
09/2011	6,357	N577MX			Acquisition by CAE Aviation
10/03/2016	9,006	N577MX	Modification	*Normal*	Removal of old sensors and installation of new sensors and antennas
In 2016	-	N577MX		*Normal*	Addition of one seat and one sensor

History of the SA227 aircraft – serial number: AT 577 B

[29] MTOW: Maximum Takeoff Weight.
[30] STC: Supplementary Type Certificate.
[31] TCAS: Traffic Collision Avoidance System.
[32] TAWS: Terrain Awareness and Warning System.

ANNEX 2

EXTRACT OF THE MAP OF MALTA AIRPORT



ANNEX 3

DATA FROM THE SANDEL EQUIPMENT AND SKYTRAK CONTROL UNIT

The data from the SANDEL and SKYTRAK equipment enabled investigators to:
- obtain a flight path of the aircraft;
- indirectly obtain additional data concerning the operation of the aircraft systems (DC and AC circuit, TCAS system).

The end of recording prevented obtaining information up to the moment of impact.

The flight path obtained from the recordings is shown below, compared to the flight path derived from analyzing the videos from three different angles.

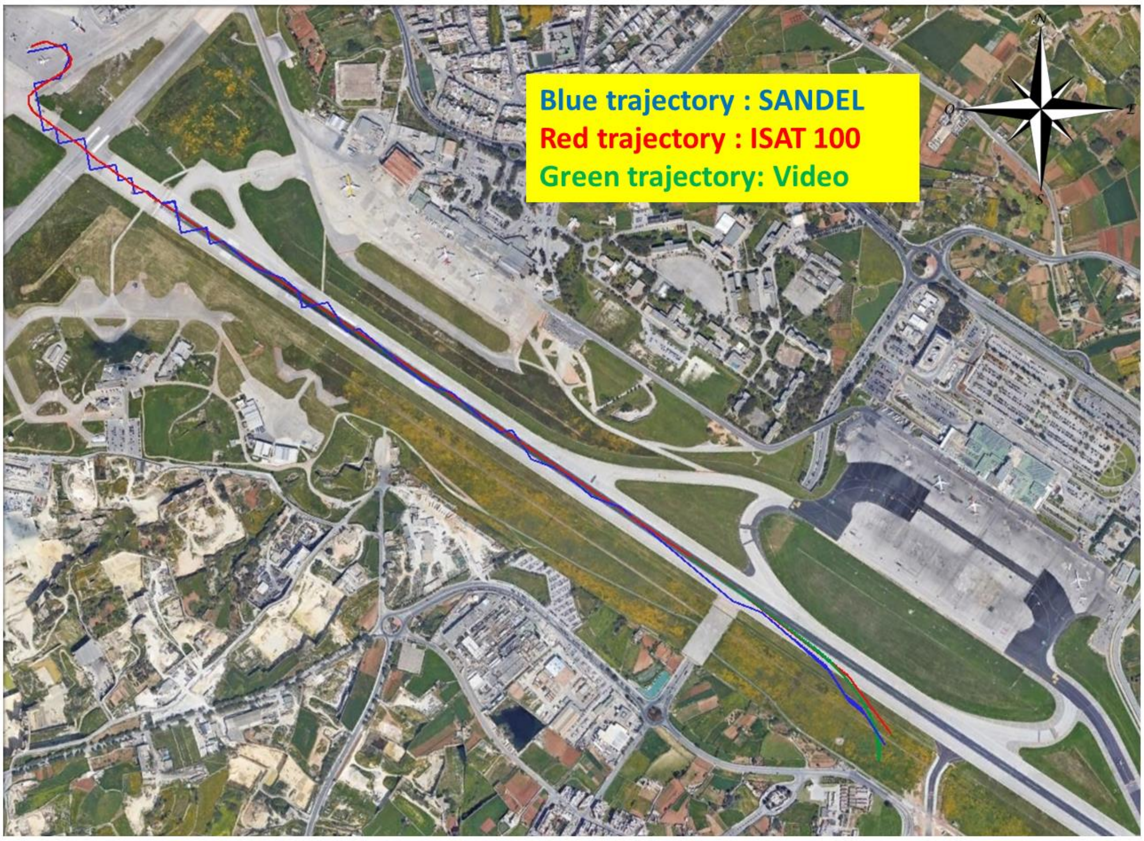


Figure 30: Compared flight paths of the aircraft after reconstitution (seen from above)

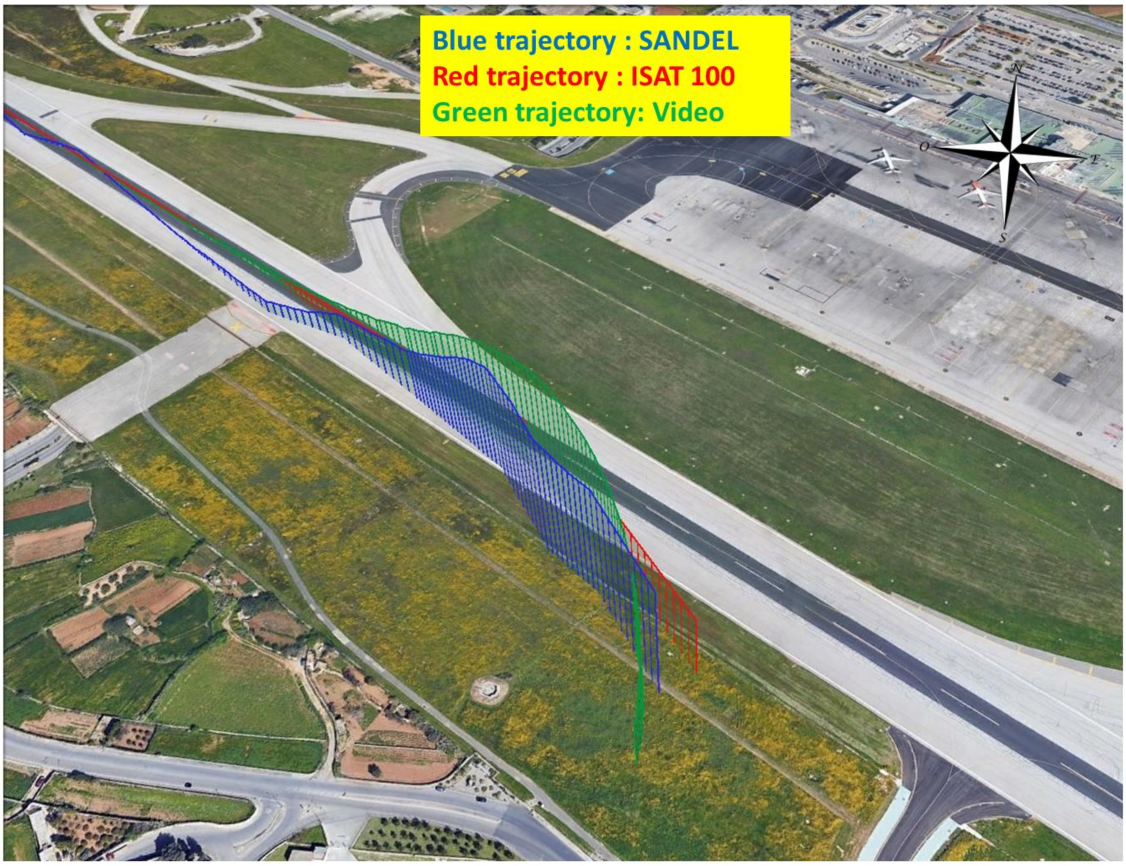


Figure 31: Compared flight paths of the aircraft after reconstitution (seen from the south side of the runway)

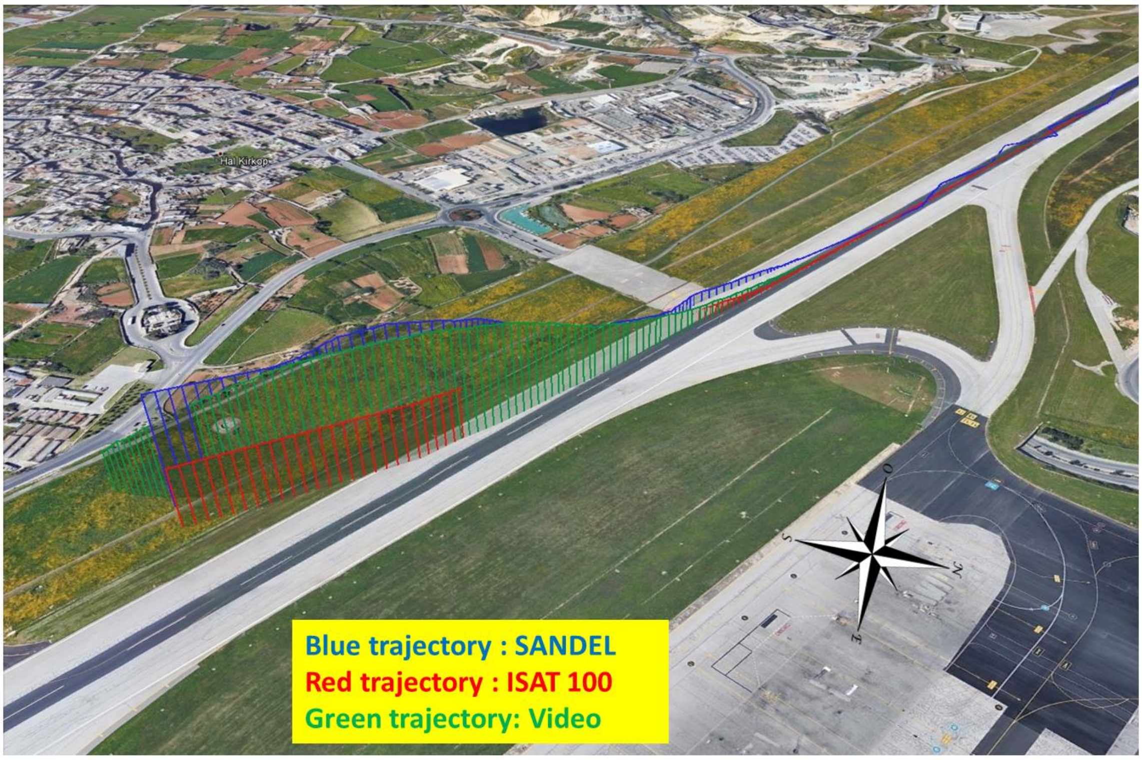


Figure 32: Compared flight paths of the aircraft after reconstitution (seen from the east side of the runway)

In combination with the SANDEL control unit, these data enabled investigators to establish the operating state of certain systems.

No DC or AC power failure of the control unit was observed up to the end of recording.
The TCAS was in operation, because the control unit received two traffic alerts (parameter TCAS1-WDS switched from 2 to 5) via the TCAS control unit:

- one during the taxiing phase on the apron or taxiways;
- a second similar signal during the line-up/takeoff phase.

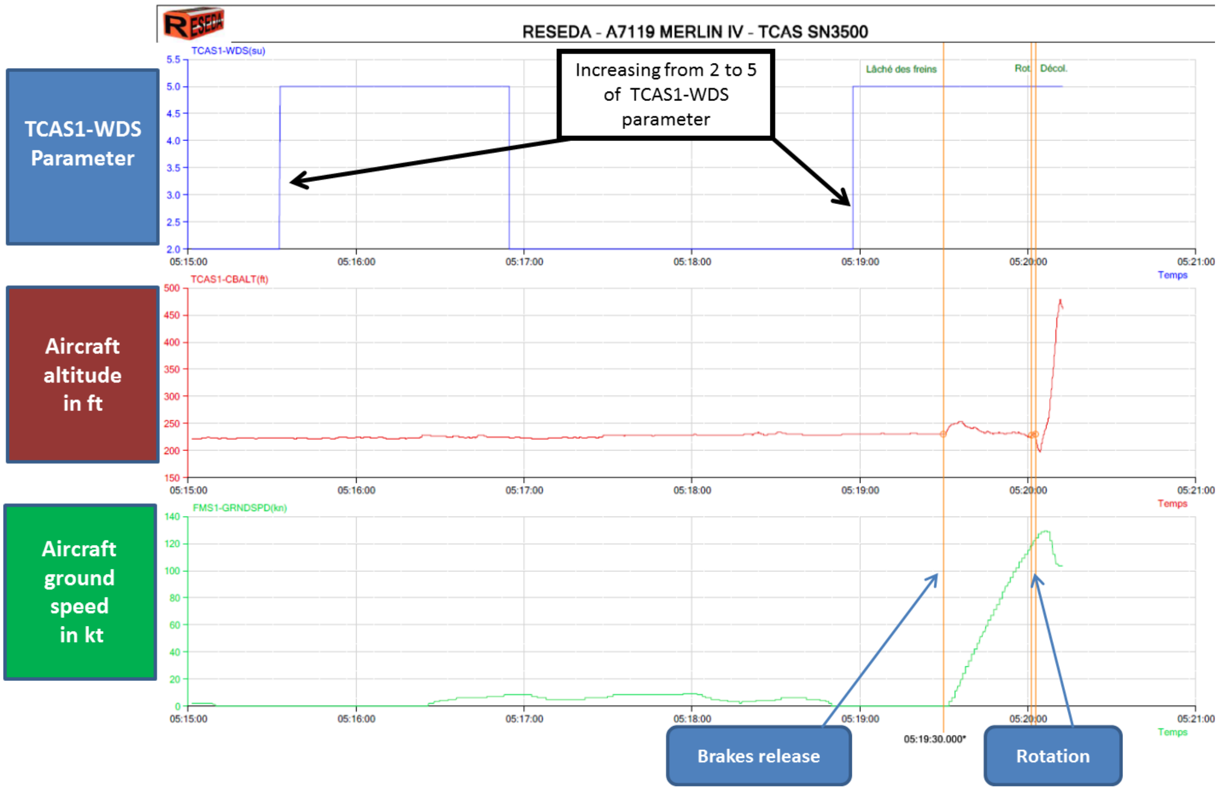


Figure 33: Identification of the two traffic alert signals (1st line) received by the SANDEL control unit

ANNEX 4

DESCRIPTION OF THE SAS "STALL AVOIDANCE SYSTEM" OF THE SA227

The aircraft is fitted with an anti-stall system named SAS (Stall Avoidance System), which in particular comprises a stick pusher and a cockpit indicator using the information provided by an angle-of-attack vane. The stick pusher is mounted in parallel on the elevator control line. The SAS mechanism actuating the stick pusher is termed the SAS Servo. The force applied by this servo control is approximately 27 kilogrammes and is controlled by a current intensity limiter, which triggers its disengagement if the current passing through it exceeds the set limit.

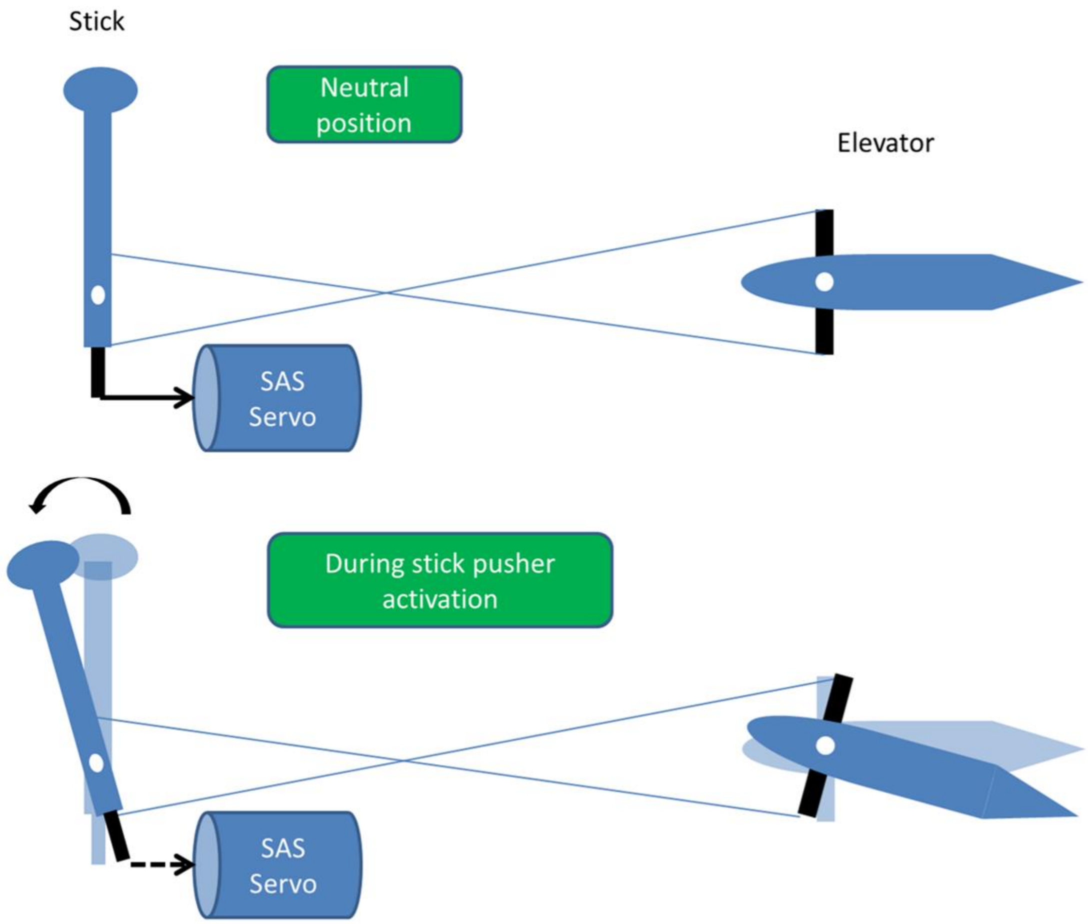


Figure 34: Diagram illustrating the installation of the stick pusher on the SA227

<u>Normal operation</u>:
According to the documentation, the system is in operation if:
- the SAS CLUTCH switch is in the *ON* position;
- the weight-on-gear contactor is in “FLIGHT” mode;
- the air speed switch is in “air speed less than 140 kt ± 5 kt” mode.

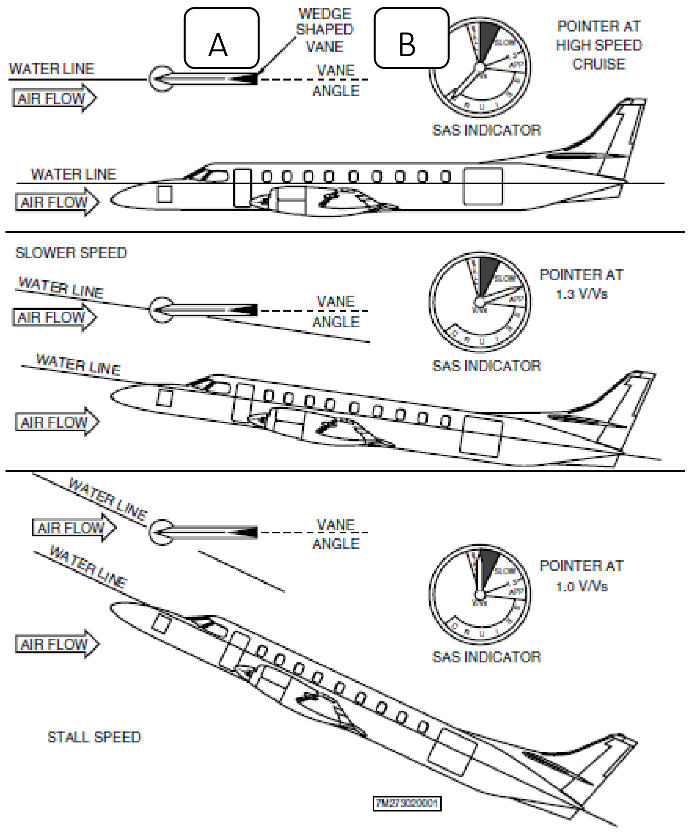
In flight, when the speed exceeds 140 kt ± 5 kt, the SAS ARM light is switched off.

According to the flight manual, the SAS is systematically tested on the ground by the crew before leaving the apron. According to the minimum equipment list (MEL), if a malfunction of this system is identified, the flight must not be performed.

<table>
<tr><td colspan="2">In addition to the speed data, the SAS of the Merlin IVC comprises:
- an angle-of-attack vane (A);
- an SAS indicator in the cockpit (B);
- a stick pusher (not illustrated).</td></tr>
<tr><td><u>At cruising speed (></u>140 kt ± 5 kt), the system is inoperative

<u>At intermediate speed</u> (1.3 times the stall speed), the pilot is visually alerted

<u>On approaching stall speed</u>, the pilot receives an aural warning

<u>Very close to stall, for an estimated angle of attack of approximately 15°</u>, a stick pusher system acts on the flight controls to prevent stalling. The force applied is approximately 27 kg.</td><td>
</td></tr>
</table>

<u>Abnormal operation</u>:
In the event of SAS malfunction during flight, the malfunction can be signalled by:
- flashing of the SAS FAULT light, which indicates a servo power interruption or servo clutch disengagement;
- SAS FAULT light on steady in flight indicates computer power failure, or computer power failure with simultaneous servo or clutch failure.

An extract of the check-lists of this system is provided below.

STALL AVOIDANCE SYSTEM (SAS) MALFUNCTIONS

SAS FAULT LIGHT ON IN FLIGHT

*1. **SAS CLUTCH or SAS SERVO SWITCH** .... OFF
2. SAS Computer Power Circuit Breaker .... PULL

CAUTION

WITH THE SAS DISENGAGED (OR INOPERATIVE) THE AIRPLANE WILL HAVE UNDESIRABLE STALL CHARACTERISTICS AT AFT CENTER OF GRAVITY LOADINGS. ADEQUATE MARGINS ABOVE THE STALL SPEED SHOULD BE MAINTAINED IN ALL OPERATIONS. ENSURE THAT TOUCHDOWN SPEED IS EQUAL TO OR GREATER THAN 1.1 V_{S1}.

NOTE

- Fault light on flashing indicates a servo power interruption or servo clutch disengagement.
- Fault light on steady in flight indicates computer power failure, or computer power failure with simultaneous servo or clutch failure.
- With the fault light on, angle of attack and stall warning indications may be unreliable.

SAS MALFUNCTION – NOSE DOWN (INADVERTENT PUSHER)

In the event of a nose down malfunction (no aural tone is heard) the following procedure should be initiated:

1. ELEVATOR CONTROL .... OVERPOWER TO MAINTAIN AIRPLANE CONTROL
*2. **SAS CLUTCH or SAS SERVO SWITCH** .... OFF
3. SAS Computer Power Circuit Breaker .... PULL

<u>WARNING</u>

PULL FORCES REQUIRED TO OVERPOWER THE STICK PUSHER MAY EXCEED 60 POUNDS.

CAUTION

WITH THE SAS DISENGAGED (OR INOPERATIVE) THE AIRPLANE WILL HAVE UNDESIRABLE STALL CHARACTERISTICS AT AFT CENTER OF GRAVITY LOADINGS. ADEQUATE MARGINS ABOVE THE STALL SPEED SHOULD BE MAINTAINED IN ALL OPERATIONS. ENSURE THAT TOUCHDOWN SPEED IS EQUAL TO OR GREATER THAN 1.1 V_{S1}.

MERLIN IVC – ICAO ANNEX 8

STALL AVOIDANCE SYSTEM (SAS) MALFUNCTIONS (continued)

AURAL STALL WARNING AT SPEEDS WELL IN EXCESS OF NORMAL STALL WARNING SPEEDS

When an aural stall warning occurs in unaccelerated flight at speeds well in excess of normal stall warning speed, possible damage to the SAS vane is indicated and an inadvertent nose down push may occur.

*1. **SAS CLUTCH or SAS SERVO SWITCH** .... **OFF**
2. SAS Computer Power Circuit Breaker .... PULL

If the stall warning horn does not silence:

3. Stall Warning Circuit Breaker .... PULL

CAUTION

WITH THE SAS DISENGAGED (OR INOPERATIVE) THE AIRPLANE WILL HAVE UNDESIRABLE STALL CHARACTERISTICS AT AFT CENTER OF GRAVITY LOADINGS. ADEQUATE MARGINS ABOVE THE STALL SPEED SHOULD BE MAINTAINED IN ALL OPERATIONS. ENSURE THAT TOUCHDOWN SPEED IS EQUAL TO OR GREATER THAN 1.1 V_{S1}.

Specific case of malfunction

Report NTSB AAR 88/10 concerning the accident of an SA227 AC aircraft contains a description of different cases of SAS malfunctions and their consequences. The cases of inadvertent activation of the stick pusher during flight reported by operators are listed in the table below:

Activation of the stick pusher	SA226	SA227
During takeoff	5	0
During climb	3	1
During descent of approach	4	10
Intermittently during flight	7	4
Intermittently during test flight	1	1

One case in particular is described on page 10. It concerns the crew of an SA226, which encountered an uncontrolled forward activation of the stick pusher during the approach phase. The crew was unable to deactivate the SAS. The two pilots had to jointly exert extreme force to overcome the force of the stick pusher. The manufacturer specifies that the maximum force that the system can apply to the pilot control stick is 119 to 146 pounds (i.e. 54 to 66 kg). Subsequent technical inspection revealed that the water accumulated underneath the cockpit floor had migrated to the electrical connector of the SAS electric motor.

ANNEX 5

DESCRIPTION OF THE POWER-ON STALL PHENOMENON APPLIED TO THE SA227 AT

During a stall, a rolling moment may be observed if one wing (or a part of it) stalls a short time before the other, due to a slightly higher local angle of attack.

This dissymmetry of angle of attack can be due to turbulence, a small sideslip angle, an aileron deflection or the effect of residual engine slipstream effect.

In the case of a power-on stall, with high angle of attack and with the max takeoff power, engine effects become preponderant, in particular:

- asymmetrical distribution of lift, which is stronger on the descending blade side, so that the left-hand wing is better supplied than the right;
- local increase in the angle of attack of the right-hand wing, due to the helicoidal slipstream (descending on the left, ascending on the right).

The right-hand wing will therefore tend to stall first, accompanied by a sharp roll to the right.

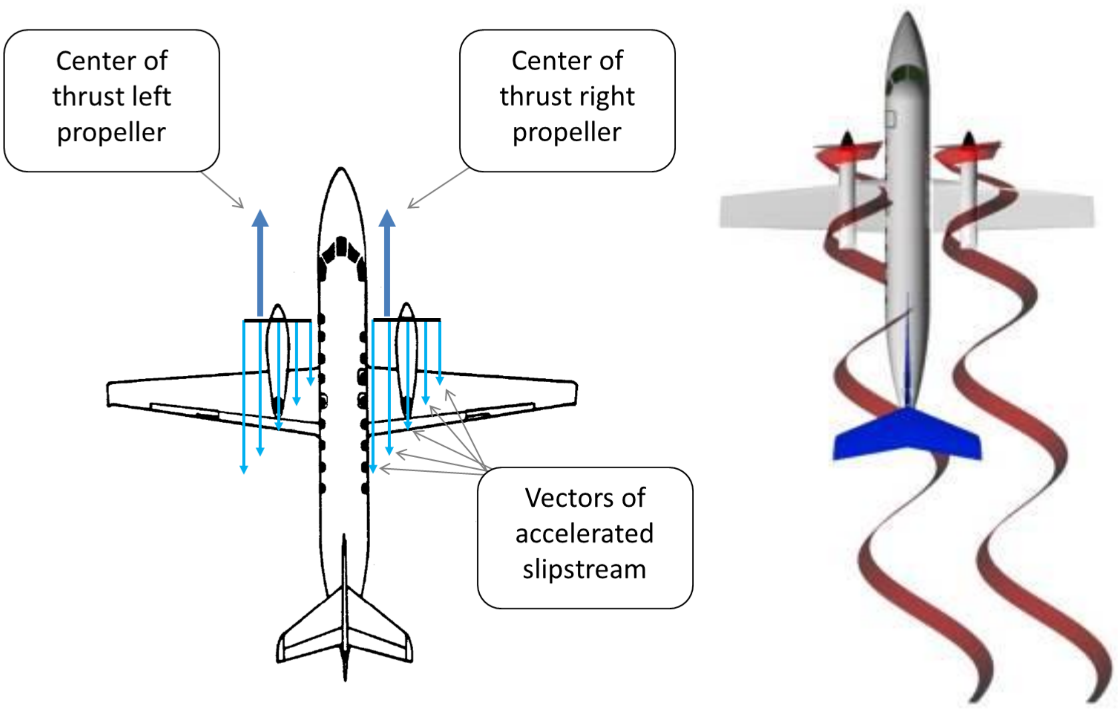
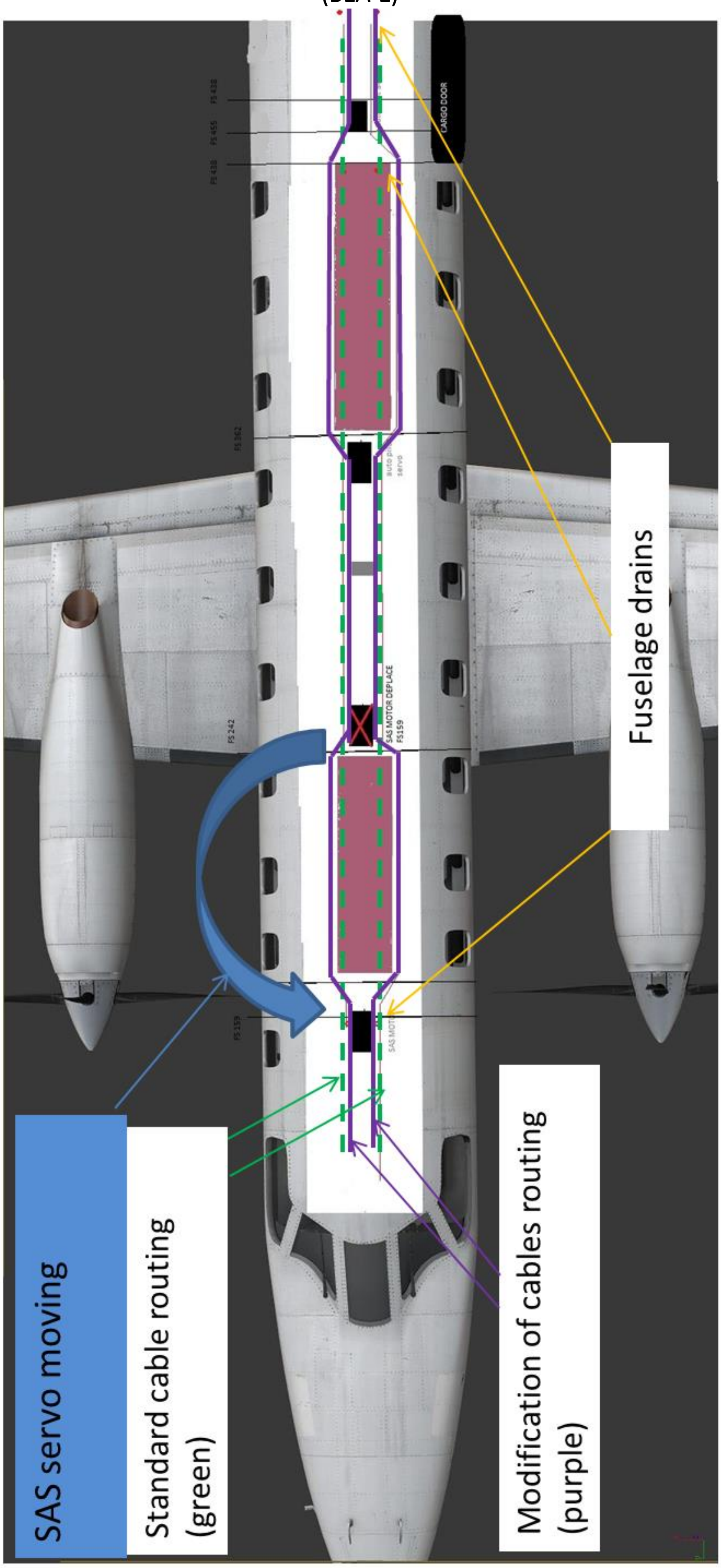


Figure 35: illustrations of the airflows and centers of thrust of the propellers on the SA227 AT

ANNEX 6

DIAGRAM ILLUSTRATING THE ROUTING OF THE CABLES OF THE AIRCRAFT INVOLVED IN THE ACCIDENT (BEA-É)



ANNEX 7

BEA REPORT ON THE JAMMING OF AN ELEVATOR CONTROL SURFACE DUE TO A CABLE WRAPPING AROUND IT

BUREAU ENQUETES-ACCIDENTS

ACCIDENT

which occurred to the aircraft registered F-BNXL

EVENT:	loss of control
IDENTIFIED CAUSE:	elevator jammed

Consequences and damage:	pilot killed, aircraft destroyed
Aircraft:	Airplane SOCATA MS 893 A Rally “Commodore”
Date and hour:	Friday 7 august 1998 at 4:30 PM
Operator:	Society
Location:	Royan airport (17)
Type of flight:	Aerial work
Person on board:	Pilot
Licence and flight experience:	Pilot 29 years old, professional pilot licence 1995, 473 flight hours among which 161 on the aircraft type and 106 hours during the last 3 months
Meteorological condition:	Wind 040° to 080°/ 8 to 10 kt gusting 15 to 20 kt, CAVOK, OAT: 33°C

History of the flight

The aircraft is performing a low pass in order to catch a streamer. The grapnel bounced on the ground and the cable wrapped around the elevator. Being jammed, the elevator led the aircraft into a dive. The aircraft crashed on the ground.

Two similar events occurred in July and August 1997.

ANNEX 8

DESCRIPTION OF CASES OF DAMAGED FLIGHT CONTROLS ON SA226/227 AIRCRAFT

These cases have been obtained from the NTSB database, which records accidents and serious incidents involving the SA226/227 aircraft. This database is not exhaustive and only covers aircraft registered in the USA.

The BEA-É has extracted the following four events:

Date	Reg.	Title	Identified cause
05/04/2006	N770S	In-flight rupture of the nose-down cable of the elevator control during takeoff	Rupture of the nose-down cable following inappropriate routing of the cable Aircraft difficult to control after reduction of engine power
28/12/1995	N159MC	Limited displacement of the elevator control surface	Loosening of a bolt in the flight control line
27/02/1995	N369AE	Malfunctions of the flight controls at the flare	Incorrect routing of the left-hand cable of the rudder control (435 h after installation)
25/08/1992	N342AE	Inverted operation of the controls on the roll axis during a test flight after maintenance	Incorrect routing of the cables during scheduled replacement of the flight control cables (flight after maintenance)

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