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Report

Accident on **13 July 2012**
at **Le Castellet aerodrome (83)**
to the **Gulfstream G-IV aeroplane**
registered **N823GA**
operated by **Universal Jet Aviation (UJT)**

Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile
Ministère de l'Ecologie, du Développement durable et de l'Energie

Safety Investigations

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SPECIAL FOREWORD TO ENGLISH EDITION

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation. As accurate as the translation may be, the original text in French is the work of reference.

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Glossary

ACO	Aircraft Certification Office
AEG	Aircraft Evaluation Group
AFIS	Aerodrome Flight Information Service
AFM	Airplane Flight Manual
AOM	Aircraft Operating Manual
ASRS	Aviation Safety Reporting System
CRH	Cockpit Reference Handbook
CRM	Cockpit / Crew Resource Management
CVR	Cockpit Voice Recorder
DGAC	French general directorate for civil aviation *Direction Générale de l'Aviation Civile*
DME	Distance Measuring Equipment
DSAC	Civil aviation safety directorate *Direction de la Sécurité de l'Aviation Civile*
DTA	DGAC air transport directorate *Direction du Transport Aérien de la DGAC*
EASA	European Aviation Safety Agency
ECM	Electronic Control Module
EHSV	Electronic Hydraulic Servovalve
EICAS	Engine Instrument and Crew Advisory System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDR	Flight Data Recorder
FMEA	Failure Mode and Effects Analysis
FMS	Flight Management System
FSI	Flight Safety International
GOM	General Operations Manual
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IPTM	Initial Pilot Training Manual

LDA	Landing Distance Available
METAR	Aerodrome routine meteorological report
MOL	Maintenance and Operations Letter
MVL	Circling approach
NDB	Non-Directional radio Beacon
NTSB	National Transportation Safety Board
NOTAM	Notice to Airmen
NWS	Nose Wheel Steering
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PM	Pilot Monitoring
POI	Principal Operations Inspector
PSIA	Aerodrome internal emergency plan Plan de Secours Interne d'Aérodrome
QRH	Quick Reference Handbook
RCO	RFFS Operational instructions *Recueil de Consignes Opérationnelles (du service SSLIA)*
RVDT	Rotary Variable Differential Transformer
SAFA	Safety Assessment of Foreign Aircraft
SMS	Safety Management System
SOP	Standard Operating Procedures
SOV	Shut Off Valve
RFFS	Rescue and Firefighting Services
TAF	Terminal Aerodrome Forecast
UHF	Ultra-High Frequencies
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VIM	Foam spraying vehicle *Véhicule d'Intervention Mousse*
ZA	Aerodrome Area
ZFW	Zero Fuel Weight
ZVA	Neighbouring aerodrome Area *Zone Voisine d'Aérodrome*

Synopsis

Loss of directional control during landing roll, lateral runway excursion, collision with trees, fire

Aircraft	Gulfstream G-IV registered N823GA
Date and time	13 July 2012 at 13 h 18[(1)]
Opertor	Universal Jet Aviation (UJT)
Place	Le Castellet aerodrome (83)
Type of flight	Public transport, positioning flight
Persons on board	Captain (PM); co-pilot (PF); 1 cabin aid
Consequences and damage	2 pilots and cabin aid fatally injured, aeroplane destroyed

[(1)]Unless otherwise specified, the times in this report are expressed in Universal Time Coordinated (UTC). Two hours should be added to obtain the legal time applicable in Metropolitan France on the day of the event.

During a visual approach to land on runway 13 at Le Castellet aerodrome, the crew omitted to arm the ground spoilers. During touchdown, the latter did not deploy. The crew applied a nose-down input which resulted, for a short period of less than one second, in unusually heavy loading of the nose gear. The aeroplane exited the runway to the left, hit some trees and caught fire.

The runway excursion was the result of an orientation to the left of the nose gear and the inability of the crew to recover from a situation for which it had not been trained. The investigation revealed inadequate pre-flight preparation, checklists that were not carried out fully and in an appropriate manner. A possible link between the high load on the nose gear and its orientation to the left was not demonstrated.

The report contains several safety recommendations regarding:

- the nose gear steering system of the G-IV;
- the recovery procedure associated with an uncommanded action of this system and the associated training;
- the arming of the ground spoilers;
- the performance of checklists by the operator’s staff;
- the rescue and fire-fighting service (RFFS) for Le Castellet aerodrome.

ORGANISATION OF THE INVESTIGATION

In accordance with ICAO Annex 13 and (EU) Regulation No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety investigation was opened by the BEA as soon as it was informed of the accident on 13 July 2012.

A team of four BEA investigators and a field investigator carried out the first actions in the investigation. The NTSB, representing the State of Manufacture, Registry and Operation, was associated with the investigation and sent a team of three investigators. Three representatives of the aircraft manufacturer, two representatives of the operator and a member of the FAA travelled and participated in the investigation. The BFU, representing the State of Manufacture of the engines, was associated with the investigation. It appointed an accredited representative who did not travel to the accident site. Three representatives from the engine manufacturer travelled and participated in the investigation.

Three working groups were then formed:

- the Aircraft group;
- the Systems and Performance group;
- the Operations group.

In accordance with international provisions, the BEA invited its foreign counterparts to participate in the work of these three groups.

A pilot from the DGAC's flight inspection agency also participated in the investigation.

1 - FACTUAL INFORMATION

1.1 History of the Flight

On Friday, 13 July 2012 the crew, consisting of a Captain and a co-pilot, took off at around 6 h 00 for a flight between Athens and Istanbul Sabiha Gokcen (Turkey). A cabin aid was also on board the aeroplane.

The crew then made the journey between Istanbul and Nice (06) with three passengers. After dropping them off in Nice, the aeroplane took off at 12 h 56 for a flight to Le Castellet aerodrome in order to park the airplane for several days, the parking area at Nice being full. The Captain, in the left seat, was Pilot Monitoring (PM). The co-pilot, in the right seat, was Pilot Flying (PF).

Flights were operated according to US regulation 14 CFR Part 135 (special rules applicable for the operation of flights on demand).

The flight leg was short and the cruise, carried out at FL160, lasted about 5 minutes.

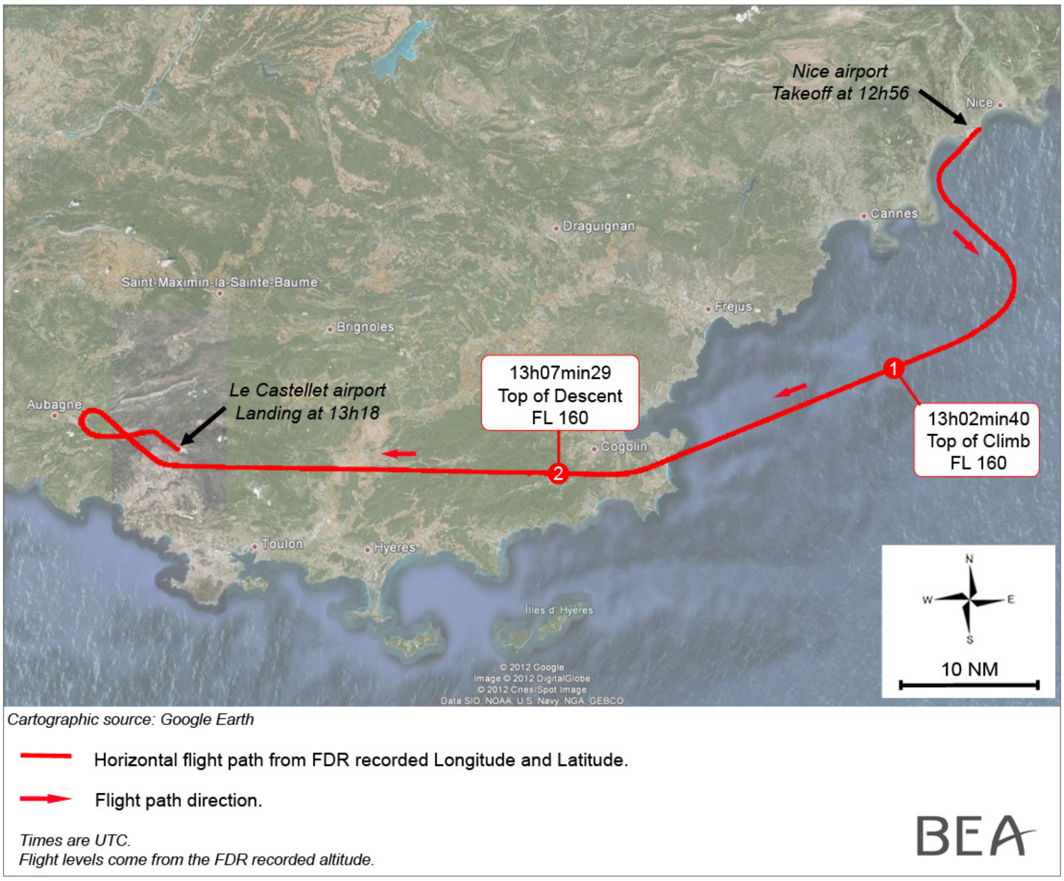


Figure 1: flight path followed by the aeroplane during the flight between Nice and Le Castellet

At the destination, the crew was cleared to perform a visual approach to runway 13. The autopilot and the auto-throttle were disengaged, the gear was down and the flaps in the landing position. The GND SPOILER UNARM message, indicating non-arming of the ground spoilers, was displayed on the EICAS and the associated single chime aural warning was triggered(2). This message remained displayed on the EICAS until the end of the flight since the crew forgot to arm the ground spoilers during the approach.

(2)The GND SPOILER UNARM message and the single chime aural warning are systematically triggered during each approach due to the extension of the landing gear before the arming of the ground spoiler (see § 1.6.7). The message remains displayed on the EICAS as long as the ground spoilers are not armed while the aural warning is triggered only once.

At a height of 25 ft, while the aircraft was flying over the runway threshold slightly below the theoretical descent path, a SINK RATE warning was triggered. The PF corrected the flight path and the touchdown of the main landing gear took place 15 metres after the touchdown zone - that's to say 365metres from the threshold - and slightly left of the centre line of runway 13(3). The ground spoilers, not armed, did not automatically deploy. The crew braked and actuated the deployment of the thrust reversers, which did not deploy completely(4). The hydraulic pressure available at brake level slightly increased. The deceleration of the aeroplane was slow.

Four seconds after touchdown, a MASTER WARNING was triggered. A second MASTER WARNING(5) was generated five seconds later.

The nose landing gear touched down for the first time 785 metres beyond the threshold before the aeroplane's pitch attitude increased again, causing a loss of contact of the nose gear with the ground. The aircraft crossed the runway centre line to the right, the crew correcting this by a slight input on the rudder pedals to the left. They applied a strong nose-down input and the nose gear touched down on the runway a second time, 1,050metres beyond the threshold.

The speedbrakes were then manually actuated by the crew with an input on the speed brake control, which then deployed the panels. Maximum thrust from the thrust reversers was reached one second later(6). The aircraft at this time was 655 metres from the runway end and its path began to curve to the left. In response to this deviation, the crew made a sharp input on the right rudder pedal, to the stop, and an input on the right brake, but failed to correct the trajectory. The aeroplane, skidding to the right(7), ran off the runway to the left 385 metres from the runway end at a ground speed of approximately 95 knots.

It struck a runway edge light, the PAPI of runway 31, a metal fence then trees and caught fire instantly.

An aerodrome firefighter responded quickly onsite but did not succeed in bringing the fire under control.

The occupants were unable to evacuate the aircraft.

(3)Runway 13: 1 750 x 30 m, LDA 1 705m.

(4)The non-deployment of the ground spoilers generated a small load on the landing gear, leading to the momentary loss of the *"on-ground"* condition. This had the effect of retracting the thrust reversers.

(5)These MASTER WARNINGs correspond to L-R REV UNLOCK warnings generated by the temporary loss of the *"on-ground"* condition of a main landing gear while the thrust reversers are unlocked.

(6)The thrust reversers were fully deployed seven seconds after the command.

(7)The skidding to the right is defined by a ground speed vector oriented to the right of the longitudinal axis of the aeroplane.

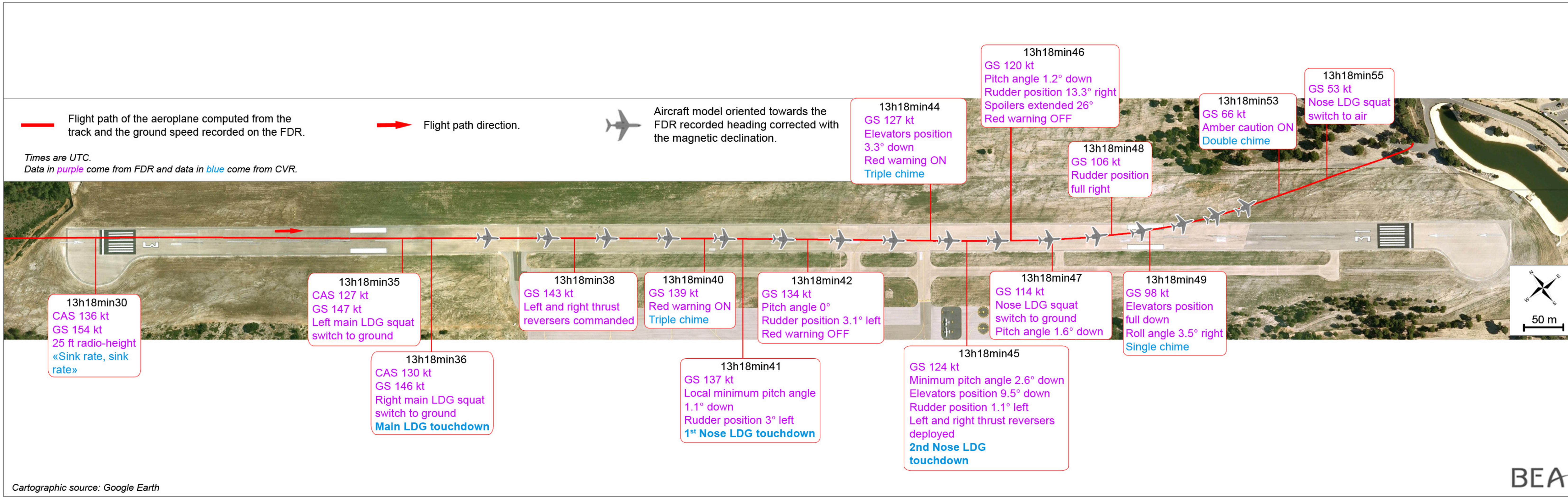


Figure 2: aeroplane flight path based on the track and the ground speed recorded on the FDR

1.2 Injuries to Persons

	Injuries		
	Fatal	**Serious**	**Light/None**
Crew members	3	-	-
Passengers	-	-	-
Other persons	-	-	-

1.3 Damage to the Aircraft

The aeroplane was destroyed.

1.4 Other Damage

During the aeroplane's runway excursion, the nose gear collided with a runway edge light and one of the PAPI lights of runway 31, which were destroyed. About twenty metres of the aerodrome perimeter fence was also destroyed. Trees were destroyed and rocks located along a road were displaced by the impact.

1.5 Personnel Information

1.5.1 Flight Crew

1.5.1.1 Captain

Male, 60 years old:

- ATP Airline Transport Pilot License dated 7 October 1974, issued by the United States civil aviation authorities;
- valid multi-engine aircraft instrument rating IR/ME (L) dated 6 August 1971;
- valid Gulfstream G-IV type rating dated 23 November 2010;
- class 1 medical certificate dated 8 March 2012.

The pilot had type ratings for the following aircraft: A310, B727, B757, B767, B777, DC10, DC6, DC7, DC9, MD11.

The last recurrent training and check was carried out between 17 and 19 October 2011.

The last proficiency checks and simulator training took place on 25 April 2012.

The last line check took place on 28 December 2011.

Experience:

- total: 22,129 flying hours, including 18,439 as Captain;
- on type: 690 flying hours, including 572 as Captain;
- in the previous three months: 99 flying hours, all on type;
- in the previous thirty days: 37 flying hours, all on type;
- in the previous twenty-four hours: 4 h 30 of flying hours, all on type.

The Captain was employed by American Airlines between 1977 and 2008. He had been flying as Captain on Boeing B777s since 2003. After retiring from American Airlines, he was hired as a pilot on a part-time basis by UJT on 25 September 2010. He followed the UJT operator's conversion training (lasting three days between 25 and 29 October 2010) and then passed the type rating course for the Gulfstream G-IV within the CAE Simuflite training organization based in Dallas (Texas) in November 2010. He paid for part of the training.

He was appointed as Captain on 28 December 2010 after a line check[(8)]. Nevertheless, he flew as co-pilot on G-IV until March 2011, during which time he flew 118 hours on 35 flights, 16 as PF, 19 as PM. He was hired full-time by UJT on 1 July 2011 and made his first flight as Captain on 19 July 2011.

[(8)]In November and December 2010, he made no flights on G-IV.

He was given CRM training during the operator's conversion training and during the type rating course.

He was given emergency evacuation training during the operator's conversion training (October 2010). The last emergency evacuation drill recorded took place on 19 October 2011.

He had previously flown to Le Castellet on a Gulfstream G-IV on 21 August 2011. He was then PM and had landed on runway 13.

Before the day of the accident, the crew had been resting in Athens since July 4.

1.5.1.2 Co-pilot

Male, 24 years old:

- CPL(A) Commercial Pilot License dated 24 June 2008, issued by the United States civil aviation authorities;
- valid multi-engine aircraft instrument rating IR/ME (L) dated 31 May 2008;
- valid Gulfstream G-IV Type rating dated 2 November 2010;
- class 1 medical certificate dated 8 December 2011;
- he was qualified as an instructor (FI/IRSE).

Experience:

- total: 1,350 flying hours, of which 556 hours on type;
- in the previous three months: 180 hours, all on type;
- in the previous thirty days: 61 hours;
- in the previous twenty-four hours: 4 h 30.

The last recurrent training and check took place from 13 to 15 November 2011.

The last proficiency checks and simulator training were dated 2 November 2011.

He was employed in 2009 as a co-pilot by a company which owned a Lockheed L-1329 JetStar and the Gulfstream G-IV N823GA, the operation of which was entrusted to UJT from February 2011. Hired by UJT on a part-time basis on 21 September 2010, he took the operator's conversion training from 21 to 24 September 2010 and obtained type rating on G-IV from CAE Simuflite on 2 November 2010. He was hired full-time on 1 July 2011.

He undertook CRM training during the operator's conversion training course (September 2010). He undertook emergency evacuation training during the operator's conversion training (November 2010). The last emergency evacuation drill recorded was held on 15 September 2011. The drill was carried out with smoke generators in the cabin and the evacuation was via the over-wing emergency exits.

1.5.2 Cabin Aid

Female, aged 29.

A cabin aid provided commercial service. She was given emergency evacuation training on 25 May 2011 as part of her duties at UJT.

The presence of cabin crew (registered as a crew member) is not required in airplanes operated on Part 135.

1.6 Aircraft Information

The Gulfstream IV (G-IV) is a business aircraft for multi-pilot operation, designed by the Gulfstream Aerospace Corporation. N823GA was certified in accordance with the FAR Part 25 regulation, including amendments 25-1 to 25-56. Jet Star Aviation Services were the owners of the aeroplane, which they purchased on 30 July 2010. It had been leased to UJT since February 2011.

N823GA was configured with 16 passenger seats.

1.6.1 Airframe

Manufacturer	Gulfstream
Type	G-IV
Serial number	1005
Registration	N823GA
Entry into service	29 July 1987
Certificate of airworthiness	DAR-39-AC-CE of 2 September 1993 issued by the FAA
Use since last inspection 150 h	37 hours and 14 cycles
Use as of the date of the accident	12,210 hours and 5,393 cycles

1.6.2 Engines

Manufacturer: Rolls Royce
Type: Tay 611-8

	Engine No. 1	Engine No. 2
Serial number	16117	16118
Installation date	August 1987	August 1987
Total running time	11,840 hours and 5,271 cycles	11,840 hours and 5,271 cycles
Run time since overhaul	5,271 hours and 2,023 cycles	5,271 hours and 2,023 cycles

1.6.3 Maintenance

The aircraft was maintained by several maintenance shops, in accordance with the approved service manual. Its maintenance inspections were up to date.

Due to the lateral deviation of the aeroplane during the landing roll, particular attention was paid to the history and maintenance of the nose gear and its steering system.

The only maintenance work on the nose gear steering system was carried out on 25 November 2008. It involved an overhaul followed by functional tests that revealed no anomalies.

Only three constituent parts of the steering system (see detailed description of the system § 1.6.5) are subject to periodic overhauls:

- the steering unit every 20,000 cycles;
- the shutoff valves (SOV # 1 and 2) every 10,000 cycles.

The minimum number of cycles not having been reached as of the date of the accident, these were original parts on the aeroplane.

The last maintenance work carried out on the nose gear was dated 22 June 2012 and involved the lubrication and re-pressurisation of the damper.

1.6.4 Weight and balance

Basic weight: 19,888 kg	
Passenger: 90 kg	
Luggage: 122 kg	
Zero fuel weight: 20,101 kg	Maximum zero fuel weight: 22,226 kg
Take-off weight: 26,723 kg	Maximum take-off weight: 33,837 kg
Fuel mass/weight: 6,804 kg	
Trip fuel: 1,134 kg	
Landing weight: 25,590 kg	Maximum landing weight: 29,937 kg
Estimated centre of gravity position during landing: 33.8%	Limit positions of the centre of gravity at the landing weight: between 31.7% and 38%

1.6.5 Nose gear steering system

The nose gear steering system is electrically controlled, hydraulically operated and actuated by the crew. It is used during taxiing, take-off and landing. The orientation of the wheels is made via the steering unit which transmits the rotational forces via the torque links. The nose wheels are not braked.

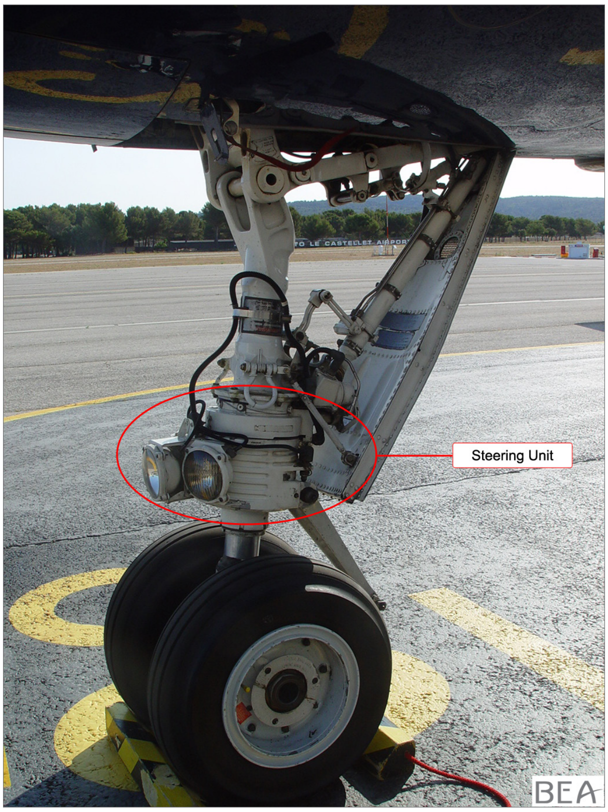


Figure 3: nose gear steering system of another G-IV

The crew can control the system:

- using the tiller and a guarded[9] ON / OFF *"PWR STEER"* switch on the left console. The control system consists of a tiller equipped with return springs returning it to neutral position, viscous dampers and potentiometers. The tiller is used to control the orientation of the nose gear up to 80° ± 2° to the left or right of the central axis of the aeroplane[10]. The PWR STEER switch and the tiller are accessible only from the left seat.

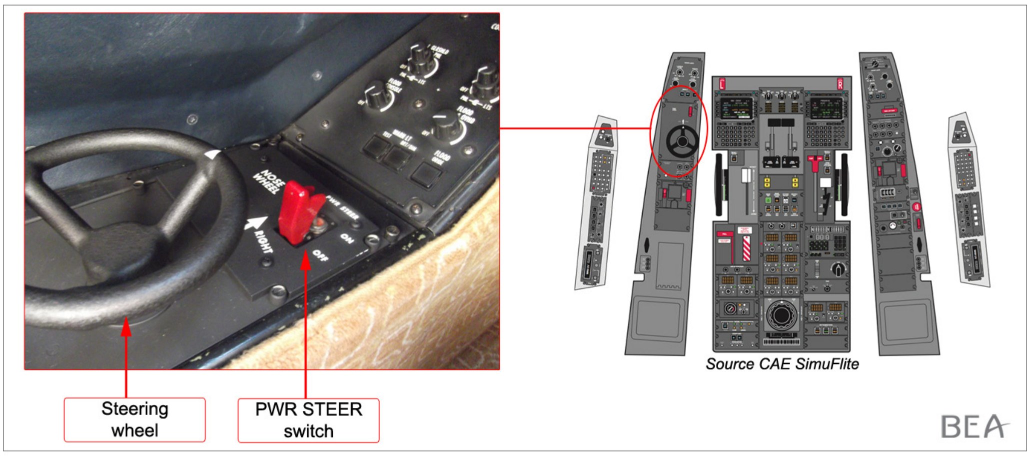


Figure 4: tiller and guarded PWR STEER switch

[9]In normal operation, the switch guard is down, the PWR STEER switch is in the *"ON"* position.

[10]This displacement is possible regardless of the speed of the aeroplane.

- through the rudder pedals. They are used to control the direction of the nose gear up to 7° ± 1° to the left or right.

The positioning of the PWR STEER switch to OFF results in disconnecting the steering system. In this case, an input on the rudder pedals or the tiller has no effect on the direction of the nose gear.

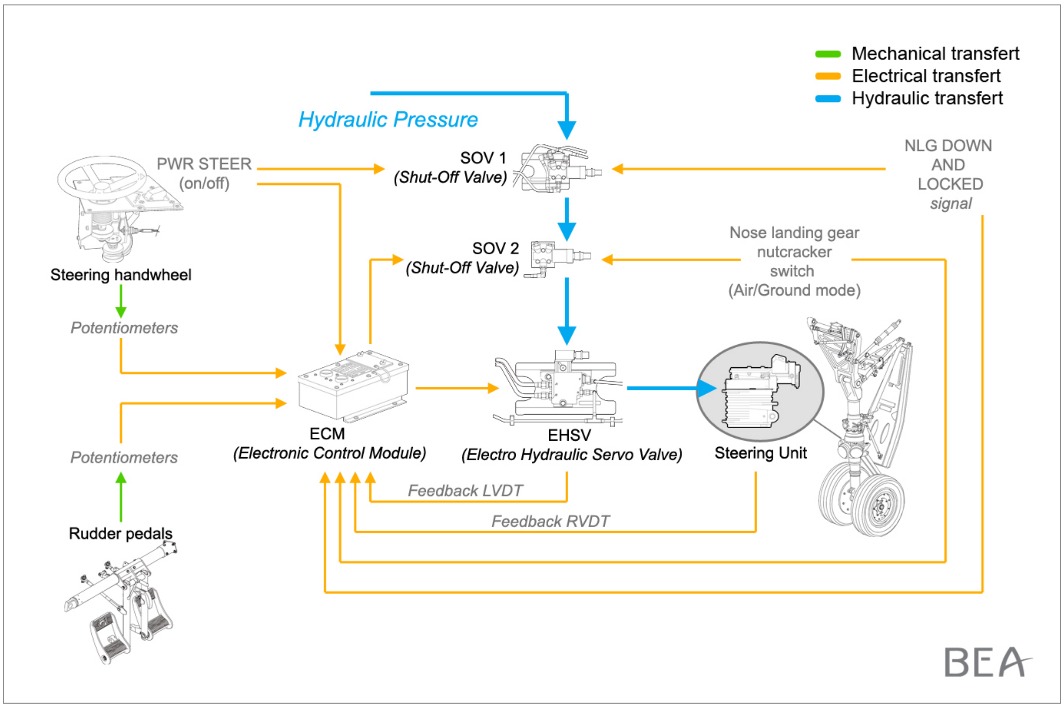


Figure 5: nose gear steering control system

The activation of the steering system starts 250 ms after the compression of the nose gear is registered by the proximity sensor. Full activation of the system is effective 750 ms later.

A STEER BY WIRE FAIL warning is generated by the ECM when the PWR STEER switch is set to OFF and the landing gear is down or in case of failure of one of the following items of equipment:

- the ECM (management computer for the nose gear steering control);
- the shutoff valves (SOV);
- the EHSV (hydraulic servovalve);
- the potentiometers of the tiller;
- the RVDT (position sensor of the steering unit);
- the potentiometers of the rudder pedals.

The detailed description of the system is provided in **Appendix 1**.

1.6.6 Tyres

The landing gears of this aeroplane are equipped with Goodyear tyres using *"Bias"* technology:

- main landing gear: Flight Eagle 34x9.25-16;
- nose gear: Flight Eagle 21x7.25-10 DT.

1.6.7 Spoilers

The aeroplane has three spoiler panels actuated by two cylinders on the upper surface of each wing. They are used in flight or on the ground, in order to reduce the lift and increase the drag on the wing on which they are deployed.

The movement of the speed brake lever from *"RETRACT"* results in the proportional deployment of the three spoiler panels per wing to a maximum of 26° in the EXTEND position. The control lever lights up blue and an SPD BRAKE EXTENDED information message is displayed on the EICAS.

Pressing the GND SPLR push-button arms the ground spoilers. The push-button lights up blue. The three panels are then automatically deployed at an angle of 55° when the aeroplane is on the ground.

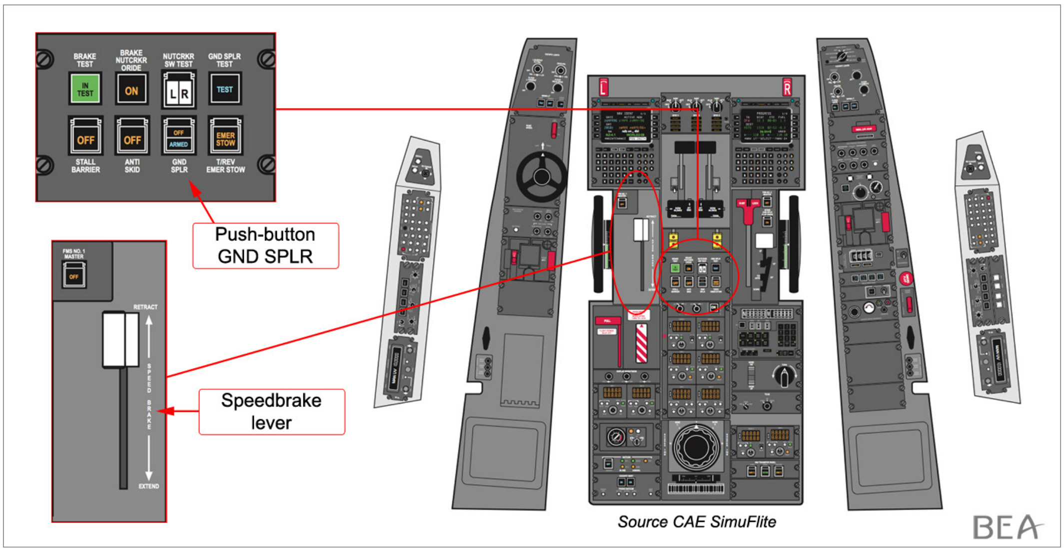


Figure 6: GND SPLR push-button and speedbrake control

The position of the ground spoilers is not shown directly to the crew in the cockpit. Only a GND SPOILER UNARM message is displayed in blue on the EICAS and an audible *"single chime"* warning is generated when they have not been armed and the landing gear is down and locked.

Gulfstream states that the ground spoilers should be armed in flight after a test of the landing gear compression sensor (called a *"nutcracker test"* in the checklist). This test is performed after the extension of the landing gear. The GND SPOILER UNARM message and the *"single chime"* aural warning are thus systematically triggered during each flight. Gulfstream states that arming them shortly before landing reduces the risk of uncontrolled deployment of the ground spoilers in flight.

In case of malfunction

On the ground, in the event of non-deployment of the ground spoilers if they have been armed, the message NO GND SPLRS lights up red on the capsule on the centre panel. There is no associated aural warning or message on the EICAS.

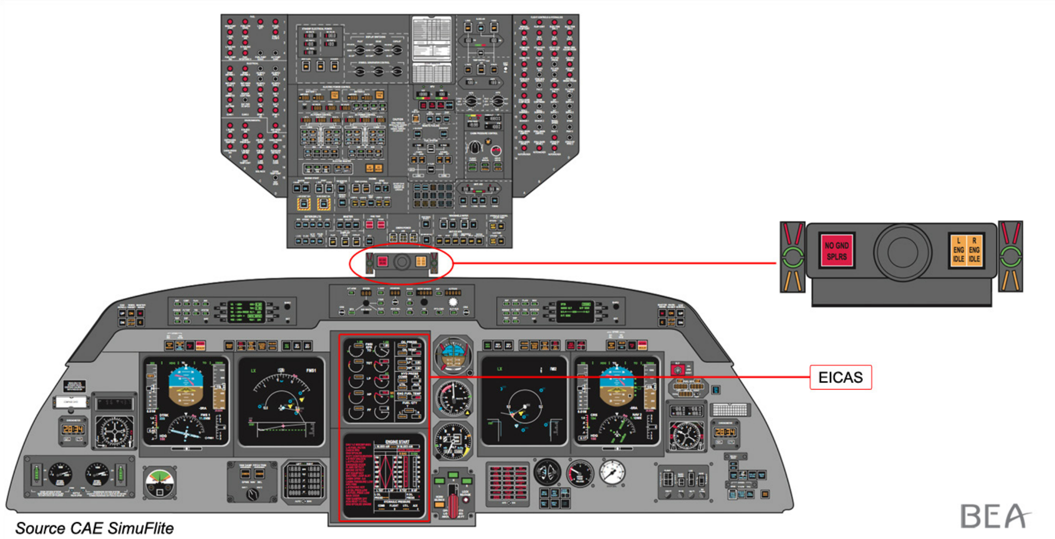


Figure 7: capsule on the centre panel and the EICAS

In flight, in the event of a system malfunction, the GND SPOILER message is displayed on the EICAS. It is associated with a *"triple chime"* aural warning.

1.6.8 Landing distances

In landing configuration (flaps to 39°) with a weight of 25,590 kg and under the conditions of the day:

- the reference speed (Vref) was 138 kt and the recommended approach airspeed (Vapp) was 148 kt(11);
- the landing distances(12) were 900 metres with no wind and 1,030 metres with a tailwind component of 10 knots.

1.6.9 Emergency exits on the G-IV

The G-IV has 6 emergency exits:

- the main entrance door;
- four over-wing exits at the level of the last two rear windows;
- the door of the luggage compartment. This exit is considered as a secondary evacuation route.

(11)The recommended approach speed is Vref + 10 kt. If there are gusts of wind, it is recommended to add half the difference between the maximum wind and the average wind, up to 10 kt. At the threshold, the speed retained will in all cases be Vref.

(12)The landing distance is the horizontal distance between transition 50 ft above the runway threshold and the aeroplane's complete stop. This is a certified distance calculated by taking into account manual braking and the automatic deployment of the ground spoilers.

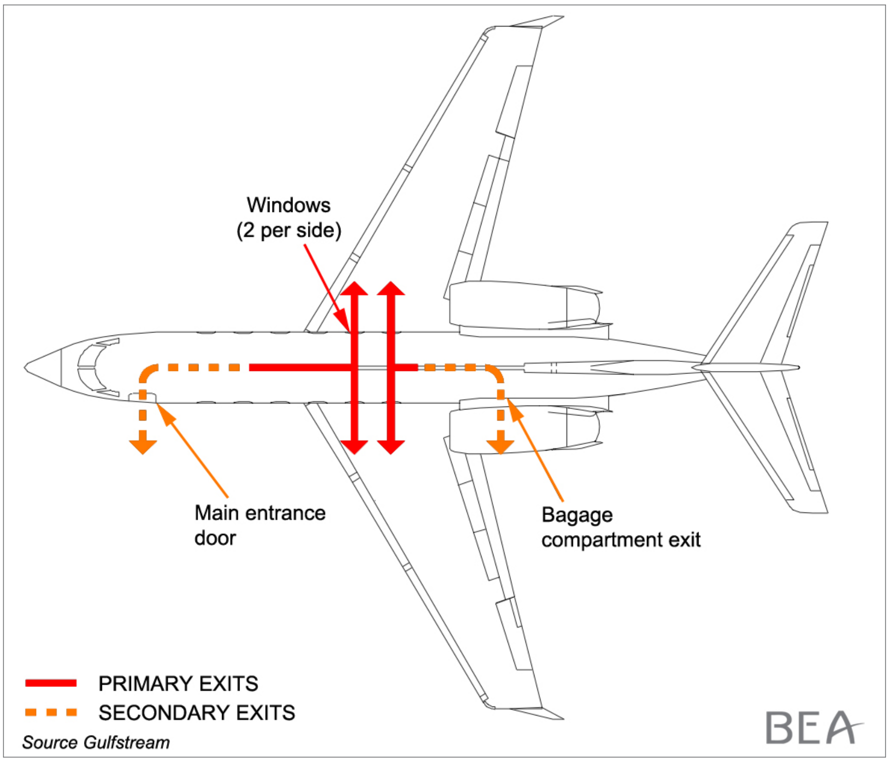


Figure 8: emergency exits

1.7 Meteorological Information

Conditions at Le Castellet aerodrome and the surrounding aerodromes

The sky was clear with horizontal visibility greater than 10 km. Low to moderate turbulence of thermal origin was observed.

At 13 h 00, the temperature recorded was 25°C and the QNH was 1012 hPa.

Surface wind[13]:

	Average wind speed 10 minutes		Maximum spot wind in the previous 10 minutes		Average wind speed 2 minutes		Maximum spot wind in the previous minute	
	Direction	Speed (kt)	Direction	Speed (kt)	Direction	Speed (kt)	Direction	Speed (kt)
13h16	200°	5	180°	12	220°	4	260°	6
13h17	200°	4	190°	10	250°	4	250°	5
13h18	210°	4	190°	10	260°	4	300°	10
13h19	220°	5	210°	13	270°	6	210°	13
13h20	220°	5	210°	13	240°	7	240°	11

At the time of the landing at 13 h 18, the maximum spot wind over a minute was 10 kt from 300°.

[13]Information provided by the Le Castellet weather station.

During the approach, the AFIS officer provided the pilots with the following wind information:

- at 13 h 16, wind from 200° at 6 kt;
- at 13 h 17, wind from 200° at 4 kt.

Note: The AFIS officer had at his disposal:

- the strength and direction of the wind averaged over 10 minutes;
- the minimum and maximum values of the strength and direction of the wind over 10 minutes; he stated that he did not usually provide these values to crews.

The observations, made between 13 h 00 and 13 h 30 at neighbouring aerodromes were as follows:

- Toulon–Hyères: wind varying from 230° to 240° at 16 kt to 19 kt;
- Marseille: wind varying from 250° to 260° at 8 kt to 12 kt;
- Le Luc: wind varying from 260° to 270° at 15 kt.

Upper-level wind at 13 h 00(14):

(14)Information from the Météo France AROME model.

Height in m	Direction:	Speed in kt:
3000	277°	42
2500	279°	37
2000	280°	32
1500	279°	25
1000	285°	21
750	275°	15
500	262°	15
250	248°	15
100	239°	15
50	235°	14
20	233°	13
10	232°	12

Forecasts available

The forecasts available at 11 h 00 and valid from 12 h00 indicated the following wind information for the aerodromes concerned:

- Toulon – Hyères: 250° at 15 kt with gusts at 25 kt; temporarily 25 kt with gusts at 35 kt;
- Marseille: 280° at 10 kt; temporarily from 200°.

1.8 Aids to Navigation

The published instrument approach procedures are based on the following means: an NDB (referenced ADC) and a DME (referenced ADC). They were in operation.

The PAPI on runway 13 was calibrated on a vertical plane of 3.4°. It was in operation at the time of the accident.

1.9 Telecommunications

During the approach the crew was successively in contact with an approach controller at Marseille Provence aerodrome and the AFIS officer at Le Castellet. The radio exchanges and telephone conversations with the AFIS officer were transcribed.

1.10 Aerodrome Information

Le Castellet is an AFIS aerodrome open to general aviation and international traffic. It is located in class G uncontrolled airspace below 4,500 ft QNH. Its reference elevation is 1,391 ft. The aerodrome, home mainly to tourism and business aviation, is located close to the Paul Ricard motorsport race track. VFR flights are permitted by day and IFR flights by day or by night.

It has a 13/31 paved runway of 1,750 x 30 m.

Runway 13 is oriented QFU 127° and the altitude at its threshold is 1,372 ft. The landing distance available (LDA) is 1,705 m.

The aerodrome has Locator instrument procedures (final approach flight path oriented to 093°) to be followed by visual manoeuvring (circling) (MVL) or circling with prescribed tracks (MVI) authorized only in the presence of the AFIS officer.

Obstacles and runway safety area

Runway 13 of the aerodrome is 3C category according to the ICAO classification, adopted by French regulations. The latter state that this type of runway has a safety area 150 metres wide and centred on the runway centre line (75 metres either side), and must be free of obstacles that might constitute a hazard for aircraft.

The trees that were struck by N823GA were located 95 metres or more from the runway centre line. The rocks were located 105 metres away. These obstacles were therefore outside the runway safety area.

NOTAM

Two NOTAM were published and mentioned:

- the presence of a «temporary massive obstacle consisting of a line of trees outside the runway safety area» north of the runway[15];
- that landings were prohibited if the crosswind component was greater than 15 kt.

1.11 Flight Recorders

The aeroplane was equipped with two flight recorders. They were read out at the BEA on 15 July 2012.

[15]These obstacles were not the ones struck by N823GA.

Flight Data Recorder (FDR)

It was a solid state recorder (SSFDR) with a recording capacity of at least 25 hours.

- Manufacturer: Fairchild
- Model: F1000
- Type number: S800-2000-00
- Serial number: 01399

Cockpit Voice Recorder (CVR)

The CVR was a protected magnetic tape recorder with a recording capacity of at least 30 minutes.

- Manufacturer: Fairchild
- Model: A100
- Type number: A100-30
- Serial number: 51240

The information regarding the accident flight was recorded on the FDR and CVR.

1.11.1 Use of Data from the FDR

Graphs showing the changes in certain parameters are included in **Appendix 2**.

1.11.1.1 Aeroplane's flight path

- In the vertical plane

The vertical path shows that during the final approach the crew intercepted the approach path indicated by the PAPI (6%) at a height of about 430 ft. This path was maintained with an indicated airspeed of 150 kt, close to the theoretical Vapp (148 kt). A tailwind component of ten knots was present on the final approach. On approaching the threshold the airspeed decreased towards the Vref of 138 kt.

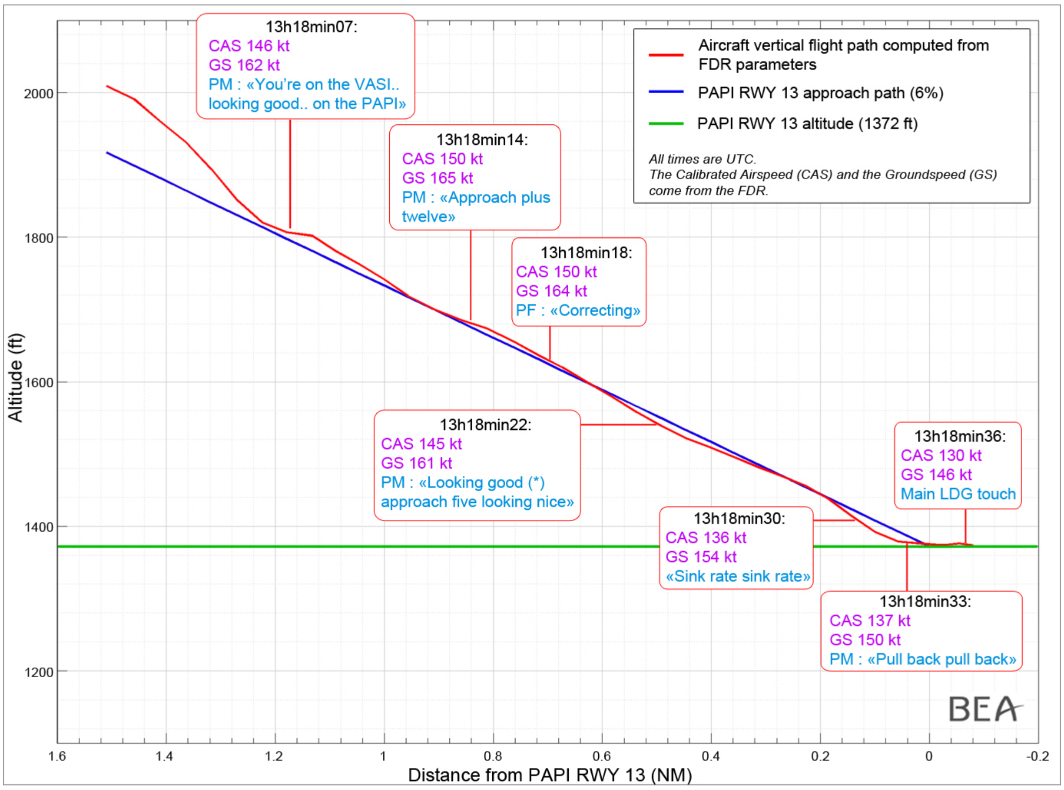


Figure 9: flight path in the vertical plane

■ In the horizontal plane

The horizontal path shows the following:

- the touchdown of the main landing gear (MLG) occurred about 15 metres behind the touchdown zone, offset 2.5 metres to the left of the runway centre line at an indicated airspeed of 130 kt and a ground speed of 146 kt;
- the first touchdown of the nose gear occurred at a distance of 785 metres from the threshold; the aircraft was then on the centre line of the runway, which it was crossing from left to right;
- the second touchdown of the nose gear occurred 1,050 metres from the threshold;
- at 1,100 metres from the threshold, the aeroplane's trajectory began to curve to the left;
- the runway excursion took place 1,320 metres from the threshold at an indicated airspeed of 95 knots and a ground speed of 93 kt; the aeroplane then travelled 300 metres before stopping.

The horizontal path is described in Chapter 1.1 History of the Flight.

1.11.1.2 Readout of the recordings from previous flights

The following points should be noted, based on the readout of recordings from previous flights:

- no nose-down input was recorded when decreasing the attitude of the aircraft on landing leading to the touchdown of the nose gear (de-rotation);
- the same crew did not arm the ground spoilers on July 4 (three flights before the accident) during a flight from Milan Linate to Athens that was made with four passengers. Arming was performed 3-4 seconds after the touchdown of the main landing gear by pressing the GND SPLRS button and the ground spoilers were deployed to their maximum deflection;
- braking pressures are generally low during landings.

1.11.1.3 Quality of recorded parameters

Of all the FDR parameters decoded at the BEA, only a part of them could be validated. The others appeared to be invalid or changed coherently but with erroneous decoded values. The table below shows all the invalid parameters:

Invalid parameters	Parameters with coherent changes despite erroneous decoded values
Vertical acceleration	Position of elevator
Longitudinal acceleration	Position of rudder
Lateral acceleration	Position of left-hand spoilers (inner panel)
Position of left aileron	Position of left-hand speedbrakes
Position of right aileron	Position of right-hand spoilers (inner panel)
Position of elevator trim	Position of right-hand speedbrakes
Left-hand thrust reverser retracted / in transit	
Right-hand thrust reverser retracted / in transit	

Table 1: list of defective parameters

1.11.1.4 FDR maintenance

The maintenance documentation for N823GA indicates that the last functional test of the FDR was conducted on 15 November 2010[16].

No mark of the data, the transmission of the data or their reception at Gulfstream could be found.

The last Gulfstream analysis report on data from the FDR available to the investigation team dated back to 2008. It reported recording problems on the following parameters:

- thrust reversers;
- ailerons;
- elevator trim.

Furthermore, the values of certain parameters mentioned in the Gulfstream analysis report also indicate that there were recording problems concerning the following parameters that were not reported by Gulfstream:

- lateral, longitudinal and vertical accelerations;
- position of spoilers.

All of these recording problems, already noted in 2008, were also found when reading and decoding the FDR data after the accident.

1.11.2 Readout of CVR data

The recording started during taxiing in Nice. This made it possible to determine, during the flight:

- the atmosphere between the pilots was good and the observable stress level low;
- the copilot read the approach chart to Le Castellet during the cruise; he informed the Captain that he had not checked the approach chart before the flight;
- the crew mentioned the proximity of the terrain, the need to reduce speed and anticipate the configuration, and the short runway length;
- several checklists were not done or requested;
- the *"before landing"* checklist was done in an incomplete manner: the PF requested the extension of the landing gear, called the checklist and then requested the extension of the flaps to their landing position. The PM performed these actions then called out: *"ok, gear down, three green, checklist is complete"* (*see §1.17.5.2* for a complete description of the *"before landing"* checklist);
- the noise level of the first touchdown of the nose gear was abnormally high;
- spectral analysis showed that after the first touchdown, the speed of the nose gear wheels, which were no longer in contact with the ground, was close to the speed of the aeroplane at that time; this speed then gradually decreased, to about the same level as that observed during the take-off from Nice, for example;
- there was no verbal exchange between the crew members during the aeroplane's landing roll.

[16] The UJT maintenance programme for this aeroplane includes a functional test of the FDR every two years.

1.11.3 Identification of warning, caution, and advisory messages and determination of the position of the PWR STEER switch

The MASTER WARNING warnings generated when the aeroplane was on the runway correspond to the L-R REV UNLOCK warning. A table identifying the warnings heard in the cockpit during the flight is provided in **appendix 3**.

The BEA also tried to determine when the PWR STEER switch was set to OFF[17]. It was set to ON during take-off because the crew was able to steer the aircraft during taxiing in Nice. Setting it to OFF and holding it in that position would have generated a warning message during the extension of the landing gear, which was not heard on the CVR or recorded by the FDR. Thereafter there was no warning message up to 13 h 18 m 53 s, three seconds after the runway excursion.

The PWR STEER switch was therefore ON before the excursion, and remained in that position at least until 13 h 18 m 53 s[18].

[17] This switch was found in the OFF position, see § 1.12.

[18] At this instant, the aeroplane was off the runway but had not yet left the aerodrome perimeter.

1.12 Wreckage and Impact Information

1.12.1 Examination of the Accident Site and Wreckage

The wreckage was located outside the aerodrome perimeter fence.

Figure 10: location of the wreckage

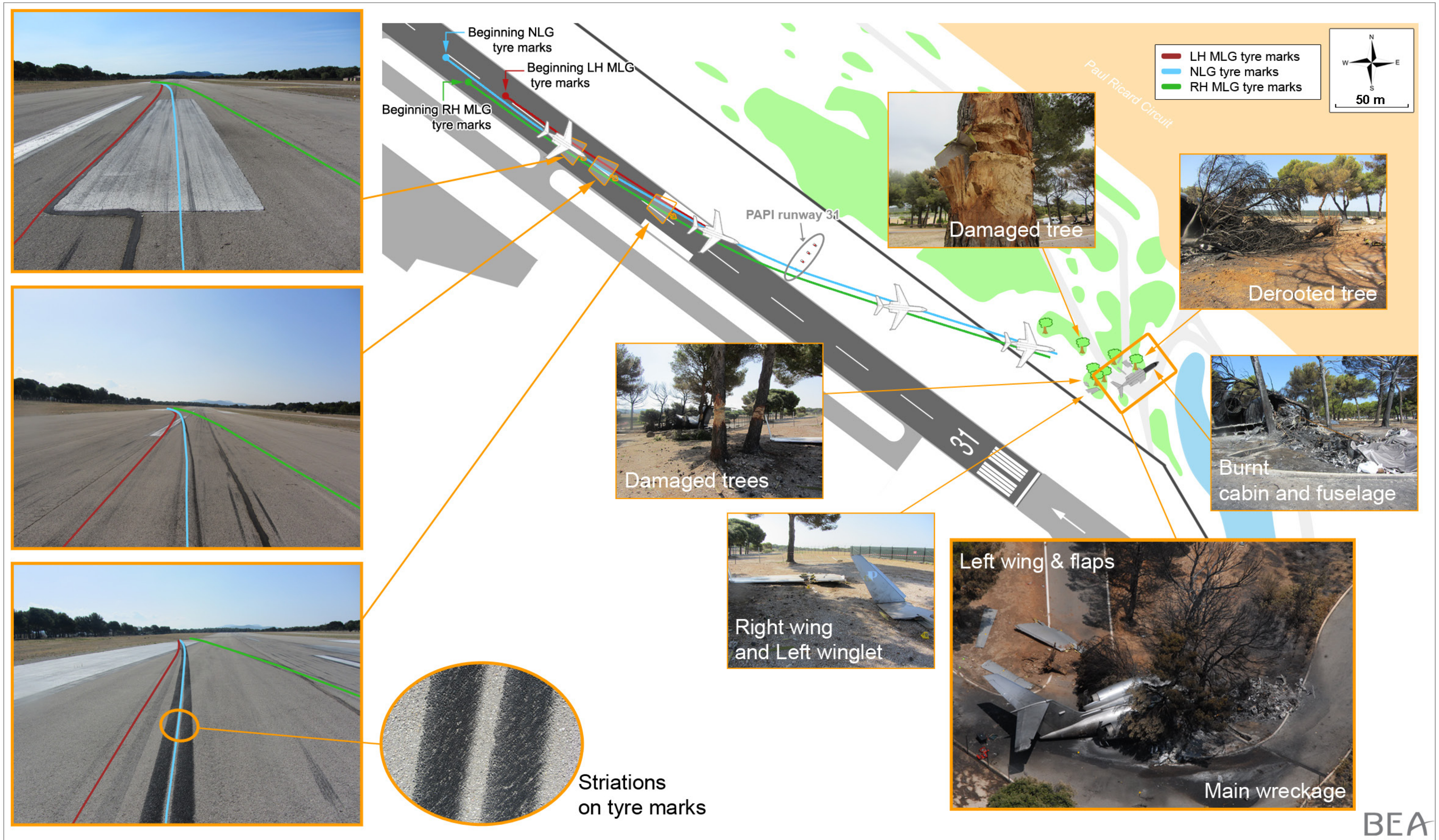
A large amount of debris from the aeroplane was found near the wreckage. This resulted from the contact between the aircraft and the fence demarcating the enclosure of the aerodrome, as well as the rocks and trees. Most of the aeroplane was destroyed by fire (figure 11).

No debris from the aeroplane was found within the aerodrome perimeter. The first part (piece of the nose gear) was located just behind the fence that the aeroplane went through.

Figure 11: area affected by the fire

The examination of the site and the wreckage showed:

- the aeroplane was in landing configuration. The thrust reversers were deployed symmetrically;
- the aeroplane was skidding to the right during the turn and the runway excursion;
- the aeroplane's multiple impacts with the vegetation resulted in the wings breaking off and slowed down the aircraft;
- the rocks at the roadside were struck by the nose gear and the right main landing gear;
- the fuselage did not come into frontal contact with the trees and was not broken;
- the fire resulted from the rupture of the wings, which contained fuel;
- all of the doors and emergency exits were found closed and locked;
- the main landing gear wheels showed no signs of punctures or abnormal wear.


Beginning NLG
tyre marks
Beginning LH MLG
tyre marks
Beginning RH MLG
tyre marks
LH MLG tyre marks
NLG tyre marks
RH MLG tyre marks
N
W
E
S
50 m
Paul Ricard Circuit
PAPI runway 31
31
Damaged tree
Derooted tree
Damaged trees
Burnt
cabin and fuselage
Right wing
and Left winglet
Left wing & flaps
Main wreckage
Striations
on tyre marks
BEA

1.12.2 Tyre marks on the runway

The first tyre marks observed on the runway attributed to N823GA were left by the nose gear[19]. They were continuous to the runway edge over a longitudinal distance (in relation to the runway centre line) of 270 metres. The marks from the right main landing gear start 30 metres after those of the nose gear, those of the left main landing gear started 25 metres after those of the right main landing gear (*see the diagram and photographs below*).

(19)These marks correspond to the *"second"* touchdown of the nose gear.

The marks were more noticeable on their right side, on the outside of the turn, and their intensity increased when approaching the runway edge.

Particular attention was paid to the nose gear marks. The tyre grooves were initially visible (*photos 1 to 3 in figure 12*) and the marks were not very noticeable. They then became darker and the tyre grooves disappeared. The width of the marks left by each tyre increased with the travel of the aeroplane and the gap between the two marks decreased until they disappeared.

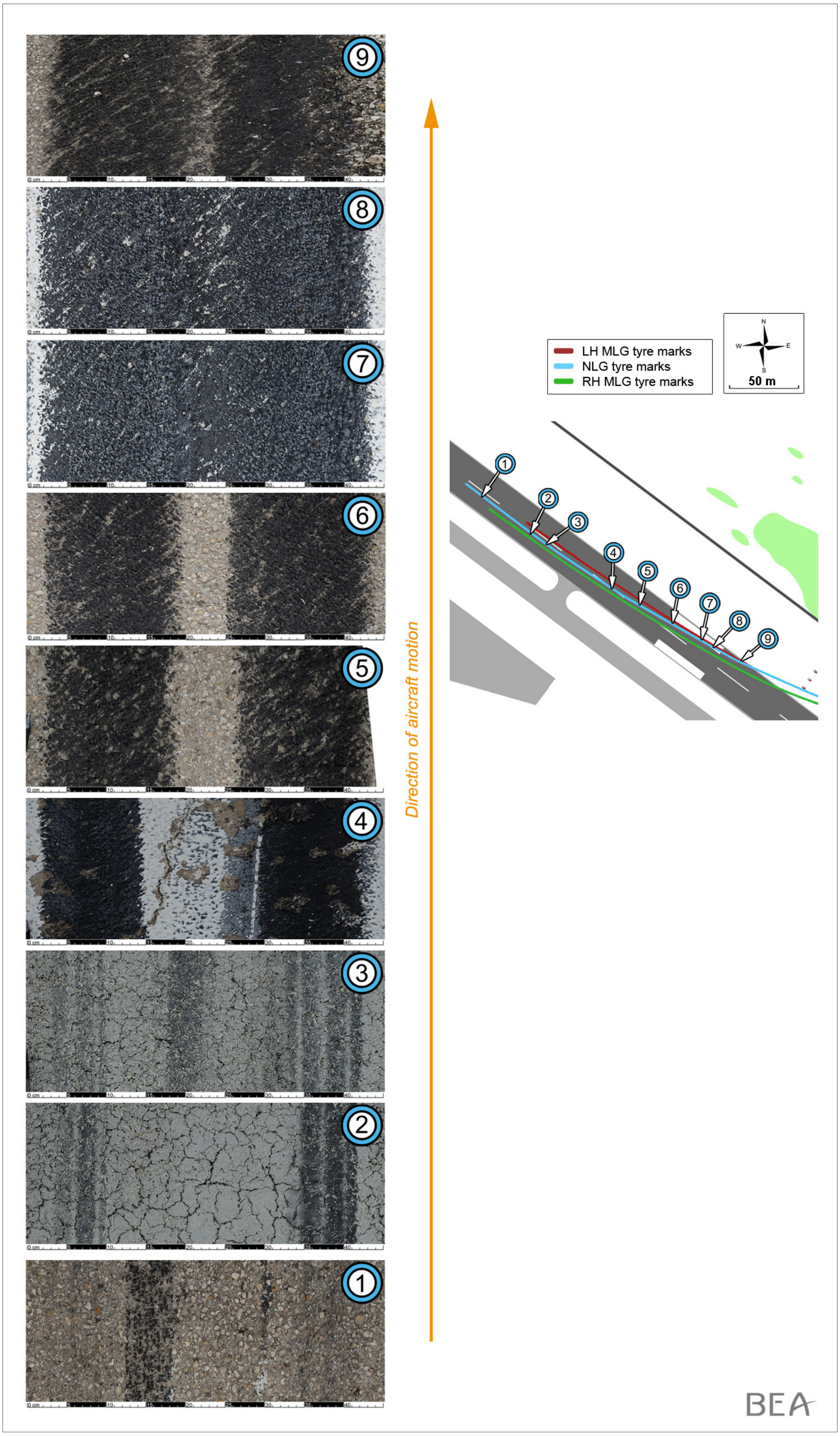


Figure 12: photos of the nose gear tyre marks

Shortly before the runway centre line (between points 3 and 4 of the diagram above) and until the runway edge these marks had striations trending towards the right in the direction of travel of the aeroplane. Their angle, measured between the edge of the mark and the striation, changed along the marks (see the measurements below).

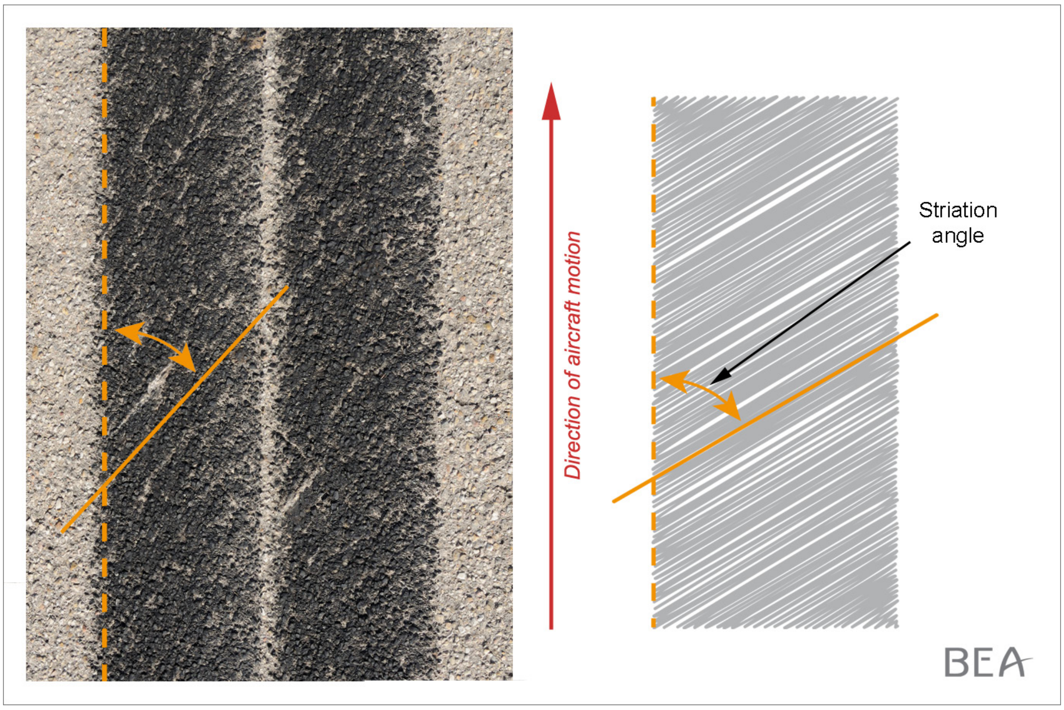


Figure 13: striations observed on the nose gear marks and method for measuring the angle

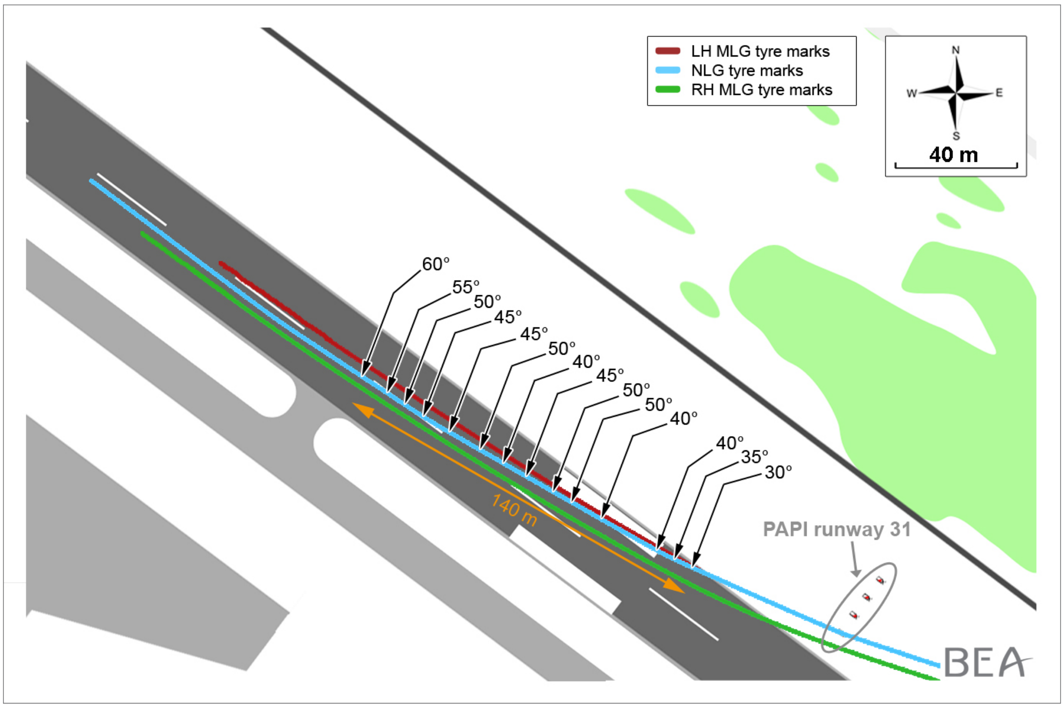


Figure 14: striation angle values along the nose gear marks

The interpretation of these striations was the subject of a study that is presented in 1.16.7.

1.13 Medical and Pathological Information

The autopsies on the bodies of the crew members did not bring to light anything that could explain the accident. The occupants died by asphyxiation in the fire area.

1.14 Fire

A fire started after the impact of the structure with the rocks and trees. The wing tanks ruptured and the fuel immediately ignited. The fire spread to a few surrounding trees.

The front of the aeroplane was totally destroyed by fire. The section to the rear of the baggage hold showed signs of heating, but was relatively preserved.

1.15 Survival Aspects

1.15.1 Survival of the occupants

The Captain was found in an area of the aeroplane corresponding to the middle of the cabin aisle. He was probably trying to evacuate the aeroplane.

The co-pilot, located in the right seat, was found on the right side of the cockpit in an area corresponding to the position of his seat. The buckle of the left strap of his harness was found at his left shoulder, outside its fastener. It is possible that the copilot also tried to evacuate.

The cabin aid was found between the two pilots, at the level of the galley located at the front of the aeroplane.

1.15.2 Emergency response

The presence of two fire-fighters is necessary to ensure level 5 RFFS service. During the event, only one fire-fighter was present at the aerodrome.

He was notified immediately after the runway excursion by the AFIS officer and intervened at the site about 3 minutes after the alert was given. He carried out the first intervention without moving about 30 metres from the wreckage using the cannon on the foam response vehicle (VIM), at full flow about 30 seconds. Hindered by trees located between him and the aeroplane, he changed strategy and decided to go around the wreckage to the south. The second intervention took place about 6 minutes after the first operation, also without moving at about 30 metres from the wreckage, first on the stretch of water on which the fuel was burning[20], then on the wreckage itself. The cannon was used at half-flow until all of the water was used up. A detailed chronology of the intervention can be found in **appendix 4**.

[20]The firefighter said in his interview that he initially thought the cockpit was located here.

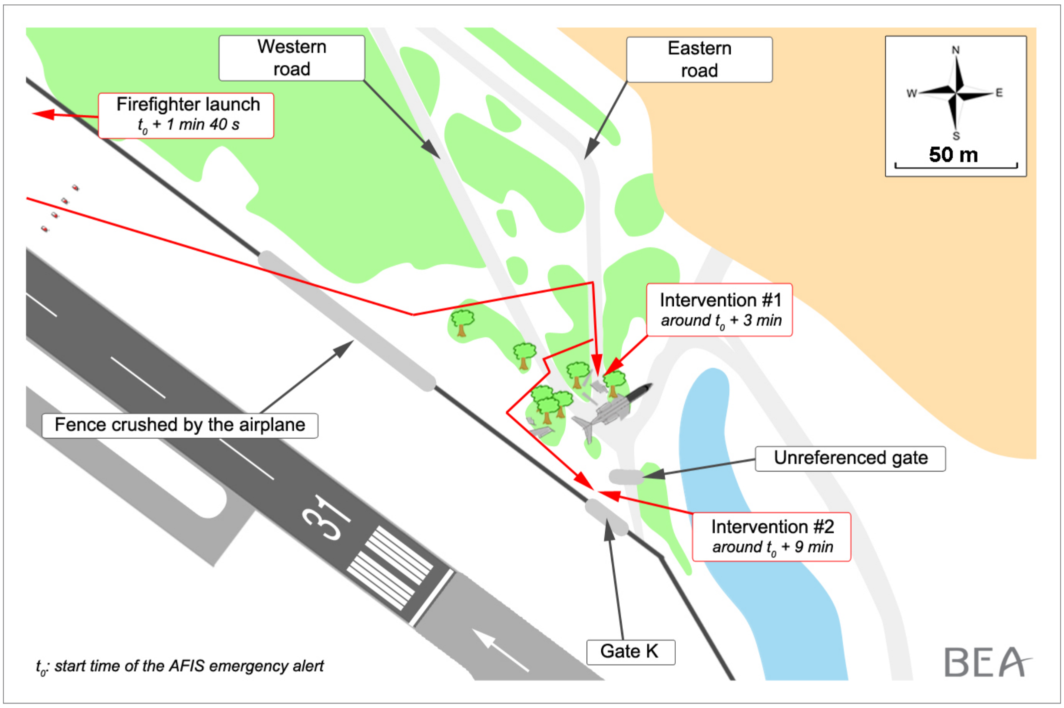


Figure 15: estimated fire-fighter routing and intervention positions, based on his interview

Firemen on board several vehicles, from outside the aerodrome, intervened as backup later.

1.16 Tests and Research

In order to understand the reasons for the aeroplane's deviation to the left, tests and research were undertaken on:

- studying the behaviour of the aeroplane on the ground: its deceleration, loads on the landing gear, the influence of the lack of ground spoilers on its performance characteristics and aeroplane braking , the lateral deviation;
- technical examinations of the nose gear steering system and of the braking system;
- a study of the tyre marks;
- a study of possible failure modes of the nose gear steering system;
- a study of the possibility that the nose gear steering was blocked by an external object.

1.16.1 Non-arming of ground spoilers by crew

During the visual approach, the PM omitted to arm the ground spoilers. In fact, they did not deploy immediately after touchdown even though the speedbrake and ground spoiler system were working. This latter point is confirmed by the following elements:

- the main landing gear nutcracker switches were functioning on the ground since the thrust reversers deployed;
- activated manually, the system's panels deployed. The mechanism was therefore not blocked;

- the red NO GND SPOILERS message did not illuminate on the screen on the cockpit centre panel. In fact if that had been the case, the crew would likely have deployed the speedbrakes more quickly[21].

In addition, the term *"ground spoilers"* is not heard on the CVR, in particular during the *"before landing"* checklist.

1.16.2 Aeroplane's deceleration on the runway

To carry out this study, the BEA developed a longitudinal model of the G-IV from data provided by Gulfstream[22]. This model was validated with the NTSB and Gulfstream by comparing the landing distances calculated using this model and those provided in the AFM.

The main forces involved in the deceleration of the aeroplane during landing are:

- the braking force exerted by the main landing gear wheels. This force depends in particular on the apparent weight (difference between the weight and lift) of the aeroplane;
- reverse thrust force;
- the aerodynamic drag force, which depends on the air speed and the aeroplane configuration, in particular the position of the ground spoilers.

The deceleration of the accident flight can be divided into two phases:

- a first phase corresponding to the first 10 seconds of the landing roll (between 365 metres and 1,050 metres from the threshold of runway 13), where it was relatively low (between 0.1 and 0.2 g);
- a second phase corresponding to the following 5 seconds (between 1,050 metres and the runway excursion), where it was higher (0.45 g).

This deceleration was compared to that of four of the other touchdowns by N823GA recorded on the FDR, in which the technique used was found to be similar to that of the accident until the first touchdown of the nose gear wheels.

The landings on the previous flights were performed on longer runways, with a slightly lower ground speed on touchdown. It is notable that during the initial phase of these landings relatively low braking pressure was applied, a likely sign of moderate deceleration, and the runway not being limited.

(21) During the event, the speedbrakes deployed 10 seconds after the wheels touched down (see figure 2).

(22) As of the date of the accident, Gulfstream had neither an aerodynamic model nor simulation means for the G-IV. These were constructed and validated by Flight Safety International (FSI) company based on data from test flights carried out by FSI as part of the development and certification of a crew training simulator.

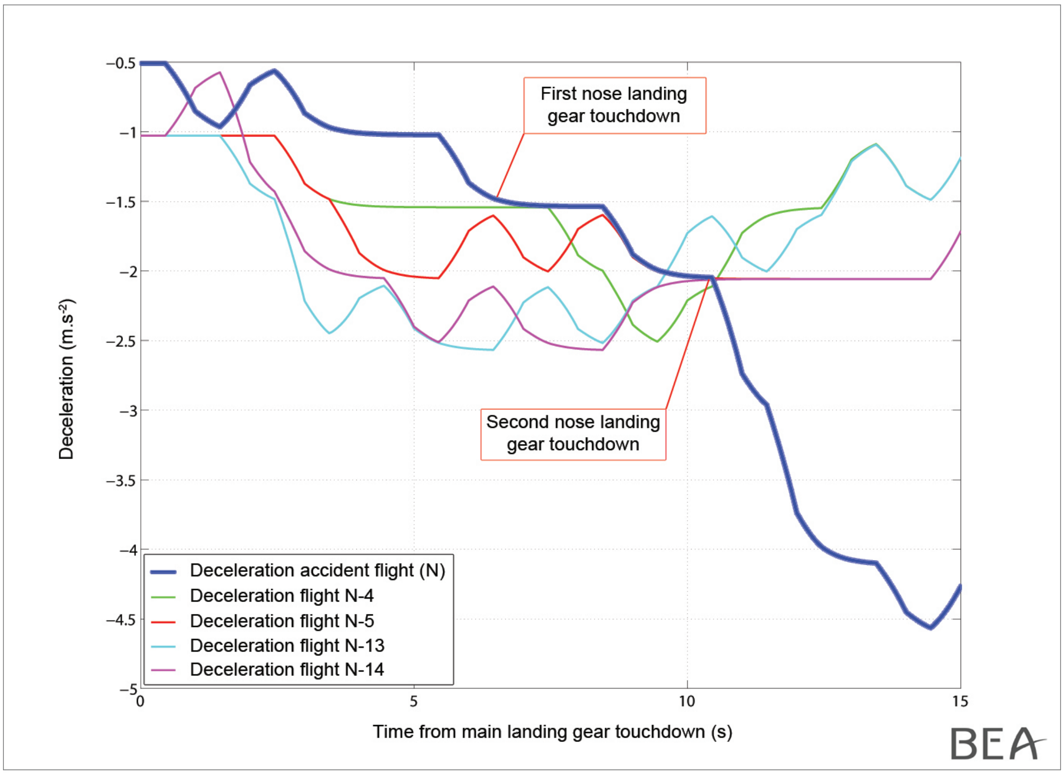


Figure 16: deceleration

Study of phase 1

In the absence of the deployment of the ground spoilers, the apparent weight remained low, which resulted in:

- inhibiting the extension of the thrust reversers due to the untimely loss of the on-ground condition;
- significantly reducing the effectiveness of the braking input[23].

During this first phase, the ground speed decreased by 22 kt.

Study of phase 2

The speedbrakes were manually extended up to 26° and the thrust reversers were deployed and were used at MAX REVERSE thrust. The increase in drag and reverse thrust forces which resulted, and the increase in the apparent weight, associated with an increase in the hydraulic pressure applied to the brakes, had the effect of increasing the aeroplane's deceleration. The retarding force exerted on the aeroplane rapidly increased, reaching values 5 to 6 times higher than that of the other landings. This increase was partly explained by that of the braking intensity that could be seen through increased braking pressures, but also by the aeroplane starting to skid and a possible orientation of the nose gear that created additional friction forces on the tyres of all three components of the landing gear.

[23] A strong braking input on a lightly loaded landing gear will trigger the anti-skid system. This may explain the slight increase in braking pressures even in the presence of significant braking input, because the pressure is measured downstream from the anti-skid system.

Figure 17: comparison of the apparent weight

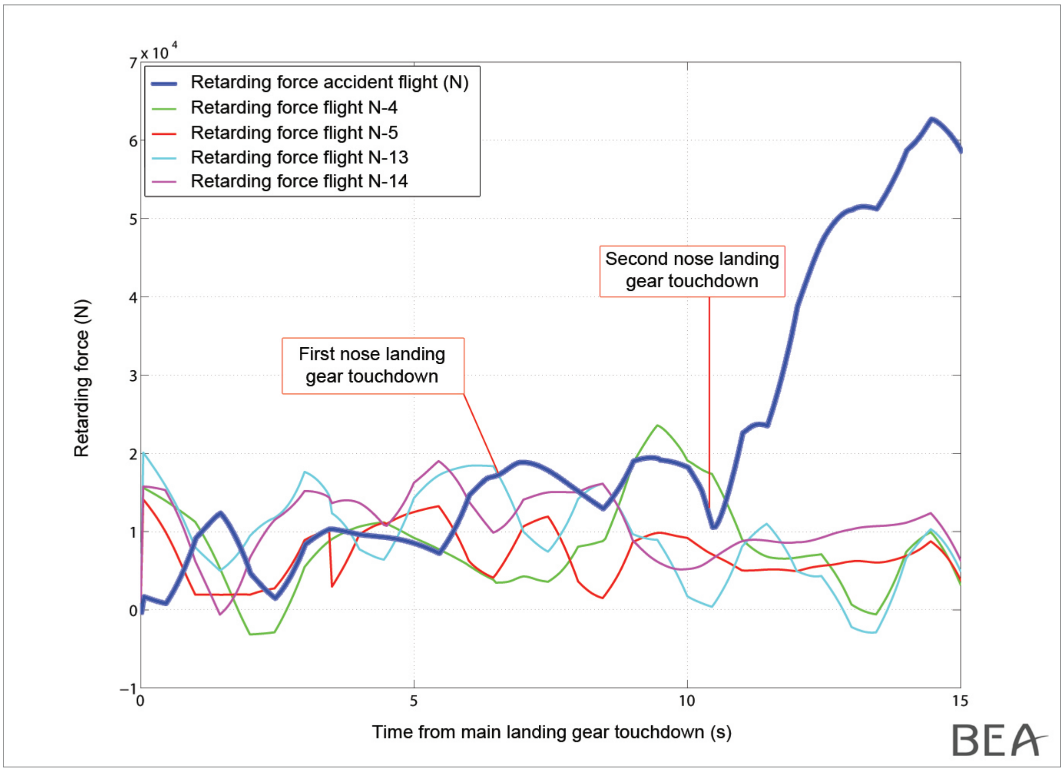


Figure 18: comparison of the retarding force[24]

During this second, relatively short (270 m) phase, the ground speed of the aeroplane decreased by 31 kt.

[24] The retarding force calculated takes into account all of the forces exerted on the main and nose landing gear. These forces come from the braking of the main landing gear wheels and by the nose gear wheel rolling, but also the forces generated by the aeroplane turning on all three sets of landing gear tyres.

A simulation showed that the aeroplane could have stopped on the runway after traveling a distance of about 400 metres after the second touchdown of the nose gear, in the absence of lateral deviation of the aeroplane with the nose gear not oriented, without skidding and making maximum use of the braking systems.

1.16.3 Estimation of vertical loads on the landing gear

Shortly after the accident, the hypothesis was advanced of a *"wheelbarrowing"* phenomenon, instability caused by the conjunction between a heavy load on the nose gear and a light load on the main landing gear. To test this hypothesis it was therefore necessary to determine the vertical forces exerted on the landing gear during the event. To do so, the model used for the study of the deceleration of the aeroplane (*see § 1.16.2*) was used and completed by integrating modelling of the landing gear by damped springs.

Calculations were also made on the landings on previous flights identified in *§ 1.16.2* for comparison purposes, given that these landings took place under normal conditions with particular regard to the loads exerted on the landing gear.

The results show that the vertical load on the nose landing gear at the first touchdown was of low value, lower than that observed on previous flights. On the second touchdown, the load reached the value of 85,000 N[25] (a value 3 times higher than the average value calculated for the other landings), close to the permissible nose gear limit load. Due to the precision of the calculations, it is nevertheless not possible to state that the limit load was not exceeded. This was followed by a rebound effect, a decompression of the nose gear characterized by a load 2 to 3 times lower than that of the other landings. The nose gear was then compressed again and the loads were similar to those of the other landings, in terms of their mean value, their amplitude and the frequency of the oscillations.

[25] The nose gear of the G-IV has been certified for a limit load of 98,000 N (ultimate load is 147,000 N).

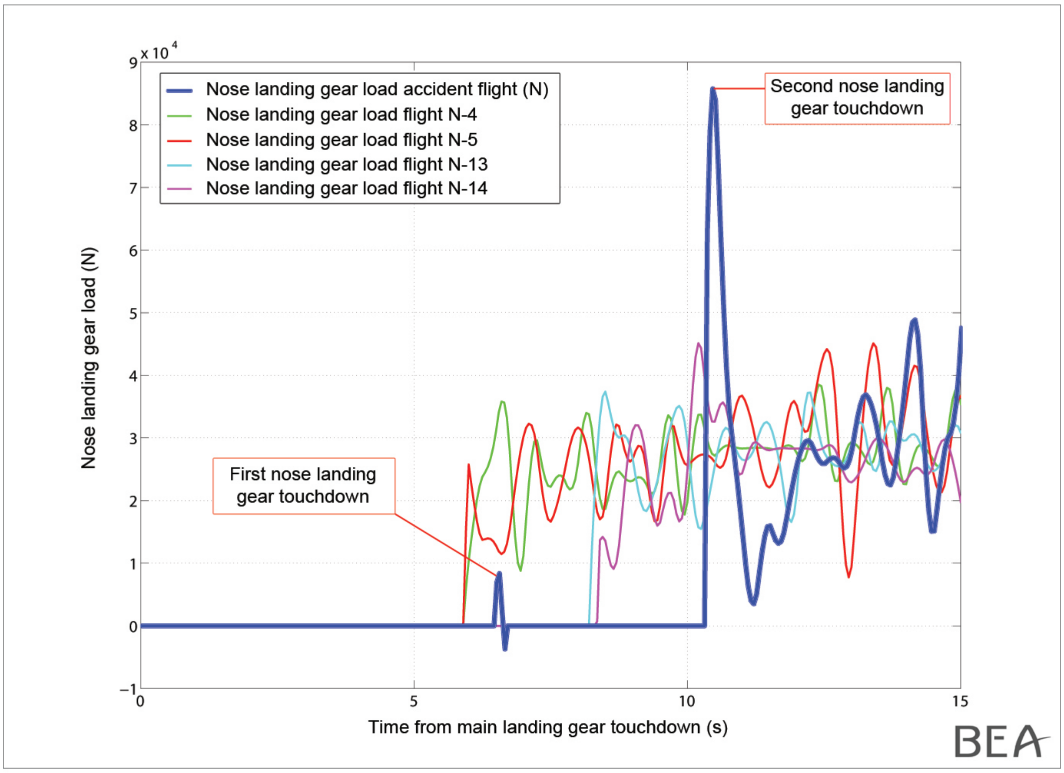


Figure 19: comparison of vertical loads on the nose gear

The calculated load on the main landing gear during the accident flight landing was about 2 to 3 times lower than for other landings during the first ten seconds of landing roll and then reached values similar to those of the other landings.

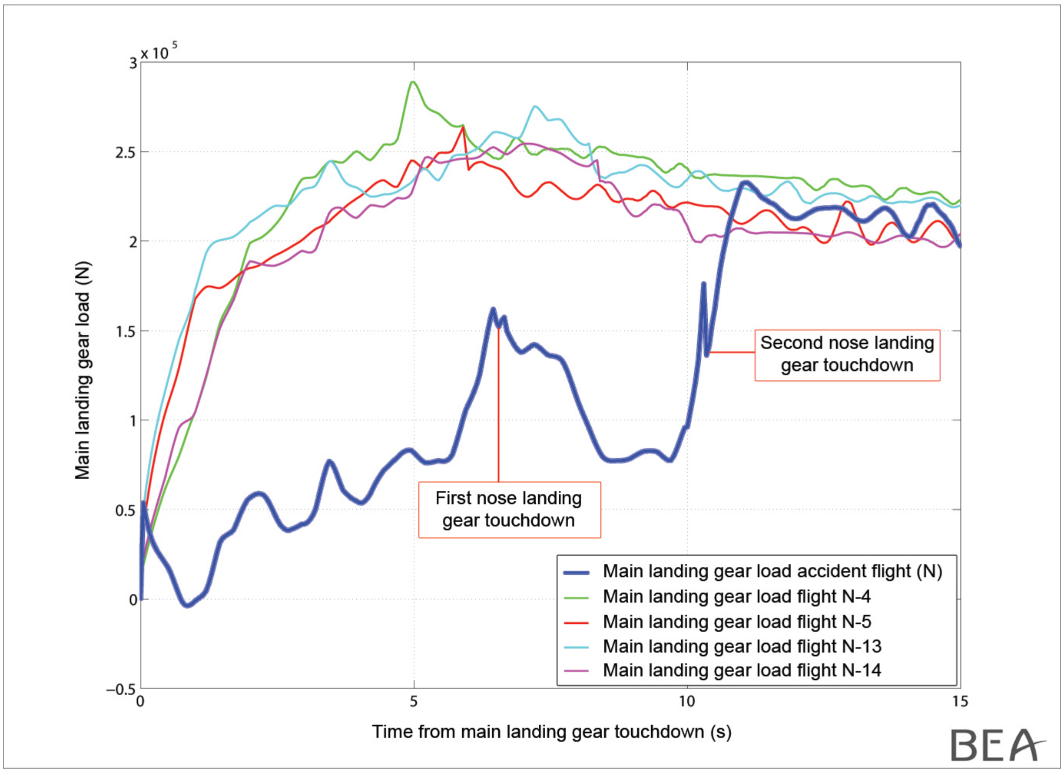


Figure 20: comparison of the vertical loads on the main landing gear

The various calculations and simulations carried out as part of this investigation, therefore, did not reveal high loads on the nose gear apart from the maximum value reached immediately after the second touchdown (*see figure 19*). The values of the loads calculated on the nose gear and the main landing gear during the accident aeroplane's landing were of the same order of magnitude as those calculated for previous landings. A *"wheelbarrowing"* phenomenon cannot therefore explain the aeroplane's lateral deviation to the left.

1.16.4 Study of the lateral deviation on the runway

In order to study the dynamics of the aeroplane on the runway and the various possibilities that might explain the lateral deviation to the left and the runway excursion, Gulfstream, the NTSB and BEA independently carried out several simulations of the aeroplane's trajectory.

The simulations carried out by Gulfstream failed to reproduce the trajectory of N823GA.

The NTSB used TruckSim[26] software to simulate and analyse the dynamic behaviour of heavy vehicles in contact with the ground. It contained many vehicle models that can be customized, allowing the NTSB to model the Gulfstream G-IV equipped with different types of tyres. The software also enabled application to the vehicle of known forces and moments at locations required by the user. The NTSB thus calculated the aerodynamic forces and moments exerted on N823GA and the thrust forces, based on the FDR parameters and data provided by Gulfstream, and declared them as input variables for TruckSim. As output, the software could calculate various parameters, in particular the trajectory of the aeroplane. The simulations were performed over a period of 4.75 seconds, between the time of the second touchdown of the nose landing gear and the time of the runway excursion. The results obtained show that only an orientation to the left of the nose landing gear wheels could reproduce the N823GA's trajectory. If they remained aligned with the aeroplane's axis, and even more so if oriented to the right, the simulated trajectory would lead to a runway excursion to the right because of the maximum deflection to the right of the rudder and therefore the predominance of the aerodynamic yaw moment. The NTSB also found that the results were not very sensitive to the aeroplane's centre of gravity, to landing gear loads, or to differential braking. Several solutions involving an orientation to the left of the wheels of the nose landing gear enabled N823GA's trajectory to be reproduced:

- solutions with a slight orientation to the left with angles ranging between 3° and 8° depending on the type of tyres used;
- solutions with a strong orientation to the left with angles of up to 50°. This is explained by the fact that beyond a slip angle of about 10°, the lateral force exerted on a tyre no longer increases and even tends to decrease.

The BEA completed the model used for the calculation of vertical loads on the landing gear (*see § 1.16.3*) integrating the lateral forces and related moments applying on the aeroplane. The aerodynamic forces and moments exerted on N823GA and the thrust forces were calculated on the basis of the FDR parameters and data provided by Gulfstream. The lateral forces exerted on the landing gear tyres were determined from the vertical loads calculated in *§ 1.16.3* and lateral friction coefficient estimated on the basis of the data measured during the G-IV tyre tests carried out at Le Castellet aerodrome (*see 1.16.7*). The results led to conclusions similar to those of the NTSB, namely:

- only an orientation to the left of the wheels of the nose landing gear was capable of reproducing the N823GA's trajectory using the vertical loads calculated in *§ 1.16.3*;
- there were multiple solutions involving an orientation to the left with low or high angles.

The BEA also studied the sensitivity of the results in relation to the vertical loads exerted on the landing gear. The calculations showed that it was possible to reproduce the N823GA's trajectory by orienting the wheels of the nose landing gear to the right by significantly reducing the loads on the main landing gear and equally increasing those applied to the nose gear. However, the load variations required exceeded the maximum estimated error for the calculations of vertical loads.

[26] The TruckSim software is developed by the American Mechanical Simulation Corporation and is used by many manufacturers and original equipment manufacturers of heavy vehicles worldwide. It is the result of research work carried out in the United States by the University of Michigan since the 60s to model and reproduce the behaviour of vehicles in contact with the ground.

These simulations show that only a situation consisting of an orientation to the left is consistent with the recorded parameters. Due to the uncertainties related to the inaccuracies of FDR parameters and the characteristics of the N823GA's tyres, it was not possible to determine from these simulations, if the wheels of the nose landing gear were slightly or strongly oriented to the left.

1.16.5 Braking efficiency of the aeroplane during sideslip

During the deviation to the left, the aeroplane's side-slip to the right gradually increased, reaching 8° at the time of the runway excursion. Side-slip has the effect of reducing braking efficiency.

Since the recovery manoeuvre foreseen by Gulfstream was based in particular on the efficiency of differential braking, the BEA asked Gulfstream to evaluate the effectiveness of differential braking in the case of G-IV side-slip.

Gulfstream said it no longer had the tools or software at its disposal needed to carry out this type of analysis.

1.16.6 Technical examinations of the nose gear steering system and of the braking system

Concerning the nose gear steering system, the potentiometers of the rudder pedals, the ECM, the torque links[27], both one-way restrictors of the hydraulic system and the position sensor of the steering unit (RVDT) were not found due to the fire-related damage. They were therefore not subject to technical reviews.

[27]Only the upper fasteners of the torque links were present on the nose gear.

The examinations undertaken on the other parts of this system did not reveal damage prior to the runway excursion. They indicate that when the aeroplane stopped:

- the tiller was in a neutral position;
- the PWR STEER switch was in the OFF position;
- the steering unit showed distortions that froze its position at an angle of between 7 and 9° to the left, probably as a result of an impact occurring after the runway excursion;
- The EHSV internal components were found to be in a position that would have commanded a nose gear right turning movement;
- the SOVs were found closed, which means that the hydraulic fluid was not circulating in the circuit; this is consistent with a positioning to OFF of the PWR STEER switch and with the loss of the on-ground condition after the rupture of the nose gear.

The examinations also showed that the bearings on the nose gear, although damaged, were not damaged prior to the runway excursion. On the steering unit, no sign of interference with landing gear tyres is visible.

Concerning the braking system, the hydraulic pressure management servo valves and the associated fuses[28] were examined:

- the servo valves were found in a position that allowed the hydraulic fluid to circulate towards the brakes;
- the fuses were found in a position that allowed the hydraulic fluid to circulate.

The brakes wear indicators were within permitted limits.

The tyres were too damaged by the fire to allow any observation of signs of braking or wheel lockup.

The other parts of the system (brake pedal displacement sensors, brake control computer) were not found due to the damage associated with the fire.

1.16.7 Study of tyre marks

Examination of the tyre marks left by N823GA on the runway revealed the presence of rectilinear striations oriented to the right, in the direction of movement of the aeroplane.

A document search revealed that studies had been conducted on car tyres in order to determine the orientation of the wheels from the striations observed on the marks left by the vehicle[29].

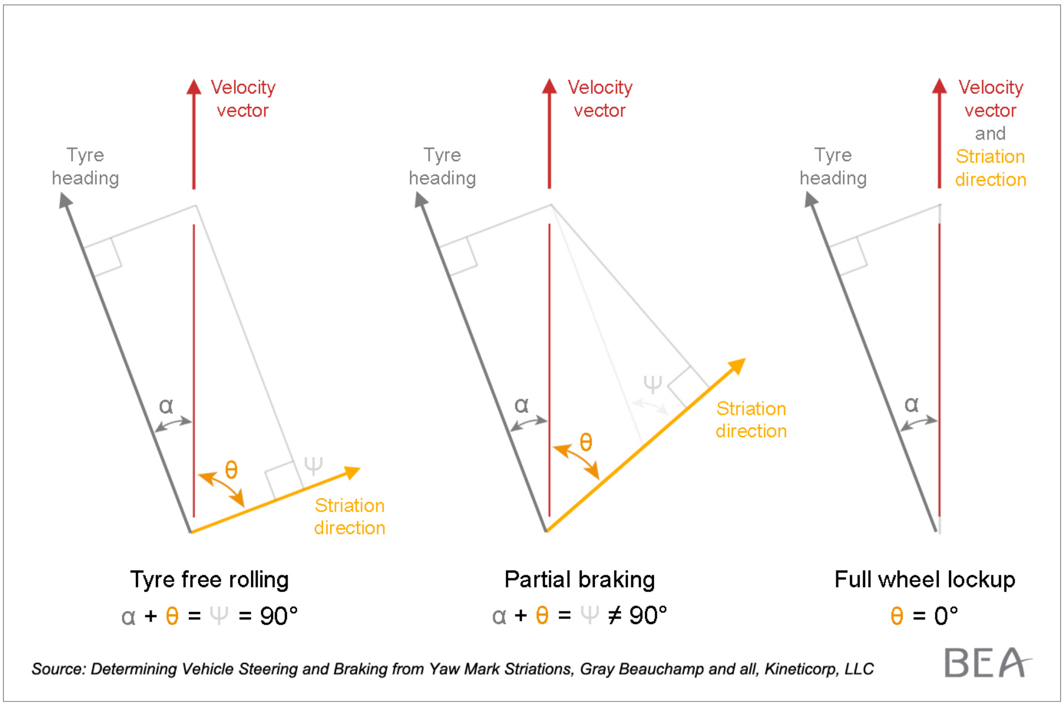


Figure 21: orientation of the striations for a braked wheel and an unbraked wheel, schematic diagram

The study includes tests that show that, for an unbraked wheel, the striations are substantially oriented at 90° in relation to the plane of the wheel (parallel to its rotation axis). Their orientation is close to the direction of movement of the wheel if it is partially braked.

The document search did not identify any study on aeroplane tyres, the tread patterns of which are different to those of car tyres, and it was decided to carry out runway tests with G-IV tyres in order to determine if the result of the studies on road vehicle tyres could be applied to aeroplane tyres.

[28]The function of the fuses is to cut off the hydraulic circuit in case of a leak detected between the servo valves and the brakes.

[29]Determining Vehicle Steering and Braking from Yaw Mark Striations, Gray Beauchamp et al, Kineticorp, LLC.

Tests were therefore carried out on the runway at Le Castellet, in conjunction with Cranfield University (UK), in the presence of the BEA and Gulfstream. A truck was modified to accommodate a metal frame at the back, on which a system of two symmetrically steerable wheels was installed. The test rig was used to generate tyre marks on the runway, for different wheel orientation angles, different loads and different ground speeds.

A detailed description of these tests is available in **appendix 5**.

Figure 22: pneumatic test rig (Cranfield University, UK)

The following points were noted during the tests:

- an orientation of the wheel to the left created striations oriented to the right and vice versa;
- the orientation of the striations was substantially perpendicular to the orientation of the wheel;
- it was not possible to visualize striations for wheel orientation values less than or equal to 10°.

The width of the marks increased with:

- an increase in the steering angle;
- an increase in the vertical load;
- a decrease in tyre inflation pressure.

The ground speed and the camber of the landing gear do not seem to have had a significant influence on the width of the marks in these tests.

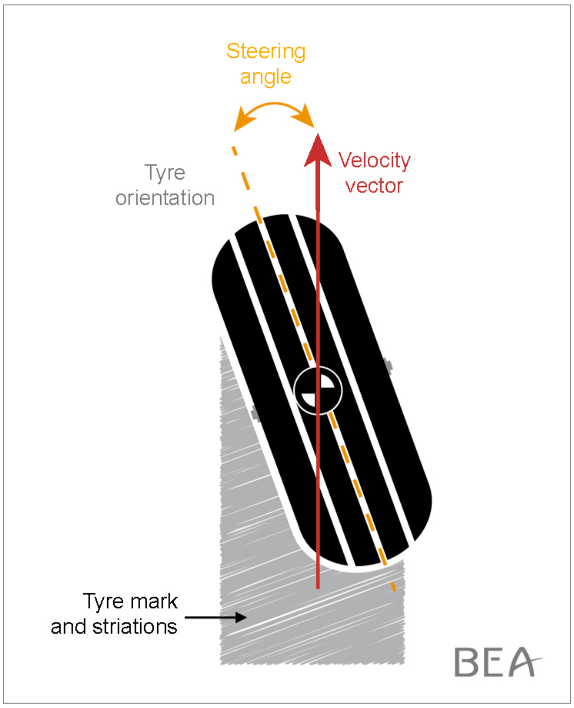


Figure 23: orientation of striations during tests, schematic diagram

Finally, a theoretical study of the striations generation principle was undertaken by the BEA. This study, based on the speed composition at the point of contact with the ground of a rotating wheel slipping sideways, confirms that a wheel oriented to the left of the flight path will generate striations to the right.

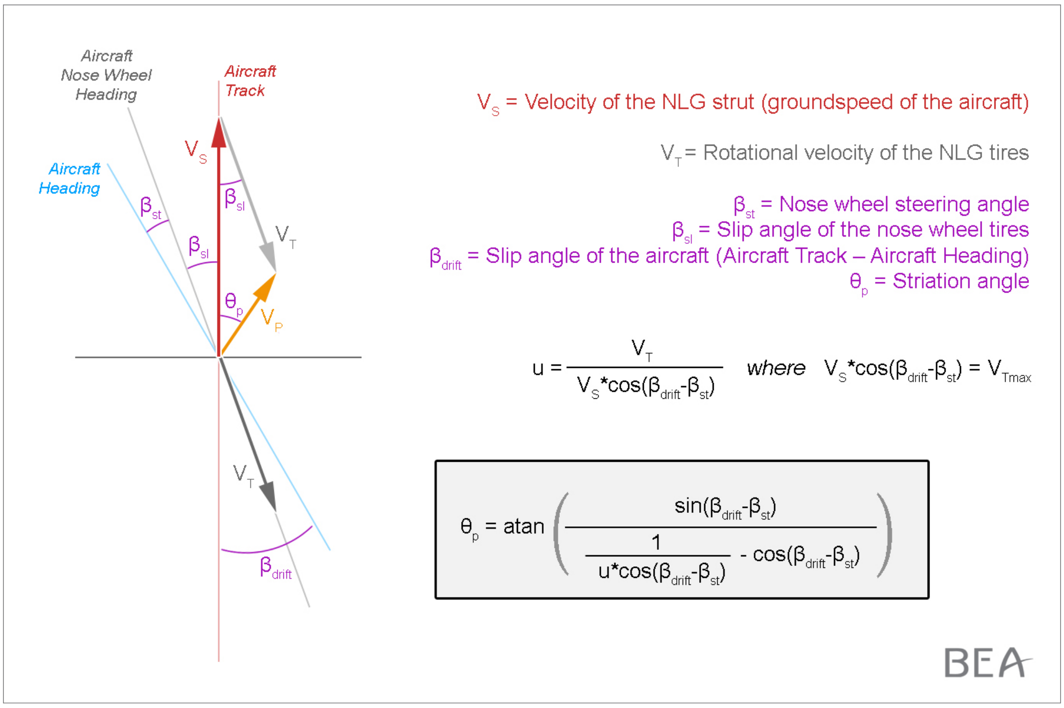


Figure 24: diagram of speed composition

The study takes into account different wheel rotation speeds, ranging from zero to the maximum theoretical value[30]. The theoretical calculations indicate that when the wheel rotates at a speed less than its maximum theoretical value, there are two wheel orientation solutions for a given striation angle value: a *''wide angle''* solution and a *''small angle''* solution (*see diagram below)*. When the speed of rotation of the wheels is close to the maximum theoretical value, the *''wide angle''* solution corresponds to a striation substantially perpendicular to the orientation of the wheel, which again is consistent with the result of the tests[31].

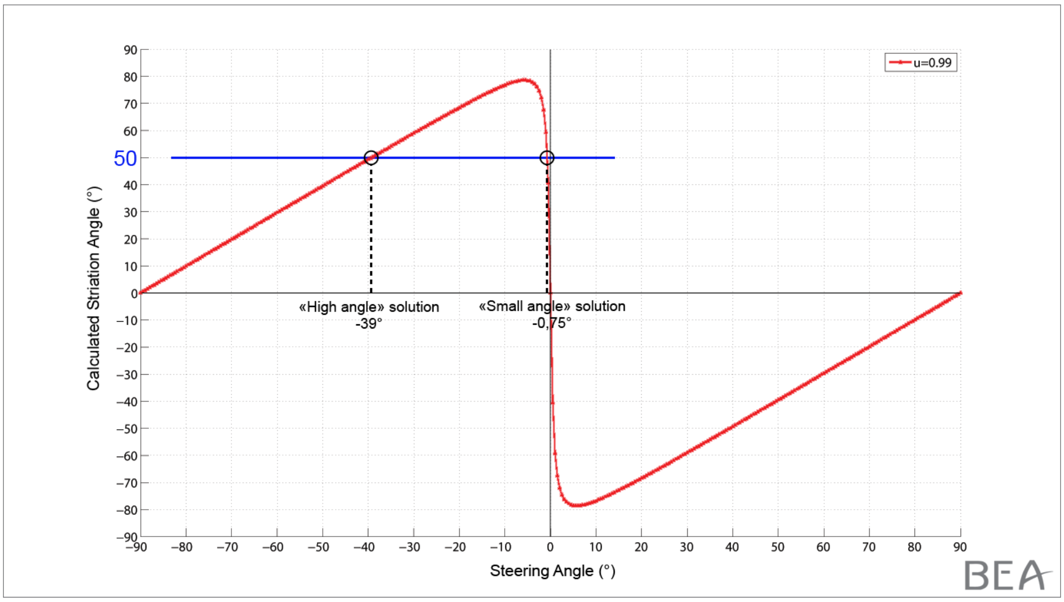


Figure 25: example of a striation angle value in relation to wheel orientation, for wheel rotation speeds close to their theoretical maximum value (u = 0.99)

The theoretical study of striations generation indicating, for the same striation angle, two possible orientations of the wheel (*''strongly''* and *''slightly''* oriented), the fact, in the case of the accident, that the aeroplane was skidding to the right leaves open the possibility that the landing gear was oriented to the right of the centre line of the aeroplane while being oriented to the left of the flight path (*small angle solution, see figure 25*).This solution was rejected because:

- the darkness of the marks of the nose gear, compared with those left by the main landing gear despite the latter being braked and more heavily loaded, cannot be explained by a slightly oriented, unbraked wheel;
- it was not demonstrated when tested at Le Castellet;
- the simulations showed that only an orientation to the left of the aeroplane axis allowed N823GA's trajectory to be reproduced.

(30)The maximum theoretical value of the rotational speed of the wheel is the projection of the forward speed of the aeroplane on the longitudinal axis of the wheel.

(31)The wheel rotation speed recordings during the tests showed that they were turning at the maximum theoretical value.

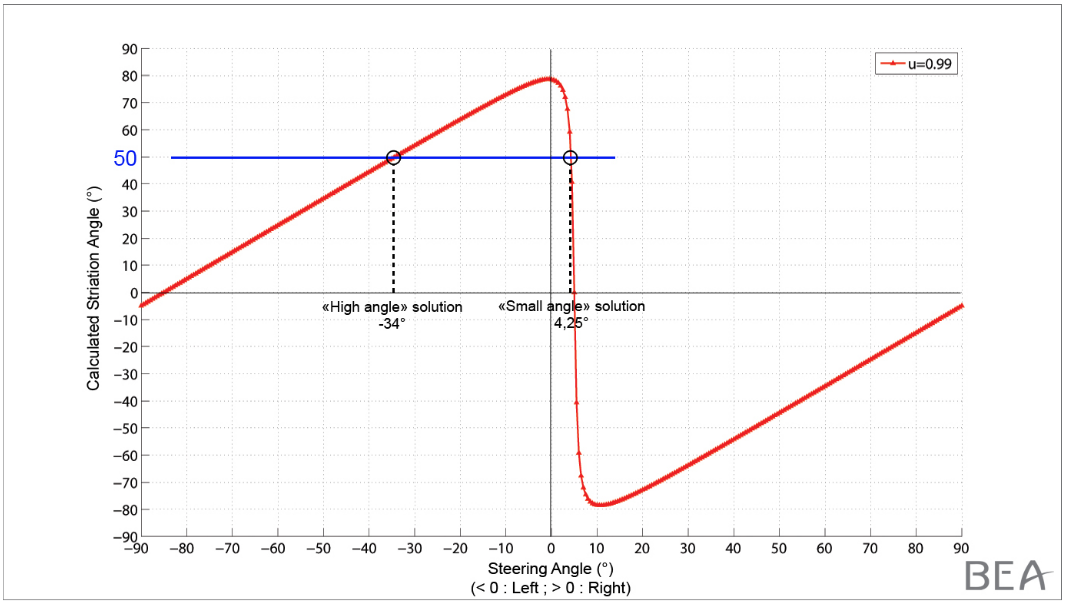


figure 26: example of a striation angle value in relation to wheel orientation,
for wheel rotation speeds close to their theoretical maximum value (u = 0.99) with a 5° right sideslip

The possibility of damage to the nose gear wheels causing them to be braked was considered, in particular because the first marks of the nose gear, after its second touchdown, preceded those of the main landing gear. Damage to the landing gear, in particular to the bearing system, could cause wheel braking and thus generate marks. It should be noted that:

- the technical examinations did not reveal any damage to the bearings or interaction between the tyres and the steering unit;
- the striations left by the nose gear left and right wheels, at a given location of the marks, are all oriented at the same angle. Damage causing braking of the wheels would probably generate different rotational speeds of the right and left wheels, since the two wheels are independent. Striations with different orientations on a given area would be present, but this was not observed.

This scenario was therefore discarded and the initial presence of marks was attributed to a slight skidding of the wheels under a heavy load.

Conclusion

The results of the tests with aeroplane tyres are consistent with those of the tests with the car tyres in the documentation review. There is no evidence of the physical existence of the *"small angle"* solution of the theoretical study.

This study shows that between the time of the second nose landing gear touchdown and the time of the runway excursion, the nose gear was strongly oriented to the left, generating marked marks and rectilinear striations.

1.16.8 Study of failure modes of the nose gear steering system

The results of the analysis of failure modes of the nose gear steering system carried out by Gulfstream at the time of certification of the aeroplane are contained in the document FAILURE MODE & EFFECTS ANALYSIS (FMEA)[32] G-IV STEERING SYSTEM referenced RM-GIV-054. It is based on documents produced by Dowty Canada Ltd., the manufacturer of the system, as well as the FMEA study of the Canadair *"Challenger"* CL-601 on which the same steering system is installed. The FMEA lists the failure modes of the system (per item of equipment), the effects of these failures, their criticality and the corrective actions to be taken by the crew.

[32]The FMEA is not a document systematically verified by the certification authorities.

As part of the investigation, the BEA studied this document. For all of the failures taken into consideration, ten effects are referenced in the document. Only the five listed below could create a lateral disturbance to the aeroplane, which could contribute to a runway excursion:

- 1.runaway steering when commanded;
- 2.steering command backlash;
- 3.loss of steering control in one direction (the nose gear cannot be returned to the centre line and rotates in only one direction);
- 4.steering inoperable, jammed nose wheel;
- 5.transient uncommanded motion, followed by steering inoperable, damped castoring nosewheel.

Effect No. 5 can be caused by a failure of the EHSV (rupture of the EHSV feedback LVDT (*see Figure 5*), an abnormal position of the slide valves in the servo valve or loss of electrical connection with the EHSV). This effect cannot have been encountered in the case of the accident because it would have generated an audible and visual warning message, which was not the case when the aeroplane was on the runway.

Effects 1 and 2 may also be ruled out: since the crew made a right input on the rudder pedals, the nose gear would have been oriented to the right despite these failures.

Effects 3 and 4 may have occurred during the accident because they do not generate a warning and involve a failure of parts that could not be examined as part of the investigation:

- effect no. 3 could be caused by a blockage of a one-way restrictor of the hydraulic system;
- effect no. 4 could be caused by:
  - jam or seizure of the feedback of the steering unit (feedback RVDT *see Figure 5*)
  - blocking of the tiller or an internal disconnection of its potentiometers.

However, these effects would have to be combined with a high amplitude left input on the steering by the crew to be consistent with the event.

Gulfstream also carried a new review of this document in the context of the investigation and determined that other failure modes specific to the G-IV were not listed in the FMEA.

Amongst them, two scenarios involving the feedback RVDT could create a lateral disturbance to the aeroplane consistent with the event:

- a disconnection and displacement of the feedback RVDT supplying a fixed value of the orientation position of the wheels. For example, if the RDVT sensor is disconnected and stuck in a position greater than 7° right, the wheels will be oriented to the left whatever the crew pedals input might be;
- a bias in the measurement of the position of the RVDT. For example a bias to the right leads to an orientation of the wheels to the left, with no input from the crew.

These scenarios do not trigger an alarm. They can be the consequence of abnormal circumstances such as excessive loading on the nose gear.

In the FMEA, the most serious consequence of these failures is classified as *''major''* within the definition for certification. Assessing the consequences of the failure modes present in the FMEA is based on the following assumptions:

- the large angles of orientation of the nose gear are only applied at low speed;
- at high speed only small orientation angles are applied to the nose gear. If a failure occurs it can be countered by input on the rudder pedals and differential braking.

In conclusion, on the basis of the information in the FMEA and that supplied by Gulfstream during the investigation, the most likely failure scenario, amongst those that may have occurred during the accident, is that of the feedback RVDT introducing an erroneous signal on the position of the nose gear. It is not possible to state, however, on the basis of the FMEA document provided and the further analysis by Gulfstream, that all the cases of system failure have been identified.

1.16.9 Study of a possible blockage of the tiller by an external object

A G-IV cockpit was inspected in order to assess whether a blockage of the tiller by an external object could occur.

A relatively strong force is required to turn the tiller as the return springs exert a significant force. It is possible to place a small object on the wheel (a Jeppesen binder for example) but the plane of the tiller is relatively horizontal and the object does not seem to exert a force sufficient to rotate it. The space is too small, especially in height, to place a larger object on it (such as a suitcase).

In conclusion, blockage of the tiller by an external object seems unlikely.

1.17 Information on Organisations and Management

1.17.1 The Operator UJT

Organization and Responsibilities

UJT holds air carrier operating certificate UJ8A869H issued by the FAA on 29 June 1999, authorizing it to transport freight and passengers on demand in accordance with 14 CFR Part 135 operating rules. Ten aircraft are registered in its fleet list, including 4 G-IIIs and 2 G-IVs. UJT has been operating G-IVs since 1 December 2008.

The flight safety department

The mission of the Flight safety department is to develop a safety culture within the airline. A Safety Management System (SMS) including a confidential system to report incidents was set up about two years before the accident. UJT does not carry out systematic analyses of its flights[33].

The information made available to the investigation team showed that the confidential incident report system is little used, if at all, by crews. The information issued by this service to crews brought to the attention of the investigation team concerned aeronautical information and not flight safety.

1.17.2 Regulatory context of the flight

UJT operating specifications included the ability to carry out positioning flights according to 14 CFR Part 91 operating rules (rules for General Aviation)[34] if these flights are not commercial in character.

The crew received the information from UJT that the flights of July 13 were to be carried out according to Part 135 operating rules.

Note: an American operator may continue to follow 14 CFR Part 135 operating rules on French territory.

On the flight plans filed for the day of 13 July, the flight type box indicated a *''G''*, corresponding to a flight operated as general aviation. This box should have indicated the letter *''N''*, corresponding to a non-scheduled air transport flight (occasional commercial flight).

1.17.3 Operating permit on French territory and SAFA inspections

UJT operating specifications included services to French territory as part its operations.

The order of 3 June 2008 on the authorization to operate air services by non-EU air carriers and on the operating permit for non-scheduled services by Community air carriers, stipulates in Article 6 that *''any foreign carrier files with the competent authority the operating program pursuant to Article 330-8-I of the Civil Aviation Code''*. This decree stipulates in Article 3 that *''the operating program for non-scheduled services is to be filed.......at least 2 days prior to their implementation''*. Services to aerodromes on French territory as part of passenger transportation for a fee is therefore subject to authorization from the DTA (Air Transport Directorate) of the DGAC. These permits require that a technical questionnaire be filled in beforehand, focusing on equipment, operational and maintenance issues concerning the aeroplane.

UJT had not sent any application for an operating permit for non-scheduled air services for the flights on 13 and 15 July 2012 made or planned to be made in French airspace. The last operating permit issued to UJT by the DGAC was dated July 2006.

[33] Part 135 regulations do not require operators to have an SMS, or a confidential system to report incidents or carry out systematic flight analyses.

[34] These rules only apply to US territory and § 91.703 provides that flights outside the US are conducted in accordance with ICAO Annex 2. A general aviation flight conducted on French territory must comply with the decree of 24 July 1991 on the conditions for the use of civil aircraft in general aviation.

UJT was inspected in France twice by the DSAC as part of SAFA inspections:

- the inspection carried out at Bergerac on 18 May 2010 noted several deviations including the absence of any application for an operating permit for non-scheduled air services, a MEL that had not been updated with the latest revisions of the manufacturer, the absence of any weight and balance documentation, and difficulty in quickly obtaining the results of this calculation by the crew. The deviations were reported to the Captain, the operator and the oversight authority (FAA);
- the inspection on 13 February 2012 carried out at Le Bourget noted several deviations that had only been notified to the Captain. It was operated as a general aviation flight, which does not require a flight clearance application.

The FAA is required to respond and follow up when it is notified of these deviations. It was not possible to know, from the FAA or the DSAC, whether the FAA responded to the inspection of 18 May 2010 or what was the content of the response.

1.17.4 Planning and preparation of the flight, landing distances

An IFR flight plan had been sent to the air navigation services. It provided for a take-off from Nice on 13 July at 12 h 30 and a 25-minute flight to Le Castellet operated as general aviation. No alternate aerodrome was indicated.

The flight dossier forwarded to the pilot contained weather information and the NOTAMs about the aerodromes of Toulon-Hyères and Marseille-Provence. It contained fuel consumption calculations, the METARs and TAFs for the aerodromes of Nice, Toulon and Marseille[35]. The crew was informed on July 12, the day before the accident, that they had to positioning the aeroplane at Le Castellet after dropping off the passengers at Nice.

[35]There is no METAR or TAF available on Le Castellet aerodrome.

UJT requests crews reassess flight landing distances for each flight operated under Part 135. The CVR recording indicates that the crew found out in flight the runway lengths of Le Castellet aerodrome and indicated they were *"short"*. Landing distances were not calculated before or during the flight.

The runway lengths required for the weight of the accident flight, depending on the type of operation, are given in the table:

	General aviation heavy aeroplane foreign operator (no increase in runway length)	Part 135 case of flight (80%)[36]	Air transport (60%)[37]
Runway length required	900 m	1,125 m	1,500 m
Runway length required with 10kt tailwind	1,030 m	1,285 m	1,715 m

[36]The landing distance must be less than 80% of the length of runway available.

[37]The landing distance must be less than 60% of the length of runway available.

At the maximum landing weight, the length of runway necessary under the conditions of the day, with no wind and for operation of the aeroplane under Part 135 was 1,255 metres (reminder: the LDA on runway 13 was 1,705 m).

1.17.5 Operating procedures for crews

The following paragraphs are based on:

- the AFM produced by Gulfstream, as revised on 5 October 2011;
- the QRH produced by Gulfstream, as revised on 5 October 2011;
- the AOM produced by Gulfstream, as revised on 10 July 2010;
- the GOM, UJT Operations Manual, as revised 8 January 2011;
- the Cockpit Reference Handbook (CRH) training manual, produced by CAE Simuflite, as revised in August 2010;
- the IPTM training manual, produced by CAE Simuflite, as revised in August 2010.

1.17.5.1 Allocation of seats

At UJT, flights on G-IVs can be piloted either from the right or left seat. The Captain is usually in the left seat and co-pilot in the right seat.

According to the testimony from airline managers, Captains are generally PF for passenger flights and PM for flights without passengers. The GOM does not mention this information.

1.17.5.2 Carrying out checklists

The GOM states that checklists must be carried out using a *''Challenge and Response»''*procedure:

- the PF requests the checklist; the PM reads each item aloud and the PF checks it and then orally confirms it. The PM completes the checklist by calling out *''xx checklist is complete''*. If the PF forgets to request a checklist, the PM must suggest it to the PF;
- the GOM states that crew members must use the checklists in order to verify the actions they have previously made. The CRH of CAE Simuflite recalls this philosophy: use normal checklists as *''done lists''* instead of *''do lists''*.

The airline's managers explained that the PF's check of the PM's actions is not systematic because the PF is concentrated on flying the aeroplane (in particular during the final approach).

Videos of flights made before the accident by UJT G-IV pilots were made available to the investigation team. They show that the checklists are carried out from memory without any check and oral confirmation by the other crew member.

Note: on the G-IV, the crew can display checklists on the EICAS (electronic checklists). The lines are displayed in blue and change to green as they are read using the flip-flop switch located on the pilot's cap. The operator indicated that the pilots used paper checklists.

1.17.5.3 Actions and "before landing" checklist

Before landing, the PM extends the landing gear at the request of the PF and calls out illumination of the associated green lights. The PM then checks the messages on the CAS. S/he then tests there is no problem with the landing gear pressure sensor (*''nutcracker test''*) before arming the ground spoilers. At the request of the PF, s/he also configures the flaps. The last actions consist in setting the WARN INHIBIT switch to ON and, if necessary, selecting the L/R AIR START IGN switch.

When these actions have been performed, the PF asks the PM for the following *"before landing"* checklist:

BEFORE LANDING	
Landing Gear	DOWN / 3 GREEN
Crew Alerting System	CHECK
Nutcracker	TEST
GND SPLR Switch	ARMED
Flaps	SET FOR LANDING
WARN INHIBIT Switch	INHIBIT
Air Start Ignition	AS REQ'D

It includes - among other things - checking the EICAS and the arming of the ground spoilers, which was not performed by the crew during the accident flight.

At UJT, selecting the landing flaps is performed after the *''before landing''* checklist.

Normal procedures also provide, when the crew has the runway in sight, that the PF calls out *''Landing Assured''* and that the PM checks the speed, vertical speed, landing gear and flaps and then calls out *''final gear and flaps recheck, ''before landing" check list complete"*. This final check of certain items, including the configuration of the aeroplane just before landing, contains no check that the ground spoilers have been armed.

1.17.5.4 Sequence of actions and call-outs on landing

The AOM indicates:

- The runway threshold is crossed at Vref. The thrust levers must be left in the IDLE position after the touchdown of the main landing gear. The PF must gradually lower the wheels of the nose landing gear to the ground, and if needed brake and use the thrust reversers. The PM must confirm the deployment of the ground spoilers. If they are not deployed, the PM calls out *''No ground spoilers''* and verifies that the PF activates the speedbrake lever. When the speed approaches 70 kt, the PF starts to decrease the reverse thrust to reach the *''idle''* position at 60 kt.

The manual states that the rudder and the rudder pedals are the primary means for steering the aeroplane during landing roll. When the speed decreases, the pilot[39] can steer the aeroplane on the ground using the tiller, while the co-pilot keeps the wings level using the control column.

The SOPs included in the IPTM indicate:

- On landing, on deployment of the thrust reversers, the PM must call out in succession *''four lights, six lights''* in response to the illumination of the lights indicating that the thrust reversers have been respectively armed and unlocked, and then deployed. The SOPs contain no call-out concerning the ground spoilers.

(38) As per Gulfstream Aircraft Operating Manual, Section 06-05-10 page 1107/1922.

(39) The manual uses the terms PF and PNF (PM) for this transitional phase, which in practice is not possible if the PF is in the right seat.

1.17.5.5 Uncommanded nose wheel steering

An abnormal procedure present in the AFM and the AOM describes the actions to take in the case of uncommanded action of the nose wheel steering system. It consists in:

- ❒ 1.using the rudder and differential braking to control and correct the flight path;
- ❒ 2.positioning the PWR STEER switch to OFF in order to disable the steering system.

This procedure, which was added by Gulfstream to the AFM and AOM as a result of the accident in Eagle (Colorado, USA) in 2004 (*see Section 1.18.1*), is not included in the rest of the operational documentation: the QRH (published by the manufacturer, which includes all the abnormal procedures in the AFM), the CRH or the IPTM.

Information to operators - Maintenance and Operations Letter (MOL)

Following the accident in Eagle, Gulfstream had sent a letter[40] dated December 14, 2004 to all G-IV operators to draw their attention to the fact that control problems of the steering system may arise during landing and be undetectable or undetected until they have occurred. The letter introduces the new *"Uncommanded Nose Wheel Steering"* procedure (described above). It states that it will be introduced in the next update of the AFM and indicates that the vigilance of crews must be increased so that they can react appropriately in case of an occurrence of this event: they must be able to apply full deflection of the rudder pedals and maximum input on the brake pedal. Gulfstream draws their attention to the adjustment of the seats and the position of the feet when landing.

[40]Maintenance and Operations Letter ref. G-IV-MOL-04-0029, see appendix 7.

This letter was not sent to all training organizations, in particular CAE Simuflite[41]. UJT indicated they were not aware of this letter.

[41]Gulfstream have indicated that MOLs have been systematically sent to the FSI training organization since 2007. MOLs have been systematically sent to CAE Simuflite since September 2012.

The changes to the G-IV AFM are subject to the approval of an FAA department (ACO), based in Atlanta. This department consults another FAA department (AEG), which assesses the changes to the AFM and provides recommendations to the ACO for their approval. At the time of its introduction, the *"Uncommanded Nose Wheel Steering"* procedure had been approved without review by the AEG.

1.17.6 Certification items related to information on the position of the spoilers

Section 25-699 (Amendment 25-23 of May 8, 1970) of the FAR Part 25 certification regulation stipulates that there must be means to indicate to the pilot the position of the lift and/or drag augmentation devices when they receive a specific command to adjust their position.

The BEA asked the FAA and EASA if the ground spoilers were included in this requirement.

According to the FAA, the ground spoilers are not considered to receive a specific command allowing their position to be adjusted (they can only have two values, extended and retracted), and are therefore not concerned by this article.

EASA did not comment on this issue, stating that the FAA was the primary certification authority.

The G-IV is not directly equipped with a position indicator for the ground spoilers. However, it is possible to infer the position of the ground spoilers by cross-checking several indications present in the cockpit:

- presence of the blue GND SPLOILER UNARM message on the EICAS, indicating that they are not armed;
- arm button for ground spoilers displaying the ARMED message in blue;
- on the ground, no *"red"* message NO GND SPLRS on the central capsule if the ground spoilers are armed.

1.17.7 Training

General framework

The Part 135 regulation defines the content of instruction and training programmes for crews and requests operators establish and maintain them. It provides the possibility to subcontract the development of the programme, crew training, instruction and tests to a certified Part 142 training school**(42)**. CAE Simuflite carries out the training and instruction of crews on behalf of UJT according to a programme that was established by UJT and approved by the FAA**(43)** in 2008.

CAE Simuflite has developed, within this framework and on the basis of the AFM and the AOM and recommendations provided by Gulfstream, standard operating procedures (SOPs) and provided UJT with the documentation corresponding to the training in question (IPTM, CRH). However, during periodic inspections and trainings, the documentation used is the QRH.

Training on G-IV

Training requirements for the type rating are established by the FAA (AEG). The result of this assessment is summarized in a document called the *"FSB Report"***(44)** and is then used to develop the initial training programme and periodic training sessions, in addition to the training requirements related to the Part 135 regulations. This document also serves as the basis for FAA inspectors during their approval process of the operators' training programmes.

On the date of the accident, the FAA had not established an FSB report for the G-IV**(45)**.The FSB report published in August 2013 did not provide for the completion of specific training in the abnormal procedure of uncommanded nose wheel steering.

The Gulfstream G-IV type rating followed by the two crew members was of the INH-A type (Initial New Hire) which is designed for G-IV pilots with no experience. It included 77 hours of theoretical classes and 28 hours on a flight simulator.

Training on the Uncommanded Nose Wheel Steering abnormal procedure

The UJT training programme provides training on normal, abnormal and emergency procedures. Since the *"Uncommanded Nose Wheel Steering"* abnormal procedure was not one of the procedures listed in the operational documentation used during initial training and theoretical training sessions (CRH, IPTM and QRH), its instruction and associated training were not carried out by CAE Simuflite. The crew of N823GA, therefore, had not been trained on this procedure, or how to handle, during the flight, the PWR STEER switch, the use of which depends on the seat (right or left) used, it being only accessible from the left seat.

(42) Regulation applicable to training centres.

(43) The programme was approved by a POI of the FAA. In this context, in particular the POI must assess the training requirements in terms of training for tasks in which their performance depends on the space used (left or right seat). The POI has indicated that the programme was an exact copy of a programme approved several years ago by a national service of the FAA. For this reason he did not conduct a full review of the programme.

(44) Flight Standardization Board.

(45) The FAA has indicated that the document was produced in 2013 to supplement the Operational Suitability Reports previously established for the G-IV. The report of the FSB was not a document required by US regulations at the time of the accident.

Training for tasks depending on the seat used

The UJT training program that contains in-flight training on procedures for the left and right seats does not mention the existence of specific instruction on tasks depending on the seat used.

It is the responsibility of the operator to assess, with the help of the FAA, the tasks that depend on the seat occupied and to suggest an associated training programme. The POI of the FAA must assess on a case-by-case basis any proposals by the operator and the parts of the training programme for these tasks before his/her approval.

UJT had not made any proposal in this respect and the manipulation of the PWR STEER switch had not been identified as depending on the seat used in abnormal AFM procedures and in the training programme. The FSB report contained no specific training requirement for tasks depending on the seat used.

1.17.8 Documentation update

At Gulfstream: the AFM and AOM were the only documents containing the update including the addition of the *"Uncommanded Nose Wheel Steering"* procedure. It was not present in the QRH. This update of the AFM had not been made mandatory by the FAA through the issuance of an Airworthiness Directive although it is designed to correct an unsafe condition detected after an accident.

At CAE Simuflite: the abnormal procedures are included in the IPTM. This manual does not contain the *"Uncommanded Nose Wheel Steering"* procedure. The IPTM was provided by CAE Simuflite to UJT at the beginning of the training of their G-IV pilots. The IPTM and CRH cite the *"Simuflite Operating Handbook"* as a reference document listing the abnormal procedures. This document is no longer updated or used.

A complete review of the AFM, the QRH and the training manuals is carried out by the FAA during the initial certification of the operator. There is no detailed review of this literature in subsequent audits. In the event of a modification of the AFM by the manufacturer occurring after the initial certification of the operator, the latter is notified but the FAA inspector responsible for monitoring the operator is not.

1.17.9 FAA monitoring actions

Monitoring of UJT operations is performed by a POI from the FAA. Eight audits were carried out in various areas by the FAA in the six months before the accident. All were deemed *"satisfactory"*, with the exception of an inspection carried out on the ground in which a mass and balance document was absent. The last two in-flight audits were carried out by a POI on 28 February 2012.

1.17.10 Organization of the RFFS Service

The decree of 18 January 2007, consolidated version dated 19 December 2009, defines the technical standards for the Aircraft Rescue and Firefighting Service (RFFS) on aerodromes and aeroplane classes according to their dimension[46], the level of protection and the amount of principal and complementary extinguishing agent required to ensure it. It also defines the training for aerodrome fire-fighters. The RFFS is approved by the Prefect. The DSAC, by delegation from the Prefect, issues personnel accreditations and conducts oversight audits every two years[47].

[46]The G-IV is Class 5 or Class 3 for positioning flights.

[47]The latest audit of the RFFS for Le Castellet was carried out by the DSAC SE on 13 October 2011.

The aerodrome operator had an Aerodrome Internal Contingency Plan (AICP) and a compendium of operational instructions from the RFFS. The documents contained all the procedures applicable to the RFFS. They were last updated in 2006.

1.17.10.1 Protection level of Le Castellet aerodrome

Le Castellet RFFS constantly had Level 1 protection. This level can be increased to 5 on prior request[48]. Level 5 is ensured by the presence of two fire-fighters and a special response vehicle for fighting aircraft fires on aerodromes[49]. The regulation does not set a deadline for the transition from Level 1 to Level 5. The operations manual of the aerodrome at Le Castellet, however, provides for a notice period of three hours.

(48)Since 12 April 2014, Le Castellet aerodrome has permanently ensured level-5 protection.

(49)Vehicle of the VIM 60 type.

The ground handling agent that managed the flight of N823GA had requested level 5 protection, which was accepted by the aerodrome operator more than three hours before the arrival of N823GA. The RFFS had been informed.

When N823GA arrived, only one fire-fighter was present on the aerodrome. The second fire-fighter, scheduled to ensure level 5 protection, arrived late. The AFIS officer was not informed of the absence of the second fire-fighter and therefore of the impossibility of the RFFS service to ensure level 5 protection.

1.17.10.2 Resources and organization of the RFFS service at Le Castellet aerodrome

The RFFS at Le Castellet has a staff of four officers with aerodrome fire-fighter certification. These officers may perform other functions in parallel: refuelling agent, ramp agent, ground handling agent, etc. The conditions for exercising these activities are described in *§ 1.17.10.4* below.

The RFFS has a response vehicle and a non-aeronautical vehicle[50].

(50)Vehicle of the *"one tonne tank/ pump truck"* type.

1.17.10.3 Aerodrome Area

The aerodrome area is defined as the area including the state-owned parts of the aerodrome and the final approach areas up to a distance of 1,200 metres or less from the runway threshold. The functions outsourced to the RFFS are carried out in the aerodrome area. That of Le Castellet aerodrome includes the racing circuit adjacent to the aerodrome, a major road to the south and a go-kart track located to the east (see the map of the aerodrome area provided in **appendix 6**).

This map does not show the exits and routes to be used by the crash and fire-fighting facilities as required by the regulations.

The RFFS service had the keys to most of the gates located inside the aerodrome area. However, it did not have the keys to some of the gates recently installed and located inside it. In particular this was the case of the gate situated outside of the aerodrome fence but within the aerodrome area, in front of which the vehicle stopped during the second intervention.

1.17.10.4 Management of other activities by personnel

The decree of 18 January 2007 states that on aerodromes with a protection level below 6 (the case of the Le Castellet aerodrome), personnel may undertake separately or simultaneously an activity other than that relating to the aircraft rescue and firefighting service when the aerodrome operating instructions define the terms of the activity's compatibility with respect to the personnel's operational objective[51].

The RCO (Operational Procedures Manual) of the RFFS deals with the implementation of these other activities when fire-fighters are on duty. The version of the RCO provided immediately after the accident indicated that the aerodrome fire-fighters must:

- ❒ wear fire-fighting clothing and remain within the limits of aerodrome area;
- ❒ be in permanent bilateral connection with the tower;
- ❒ have a fire-fighting vehicle in operational condition and fully equipped, and remain in its immediate vicinity;
- ❒ be able to abandon tasks in progress without any delay;
- ❒ be able to board the fire engine, prepare for an intervention and apply the procedures in the case of a standby, alert or accident.

In a version modified after the accident, it was added that:

- ❒ *''during the refuelling of an aeroplane or helicopter:*
  1.The foam response vehicle must be at its location
  2.Fire-fighting clothing must be in the truck
  3.Fire-fighters must carry no phones
  4.The UHF radio station must be flameproof
  5.A light goods vehicle must be at their disposal to quickly rally the location of the foam response vehicle
  6.Clothing must be appropriate for refuelling

In the event of an accident, the officers must immediately stop performing their tasks and apply the accident intervention procedure''.

The Aerodrome Internal Contingency Plan (AICP) indicates that:

- ❒ to the extent possible, the AFIS officer must report the arrival of all commercial aeroplanes with more than 10 seats as of the first contact with the crew (five minutes before landing) to the RFFS;
- ❒ for a period of 30 minutes before the scheduled landing, and up to 15 minutes after engine shutdown, RFFS personnel must remain within the immediate vicinity of the fire-fighting equipment with the response vehicle and be ready to intervene.

Note: the order of 18 January 2007 indicates that the correctly constituted duty crew must be available for a landing at least 10 minutes before it takes place and up to 15 minutes after engine shutdown.

[51]The operational objective of the RFFS is to be able to reach, under optimal driving conditions for vehicles (visibility, road surface condition), each end of the runway and be able to continuously project:
- within 3 minutes after the alert is given, a foam rate equal to at least 50% of the rate provided in appendix 1 for at least 1 minute;
- no later than 4 minutes after the alert is given, the total quantity of fire extinguishing agents provided in appendix 1.

1.18 Additional Information

1.18.1 Previous events

Events involving losses of directional control on Gulfstream G-IVs have been identified and studied. Some have resulted from a malfunction of the nose gear steering system. One event is linked to an omission to arm the ground spoilers.

Event on 1 March 2002 at the Anchorage airport (Alaska, USA) (source ASRS)

On landing, upon contact of the nose gear with the runway, the aeroplane sharply deviated to the right. The crew tried to counter the deviation by an input on the rudder pedals and on the tiller, by differential braking and asymmetric control of the thrust reversers. They stated they were able to regain control of the aeroplane by applying differential braking. They noted that a STEER BY WIRE FAIL warning was present on the EICAS. The crew managed to stop the aeroplane on the runway.

Since the incident was not investigated, the cause was not identified.

Event on 29 November 2004 in Eagle (Colorado, USA) (source NTSB)

Shortly after the touchdown of the nose gear, the aeroplane deviated to the right in an uncommanded manner. The PF applied a full input on the rudder pedals, to no effect. He stated that he turned the tiller to the left and braked sharply left (differential braking with a pressure difference of 200 psi recorded by the FDR). These inputs initially allowed him to counter the deviation to the right and return the aeroplane parallel to the runway centre line. The right main landing gear, however, entered into contact with snow on the edge of runway, which caused the runway excursion to the right.

A STEER BY WIRE FAIL warning was generated about two seconds after the start of the deviation, thereby disconnecting the nose gear steering system. The investigation determined that contamination by a foreign object inside the EHSV had enabled the presence of water, which, at cold temperatures had frozen and caused a blockage of the EHSV, generating an uncommanded movement of the nose gear to the right.

This event led Gulfstream to add the Uncommanded Nose Wheel Steering procedure to the AFM and AOM and send a letter to G-IV operators (see above *§1.17.5.5* and **appendix 7**).

Event on 1 August 2008 at the aerodrome of Haikou (China) - Non deployment of ground spoilers (source Gulfstream)

After the touchdown of the main landing gear on a wet runway, the ground spoilers, which had not been armed by the crew, did not deploy automatically. The crew applied a strong input on the right rudder pedal while the aeroplane was slightly to the left of the runway centre line. When the nose gear touched down, the aeroplane deviated to the right. The crew applied a strong input on the left rudder pedal for about three seconds. The aeroplane started back to the left. The crew once again applied an input on the right rudder pedal and then a nose-down input. The aeroplane continued its movement to the left and stopped after making a complete half-turn.

The crew indicated they had not braked during the landing roll and attempted to regain control of the aeroplane by turning the tiller to the right.

Summary of previous events

Several points emerge from the study of previous events:

- although it was not indicated in the procedures, the crews used the tiller to try to regain control of the aeroplane;
- one event led to a runway excursion despite the automatic disconnection of the steering system.

1.18.2 Interviews

Interviews concerning the Captain

Several UJT pilots who flew with the Captain said he was not accustomed to short flights. They also agreed in stating that he was not comfortable with handling the FMS, carrying out checklists and in his role as PM in general. He had a strong personality and sometimes imposed his decisions. Two co-pilots who flew with him reported that he had already forgotten to arm the ground spoilers. One of them said that during a landing, the Captain, although PM during the flight, had pushed the controls during the landing roll so that *"the directional control was more effective"*.

Interviews concerning the co-pilot

The co-pilot was considered to be rigorous, particularly with respect to compliance with procedures. He was rather quiet.

Interviews with CAE Simuflite instructors

Two CAE Simuflite instructors indicated that the checklists were taught in *"challenge and response"* mode. There is no scenario for the simulator in which the manipulation of the PWR STEER switch is included. They did not recall a pilot handling the switch during a flight or training.

One of them said that the pilot in the left seat always had to have a hand on the tiller while the aeroplane was on the ground, in order to respond quickly in the event of an uncommanded manoeuvre of the steering system for the nose gear (the tiller is more effective than the rudder). The other said the pilot in the left seat did not have to have a hand on the tiller during landing before the speed reached 60 to 80 kt.

Interview with two G-IV Captains

Two G-IV Captains made the following remarks:

- in case of loss of directional control on the ground during landing, they indicated that they would have:
  - 1. made inputs on the tiller;
  - 2. made inputs on the rudder pedals;
  - 3. applied differential braking.

Note: they did not mention any action on the PWR STEER switch.

- in case of omission to arm the ground spoilers, they would have made inputs on the ground on the speedbrake control.

Interviews with the POI

The POI who performed the literature review at the beginning of the operation of G-IVs at UJT said the training programme was a copy of an older programme, previously approved by the FAA. He had not found it necessary to study that of the UJT in detail.

The UJT POI said he had taken up this duties at UJT three months before the accident. He indicated the following:

- cooperation with UJT was generally good;
- he had requested permission from his management to visit CAE Simuflite to observe the training course. His management had replied that this was not one of the required items.

Interview with the first aerodrome fire-fighter

He said he combined the functions of aerodrome fire-fighter, fuelling agent and ramp agent. He finished refuelling a helicopter five to ten minutes before the accident. He contacted the AFIS officer when the fuelling was over and asked him the arrival time of the next traffic. The officer replied it would arrive within 10 to 15 minutes. He returned to the RFFS hangars with the refuelling truck. He then took a car to go to the terminal and hand in the refuelling chits to Operations.

While he was in the terminal, he saw the aeroplane pass by, but did not pay any special attention to it. He received the alert from the AFIS officer, immediately went out and travelled by car to the RFFS hangar. He put on his firefighter overalls and left with the response vehicle. He went straight to the scene and followed the tracks left by the aeroplane.

He crossed the aerodrome fence, drove on one of the large stone blocks at the edge of road and decided to intervene on the left side of the aeroplane. He activated the cannon and projected foam onto the wreckage for about 30 seconds without moving. He heard the forest fire-fighting helicopter flying over the site.

The presence of trees made his action ineffective. He decided to change position and go round the aeroplane by the rear. He positioned himself on the right side of the aeroplane, in front of a closed gate for which he did not have the key, after driving over a fence. He tried to extinguish the fire on the stretch of water nearby because he believed that the cockpit was in it. He then intervened on the aeroplane but quickly ran out of water. He then used powder which he projected onto the aeroplane.

Interview with the second aerodrome fire-fighter

He was on standby on the day of the accident. He was warned at 12 h 45 local time of the arrival of the aeroplane and the need to return to the aerodrome. He said he was late. He actually arrived on the scene after the accident at around 15 h 45 local time.

Interview with the RFFS officer

He indicated he had wanted to include the racing circuit in the aerodrome area because he wanted to have access to the fire-fighting resources of the racing circuit. From his point of view, even if the material resources were not specifically adapted to aviation, the human resources (14 fire-fighters) could provide significant reinforcements in the case of an aircraft fire.

2 - ANALYSIS

2.1 Scenario

Management of the flight, the approach, non-arming of ground spoilers

Between Nice airport and Le Castellet aerodrome which was not familiar to the crew, the flight was short. The cruise, which lasted only five minutes, left the crew little time to prepare for their arrival. The flight was the last of the day and it was made without any passengers, with the co-pilot in the right seat as PF. This context may have been conducive to lax pre-flight planning and management of the flight by the crew with a heavy workload during the cruise and the approach. Despite having been warned the day before of the need to park the aeroplane at Le Castellet, the copilot learnt the characteristics of the aerodrome during the flight. Few checklists and briefings were heard throughout the flight. During the flight, the crew referred to the proximity of the terrain, the need to reduce speed and anticipate the configuration, and the short runway length. The crew nevertheless understated the impact of a short flight on the preparation of the arrival.

During the visual approach, the PM omitted to arm the ground spoilers, and the crew did not notice the display of the GND SPOILER UNARM message on the EICAS.

The inadequate and incomplete application of the *"before landing"* checklist as well as the likely omission to check the messages displayed on the EICAS meant they did not detect this omission before the wheels touched down.

Touchdown of the main landing gear, braking and selection of thrust reversers

The touchdown of the main landing gear occurred near the touchdown zone. The crew immediately applied an input on the brake pedals and selected the thrust reversers. They did not initially detect that the ground spoilers had not deployed.

Due to the lack of their deployment, the load on the landing gear remained low, which resulted in:

- rendered braking ineffective;

Note: the absence of any recording of inputs by the crew on the brake pedals prevents any determination of the exact input on the pedals. Crews are generally unaccustomed to braking sharply because the runways are often long. At Le Castellet, given the low initial deceleration of the aeroplane and the relatively short runway, it is probable that the crew attempted during the landing to brake significantly; the low braking pressure values recorded may be explained by the tripping of the anti-skid system on lightly loaded landing gear.

- significantly delay the deployment of the thrust reversers due to the temporary loss of an on-ground condition of the main landing gear. The concomitance of the loss of this condition and the start of deployment of the thrust reversers generated MASTER WARNING warnings corresponding to the L-R REV UNLOCK message, interrupted the deployment of the thrust reversers and delayed their full deployment for seven seconds.

Slight deceleration and de-rotation of the aeroplane

During the first part of the landing roll, the crew's attention was probably perturbed by several factors:

- the thrust reversers were not deployed despite their selection;
- several MASTER WARNING warnings were triggered.

Immediately after the first touchdown of the nose gear, the latter came back up again due to the nose-up inputs maintained by the PF and the lack of deployment of the ground spoilers, which induce a pitch-down moment once extended. The realization that the runway was *"short"* (*see 1.17.4*) led the crew[52] to apply a strong nose-down input probably to increase the pressure of the aeroplane on the ground. Aborting the landing was no longer an option at this time due to the selection of thrust reversers.

[52]It was not possible to determine whether this action was carried out by the co-pilot, the captain, or both.

The exact value of the load applied to the nose gear on the second touchdown is difficult to assess but calculations from simulations indicate that it was unusually high - while likely remaining below the certified limit load - for a very short time, less than one second. Subsequently, this load was consistent with that calculated for previous landings.

Just as they applied the nose-down input, the crew detected that the ground spoilers were not deployed and so actuated the speedbrake control handle. This choice did not allow them to benefit from a full deflection of the panels (55°), which could have been obtained by pressing the GND SPLR push button on the centre console.

Deviation to the left and runway excursion

Just when the nose gear touched down for the second time, the aeroplane was to the right of the runway centre line and slightly correcting to the left. The peak load on the nose gear associated with a left yaw rate may have caused the aeroplane to start skidding to the right. The trajectory curved towards the left of the runway and the crew began their corrective manoeuvre by applying right input on the rudder pedals. At this point, in theory the steering control system was not yet active, and the wheels of the nose gear were aligned with the longitudinal axis of the aeroplane.

Shortly before crossing the runway centre line, the marks left by the nose gear were highly noticeable and sometimes overlapped. They had striations to the right, a sign of a strong overswing to the left. The skidding to the right continued to increase and the aeroplane increased its deviation to the left despite:

- the full orientation to the right of the rudder corresponding to a maximum input to the right on the rudder pedals and;
- the significant differential braking to the right.

From then on the crew could not avoid the runway excursion at high speed, which occurred between four and five seconds after the start of the deviation to the left.

Collision with obstacles and emergency response

The aeroplane then crossed the perimeter fence of the airport and caught fire immediately after the impact with the trees. At the time of the landing of N823GA, a fire-fighter had finished refuelling duties and was in the reception area of the air terminal. He quickly went to his vehicle, went to the RFFS hangar, put on his protective suit and left with the response vehicle. A second fire-fighter was scheduled to ensure the level 5 protection, but he was late coming from his home and had not arrived on the aerodrome. The first fire-fighter therefore fought the fire alone.

Seeing that his first response was rendered ineffective by the presence of trees, he decided to change strategy, to go around the wreckage via the south before attempting a second operation. He stopped in front of a gate to which he did not have the key. He intervened, from that position, first on the stretch of water considering that a part of the aeroplane was located there, then on the wreckage. Several minutes elapsed between the first and the second interventions.

Several factors could have hindered or decreased the effectiveness of the intervention:

- the absence of the second fire-fighter could have made it more difficult to choose strategic intervention options: the positioning of the vehicle, the choice of routing and handling the equipment. The fire-fighter had to manage driving the vehicle, handling the radio and the foam cannon, alone and all at the same time;
- the presence of several obstacles: rocks along a road, trees located between the response vehicle and the wreckage during the first intervention, a gate to which he had no key for the second. Moreover, the presence of trees made it necessary to spray the foam on separate two occasions, which reduced the effectiveness of the operation accordingly.

2.2 Lateral Deviation of the Aeroplane

Several hypotheses were made during the investigation to explain the deviation to the left of the aeroplane on the runway:

- the hypothesis of a phenomenon of *"wheelbarrowing"* throughout the deviation to the left until the runway excursion, was excluded. This was because the calculations of the loads on the landing gear showed that the nose gear suffered an unusually high load for only a short time, less than one second. In parallel, the load on the main landing gear, once the speedbrakes were deployed, was comparable to that calculated for previous flights;
- locking of the wheels of the main landing gear was excluded because of the condition of the tyres after the accident and the examination of the marks on the runway;
- the study of the tyre marks showed that the nose gear wheels, which were initially on the aeroplane's axis, gradually shifted to the left at angle values greater than those that could be commanded using the rudder pedals. The results of simulations carried out by the NTSB and the BEA to study the dynamics of the aeroplane during the landing roll all showed that only an orientation to the left of the nose gear could explain the deviation to the left of the aeroplane, in the presence of the recovery input on the brakes and rudder pedals undertaken by the crew. These simulations, which were carried out for tyres with different adhesion characteristics, showed that scenarios made it possible to reproduce flight paths identical to that followed by N823GA when the nose gear was oriented to the left, beyond the values that can be commanded on the rudder pedals.

All of these elements therefore show that the nose gear was oriented to the left at values greater than those that can be commanded with the rudder pedals. This orientation caused the lateral deviation of the aeroplane and its runway excursion.

2.3 Leftwards Orientation of the Nose Gear Steering System

Since the position of the tiller is not one of the recorded parameters, it is not possible to know the Captain's input on the tiller. Given that the nose gear steering system does not include any high speed inhibition, the possibility cannot be excluded that the aeroplane's deviation to the left was the consequence of a left input on the tiller.

The second hypothesis to explain the leftwards orientation of the nose gear steering system is a failure in the latter. A link between unusually high load on the nose gear after the nose-down input by the crew and the possible failure of the steering system is feasible, but was not formally established by the investigation. This failure occurred without triggering a warning and without disconnecting the nose gear steering system, which therefore remained oriented to the left without entering *"free caster"* mode.

Amongst the cases of failures identified, two scenarios involving the feedback RVDT could create lateral disturbance of the aeroplane:

- disconnection and a shift of the feedback RVDT supplying a fixed value of the wheel orientation position;
- bias in the measurement of the position of the RVDT.

These scenarios do not generate a STEER BY WIRE FAIL warning and are consistent with the event, especially with the tyre marks and the crew actions. However, it was not possible to confirm them by technical examinations, these elements of the system having been severely damaged or not found at the site of the accident.

The investigation also revealed that a part of the nose gear steering control system is monitored and that numerous cases of malfunctions do not lead to the generation of a STEER BY WIRE FAIL warning. They therefore do not cause the disengagement of the nose gear steering system.

The postulates of the FMEA according to which at high speed only small orientation angles of the nose gear are applied and a failure can be countered by an input on the rudder pedals and differential braking were found to be inadequate in the case of the accident and in a previous accident (*cf. accident in Colorado §1.18.1*). These risk reduction means, therefore, are not as robust as stated in the FMEA, especially since even with a functional system, it is possible to command large angles of orientation using the tiller, regardless of the speed.

These items were not brought to light either by the manufacturer or by the certification authority.

2.4 Introduction of a New Procedure, Training and Documentation Update

The introduction in 2005 of the recovery procedure for the loss of steering control, *''Uncommanded Nose Wheel Steering''*, based on the use of differential braking, use of the rudder and disconnection of the steering system, was accompanied by an update by Gulfstream of the AFM and the AOM and was the subject of communication by means of a MOL sent to G-IV operators. The QRH was not updated by Gulfstream, for a reason that was not identified by the investigation.

The study of similar events and the interviews carried out during the investigation showed that this procedure was not applied as a whole by some G-IV crews. For example, the inputs carried out or spontaneously mentioned by the crews did not include any input on the PWR STEER switch. Although they had followed initial training and recurrent training consistent with the training programme approved by the FAA, UJT pilots had never been trained in this procedure.

When introduced, the *''Uncommanded Nose Wheel Steering''* procedure approved by the FAA, had not been tested in flight either by FAA pilots or by those of Gulfstream. It corresponded to a possible response, without demonstrating the effectiveness of the recovery of the aeroplane's flight path in the case of a failure of the nose gear steering system. The feasibility of its implementation, regardless of the place occupied by the PF, was not the subject of any special study either.

Training organizations, CAE Simuflite in particular, had access to the latest updates of the AFM and the AOM. In the absence of an Airworthiness Directive issued by the FAA requiring the application of this new procedure, they were not made aware of the existence of this new procedure when introduced. They were not addressees of the MOL and had not identified the fact that the procedure had been added. Furthermore, since they used the QRH (not updated) as the basis for training in abnormal procedures, none of the simulator sessions could contain scenarios including this procedure. Finally, CAE Simuflite was using outdated documentation: the IPTM and CRH, in particular, referred to the *''Simuflite Operating Handbook''* document. It contained all the abnormal procedures but was no longer updated.

The speed and scale of the lateral deviation of the aeroplane required immediate and appropriate action by the crew. These inputs, which had to be performed in a very short time, could only be carried out as a result of appropriate instruction and training which the crew were not given.

2.5 Monitoring by the Authorities

As part of the monitoring of the operator and the issuance of its accreditations, the FAA carries out a documentation review of the AFM, the QRH and the training programme. The POI who carried out this review indicated that the training programme was a copy of an older program, previously approved by the FAA and had not considered it necessary to study that of UJT in detail. Nor did he detect the updating problem of the QRH and the procedural differences between this document and the AFM.

FAA monitoring of training organizations was not addressed during the investigation.

Finally, the investigation team could not obtain from the DGAC or from the FAA the result of monitoring requested after the SAFA inspection carried out in France on a flight operated by UJT in 2010.

2.6 Use of Ground Spoilers, G-IV Compliance with Certification Requirements

The deployment of ground spoilers was an essential factor in ensuring the deceleration and the performance of the aeroplane during landing. The failure to arm them, which remained undetected until the landing roll, led to a degraded situation.

The incomplete use of the *"before landing"* checklist as a list of actions to perform, and not a means of checking actions performed, was the main contributor to this oversight leading to the late deployment of the speedbrakes.

From the point of view of operational procedures, the PM could have warned the PF when the NO GND SPLRS warning was triggered, corresponding to a malfunction. On the other hand, since he did not have any information at his disposal about the actual position of the panels, he was unable to ensure their actual deployment, as required by the procedure in the AOM. This is particularly critical in the case of failure to arm the ground spoilers. In this case, only the blue GND SPLRS UNARM message would have allowed the omission to be detected.

The investigation led the BEA to question the FAA and EASA on the compliance of the G-IV with the requirements of section 25-699 of the Certification regulations on the provision to pilots of the indication of position of lift and/or drag augmentation devices when a specific command can be used to adjust their position. The FAA considers that the ground spoilers had no specific command that could be used to adjust their position. This interpretation led it to exclude them from the requirements of this section.

Since EASA has not ruled on this point, the compliance of the G-IV with this criterion is questionable. In any event, the lack of information on the position of the panels makes it harder for the crew to be aware of their true position.

The investigation showed that the failure to arm the ground spoilers was not an isolated case and had already occurred during previous flights. It contributed to at least one loss of control during a landing by another operator (*see the incident in China, § 1.18.1*).

2.7 Operator's Methods and Performance of Procedures

Operator's safety culture

The operator had a safety management system and a confidential feedback system, which was not required by US regulations. The investigation revealed that these systems had not achieved, on the day of the accident, a sufficient degree of maturity to enable effective feedback in terms of improving safety: feedback to the crews did not contain information on flight safety as such, and the feedback system was not yet used by crews.

The change in US regulations is consistent with a generalized extension of these systems.

Framework for flights

Although the list of flights on 13 July 2012 called for the implementation of the flight under Part 135 rules, the actual management of the flight by the crew was halfway between Part 135 transport rules and the rules for general aviation, as suggested by the interviews of the operator's managers, who stated that this flight was carried out according to general aviation rules. Furthermore, no particular attention was paid by the crew to the landing distance margins on arrival at Le Castellet.

This may be partly a consequence of the changes to the operating environment for the aeroplane between the Part 91 regulation (general aviation) and the Part 135 regulation. These changes require the crew to identify the practical rules applicable for each flight. It is possible that they may generate a certain confusion about flight management techniques and alter the crew's perception of the usefulness, from the safety point of view, of the regulatory benchmarks in one or the other frameworks (fuel reserves, runway lengths, for example).

Similarly, the agents in charge of the application of the SAFA system must take into account the context of the flights, which probably complicates the perception and monitoring of the operator's safety level. For example, the operator had not requested a permit from the DGAC to provide the French territory with air transport services since 2006, despite a notification issued to it after an SAFA inspection in France. In the absence of any such request, the DGAC was unable to check that this operator, the aeroplane and the crew complied with the requirements of French regulations.

The flights on 13 July 2012 having been operated as general aviation, it is possible that this was the case with other previous flights. For these flights, the SAFA inspections are less restrictive than those made in the context of an air transport flight.

Although it is not possible to assert that there was a link between these changes in framework and the accident, this issue should be taken into account in the SMS.

Performance of checklists

During the flight, the *"before landing"* checklist, which was not fully verbalized or carried out in *"challenge and response"* mode, i.e. without any check or confirmation by the other pilot, did not provide the crew with a check step. As a result, they did not detect the failure to arm the ground spoilers during the approach.

The way in which CAE Simuflite trains pilots on carrying out checklists was not studied during the investigation. The analysis of the accident flight, the video recordings of flights by UJT pilots and interviews, shows that carrying out the checklists in *"challenge and response"* mode was not systematic within the operator's personnel. This had not been identified as a problem during in-flight audits by the FAA.

The items contained in a checklist, especially for that before landing, are those that are essential to ensure safety. A forgotten item that is not detected in the checklist compromises the safety of the flight because there are rarely any other safety nets. Using a checklist as a list of actions to carry out does not provide a step for cross-checking items and makes the flight more susceptible to errors and omissions.

2.8 Manufacturer's Procedures - Arming of Ground Spoilers

The arming of ground spoilers is usually done by the PM after extending the landing gear. The generation of a *"single chime"* type of audible warning and the display of the GND SPOILER UNARM information message on the EICAS when the landing gear is extended are therefore systematic, which may decrease the perception of an abnormal situation by the crew when it continues long after the extension of the landing gear.

In the absence of a checklist formally conducted in challenge and response mode, the EICAS message GND SPOILER UNARM loses its effectiveness because it may not be detected by the crew. This is even more critical in that the order of the items in the *"before landing"* checklist, placing the EICAS check before arming the ground spoilers, may get crews used to the presence of the GND SPOILER UNARM message when checking the EICAS. For its part, the audible alert that is generated only once immediately after the extension of the landing gear, does not help the crew to detect an omission to arm the ground spoilers.

2.9 Organization of the RFFS Service

The presence of a single fire-fighter may have reduced the effectiveness of his intervention: alone, he had to simultaneously take charge of the response vehicle, VHF communications, handling the cannon and the additional fire-extinguishing agents. Nor was he able to share intervention strategy for the fire.

The Operational Procedures Manual contained no explicit procedure requesting the RFFS service to warn the AFIS officer of the unavailability of a fire-fighter, thereby reducing the level of protection. Not having been informed of the absence of a fire-fighter on the arrival of the aeroplane, the AFIS officer could not pass on this information to the crew before landing.

The level of protection of the aerodrome at Le Castellet allowed the aerodrome operator to entrust ancillary tasks to RFFS personnel. The instructions defined the conditions for carrying out these activities but were not very precise: for example, the action to be taken according to the type of activity was not specified. After the accident, the Operational Procedures Manual was supplemented in order to specify these procedures. The instructions also stated that the personnel should remain within the immediate vicinity of the response vehicles over a period covering the landing of the aeroplane, which was not the case in practice and seems unlikely to happen in the event of regular aircraft traffic (the response vehicle remained parked in the RFFS hangar).

Finally, the aerodrome area, as defined at the time of the accident, did not guarantee access anytime and anywhere for aerodrome fire-fighters. In particular, the aerodrome fire-fighter found himself in front of a gate for which he had no key, and was restricted in positioning the response vehicle during the second operation.

3 - CONCLUSION

3.1 Findings

- the pre-flight planning was incomplete;
- during the flight, numerous checklists were not carried out or called for. The *''before landing''* checklist was carried out in an incomplete manner;
- the crew omitted to arm the ground spoilers during the approach and they did not detect this in flight;
- the flight path and speed were stabilized and the touch occurred near the touchdown zone;
- not being armed, the ground spoilers did not deploy on main landing gear touchdown and the crew did not notice it;
- the non-deployment generated a low load on the landing gear causing a temporary loss of on-ground condition of the main landing gear;
- the temporary loss of the on-ground condition inhibited the deployment of the thrust reversers for seven seconds and caused the triggering of the MASTER WARNING alarms;
- the low load on the landing gear prevented effective braking;
- the deceleration was relatively low on the first two thirds of the runway;
- the crew applied a strong nose-down input that generated an unusually high load, for a short period, on the nose gear;
- following the second touchdown of the nose gear the aeroplane veered to the left due to an orientation to the left of the nose gear;
- the leftwards orientation of the nose gear could have been caused by a left input on the tiller or by a failure in the steering system;
- the crew immediately responded to the lateral deviation with an input on the rudder pedals and differential braking but were unable to maintain control of the aeroplane; they did not set the PWR STEER switch to OFF when the aeroplane was on the runway;
- the runway excursion occurred at a high speed;
- the aeroplane struck some trees and immediately caught fire;
- the occupants were unable to evacuate the aeroplane;
- only one fire-fighter was present during the intervention, and he was unable to bring the fire under control;
- the level-5 RFFS protection was not ensured because one fire-fighter was late and was absent from the aerodrome at the time of the aeroplane's arrival;
- performing the checklists in *"challenge and response"* mode, as instructed by the UJT operations manual, was not systematic at the operator;
- only the AFM and the AOM were updated after the addition of the *''Uncommanded Nose Wheel Steering''* procedure in 2005; this procedure was not included in the UJT training programme;
- operators had been made aware of the addition of this procedure via a MOL that had not been sent to all G-IV pilot training organizations;
- the crew had not been trained to carry out this procedure;
- this procedure cannot be carried out by the pilot flying alone when the latter is in the right seat; this specificity was not highlighted in the operational documentation and had not been taken into account in the training programme;
- the documentary audit by the FAA POI at the time of approval of the training programme did not detect this absence. It did not detect the absence of any documentation update;

- this procedure was not evaluated during test flights either by Gulfstream or by the FAA before its introduction;
- the G-IV has no spoiler position indicator in the cockpit;
- the FMEA study of the nose gear steering system showed that at least two identified scenarios could match that of the accident; the study highlighted the fact that some of the FMEA assumptions were found to be inadequate in the case of the accident and in a previous accident;
- several failure modes of the nose gear steering system do not generate a STEER BY WIRE FAIL alarm; under these conditions, the steering system does not automatically disengage.

3.2 Causes of the accident

Forgetting to arm the ground spoilers delayed the deployment of the thrust reversers despite their selection. Several MASTER WARNING alarms were triggered and the deceleration was low. The crew then responded by applying a strong nose-down input in order to make sure that the aeroplane stayed in contact with the ground, resulting in unusually high load for a brief moment on the nose gear. After that, the nose gear wheels deviated to the left as a result of a left input on the tiller or a failure in the steering system. It was not possible to establish a formal link between the high load on the nose gear and this possible failure. The crew was then unable to avoid the runway excursion at high speed and the collision with trees.

The aerodrome fire-fighter, alone at the time of the intervention, was unable to bring the fire under control after the impact. Although located outside of the runway safety area on either side of the runway centre line, as provided for by the regulations, the presence of rocks and trees near the runway contributed to the consequences of the accident.

The accident was caused by the combination of the following factors:

- the ground spoilers were not armed during the approach;
- a lack of a complete check of the items with the *"before landing"* checklist, and more generally the UJT crews' failure to systematically perform the checklists as a challenge and response to ensure the safety of the flight;
- procedures and ergonomics of the aeroplane that were not conducive to monitoring the extension of the ground spoilers during the landing;
- a possible left input on the tiller or a failure of the nose gear steering system having caused its orientation to the left to values greater than those that can be commanded using the rudder pedals, without generating any warning;
- a lack of crew training in the *"Uncommanded Nose Wheel Steering"* procedure, provided to face uncommanded orientations of the nose gear;
- an introduction of this new procedure that was not subject to a clear assessment by Gulfstream or the FAA;
- failures in updating the documentation of the manufacturer and the operator;
- monitoring by the FAA that failed to detect both the absence of any updates of this documentation and the operating procedure for carrying out checklists by the operator.

4 - SAFETY RECOMMENDATIONS

Note: In accordance with Article 17.3 of European Regulation (EU) 996/2010 of the European Parliament and Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation shall in no case create a presumption of blame or liability for an accident, a serious incident or an incident. The addressee of a safety recommendation shall inform the safety investigation authority which issued the recommendation of the actions taken or under consideration, under the conditions described in Article 18 of the aforementioned Regulation.

4.1 Nose gear steering system

During the landing roll, the nose gear was not oriented as commanded via rudder pedals by the crew. The investigation showed that a left input on the tiller or a malfunction in the nose gear steering system could have caused the aeroplane's lateral deviation.

In the possible case of a malfunction, the latter would not have been detected by the on-board computer managing the steering system (ECM), no STEER BY WIRE FAIL warning would have been generated and the steering system would not have automatically disengaged.

Control of the aeroplane could not be recovered despite the corrective manoeuvre initiated by the crew on the rudder pedals and differential braking. The aeroplane then ran off the runway at high speed.

In addition, the investigation showed that:

- several failure modes of the nose gear steering system are not detected; in this configuration no warning is generated and the steering system does not automatically disengage;
- the postulates of the FMEA according to which at high speed only small orientation angles of the nose gear are applied and a failure can be countered by an input on the rudder pedals and differential braking were found to be inadequate in the case of the accident and in a previous accident.

The investigation also showed that the nose gear steering system malfunctions were not isolated cases.

Consequently, the BEA recommends that:

- **FAA and EASA assess the appropriateness of making inhibition of the nose gear steering system at high speed on G-IVs mandatory, to prevent the nose gear from being oriented at large angles at high speed [Recommendation 2015-031] and [Recommendation 2015-032]**

- **FAA and EASA carry out a study to identify the aircraft that may be affected by the previous recommendation [Recommendation 2015-033] and [Recommendation 2015-034]**

4.2 Effectiveness of the Uncommanded Nose Wheel Steering Procedure

Following a runway excursion that occurred in 2004 with a G-IV, Gulfstream introduced the *''Uncommanded Nose Wheel Steering''* abnormal procedure in 2005. At the time of its introduction, this procedure was not tested and was not subject to flight testing. The FAA approved the introduction of this procedure in the AFM without its actual effectiveness being verified during test flights. This procedure is based in particular on the effectiveness of differential braking. During the investigation, Gulfstream were unable to assess the effectiveness of the braking of a G-IV when side-slipping.

Consequently, the BEA recommends that:

- **FAA in conjunction with Gulfstream evaluate the effectiveness of the *Uncommanded Nose Wheel Steering* procedure in order to ensure that the actions proposed in this procedure effectively enable control of the aeroplane to be regained in the case of a lateral deviation due to a malfunction in the speed range in which this procedure is required. [Recommendation 2015-035]**

4.3 Training for the Uncommanded Nose Wheel Steering Procedure

The crew did not set immediately the PWR STEER switch to OFF following the lateral deviation of the aeroplane as advocated by the *''Uncommanded Nose Wheel Steering''* procedure. The investigation showed that:

- the crew of N823GA had not been trained in this procedure and that many G-IV pilots did not know it;
- the fact that it could not be fully carried out from the right seat had not been identified by the FAA, Gulfstream or training organizations;
- the documentation used during initial and recurrent training by UJT was not up to date and did not contain this procedure;
- Gulfstream did not automatically send the MOL (Maintenance and Operations Letter) to all of the G-IV training organizations; it had not sent it to CAE Simuflite, responsible for the training of UJT pilots.

Consequently, the BEA recommends that:

- **FAA and EASA ensure that G-IV operators and organizations training G-IV pilots complete their training by adding the training on the *Uncommanded Nose Wheel Steering* abnormal procedure and ensure that this training is actually followed by the G-IV pilots and is adapted for the seat occupied in the cockpit [Recommendation 2015-036] and [Recommendation 2015-037]**

- **FAA and EASA ensure that the updating process of the documentation for operators and training organizations ensures that the procedures and training programmes provided for crews contain the latest updates of the manufacturer's procedures [Recommendation 2015-038] and [Recommendation 2015-039]**

- **FAA and EASA ensure that training organizations are systematically sent the information and safety warnings issued by manufacturers [Recommendation 2015-040] and [Recommendation 2015-041]**

4.4 Ground Spoilers

This accident illustrated the importance of ground spoilers to ensure effective braking and deceleration when the aeroplane is on the ground. They are also considered to certify landing distances. This accident also showed that an omission was the cause of a degraded situation. The late deployment of the speedbrakes was furthered by several factors, including:

- improper completion of the *"before landing"* checklist;
- the absence of any indication of the spoiler position in the cockpit of the G-IV;
- the absence, under normal procedures, of any call-out concerning the activation of the ground spoilers when the aeroplane was on the ground;
- an aeroplane design that does not provide for the automatic deployment of ground spoilers when the thrust reversers are selected, as may be the case on other aeroplanes of the same generation.

The investigation also showed that the failure to arm the ground spoilers is not an isolated case and has already contributed to loss of directional control during landing.

During the investigation, it was not possible to obtain a harmonized interpretation between FAA and EASA with regard to the applicability of § 25-699 of the Certification Regulation for ground spoilers.

Consequently, the BEA recommends that:

- **FAA and EASA ensure that G-IV operators and Gulfstream set up procedures conducive to verifying the activation of the ground spoilers during landing, similar to that used for thrust reversers. [Recommendation 2015-042] and [Recommendation 2015-043]**

- **EASA in coordination with FAA assess the compliance of the G-IV with the certification requirements relating to the indication of the position of the ground spoilers. [Recommendation 2015-044]**

- **EASA and FAA ensure that the Certification Specifications (article 25-699 of the CS 25 / FAR 25 regulations) require that information on the position of the ground spoilers be available on landing. [Recommendation 2015-045] and [Recommendation 2015-046]**

The arming of ground spoilers is usually done by the PM after extending the landing gear. The generation of a «single chime» type of audible warning and the display of the GND SPOILER UNARM information message on the EICAS when the landing gear is extended are therefore systematic, which may decrease the perception of an abnormal situation by the crew when it continues long after the extension of the landing gear.

In the absence of a checklist formally conducted in challenge and response mode, the EICAS message GND SPOILER UNARM loses its effectiveness because it may not be detected by the crew. For its part, the audible alert that is generated only once immediately after the extension of the landing gear, does not help the crew to detect a failure to arm the ground spoilers.

Consequently, the BEA recommends that:

- **FAA ensure that Gulfstream review the warning logic when the ground spoilers are not armed, and the spoiler arming procedure, in order to cover the situation of a failure to arm the spoilers brought to light by this investigation. [Recommendation 2015-047]**

4.5 Operator's Methods and ''*before landing*'' Checklist

The investigation showed that the checklists were not carried out in *''challenge and response''* mode during the event flight. The investigation also showed that the practice was sometimes observed among the operator's personnel. This practice does not provide the crews with a cross-check step and makes the flight more vulnerable to errors or omissions. The FAA, in its oversight of the operator, did not detect this deviation.

Consequently, the BEA recommends that:

- **FAA ensure that carrying out checklists in *''challenge and response''* mode becomes systematic practice at UJT. [Recommendation 2015-048]**

- **UJT and CAE Simuflite remind crews of the significance and importance of carrying out checklists in *''challenge and response''* mode. [Recommendation 2015-049] [Recommendation 2015-050]**

The investigation showed the order of items on the «before landing» checklist, placing the EICAS check before arming the ground spoilers, could habituate crews to the presence of the GND SPOILER UNARM message when checking the EICAS, when the checklist was carried out as a list of actions to be performed.

Consequently, the BEA recommends that:

- **FAA, in conjunction with Gulfstream, review the relevance of changing the order of the items on the *''before landing''* checklist in order to place the EICAS check after arming the ground spoilers. [Recommendation 2015-051].**

4.6 Level of RFFS Protection Provided

The second fire-fighter, on standby, and planned to ensure level 5 RFFS service, as requested by the operator, arrived late and was not present at the time of the accident. Since the accident, the Le Castellet aerodrome operator has added to the Operational Procedures Manual for the RFFS a procedure explicitly requesting the RFFS service to warn the AFIS officer in the event of a decrease in the level of protection initially guaranteed. At the time of the accident the AFIS officer, not having been informed of the absence of a fire-fighter on the arrival of the aeroplane, could not pass on this information to the crew before landing.

In addition, the level of protection at Le Castellet aerodrome allowed the aerodrome operator to entrust ancillary tasks to RFFS personnel. The instructions defined the conditions for carrying out these activities but were not very realistic or precise: for example, the action to be taken according to the type of activity was not indicated. After the accident, the Operational Procedures Manual was supplemented in order to specify these procedures.

Consequently, the BEA recommends that:

- **DGAC ensure that aerodrome operators have defined procedures that guarantee that the level of protection provided corresponds to that indicated, including:**
  - **informing the ATC service (or the AFIS agent) in case of an unexpected decrease in the level of RFFS protection initially guaranteed;**
  - **the definition of the conditions for carrying out each of the ancillary tasks requested of aerodrome fire-fighters so that they do not jeopardize the outcome of the operational objective. [Recommendation 2015-052]**

  and that it ensures that these procedures are in fact applied. [Recommendation 2015-053]

Finally, the aerodrome area, as defined by the aerodrome operator at the time of the accident, did not guarantee access at all times and to all places for aerodrome fire-fighters. Specifically, the aerodrome fire-fighter found himself in front of a gate close to the runway to which he did not have the key. He was therefore restricted in positioning the vehicle during the second intervention.

Consequently, the BEA recommends that:

- **The operator of Le Castellet aerodrome ensure that the RFFS service has access at all times and to all places in the aerodrome area. [Recommendation 2015-054].**

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appendix 1

Description of the nose gear steering system

The Nose Wheel Steering system (NWS) is controlled electrically, hydraulically operated and mechanically actuated.

The NWS is used during taxiing, take-off and landing, and is automatically activated by the nose gear compression sensor (a two-position sensor (air/ground) located on the nose gear).

In the cockpit, there are two ways of commanding the nose gear steering system:

- by the **steering control wheel**, located on the left console. It consists of a guarded *"PWR STEER"* ON/OFF switch (in the ON position), a tiller fitted with return springs to restore it to the neutral position, viscous dampers and potentiometers. The orientation of the nose gear can be commanded up to 80° ± 2° to the left or right of the centre line of the aeroplane using the tiller;
- or the **rudder pedals** by the pilot or co-pilot. The orientation of the nose gear can be commanded up to 7° ± 1°. Potentiometers are mounted on a support under the cockpit and are mechanically connected to the control cable of the rudder.

The potentiometers of the tiller or the rudder pedals transform the mechanical command into an electrical signal that is sent to the Electronic Control Module (ECM). The latter outputs a centreline electrical signal to the Electro Hydraulic Servo valve (EHSV) until the system goes into *"ground"* mode (compression of the nose gear). At that moment, the signal is gradually increased at intervals of 750 ms until it reaches the position commanded by the rudder pedals, or by the tiller, or a combination of both. This gradual increase prevents a sudden rotation of the steering unit when the nose gear comes into contact with the ground, in particular during landings in a crosswind.

The EHSV is the hydraulic servo valve that controls the transmission of the hydraulic fluid to the steering unit in order to rotate it according to the command.

The steering unit, located on the nose gear, consists of two sub-units:

- the stator, a cylindrical part integral with the landing gear box;
- the rotor, a cylindrical part which rotates around the stator. It is connected to the axle of the wheels of the nose gear by the torque links.

These sub-units (stator and rotor), in contact with one another, form cavities which, when filled with hydraulic fluid, allow the steering unit to rotate.

The steering unit also has a position sensor located on its outer rear part (RVDT) which is designed to convert the mechanical position signal into an electrical signal.

This signal is sent to the ECM where it is algebraically added to the input signals from the rudder and/or the tiller. The resulting signal is sent to the EHSV. When the nose gear approaches the commanded position, the sum of the signals sent to the EHSV tends to become zero. The servovalve then maintains the nose gear in this position. An external force tending to change the orientation of the nose gear would create an offset in the servo valve which would tend to counteract this force.

Two Shutoff Valves (SOV) that normally maintain the hydraulic circuit closed are used to control the hydraulic power of the system. They are placed in series in the circuit, but are electrically commanded separately. SOV no. 1 is powered by the *"PWR STEER"* ON/OFF switch in the cabin and the *"Nose gear down and locked"* signal. SOV no. 2 is powered by the ECM when the compression switch of the nose gear switches to *"ground"* mode. To avoid powering up the hydraulic circuit when the nose gear is retracted, an extra precaution has been added by energizing the hydraulic power source through the hydraulic circuit used to extend the landing gear.

Steering systems using an ECM of the 5250-1 type number (like the one installed on N823GA) contain a test circuit (BITE - Built-In Test Equipment) integrated with ten error codes that appear on a digital screen with seven segments on top of the ECM. A push-button located on the upper face of the ECM is used to initialize the microprocessor and carry out a verification test of the system. The BITE cannot be manually activated in flight, but if the landing gear is down and locked (pre-landing check), the BITE circuit passively checks for dormant malfunctions and automatically cuts the system[(1)] via the SOV 2 shutoff valve if a malfunction is detected. The STEER BY WIRE FAIL warning message is displayed on the Engine Instrument and Crew Advisory System (EICAS) and an aural warning (double chime) is generated.

[(1)]The system is in castoring mode.

The ECM incorporates a *"watchdog"* timer with an interval of about 220 milliseconds. This timer is reset every 82 milliseconds provided no malfunction is detected in the system. If malfunctions occur, the timer stops after 220 milliseconds and cuts the system by activating the shutoff valve SOV no. 2. The STEER BY WIRE FAIL warning message is displayed on the EICAS and an aural warning (double chime) is generated. If the breakdown is corrected, turning the system off and on again will remove the EICAS message and the system will return to its nominal state.

The system includes two channels to provide a means of checking the status of the system. One channel is necessary to perform the task and the second channel is a mirror image used as a comparator of the first channel. Any malfunction of a component in one of the channels will cause the system to shut down and activate the STEER BY WIRE FAIL message on the EICAS.

The ECM described above uses a seven-segment LED dial to indicate the location of breakdowns. The numeric codes of the BITE indicate Line Replaceable Units (LRU) during line maintenance.

CODES	LRU
0	No Fault
1	ECM Fault
2	Solenoid Valve Fault
3	EHSV Fault
4	Handwheel Potentiometer Fault
5	Feedback RVT Fault
6	Rudder Potentiometer Fault
7	Short Circuit
8	LED Check
9	Test Incomplete

Note:

❒ On aeroplanes MSN 176 1000-1242 with the ASC 176 and aeroplanes MSN 1243 and following (which was not the case of N823GA), a pressure switch for the nose gear steering circuit (NWS pressure switch) and an electrical circuit are available to provide an alert to the crew after a problem with the steering system of the nose gear during take-off or landing. The extra equipment is used to monitor additional parameters. On an aeroplane with this change, a STEER BY WIRE FAIL message is displayed on the EICAS when one of the following conditions is met:

- the nose gear compression sensor is locked in the «ground» position although the aircraft is in flight;
- the shutoff valves (SOV) are locked in the open position although the aircraft is in flight;
- the nose gear steering system is not functional due to a loss of hydraulic power when the aeroplane is on the ground;
- improper installation of the ECM or ECM connectors.

In aeroplanes with the ASC 302A (which was not the case of N823GA), the pilot can select normal control of the steering (tiller or rudder pedals) or control only of the tiller (decoupling of commands).

appendix 2

FDR Parameters

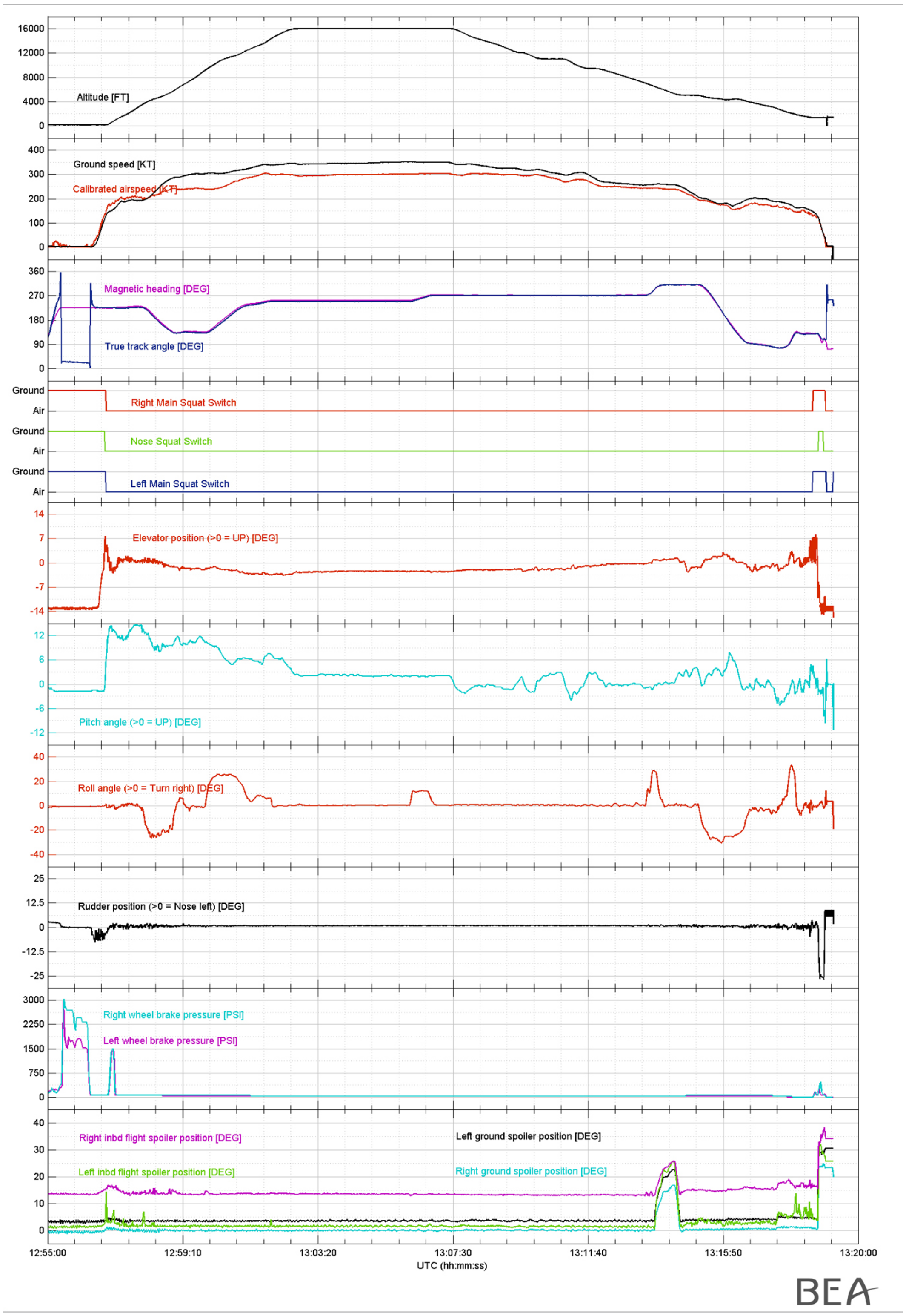


Figure 1: attitudes and position of aeroplane flight control surfaces (complete flight)

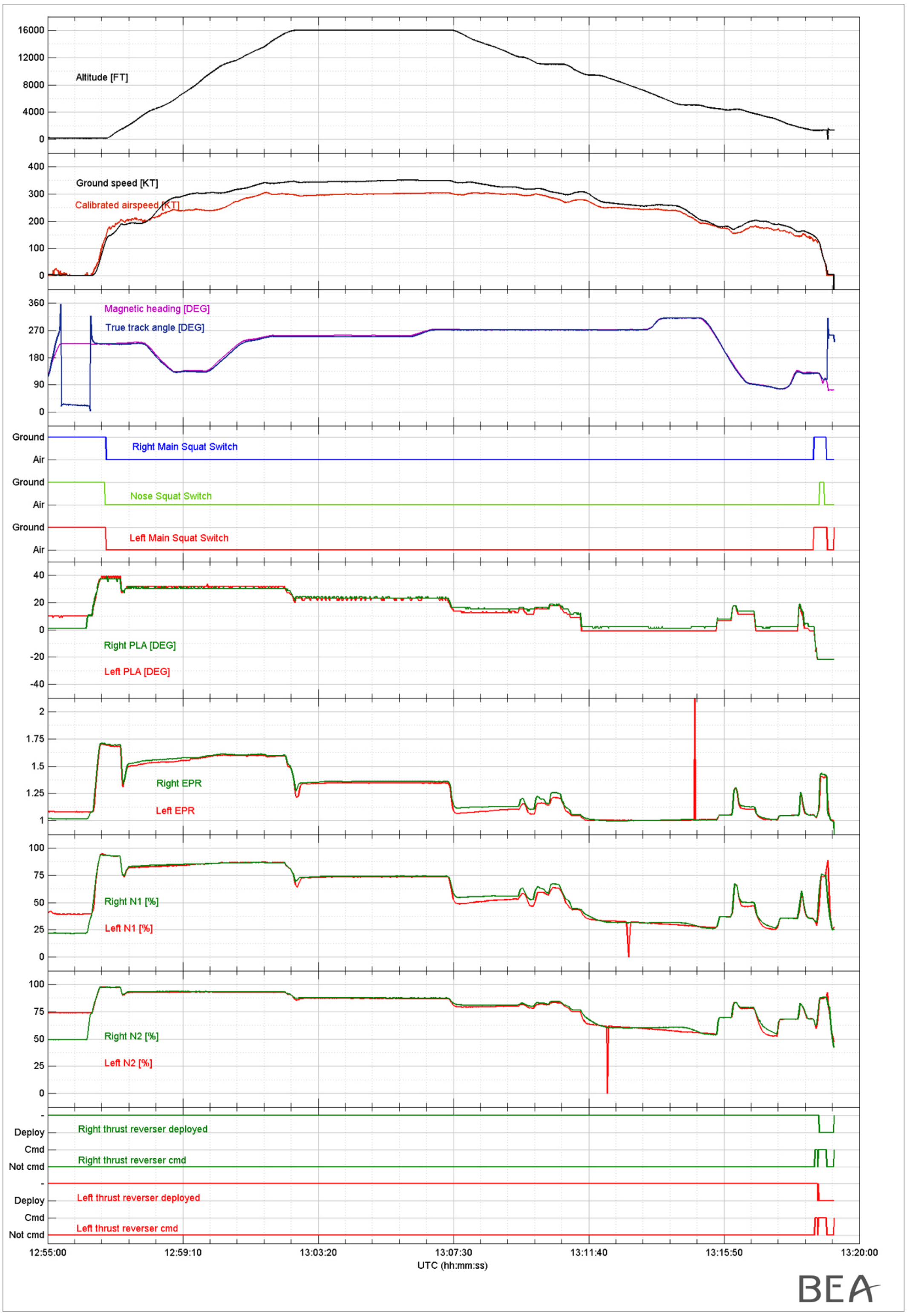


Figure 2 : engine parameters (complete flight)

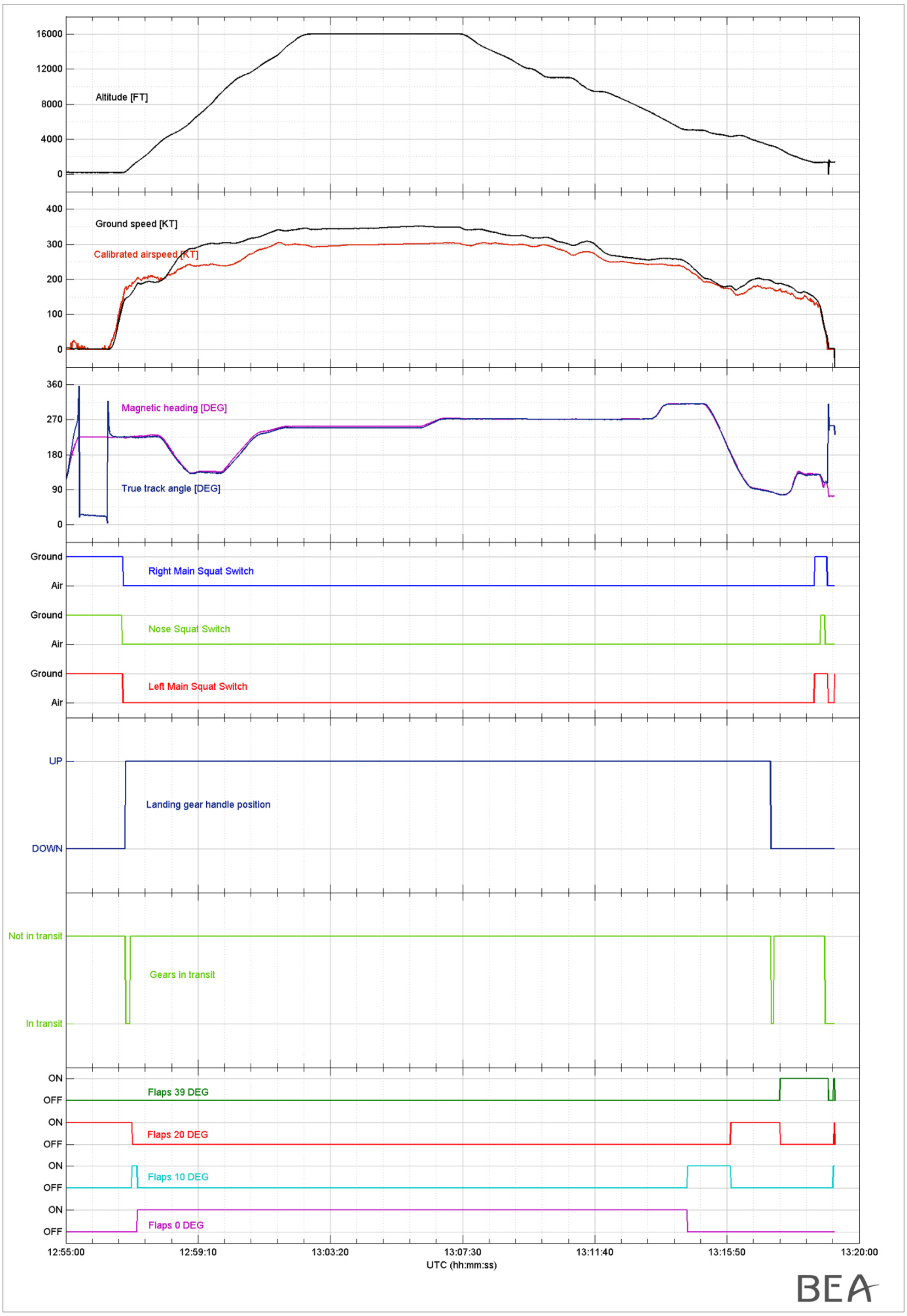


Figure 3: configuration of flaps and landing gear (complete flight)

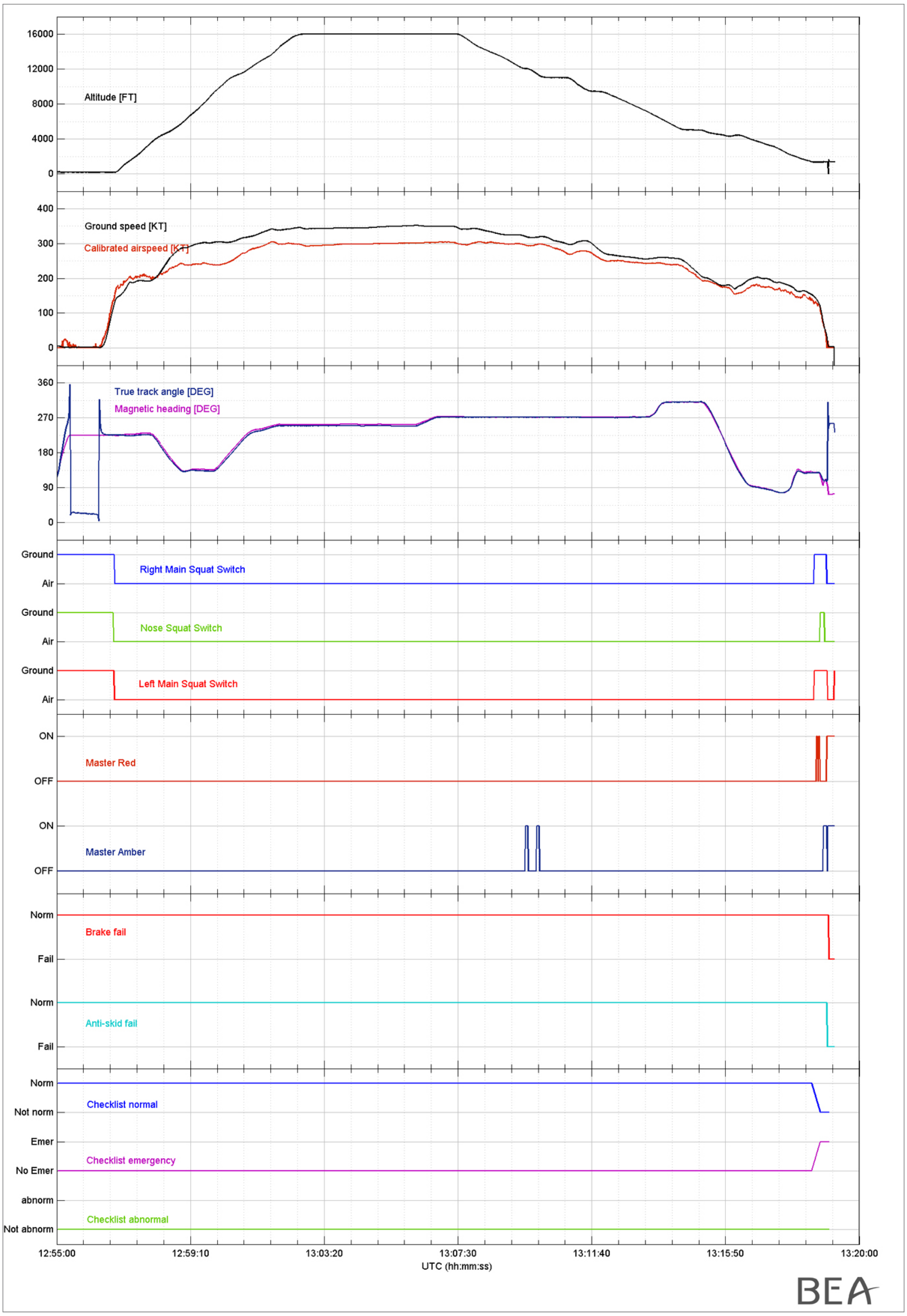


Figure 4: alarms and warnings (complete flight)

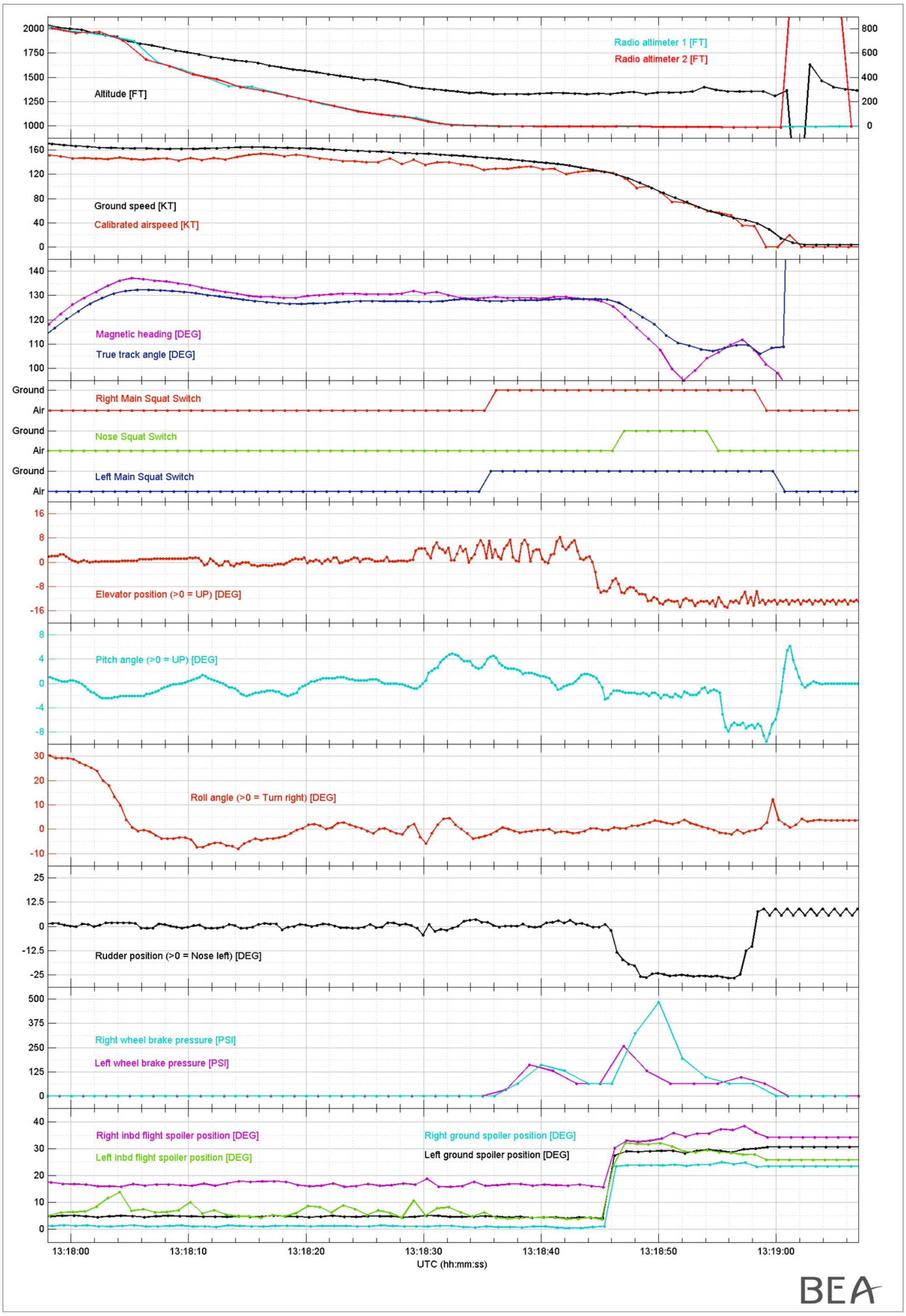


Figure 5: attitudes and position of aeroplane flight control surfaces (last minute)

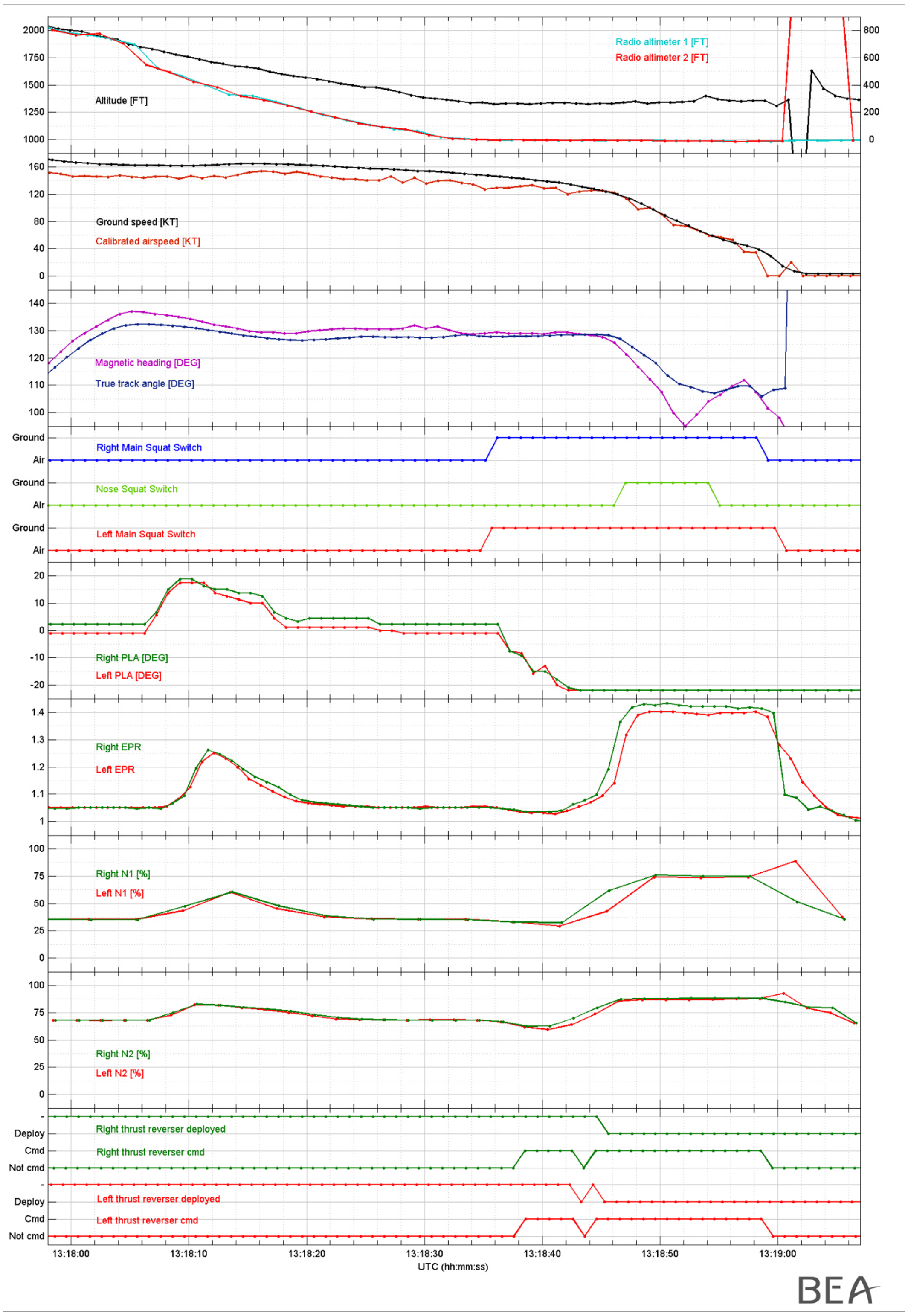


Figure 6: engine parameters (last minute)

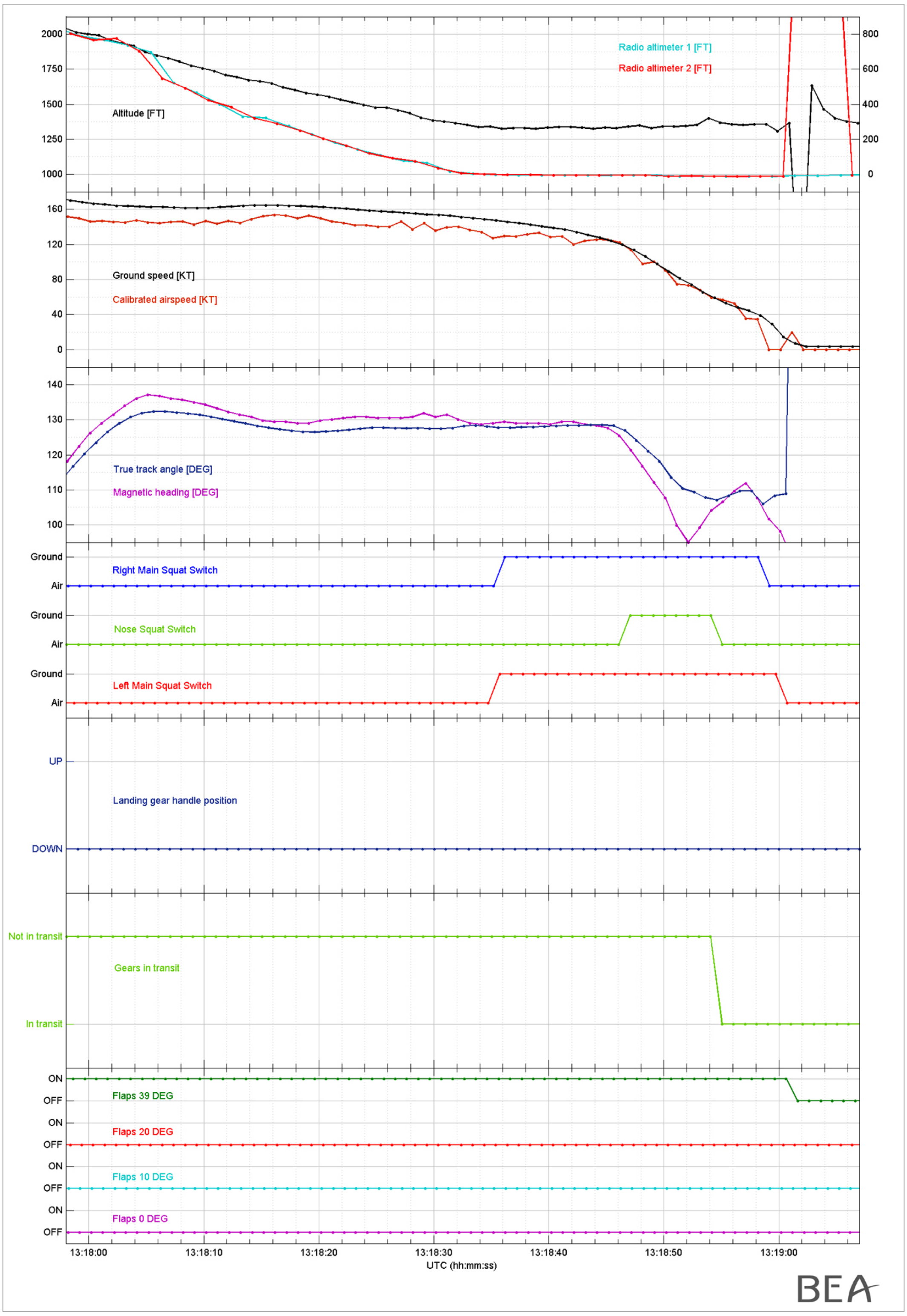


Figure 7: configuration of flaps and landing gear (last minute)

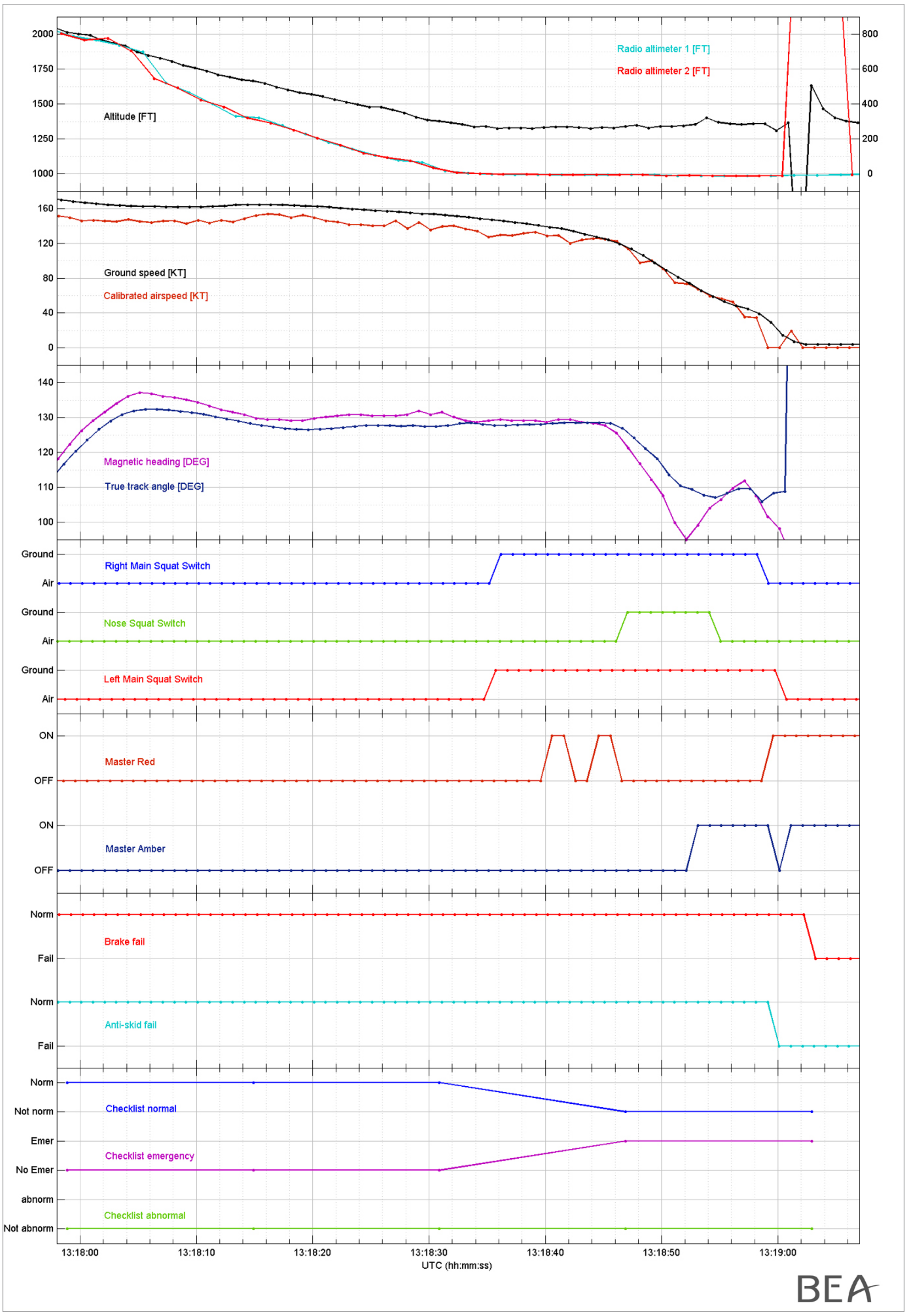


Figure 8: alarms and warnings (last minute)

appendix 3

Determination of warning, caution and advisory messages generated in the cockpit

The table below shows the sequence of messages up to 13 h 18 min 53 as well as the probable reason for their generation:

Number	UTC time	Type of message	Probable event
1	13 h 09 min 37	caution message	ALT MODE OFF
2	13 h 09 min 58	caution message	ALT MODE OFF
3	13 h 13 min 46	advisory message	SPD BRAKE EXTNDED
4	13 h 17 min 20	advisory message	GND SPOILER UNARM
5	13 h 18 min 41	warning message	L-R REV UNLOCK
6	13 h 18 min 45	warning message	L-R REV UNLOCK
7	13 h 18 min 49	advisory message	SPD BRAKE EXTNDED
8	13 h 18 min 53	caution message	Undetermined (off track)

appendix 4

Chronology of emergency response

At the time of the accident, a single aerodrome firefighter was present. He was located in the reception area inside the air terminal. The RFFS manager was not on duty and was not present. The second firefighter had not yet arrived on the airfield.

The AFIS officer triggered the alert at 13 h 18 min 52 s, at the time of the runway excursion. He informed the firefighter of the aeroplane type (M20) and the number of persons on board (3 passengers, unknown number of crew members).

Note: these data were incorrect and the AFIS officer subsequently rectified the information on the Le Castellet frequency concerning the aeroplane model and the number of occupants.

The fire-fighter, who was present in the terminal, immediately went by car to the RFFS hangar.

At 13 h 20 min 32 s, he called out the departure of the foam response vehicle (VIM). He approached the wreckage following the path of the aircraft taken during its runway excursion.

He performed a first response without moving using the foam gun at full flow (about 30 meters from the wreckage) for about 30 seconds. Hindered by trees located between him and the aeroplane, he changed strategy and decided to go around the wreckage by the south.

The estimated time of the first intervention was around 13 h 22 min.

At 13 h 23 min, he requested outside assistance via the Le Castellet frequency.

On the way between the first and second intervention, he stopped at the level of the *''West''* road, probably to discuss with a circuit maintenance engineer on the strategy to adopt.

Photo 1

On photo 1, the foam response vehicle (VIM) has stopped (discussion with circuit staff). It is on its way to the site of the second intervention.

At 13 h 26 min 06 s, the public safety helicopter announced it was taking off.

At 13 h 27 min 07s, the firefighter issued the following message: ''*Except that the aeroplane is blocked ... it is cut into two and the rest of the aeroplane that is to say the cockpit is in the water''*.


Photo 2


Photo 3

On photo 2, (taken by the helicopter that had just taken off), the foam response vehicle (VIM) is in front of a gate not referenced, inside the racing circuit. It has not yet carried out its second intervention.

On photo 3, two outbreaks of fires are visible (wreckage and the slick of kerosene in the pond). The mark of water on the *''east''* road (red circle) shows the location of the first intervention (puddle caused by the drainage of the system).

Photo 4


Photo 5

The second intervention probably took place at about 13 h 28 on the lake and then on the wreckage. About 6 minutes elapsed between the photo taken on the *''west''* access road and photos 4 (second intervention had not yet started) and 5 (second intervention under way).

On photo 5, the vehicle is approximately 30 meters from the wreckage with the water cannon being used at half flow rate until it ran out of water.

At the end of the intervention using foam, he used a powder agent.

At 13 h 41 min 12 s, he said, ''*Yeah so (*) fire-fighters (*) they have now take control of the operations I'm stay next to them er if ever they need some ... of something''* (note: the firefighters in question are those from Le Beausset).

At the end of the intervention and the depletion of the water on board, there were 375 l of foam concentrate in the VIM60 and no powder agent.

appendix 5

Runway tests

Test Platform

Cranfield University (UK) has a test platform capable of creating tyre marks on the ground, for different orientation angles of wheels, different loads and different speeds. The University built a truck to accommodate a metal frame on which is installed a system of two unbraked wheels that can be oriented symmetrically (see photograph below) and tilted sideways. The load on the wheels is controlled by an actuator.

Figure 1 - tyre test platform

The system is equipped with cameras (one of which is thermal) and sensors to measure the forces, rotation speed of the wheels, travel speed of the truck, rotation angle of the wheels, GPS, etc. All of these parameters are recorded.

Description of Tests

The tests took place on 8 and 9 July 2014 on Runway 13 at Le Castellet aerodrome in the presence of the BEA and Gulfstream. In order to approximate the conditions of the event as closely as possible, the tests were carried out with Goodyear Flight Eagle 21x7.25-10 DT tyres, identical to those fitted on the nose gear of N823GA.

For each test, the truck began its acceleration from the threshold of runway 13. The wheels of the test platform were initially oriented on the centreline and were then gradually rotated to reach the requisite steering angle.

For each test, five conditions were defined:

Conditions	Values
Orientation	10°, 20°, 30° (Left and Right)
Vehicle speed	40 mph[1] , 60 mph[2]
Load applied to the wheel	1 000 kg[3] , 1 200 kg[4]
Tyre pressure	93 psi, 116 psi
Lateral camber of the wheel	0°, 7°

Following the passage of the truck, the marks were examined. Their width and the angle between the edge of the mark and the striation (when it was visible) were measured.

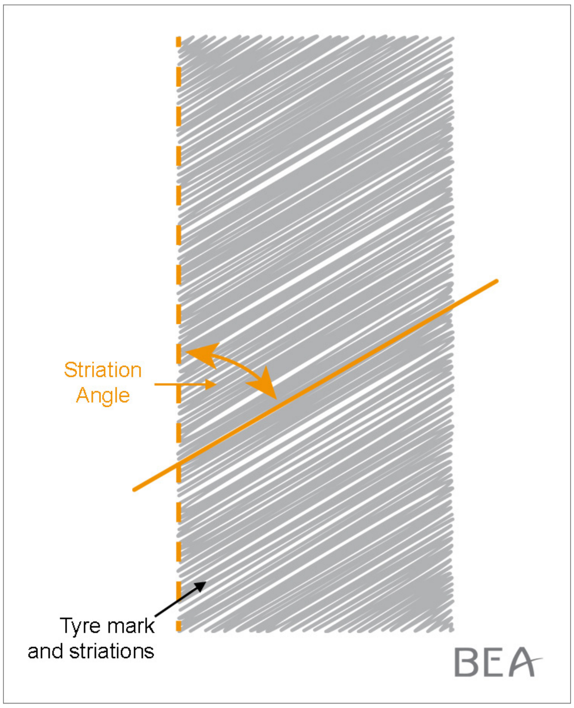
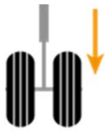
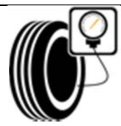


Figure 2: convention for measuring the striation angle

[1] i.e. approximately 35 kt.
[2] i.e. approximately 52 kt.
[3] i.e. approximately 9.8 kN.
[4] i.e. approximately 11.8 kN.

The various tests[5] are listed below:

Test no.	 Orientation (°)	 Vehicle speed (mph)	 Load on wheel (x100 kg)	 Tyre pressure (psi)	 Camber
07	30	40	10	93	0
08	10	40	12	93	0
09	20	40	10	93	0
10	10	40	12	93	0
11	20	40	12	93	0
12	32	40	12	93	0
13	20	40	12	93	7
14	10	60	12	93	7
15	20	60	12	93	7
16	30	60	12	93	7
17	30	60	12	93	0
18	30	60	12	116	7

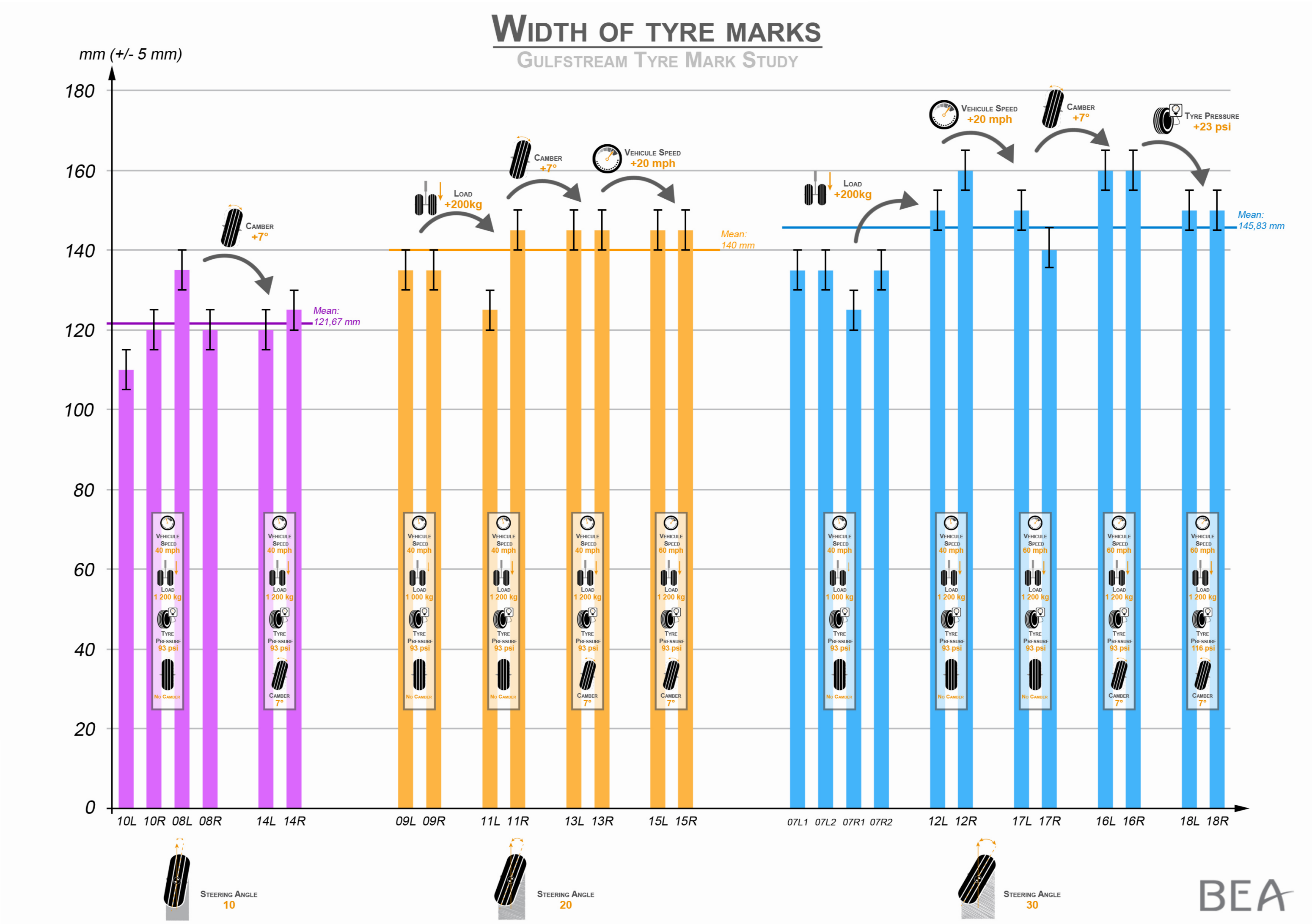
Tyre wear was the only criterion not taken into account and was heterogeneous from one test to another. The manufacturer provided several tyres with different levels of wear for these tests. The goal being to approximate the conditions of the event, it was not relevant to have new tyres.

Measurements

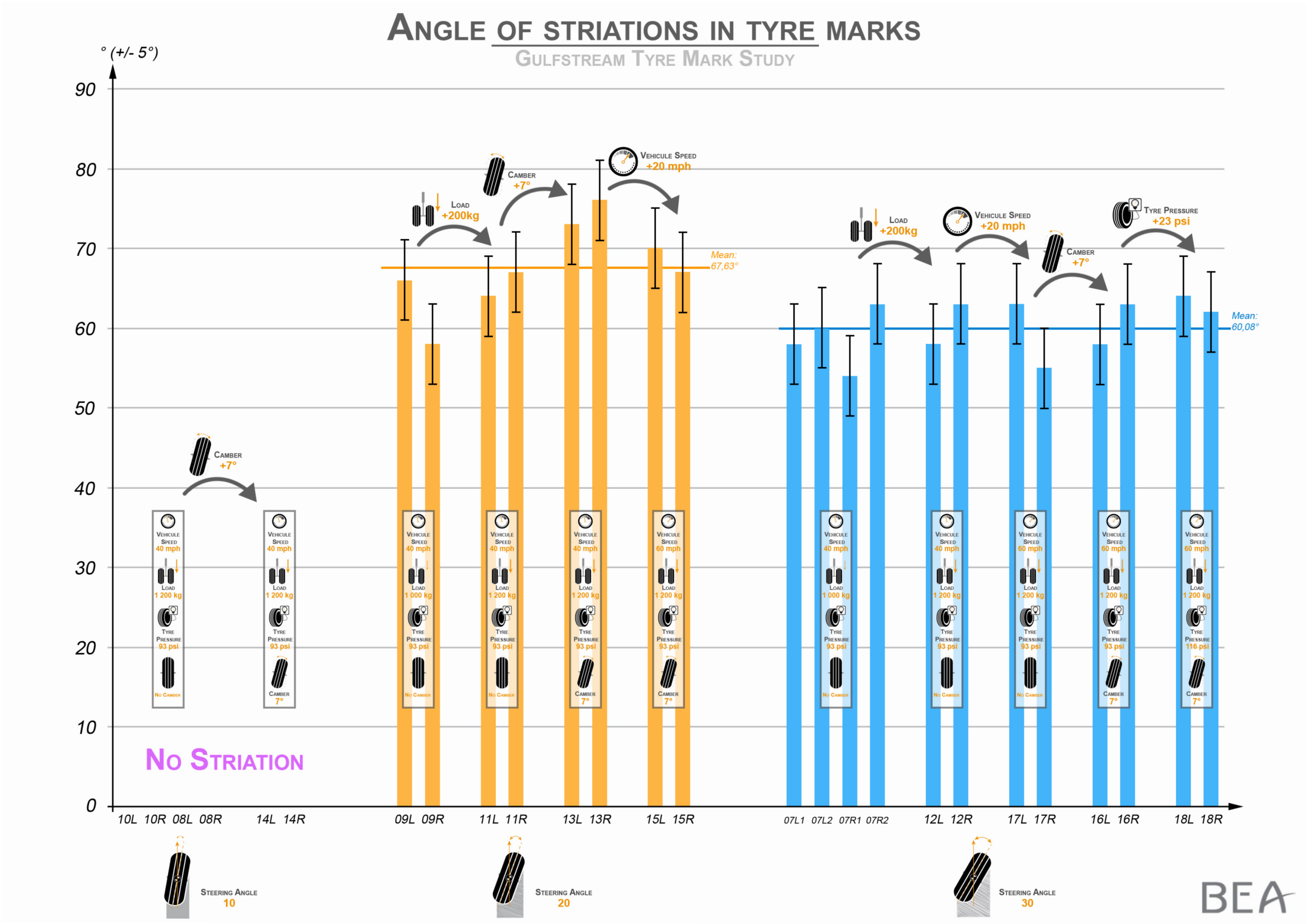
The following illustrations show the various measurements made. For ease of reading, the various tests were grouped by steering angle (10, 20 and 30°). The measurements made on the mark left by the tyre oriented to the left and that oriented to the right are differentiated (L and R) for each test, but are considered in absolute values (without taking into account the direction of the striations). Finally, the various tests are presented here such that to pass from one to another on the graph, only one of the test parameters has been changed. Tests nos. 8 and 10 were carried out under similar conditions and measurements were made at two different points on the marks of test no. 7.

An illustration of marks and measurements for one of the tests is available at the end of this appendix.

[5] The tests start at number 7. Test nos. 1-6 were made in order to become familiar with the machine and the environment. No measurement was made on these tests.



Width of tyre marks
Gulfstream Tyre Mark Study
mm (+/- 5 mm)
180
160
140
120
100
80
60
40
20
0
Camber +7°
Mean: 121,67 mm
Load +200kg
Camber +7°
Vehicule Speed +20 mph
Mean: 140 mm
Load +200kg
Vehicule Speed +20 mph
Camber +7°
Tyre Pressure +23 psi
Mean: 145,83 mm
10L 10R 08L 08R 14L 14R
09L 09R 11L 11R 13L 13R 15L 15R
07L1 07L2 07R1 07R2 12L 12R 17L 17R 16L 16R 18L 18R
Steering Angle 10
Steering Angle 20
Steering Angle 30
BEA



Angle of striations in tyre marks
Gulfstream Tyre Mark Study
° (+/- 5°)
No Striation
Mean: 67,63°
Mean: 60,08°
Camber +7°
Load +200kg
Vehicule Speed +20 mph
Tyre Pressure +23 psi
10L 10R 08L 08R 14L 14R 09L 09R 11L 11R 13L 13R 15L 15R 07L1 07L2 07R1 07R2 12L 12R 17L 17R 16L 16R 18L 18R
Steering Angle 10
Steering Angle 20
Steering Angle 30
BEA

Test Results

The tests resulted in the following findings:

- the orientation of the striations is a parameter directly related to the orientation of the wheels;
- a wheel oriented to the left creates striations oriented to the right (in the direction of travel of the vehicle) and vice-versa;
- no striations were observed for wheel orientations of 10°;
- the angle of the striations (whatever their direction) appears to be primarily dependent on the orientation of the wheels. The other parameters (load, vehicle speed, camber, tyre pressure) do not appear to have a significant influence on the striation angle[6];
- the striations appear to be more or less perpendicular to the orientation of the wheel: a steering angle of 20° will create striations measured at 70°, and striations measured at 60° for an angle of 30°;
- The width of the tyre marks depends on all the parameters:
  - an increase in orientation of the wheel increases the width of the marks;
  - an increase in load increases the width of the marks;
  - an increase in tyre pressure decreases the width of the marks;
  - an increase in the speed of the vehicle does not have much influence on the width of the marks;
  - an increase in the camber does not have much influence on the width of the marks. However the latter seem darker.

[6]This is particularly visible in the tests with a steering angle of 30°.

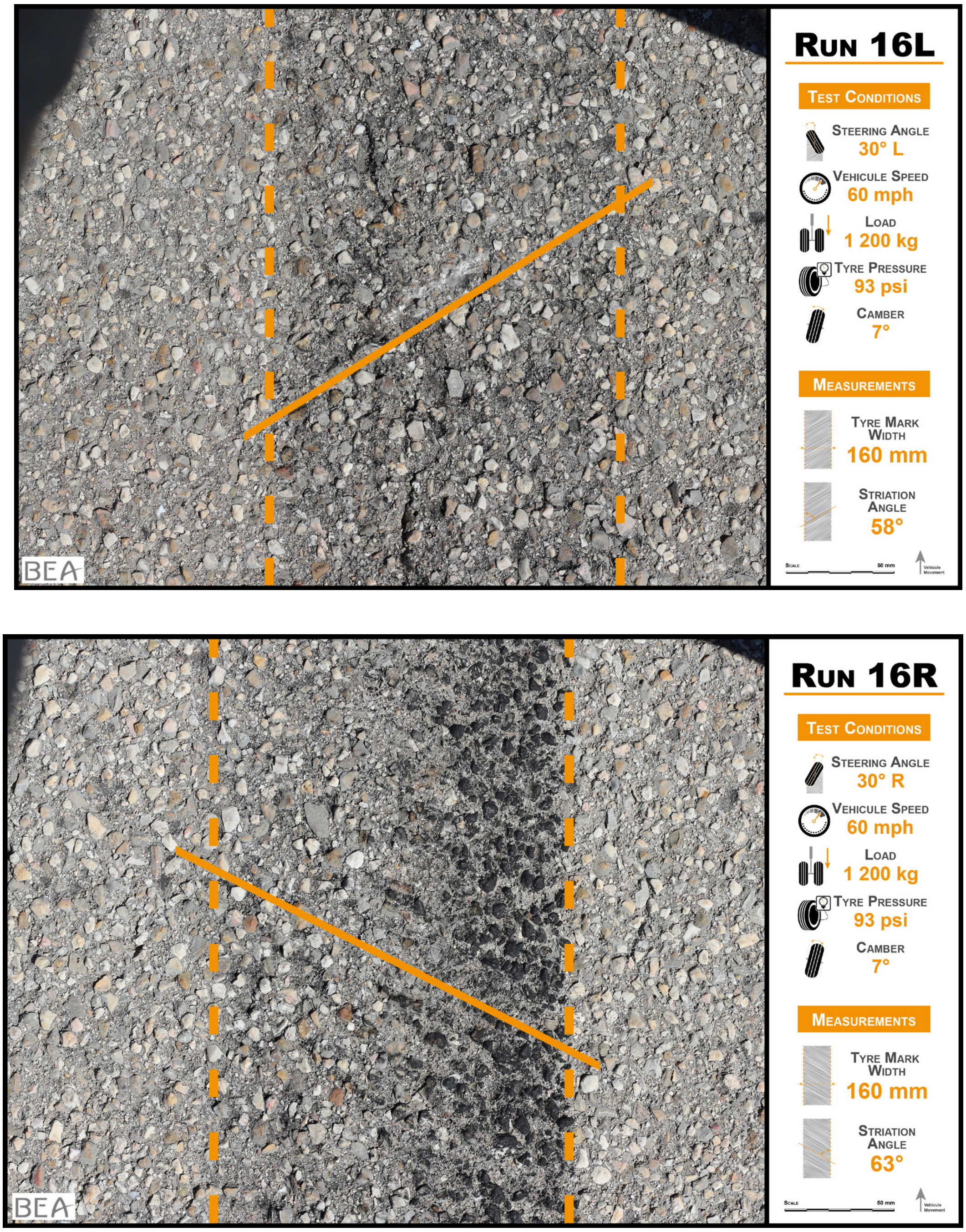
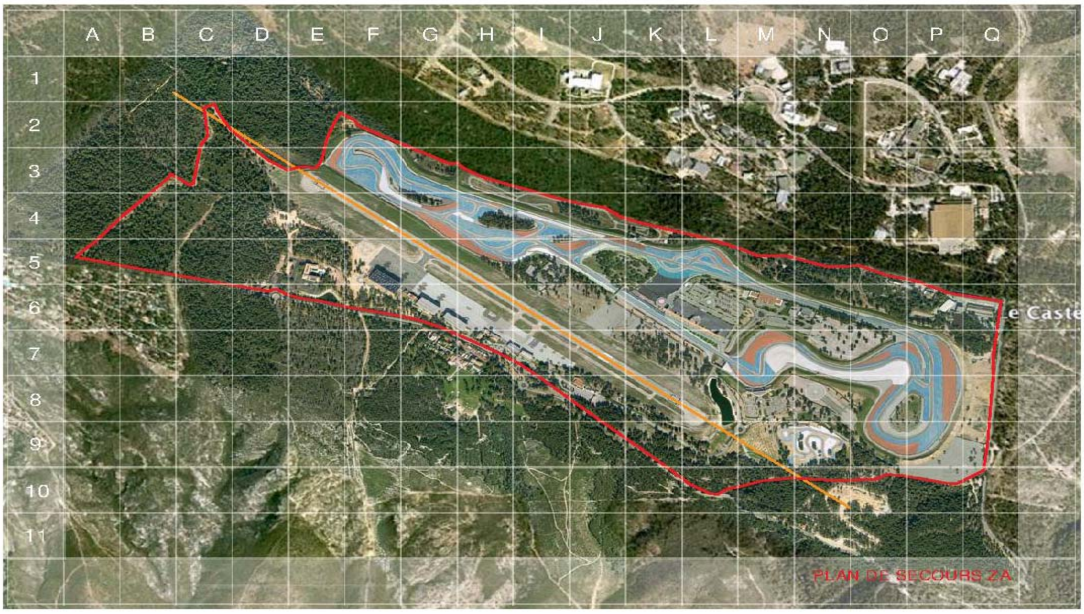


Figure 3: photograph taken at the end of a test

appendix 6

Plan of Le Castellet Aerodrome ZA



From the RFFS Operational Procedures Manual (RCO) at Le Castellet aerodrome

appendix 7

Maintenance and Operations Letter

Gulfstream
A GENERAL DYNAMICS COMPANY

MAINTENANCE AND OPERATIONS LETTER

December 14, 2004
GIV-MOL-04-0029

TO: All Gulfstream IV Operators

SUBJECT: Landing Gear (ATA 32) – Uncommanded Nose Wheel Steering Inputs Require Special Attention

A Gulfstream IV operator recently experienced a nose wheel steering control problem during landing. The cause of this event is currently under investigation.

There are several factors that can make nose wheel steering during landing very challenging; from environmental factors, such as runway conditions and the presence of crosswinds, to uncommanded nose wheel steering. Uncommanded nose wheel steering can go undetected, with no indication in the cockpit until the event has occurred. Vigilance is required on the part of the flight crew to prepare for an unlikely event of this nature.

Normal preparation for countermanding the potential of a nose wheel steering problem during landing requires the pilot to have the capability to apply both full rudder deflection and full brake pedal actuation. Typically flight crews land with their heels on the floor, actuating the rudder pedals for directional control and then slide their feet up the pedals to actuate the brake pedals. For crosswind landings, or potential steering failures, the habit of having your heels on the floor requires that crews assure that brake application is possible with simultaneous full rudder pedal deflection. Proper seat adjustment requires a position that allows for full rudder deflection with the feet located on the brake pedals, and free angular rotation of the ankle is available to command full braking. This usually requires there be a slight bend in the knee with full rudder pedal deflection.

In addition to proper seat positioning, the following steps will be added to the next available revision of the Airplane Flight Manual (AFM) to assist flight crews in the unlikely event an uncommanded steering input is encountered during landing:

Uncommanded Nose Wheel Steering

1. Use differential brakes and rudder for directional control.
2. Nose Wheel Steering Switch..................OFF

The information provided in this letter has been approved by Gulfstream Flight Operations. If you have questions or comments regarding this communication, please contact Gulfstream Customer Support at 800-810-GULF (4853) or 912-965-4178. A Flight Operations representative will be available to answer any questions you may have regarding this subject.

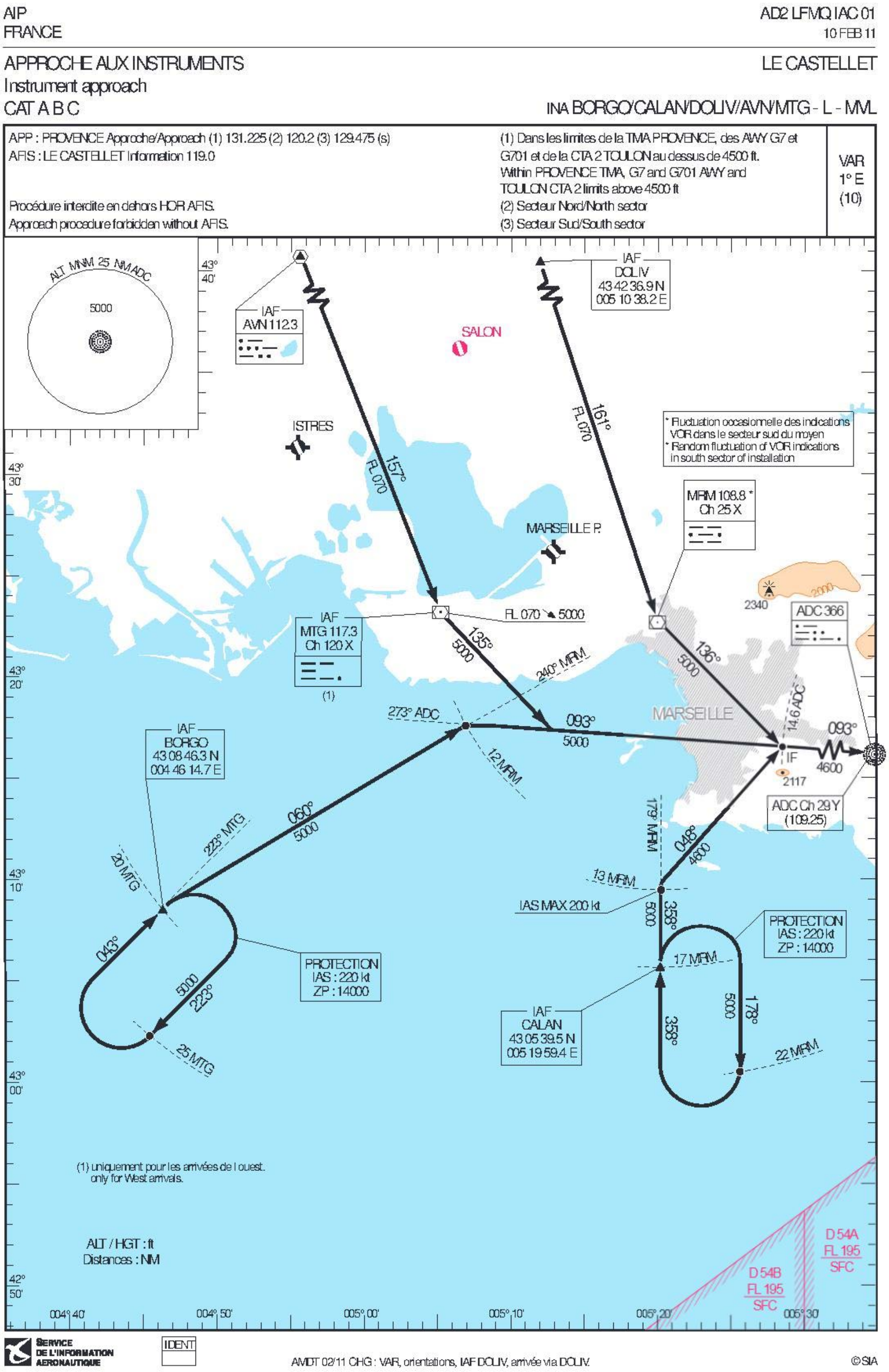
Sincerely,

Mark Burns
Vice President, Customer Support

P. O. Box 2206, Savannah, Georgia 31402-2206 • Telephone: (912)-965-3000 • gulfstream.com

appendix 8

Le Castellet Aerodrome Approach Charts



APPROCHE AUX INSTRUMENTS — **LE CASTELLET**

Instrument approach

CAT A B C

ALT AD : 1391 (50 hPa)

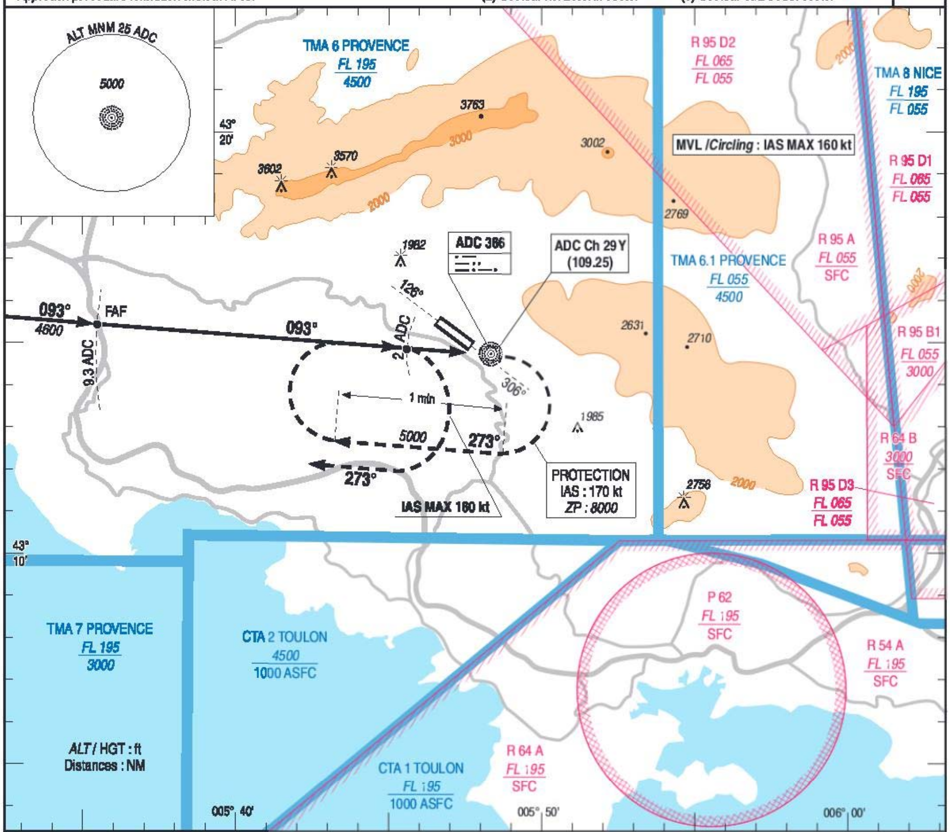
FNA BORGO/CALAN/DOLIV/AVN/MTG - L - MVL

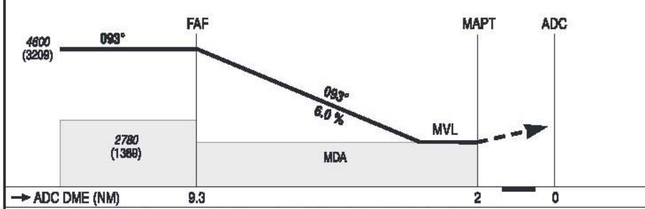
APP : PROVENCE Approche/*Approach* (1) 131.225 (2) 120.2 (3) 129.475 (s)
AFIS : LE CASTELLET Information 119.0

Procédure interdite en dehors HOR AFIS.
Approach procedure forbidden without AFIS.

(1) Dans les limites de la TMA PROVENCE, des AWY G7 et G701 et de la CTA 2 TOULON au dessus de 4500 ft.
Within PROVENCE TMA, G7 and G701 AWY and TOULON CTA 2 limits above 4500 ft
(2) Secteur nord/*North sector* (3) Secteur sud/*South sector*

VAR
1° E
(10)





API : Au **MAPT** tourner à **droite RM 273°** (IAS MAX 160 kt) en montée. A ***4600*** (3209) tourner à **droite vers ADC** en montée vers ***5000*** (3609) pour intégrer l'**attente ADC.**

*Missed APCH : At **MAPT** turn **right MAG 273°** (IAS MAX 160 kt) climbing. At **4600** (3209) turn **right to ADC** climbing to **5000** (3609) to enter **holding pattern ADC.***

MNM AD : distances verticales en pieds, VIS en mètres./*Vertical distances in feet, VIS in meters.* REF HGT : *ALT AD*

CAT	MVL / *Circling* HJ (1)	
	MDA (H)	VIS
A	***2700*** (1300)	1500
B		1600
C		2400

Observations /*Remarks* : (1) MVL interdites au Nord-Est de la piste. / *(1) Circling prohibited NE of RWY.*

APPROCHE AUX INSTRUMENTS
Instrument approach
CAT A B C
ALT AD : 1391 (50 hPa)

LE CASTELLET

L - MVL

APP : PROVENCE Approche/Approach (1) 131.225 (2) 120.2 (3) 129.475 (s)
AFIS : LE CASTELLET Information 119.0

Procédure interdite en dehors HOR AFIS.
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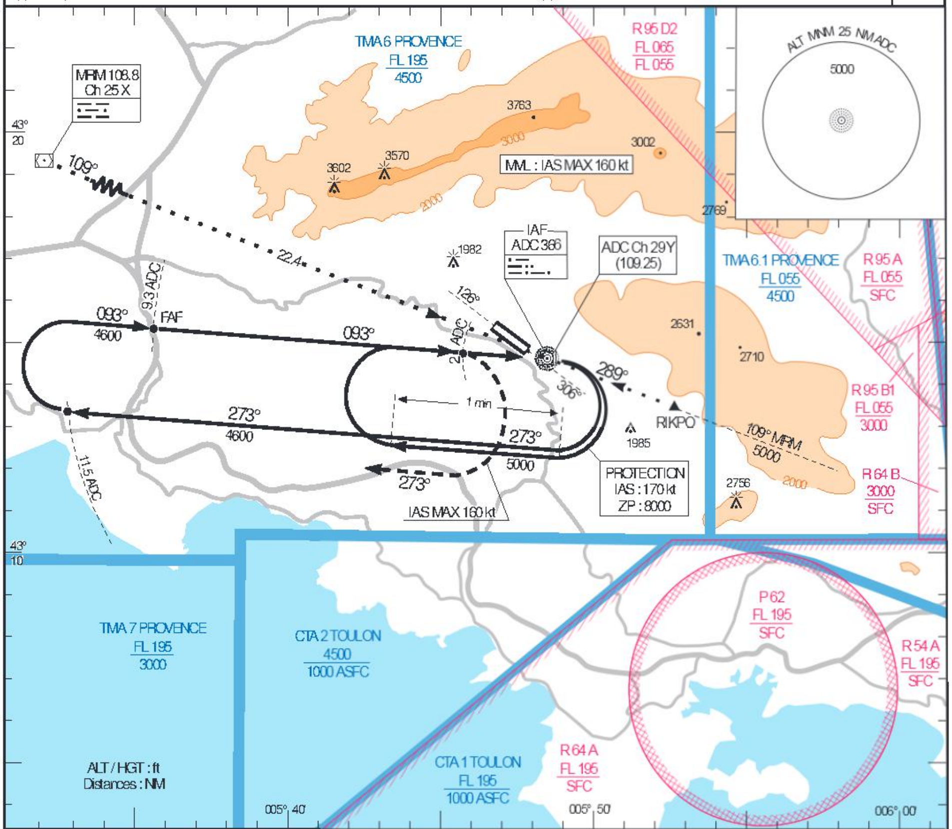
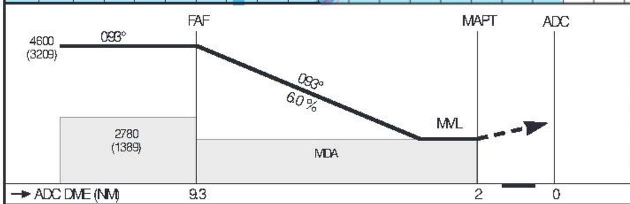
Within PROVENCE TMA, G7 and G701 AWY and TOULON CTA 2 limits above 4500 ft
(2) Secteur nord/North sector
(3) Secteur sud/South sector

VAR
1° E
(10)





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CAT	MVL / Circling HJ (1) MDA (H)	VIS
A	2700 (1300)	1500
B	2700 (1300)	1600
C	2700 (1300)	2400

Observations / Remarks : (1) MVL interdites au Nord-Est de la piste. / (1) Circling prohibited NE of RWY.

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