AAIS Case Reference: 05/2013

AIR ACCIDENT INVESTIGATION SECTOR

PRELIMINARY

SERIOUS INCIDENT INVESTIGATION REPORT

UNRELIABLE AIRSPEED

Airbus A340-600
A6-EHF
ETIHAD AIRWAYS
International Water after Passing Colombo FIR Entering Melbourne FIR
3 February 2013

General Civil Aviation Authority
of
United Arab Emirates

AIRCRAFT ACCIDENT BRIEF

GCAA AAI Report No.:	05/2013
Operator:	ETIHAD AIRWAYS
Aircraft Type and Registration:	Airbus 340-600, A6-EHF
No. and Type of Engines:	4 (four) Rolls-Royce (RR) TRENT 500 Engines
Date and Time (UTC):	2nd February, 2013, 00:50 UTC
Location:	Between Waypoints ELATI and PIPOV after Passing Colombo FIR Entering into Melbourne FIR
Type of Flight:	Passenger Transport
Persons on Board:	295 persons (4 flight crewmembers, 13 cabin crew and 278 passengers)
Injuries:	None
Nature of Damage:	No damage on the Aircraft

The General Civil Aviation Authority (GCAA) was informed of this serious incident, on 6 February 2013 and initiated an investigation on the same day.

In accordance with the Standard Practice of Annex 13 to the Convention on the International Civil Aviation, the International Civil Aviation Organization (ICAO) and the State of Design and Manufacture (France BEA) were notified. The BEA assigned an Accredited Representative to the Investigation. The United Arab Emirates (UAE) Air Accident Investigation Sector (AAIS) of the GCAA is leading the Investigation and will issue the Final Report.

Notes:

1. All times in this Report are Coordinated Universal Time (UTC)
2. The word “Aircraft” in this Report implies the aircraft involved in the serious incident
3. The word “Team” in this Report implies the Investigation Team

OBJECTIVE

This Investigation is performed in accordance with the UAE Federal Act No 20 of 1991, promulgating the Civil Aviation Law, Chapter VII, Aircraft Accidents, Article 48, CAR Part III Chapter 3 and in conformity with Annex 13 to the Convention on International Civil Aviation.

The sole objective of this Investigation is to prevent aircraft accidents and incidents by identifying and reducing safety-related risk. It is not the purpose of this activity to apportion blame or liability.

The information contained in this Preliminary Report is derived from the factual information gathered during the ongoing Investigation of the occurrence. Later interim reports or the Final Report may contain altered information in case that new evidence appears during the ongoing Investigation that requires changes to the information depicted in this Report.

Any specific safety issues identified during the course of this Investigation will be advised to all parties through the GCAA Safety Recommendations (SR) procedure.

Reports are publicly available from:

http://www.gcaa.gov.ae/en/epublication/pages/investigationreport.aspx

TABLE OF CONTENTS

ABBREVIATIONS

AAIS	UAE GCAA Air Accident Investigation Sector
ADIRU	Air Data Inertial Reference Unit
ADM	Air Data Module
ADR	Air Data Reference
ADV	Advisory
ALTN	Alternate
AOA	Angle of Attack
ATA	Air Transport Association Chapter
ATC	Air Traffic Control
ATPL	Air Transport Pilot License
AUTO	Automatic
BEA	Bureau d'Enquêtes et d'Analyses
CAR	UAE Civil Aviation Regulation
CAS	Computed Air Speed
CAPT	Captain
Cb	Cumulonimbus
CG	Center of Gravity
C of A	Certificate of Airworthiness
C of R	Certificate of Registration
CPL	Commercial Pilot License
CVR	Cockpit Voice Recorder
E/WD	Engine/Warning Display
ECAM	Electronic Centralized Aircraft Monitoring
EFIS	Electronic Flight Indication System
ELP	English Language Proficiency
ENG	Engine
EPR	Engine Pressure Ratio
FCC	Flight Control Computer
FCDC	Flight Control Data Concentrator
FCPC	Flight Control Primary Computer
FCSC	Flight Control Secondary Computer
FCTM	Flight Crew Training Manual
FCU	Flight Control Unit
FD	Flight Director
FDR	Flight Data Recorder
FIR	Flight Information Region
FL	Flight Level
FMGEC	Flight Management Guidance and Envelope Computer
FMGES	Flight Management Guidance and Envelope System
FO	First Officer
F/O	First Officer
GCAA	UAE General Civil Aviation Authority

HF	High Frequency
HP	High-Pressure
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IR	Inertial Reference
IRS	Inertial Reference System
ISIS	Integrated Standby Instrument System
LP	Low-Pressure
MAN	Manual
mbar	millibars
MCC	Maintenance Control Center
ND	Navigation Display
M/E	Multi Engines
MMO	Maximum Operating Mach
MSN	Manufacturer Serial Number
No.	Number
NOC	Network Operations Centre
PF	Pilot Flying
PFD	Primary Flight Display
PHC	Probe Heat Computer
PLAN	Flight Plan
P/No.	Part Number
PRIM	Flight Control Primary Computer
QAR	Quick Access Recorder
QRH	Quick Reference Handbook
RR	Rolls-Royce
RVSM	Reduced Vertical Separation Minimum
RWY	Runway
SD	System Display
SDAC	System Data Acquisition Concentrator
SEC	Flight Control Secondary Computer
SFCC	Slat and Flap Control Computer
S/No.	Serial Number
SPD LIM	Speed Limit
SR	Safety Recommendation
STBY	Standby
TAT	Total Air Temperature
UAE	United Arab Emirates
UTC	Coordinated Universal Time
VIB	Vibration
VLS	Lowest Selectable Speed
VMC	Visual Meteorological Conditions
VMO	Maximum Operating Speed

VS1G	Stall Speed at 1g Load Factor
VSW	Stall Warning Speed

SYNOPSIS

On 3 February 2013, at approximately 0049 UTC, an Airbus 340-600, registration A6-EHF, was on en-route, departed from Abu Dhabi International Airport on a scheduled passenger service to Melbourne International Airport with a total of 295 persons onboard: 4 flight crew members, 13 cabin crew and 278 passengers. The captain was the pilot flying and the first officer was the pilot monitoring.

While cruising at FL350, just leaving Colombo FIR and entering Melbourne FIR, the Aircraft encountered moderate to heavy turbulence and experienced significant airspeed oscillations on the captain's and standby indicators. The autopilot, autothrust and flight directors were disconnected automatically. The Aircraft's flight control law changed from "Normal" to "Alternate" Law, which caused the loss of some of the flight mode and flight envelope protections. The change from Normal to Alternate Law occurred twice, thereafter the Alternate Law stayed until the end of the flight. Autothrust and flight directors were successfully re-engaged, however, both autopilots (autopilot 1 and 2) could not be re-engaged thus the Aircraft was controlled manually until its landing. Associated with that, the Aircraft experienced high N_1 vibration on No. 2 engine.

The flight crew decided to divert to Singapore Changi International Airport since the Aircraft had lost the capability to maintain Reduced Vertical Separation Minimum (RVSM). Before landing, the flight crew dumped fuel in order to land the Aircraft below its maximum landing weight.

The landing was uneventful and none of persons onboard was injured.

The GCAA preserved the Flight Data Recorder for download, readout and analysis.

1 FACTUAL INFORMATION

1.1 History of the Flight

On 2 February 2013, , an Airbus 340-600 Aircraft, registration mark A6-EHF departed Abu Dhabi, United Arab Emirates (UAE) on a scheduled passenger flight number ETD460 to Melbourne, Australia with a total of 295 persons on board: 4 flight crew members, 13 cabin crew and 278 passengers. The captain was the pilot flying (PF).

At approximately 0049 UTC, the Aircraft was cruising at FL350[1] on airway N640 between waypoints ELATI and PIPOV just entering Melbourne FIR[2] from Colombo FIR, with autopilot (AP) 1 and autothrust (A/THR) engaged.

The Aircraft was flying in IMC[3] conditions with Alto Cumulus approximately 5,000 to 7,000 feet thick and in light turbulence as stated by the captain and confirmed by the recorders data analysis. The weather radar was showing almost no or very few green returns with the setting on Gain: Auto and Radar Tilt on -0.8 manually.

The turbulence started to increase slightly and radar returns became stronger from mainly black to 80% green, then from green to 80% yellow. There is no auto function of the radar tilt on this Aircraft. Suddenly, the radar returns showed 2-3 millimeters of solid red around the aircraft symbol.

The airspeed indication on the captain's Primary Flight Display (PFD1)[4] started to oscillate slightly, then at 00:50:04, it dropped from 283 Knots to 77 Knots in 2 seconds then briefly back to around 270 knots, while the airspeed on first officer's PFD and on the standby instrument were stable.

At 00:50:10, the captain's airspeed indication decreased from 270 to 76 knots, the first officer's indication was constant while the standby indication decreased from 280 knots to 142 knots.

At 00:50:12, autopilot 1, autothrust and both flight directors were automatically disengaged. On the ECAM[5] page, the flight crew noticed AUTO FLT AP OFF in red[6] and A/THR OFF in amber[7].

At 00:50:15, the Aircraft's flight control law changed from Normal to Alternate Law. All anti-icing and probes/window heaters were turned ON by the flight crew.

At 00:50:18, the captain's airspeed indication increased from 76 knots to 285 knots subsequently both flight directors automatically re-engaged.

At 00:50:22, when the captain's and standby airspeed indications recovered and showed constant at about 282 knots on the captain's side and 276 knots on standby indicator subsequently the control law returned to Normal Law.

At 00:51:02, the captain successfully re-engaged the autothrust while the Engine Pressure Ratio (EPR) started to decrease to match the selected 0.75 Mach Number, simultaneous to that the Aircraft started to depart its cruise altitude.

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[1] FL350 = 35,000 feet above mean sea level when the pressure at sea level is 1013.2 mbar.

[2] Flight Information Region is a specified region of airspace in which a flight information service and an alerting service are provided which is the largest regular division of airspace in use in the world today.

[3] IMC : Instrument Meteorological Conditions

[4] PFD1 : Left Primary Flight Display

[5] Electronic Centralized Aircraft Monitoring is to provide information of the status of aircraft and its systems including caution and warning messages, and Indicate required flight crew actions in most normal, abnormal and emergency situations.

[6] AUTO FLT AP OFF Warning means that autopilot system is disengaged

[7] A/THR OFF Caution means that autothrust is disengaged

Between 00:51:04 and 00:51:48, airspeed significant fluctuations started again on the captain's PFD and the standby indication while the first officer's PFD was stable although airspeed indication reduced continuously from 290 knots to 259 knots.

At 00:51:28, the flight control law reverted to Alternate Law and continued so until the end of the flight. The flight crew noticed NAV ADR DISAGREE in amber[8] and ALTN LAW PROT LOST in amber[9] on the ECAM page.

At 00:51:30, the autothrust automatically disconnected for the 2nd time.

After stabilizing the aircraft, at 00:51:46, the captain transferred control to the first officer since all the first officer's instruments seemed to function properly.

After 00:51:48, the captain's and standby airspeed indications recovered and stabilized about their previous values.

Thereafter, the first officer brought the Aircraft to the FL350 target altitude after its inadvertent climb to around 832 feet above that altitude subsequent to the autopilot's disengagement. The first officer also noticed that red SPD LIM[10] had appeared at the bottom of the speed tape on the right PFD.

At 00:51:54, the autothrust was re-engaged successfully.

The flight crew attempted to re-engage the autopilot several times but neither autopilot 1 nor 2 was successfully re-engaged. The captain's air data was switched to Air Data Reference 3 (ADR 3)[11].

The first officer continued to fly the Aircraft manually with autothrust engaged.

At the time the flight crew initiated the ADR CHECK PROC[12] checklist, the three speed indications (captain, first officer and the Standby) returned to normal except that the speed tapes were showing the SPD LIM flag in red and remained so for the rest of the flight. Consequently the ADR CHECK PROC was not performed. There was no other ECAM action to be completed.

At that time, the flight crew tried to communicate with Brisbane Air Traffic Control (ATC) on the High Frequency (HF) radio in an attempt to advise of the situation but contact could not be established. Consequently a message was sent, via CPDLC[13], to Melbourne ATC declaring PAN-PAN emergency due to Aircraft performance, weather and turbulence.

Together with another captain, who was present on the flight deck having returned from his rest, the flight crew performed reset of all Flight Control Computers (FCCs) and Flight Management Guidance and Envelope Computers (FMGECs) by using the QRH COMPUTER RESET TABLE in an attempt to recover at least one autopilot. Both autopilots were unable to engage after the reset.

The flight crew communicated with the MCC[14] Duty Manager who advised that the Aircraft had sent a N1 high vibration message on No. 2 engine. The flight crew did not notice any Advisory (ADV) message but they could confirm the high N1 vibration on the ECAM ENG (Engine) page.

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[8] NAV ADR DISAGREE caution warning means that two ADR outputs are erroneous, but different, and the remaining ADR is correct, or if all three ADRs are erroneous, but different.

[9] ALTN LAW PROT LOST caution warning means that Dual NAV ADR or NAV IRS failures will cause the loss of autopilot (AP) and autothrust (A/THR) and the flight controls law revert to Alternate Law (ALTN LAW)

[10] SPD LIM red flag warning means Lowest Selectable Speed (VLS) and Stall Warning Speed (V_{SW}) are lost.

[11] ADR3 is the Air Data Reference of the standby system

[12] ADR CHECK PROC is a QRH procedure to identify and to isolate the affected ADRs when unreliable speed indication occurred

[13] Controller Pilot Data Link Communications (CPDLC) is a datalink communication between pilots and controllers which is considered to be the primary means of communication over oceans and in remote areas.

[14] MCC is the Operator's Maintenance Control Center which supports and provides advises on any operational and technical issues during any phase of the operation of the aircraft which is reported by the flight crew.

The MCC also suggested an attempt to reset the computers of both System Data Acquisition Concentrator (SDAC) and Flight Control Data Concentrator (FCDC). After consulting the QRH COMPUTER RESET TABLE, the flight crew attempted the resets but with no effect.

In coordination with the MCC, the flight crew decided to divert to Singapore (WSSS[15]) due to the availability of maintenance and parts and the NOC[16] was informed of the flight crew decision.

Thereafter, the captain advised Melbourne ATC of about the loss of RVSM capability via CPDLC.

The flight crew stated that it took them about 20 minutes to get a reply and clearance from Melbourne ATC via CPDLC to divert towards WSSS and they also tried to communicate via the HF but the quality was very poor.

During the diversion, the Aircraft descended to FL290 in order to vacate the RVSM airspace and to maintain Visual Meteorological Conditions (VMC) since the flight crew could not ascertain the serviceability of the weather radar. However, later on the flight crew realized that it was working normally as the Cumulonimbus clouds on approach to WSSS were displayed properly.

Shortly before descent, with authorization from Jakarta ATC, the flight crew started to dump about 12 tons of fuel in order to land in Singapore at or below the maximum landing weight.

At FL290, other first officer who had returned into the cockpit from his rest took over from the duty first officer. The relieving first officer continued to fly the Aircraft manually until FL100, then, the captain took over the controls and performed an uneventful Instrument Landing System (ILS) approach and landing on Runway (RWY) 02L at Singapore.

1.2 Injuries to Persons

Injuries	Flight Crew	Cabin Crew	Other Flight Crew Onboard	Passengers	Total Onboard	Others
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor	0	0	0	0	0	0
None	2	13	2	278	295	0
TOTAL	**2**	**13**	**2**	**278**	**295**	**0**

1.3 Damage to Aircraft

There was no damage to the aircraft.

[15] WSSS is the ICAO's 4 letter airport code for Singapore Changi International Airport

[16] NOC is the Operator's Network Operations Centre (NOC) is the 24hours designated control centre for Operator's global operations and is resourced to ensure the daily supervision and management of the flight operation, including aircrew.

1.4 Other Damage

None

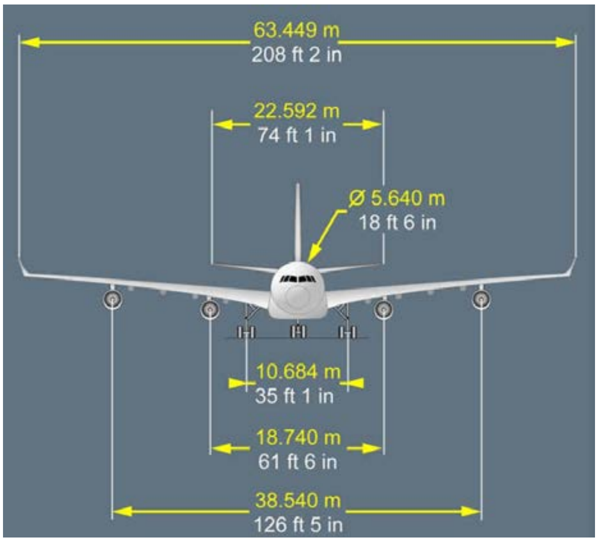
1.5 Personnel Information

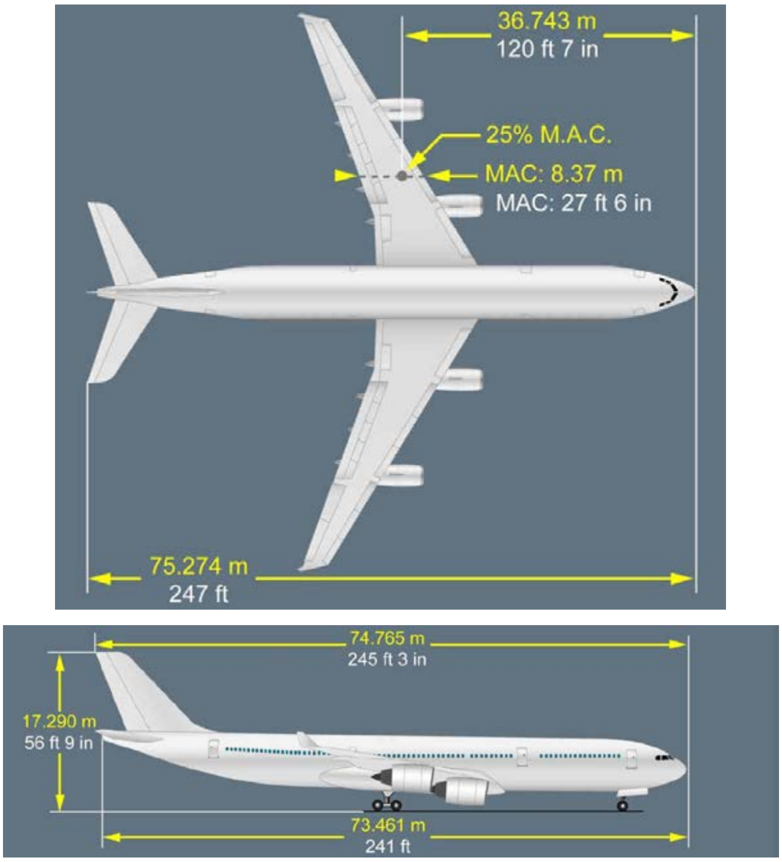
	Captain (on Duty)	First officer (on Duty)	Captain B (Relief)	First Officer B (Relief)
Gender	Male	Male	Male	Male
Date of Birth	31 January 1974	6 September 1988	2 December 1969	22 May 1981
Foreign License Number	Airline Pilot Aeroplanes (Belgium) B 106324	---	Airline Transport Pilot (South Korea) 1933	Airline Transport Pilot (Jordan) 3289
Foreign License Validity	2 June 2008	---	Not Available	18 September 2013
UAE License Number	15984 (Aeroplane)	31870 (Aeroplane)	21947 (Aeroplane)	41662 (Aeroplane)
UAE License Validity	24 March 2016	16 October 2019	13 June 2018	28 June 2019
UAE License Category and Rating	ATPL; M/E Land, A332, A343, A345, A346, ETOPS, CAT III	CPL; M/E Land, INSTRUMENT. A340	ATPL; M/E Land, A330, A340 (P2)	ATPL; M/E Land, A330(P2), A340 (P2)
Class and Date of Last Medical	Class I (One); 11 November 2012	Class I (One); 05 February 2012	Class I (One); 14 February 2012	Class I (One); 8 February 2012
Flying Experience				
Total All Types	10,636.20 Hours	520.04 Hours	9,159.04 Hours	5,759.16 Hours
Total Command on All Types	3,050.47 Hours	---	2,135.04 Hours	1,141.11 Hours
Total on Type	1,094.54 Hours	324.21 Hours	216.46 Hours	189.38 Hours
Total last 1 Year	866.57 Hours	369.35	369.35 Hours	563.22 Hours
Total last 28 Days	71.30 Hours	48.48 Hours	23.49 Hours	27.30 Hours
Total last 14 Days	28.20 Hours	41.54 Hours	23.49 Hours	19.11 Hours
Total last 7 Days	5.26 Hours	20.49 Hours	2.21 Hours	2.21 Hours
English Language Proficiency (ELP)	Level 5	Level 6	Level 5	Level 6

The flight crew performance will be discussed in the Final Report.

1.6 Aircraft Information

Manufacturer :	Airbus
Type :	A340-600
Registration :	A6-EHF
MSN :	837
Engine Manufacturer and Model :	Rolls-Royce TRENT 500
C of A Date of Issue :	28 August 2007 (first issue)
C of R Date of Issue :	7 November 2007 (first issue)

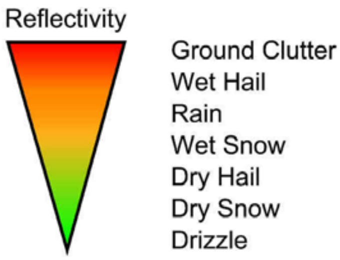




3-VIEW DRAWING

1.6.1 Weather Radar

The weather radar has one main function: weather detection. Weather detection is based on the reflectivity of water droplets. The intensity of the weather echo is linked to droplet size, composition and quantity (e.g. the reflection of water particles is five times greater than ice particles of the same size). The crew must be aware that the weather radar does not detect weather that has small droplets (e.g. clouds or fog), or that does not have droplets (e.g. clear air turbulence).



When the radar is operating, and when the navigation display (ND)[17] is not in PLAN mode[18], the ND displays the weather radar picture. The echoes appear in different colors, depending on the precipitation

[17] The electronic flight instrument system (EFIS) displays mostly flight parameters and navigation data on the primary flight displays (PFDs) and navigation displays (NDs)

[18] This mode statically displays the flight plan legs on a map oriented to true north.

rates (black, green, yellow, red or magenta). The selected ND range will determine how often the image is refreshed.

The tilt angle appears in blue in the lower right-hand corner of the screen along with MAN (Manual) indication. The value of the tilt angle is in degrees, and quarters of a degree. This tilt refers to the angle between the horizon and the radar beam axis (antenna). The radar uses inertial reference system (IRS) data to stabilize its antenna. As a consequence, antenna tilt is independent from the aircraft's pitch and bank angles.

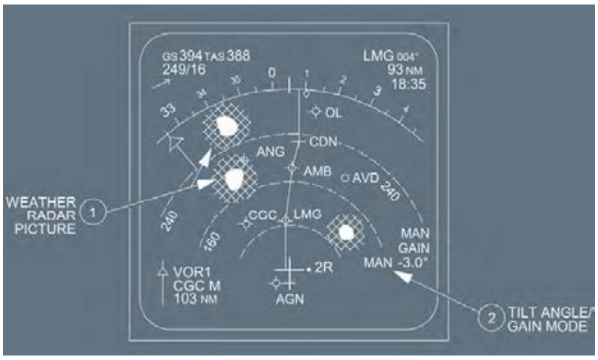
The installed weather radar is not equipped with auto-tilt function which automatically sets the tilt of the beams (set on average of the lower and the upper beam tilts) to optimize the weather radar detection.

To ensure efficient weather monitoring, the flight crew must effectively manage the tilt, taking into account the flight phase and the ND range. Usually, the appropriate tilt value provides ground returns on the top of the ND.

At high altitude, a cell may have ice particles. Reflection of ice particles is weak. An incorrect tilt may lead to only scan the upper (less reflective) part of a cell. As a consequence, a cell may not be detected or may be underestimated.

The flight crew use the GAIN knob to adjust the intensity of the colors of the weather displayed. In standard operation, the flight crew should set the GAIN knob to AUTO (Automatic). The flight crew may manually tune the gain to analyze cells. To detect the strongest part of a cell displayed in red on the ND, the flight crew can slowly reduce the gain. The red areas will slowly become yellow areas, and the yellow areas will become green areas. The last part of the cell to turn yellow is the strongest area. After a cell analysis, the flight crew should reset the GAIN knob to AUTO.

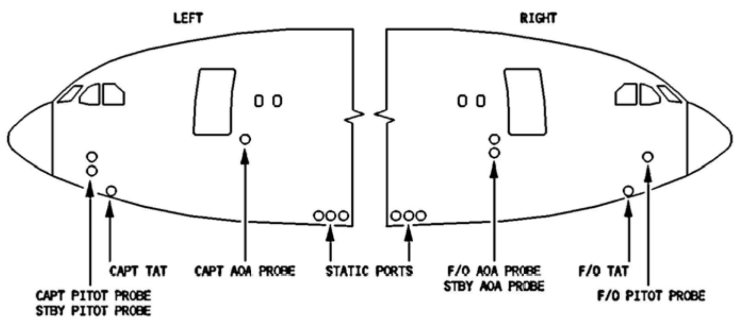
When the manual gain mode is selected, “MAN GAIN” appears in white.



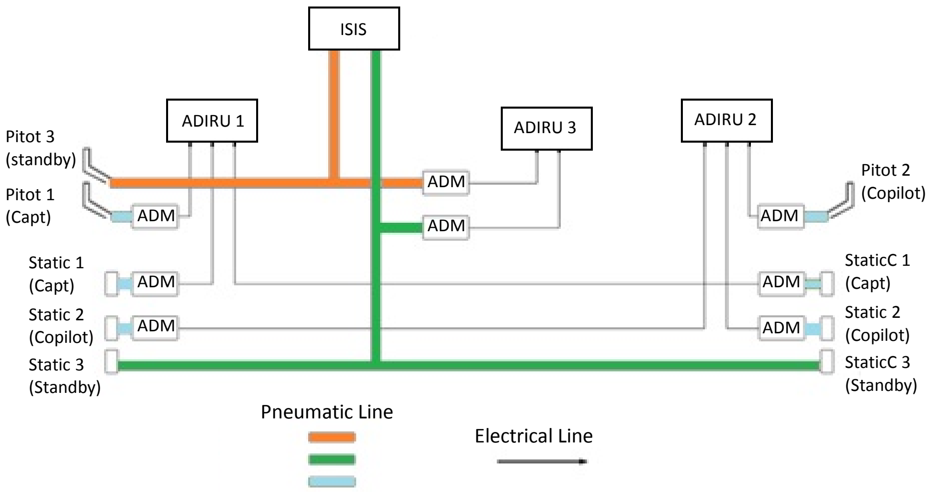
1.6.2 Airspeed Measuring System

The A340-600 has 3 independent systems to provide airspeed and altitude data: captain, first officer and standby systems. The airspeed is measured from the comparison of the total pressure by means of a pitot probe and the static pressure by means of two static ports, which means that the aircraft has three pitot probes and six static pressure ports/sensors. The probes are electrically heated to prevent ice built up during flight and are fitted with drain holes to remove water and/or ice following deicing. The probes are automatically controlled and monitored by three independent Probe Heat Computers (PHCs). Each PHC protects against overheating and indicates fault.

In addition to the pitot probes and static ports, the aircraft also has two Total Air Temperature (TAT) sensors and three Angle of Attack (AOA) sensors.



Each pneumatic air pressure measurement from the pitot probes and static ports are converted into digital electrical signals by eight Air Data Modules (ADMs).



The main items of airspeed information used by the pilot and various aircraft systems are the Computed Air Speed (CAS) and the Mach Number. Three Air Data Inertial Reference Unit (ADIRU) computers are used to detail the CAS and Mach Number.

Each ADIRU has two separate modules: an Air Data Reference (ADR) module which calculates the aerodynamic parameters, such as static air temperature, total air temperature, angle of attack, altitude, calibrated airspeed and Mach Number; and an Inertial Reference (IR) module which provides parameters delivered by the inertial units, such as attitudes and ground speed.

Therefore, the aircraft has three airspeed information decomposition systems which function independently. The pitot probe and two static ports called the “captain probes” deliver ADR 1, while the “first officer probes” deliver ADR 2, and “standby probes” deliver ADR 3.

The CAS is displayed on captain’s PFD from ADIRU 1, first officer’s PFD from ADIRU 2, and the standby instrument known as the Integrated Standby Instrument System (ISIS).

The ISIS determines its airspeed and altitude information directly from the pneumatic inputs of the “standby probes” without being processed by ADMs or an ADR module. The ISIS is a standby instrument integrating airspeed, altitude and aircraft attitude information, which uses the same total and static pressure sensors as ADR 3.

The ADIRUs transmit the calculated parameters to various aircraft systems, including: the Flight Management, Guidance and Envelope System (FMGES) and the fly-by-wire flight controls system.

1.6.3 Flight Guidance System

The flight guidance system of the aircraft uses two FMGECs. The flight guidance part of each computer controls the Flight Director (FD), autopilot (AP) and autothrust (A/THR) which is connected to a Flight Control Unit (FCU).

Flight Director 1 displays the guidance commands from FMGEC 1 on the captain's PFD and Flight Director 2 displays the guidance commands from FMGEC 2 on the first officer's PFD in normal operation with FD push-buttons lit on the FCU (FD engaged).

FMGEC 1 controls the autopilot 1 function and FMGEC 2 controls the autopilot 2 function. The autothrust function is controlled by the FMGEC associated to the engaged autopilot.

The CAS, Mach Number and altitude deviations from all three ADRs are continuously monitored by both FMGECs. At least two ADR outputs must be considered valid for use by the FMGEC. If the computers detect excessive deviation between one ADR output and the outputs of the other two ADRs, then the first ADR output is rejected. If the output of one of the two remaining ADRs is invalid, the autopilot, autothrust and flight director are automatically disconnected. The flight director will automatically re-engage when its associated FMGEC detects at least two valid and consistent ADR outputs.

When the associated autopilot and autothrust become available again, the flight crew needs to re-engage them.

1.6.4 Flight Control System and Protections

The Airbus A340-600 is equipped with fly-by-wire flight controls. The flight control surfaces are electrically controlled and hydraulically actuated. The pilot input on the two side-stick controllers and autopilot inputs are transmitted in the form of electrical signals to flight control computers. The aircraft has three flight control primary computers, called FCPC or PRIM, two flight control secondary computers, called FCSC or SEC, two slat and flap control computers, called SFCC. The role of these computers is to calculate the position of the various control surfaces as a function of the pilot's inputs or autopilot input.

The relationship between the input on the side-sticks or autopilot, and the aircraft's flight control surfaces, is referred to as control law, which determines the handling characteristics of the aircraft.

There are three sets of control laws: Normal, Alternate and Direct Law, and they are provided according to the status of the computers, peripherals, and hydraulic generation.

Normal Law

Flight control normal law provides:

- Pitch control flight mode protection: pitch attitude; load factor; high speed; and high angle of attack
- Lateral control flight mode protection: bank angle
- Flight envelope
- Maneuver load alleviation

The normal law flight mode is a load factor demand law with auto trim and full flight envelope protection.

In manual flight, it provides elevator and Trimmable Horizontal Stabilizer (THS) control from the sidestick controllers to achieve a load factor proportional to stick deflection, independent of speed.

With the autopilot engaged, it provides elevator and THS control according to autopilot and load factor demand. Pitch trim is automatic in both manual and autopilot mode.

Alternate Law

In some double failure cases, the integrity and redundancy of the computers and of the peripherals is not sufficient to achieve Normal Law and its associated protections. System degradation is progressive, and will evolve according to the availability of remaining peripherals or computers.

In addition, depending on the type of failure, the control law may either be Alternate 1 (ALTN1) or Alternate 2 (ALTN2).

Alternate Law characteristics (usually triggered in case of a dual failure):

- In pitch: same as Normal Law
- In roll: same as in Normal Law (ALTN1), or Roll Direct (ALTN2)
- In yaw: same as in Normal Law (ALTN1), or degraded (ALTN2)
- Most protections are lost, except:
  - Load factor protection
  - Bank angle protection, if normal roll is still available (ALTN1 only).

At the flight envelope limit, the aircraft is not protected:

- In high speed, natural aircraft static stability is restored with an overspeed warning
- In low speed (at a speed threshold that is below VLS), the automatic pitch trim is not available, and natural longitudinal static stability is restored, with a stall warning at 1.03 VS1G[19].

In certain failure cases, such as the loss of VS1G computation or the loss of two ADRs, the longitudinal static stability cannot be restored at low speed. In the case of a loss of three ADRs, it cannot be restored at high speed.

In Alternate Law, maximum operating speed or Mach (VMO/MMO) settings are reduced, and α FLOOR [20] protection is inhibited.

Direct Law

In most triple failure cases, direct law is triggered. When this occurs:

[19] Stall speed at 1g load factor, VS1G, is defined as the one-G stall speed at which the airplane can develop a lift force (normal to the flight path) equal to its weight.

[20] ALPHA (α) FLOOR protection is triggered when the FMGECs receive a signal elaborated by the PRIMs. This signal is sent when the aircraft's angle of attack is above a pre-determined threshold function of the aircraft's configuration.

- Elevator deflection is proportional to stick deflection. Maximum deflection depends on the configuration and on the CG
- Aileron and spoiler deflections are proportional to stick deflection, but vary with the aircraft configuration
- Pitch trim is commanded manually
- Yaw damper and minimum turn coordination are provided.

In normal situation, Each FCPC receives airspeed information from the three ADRs and compares the three values. The FCPCs do not use the pressure altitude.

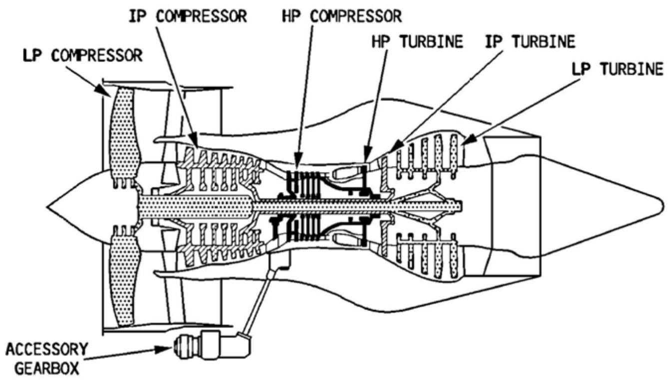
When one ADR output deviates excessively from the other two, it is automatically rejected by the FCPCs and the average value of the two remaining output becomes the chosen value. However, if the difference between these remaining outputs becomes too big, the FCPCs reject them and both autopilots and autothrust are automatically disconnected and the flight control revert to alternate 2 law.

The NAV ADR DISAGREE caution message on the ECAM is triggered by the FCPCs when only 2 ADRs are used and when these 2 ADRs disagree. This caution message appears when one ADR output deviates too much to the other two for more than 10 seconds. The high speed protection (SPD LIM) and low speed protection VLS and VSW are lost on both PFDs. This situation is latched for the remainder of the flight, until the FCPCs are reset on the ground, without any hydraulic pressure.

However, if the ADR output anomaly is only transient, the AP and the A/THR can be re-engaged when the NAV ADR DISAGREE caution message disappears.

1.6.5 Engine

The four (4) Rolls-Royce (RR) TRENT 500 engines installed on the aircraft are three-spool high bypass turbofan engines.



Low-pressure (LP) compressor / turbine

The low-speed rotor (N1) consists of single stage LP compressor (front fan) connected to a five stage LP turbine.

Intermediate pressure (IP) compressor / turbine

The intermediate speed rotor (N2) consists of eight-stage intermediate pressure compressor connected to a single-stage IP turbine.

High-pressure (HP) compressor / turbine

The high-speed rotor (N3) consists of a six-stage HP compressor connected to a single-stage HP turbine.

Combustion chamber

The annular combustion chamber is fitted with 20 fuel nozzles and 2 igniters.

Accessory gearbox

The accessory gearbox, located at the bottom of the fan case, receives torque from the horizontal HP rotor drive shaft and drives the gearbox mounted accessories.

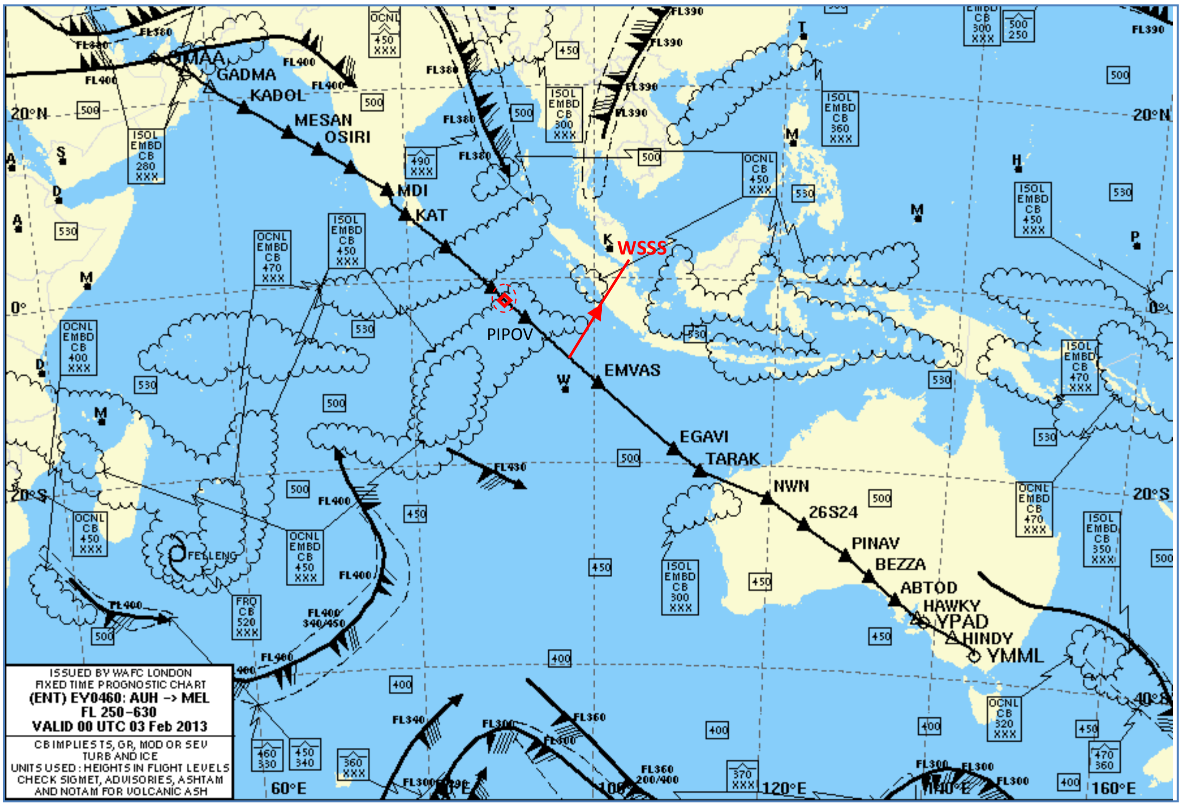
The engine primary parameters are permanently displayed on the upper ECAM Engine/Warning and Display (E/WD).

The secondary parameters are displayed on the lower ECAM system display (SD), when selected either automatically or manually.

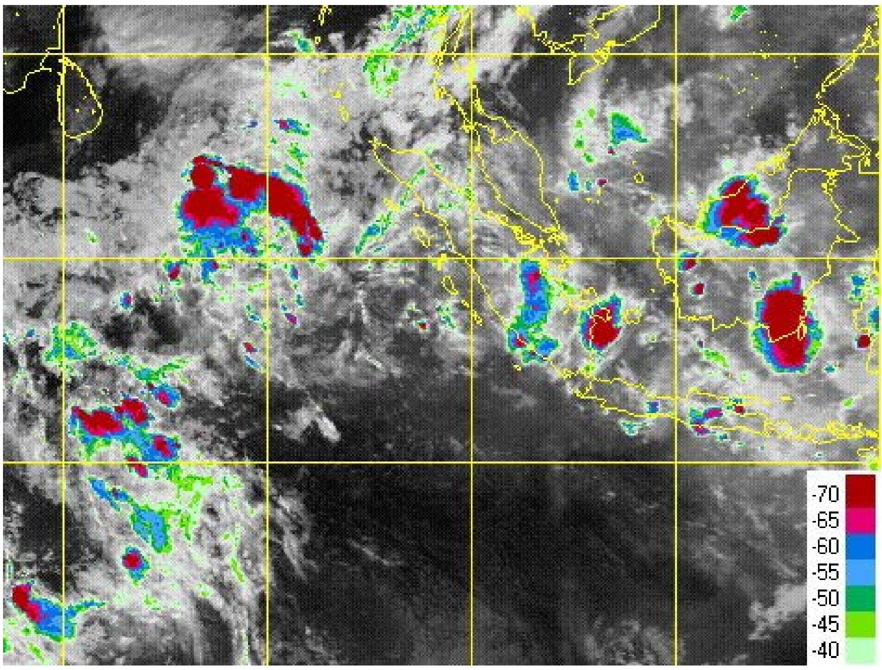
Vibration (VIB) indication is a secondary engine parameter and is indicated in green. It pulses in case of an advisory in flight if N1 VIB is higher than 2.8 units, or 3.6 units with engine anti-ice On (ENG ANTI ICE ON). If VIB indication is not displayed, the ENGINE system page is automatically called up, in case of a vibration advisory.

1.7 Meteorological Information

The dispatch documents provided to the flight crew included a fixed time prognostic chart of the Indian Ocean valid for 00:00 UTC, 3 February 2013 from FL 250 to FL 630. This chart including the flight route plan, indicated an area of isolated embedded cumulonimbus clouds up to FL 450 in the area where the incident occurred before the PIPOV waypoint, just after passing into the Melbourne FIR from the Colombo FIR. The area of isolated embedded cumulonimbus clouds stretched longitudinally from approximately 68^0E to 99^0E and latitudinally from approximately 19^0S to 0^0 (equator line). The red point mark is the Aircraft's position when the occurrence of the incident started, while red line indicates the flight diversion towards Singapore Changi International Airport.



A color satellite image of the area where the incident occurred taken at 16:30 UTC 2 February 2013 was also provided in the dispatch package. This image was taken about 8 hours 20 minutes before of the incident. The image indicated an area of intense convective activity from approximately 5^{0}N down to the equator latitudinally and from approximately 86^{0}E to 92.5^{0}E longitudinally.



1.8 Aids to Navigation

The aids to navigation became a factor in the occurrence of the incident when the Aircraft experienced the disengagement of the autopilot and loss of RVSM capability.

The captain performed an uneventful standard instrument landing system (ILS) approach and landing on RWY 02L at Singapore.

1.9 Communications

Shortly after the occurrence, HF communication was used by the flight crew to communicate with Brisbane ATC and Melbourne ATC, but contact could not be established.

A message via CPDLC was transmitted to Melbourne ATC declaring an emergency: "*PAN PAN unable maintain altitude due to A/C perform, weather, turbulence*"; and "*Aircraft's loss of RVSM capability*". Melbourne ATC replied via CPDLC about 20 minutes later and provided clearance to the Aircraft to divert to Singapore.

SATCOM was used to communicate with the Operator's MCC and NOC to obtain resolve the technical and operational issues and to coordinate the diversion. SATCOM was also used to inform Operator's NOC of the intention to divert.

The flight crew established communication with Jakarta ATC in order to obtain authorization for dumping fuel before the descent towards WSSS.

There were no communications issues between the Aircraft and Changi Approach, Tower or Ground.

1.10 Aerodrome Information

Not applicable

1.11 Flight Recorders

The Aircraft was equipped with a Cockpit Voice Recorder (CVR), a Digital Flight Data Recorder (DFDR) and a Digital AIDs Recorder (DAR) which is also called a Quick Access Recorder (QAR).

The DFDR was an L-3 Comm, P/No. 2100-4043-02 and S/No. 000285751. The DFDR was taken to the Flight Recorder Laboratory at the GCAA Headquarters in Abu Dhabi for download and analysis. The GCAA-AAIS was able to retrieve useful information from the DFDR.

The DAR information was retrieved by the Operator as part of his Flight Data Monitoring (FDM) program. The data provided valid information and will be used in the later analysis.

The CVR recorded the final 120 minutes of the flight. Since the diversion flight took approximately 3 hours from the occurrence until the Aircraft landing, the information pertaining to the incident was not captured.

1.12 Wreckage and Impact Information

Not Applicable

1.13 Medical and Pathological Information

Not applicable

1.14 Fire

Not applicable

1.15 Survival Aspects

Not applicable

1.16 Tests and Research

To be defined

1.17 Organizational and Management Information

The Operator was established by Royal (Amiri) Decree in July 2003 and commenced commercial operations in November 2003, and currently (as of February 2013), has a fleet of 67 Airbus and Boeing aircraft operating more than 1,300 flights per week, serving an international network of 85 passenger and cargo destinations in 55 countries.

1.18 Additional Information

1.18.1 Unreliable Airspeed Indications - Operator's Flight Crew Training Manual

The ADRs detect most of the failures affecting the airspeed or altitude indications. These failures lead to:

- Lose the associated speed or altitude indications in the cockpit
- Trigger the associated ECAM alerts

However, there may be cases where an airspeed and/or altitude output is erroneous and the ADRs do not detect it as erroneous. In such a case, no ECAM alert is triggered and the cockpit indications may appear to be normal whereas they are actually false. Flight crews must have in mind the typical symptoms associated with such cases in order to detect this situation early and apply the "UNRELIABLE SPEED INDIC/ADR CHECK PROC" QRH procedure.

Main Reasons for Erroneous Airspeed/Altitude Data

The most probable reason for erroneous airspeed and/or altitude information is an obstruction of the pitot and/or static probes. Depending on how the probe(s) is obstructed, the effects on cockpit indications differ.

It is highly unlikely that all of the aircraft probes will be obstructed at the same time, to the same degree and in the same way. Therefore, the first effect of erroneous airspeed/altitude data in the cockpit will most probably be a discrepancy between the various indications (CAPT PFD, F/O PFD and STBY instruments).

Consequences of Obstructed Pitot Tubes or Static Probes

All the aircraft systems which use anemometric data, have built-in fault accommodation logics. The fault accommodation logics rely on a voting principle: When the data provided by one source diverges from the average value, the systems automatically reject this source and continue to operate normally using the remaining two sources. The flight control system and the flight guidance system both use this voting principle.

Normal Situation

Each FCPC receives speed information from the three ADRs and compares the three values. The FCPCs do not use pressure altitude.

Each FE (Flight Envelope) computer receives speed and pressure altitude information from the three ADRs and compares the three values.

One ADR Output is Erroneous and the Two Remaining Outputs are Correct

The FCPCs and the FEs eliminate the erroneous ADR. On A340-500/600s, if one ADR deviates, and if this ADR is used to display the speed information on either the CAPT or F/O PFD, a NAV IAS DISCREPANCY ECAM caution is triggered. Furthermore, the autoland capability is downgraded to CAT 3 SINGLE.

Two ADR Outputs are Erroneous, but Different, and the Remaining ADR is Correct, or if All Three ADRs are Erroneous, but Different

Both the AP and A/THR disconnect. If the disagree lasts for more than 10 s, the FCPCs trigger the NAV ADR DISAGREE“ ECAM caution.

The flight controls revert to ALTN 2 law. The high speed and low speed protections are lost.

On both PFDs:

- The SPD LIM flag appears
- No VLS and no VSW is displayed

This situation is latched for the remainder of the flight, until the FCPCs are reset on ground, without any hydraulic pressure.

However, if the anomaly is only transient, the AP and the A/THR can be re-engaged when the disagree disappears.

In-Service Experience of High Altitude Pitot Obstructions

Analysis of the in-service events shows that:

- At high altitude, typically above FL 250, the cases of unreliable speed situation are mostly a temporary phenomenon: They are usually due to contamination of the pitots, by water or ice, in particular meteorological conditions. In-service experience shows that such a contamination typically disappears after few minutes, allowing a recovery of normal speed indications.

1.18.2 "UNRELIABLE SPEED INDIC/ADR Check PROC" QRH Procedure

The "UNRELIABLE SPEED INDIC/ADR CHECK PROC" procedure according to the Operator's Flight Crew Training Manual (FCTM) has two objectives:

- To identify and isolate the affected ADR(s),
- If not successful, to provide guidelines to fly the aircraft until landing.

It includes the following steps:

1. Memory items (if necessary),
2. Troubleshooting and fault isolation,
3. Flight using pitch/thrust references or the Back-Up Speed Scale (BUSS, below FL 250), if troubleshooting has not been successful in isolating the faulty ADRs.

When to Apply This Procedure

The flight crew should consider applying the relevant "UNRELIABLE SPEED INDIC/ADR CHECK PROC" procedure when:

- The "UNREL SPD PROC… APPLY" action line is displayed on ECAM, for example due to the NAV ADR DISAGREE or A.ICE CAPT (F/O) (STBY) PITOT HEAT alerts, or
- The flight crew suspects an erroneous indication, without any ECAM alert.

The flight crew can suspect an erroneous speed/altitude indication, in the following cases:

1. A speed discrepancy (between ADR1, 2, 3 and standby indications),
2. Fluctuating or unexpected changes of the indicated airspeed or altitude,
3. Abnormal correlation between the basic flight parameters (pitch, thrust, airspeed, altitude and vertical speed indications). For example:
   - The altitude does not increase, whereas there is an important nose-up pitch and high thrust,
   - The IAS increases, whereas there is an important nose-up pitch,
   - The IAS decreases, whereas there is an important nose-down pitch,
   - The IAS decreases, whereas there is a nose-down pitch and the aircraft is descending.
4. An abnormal behavior of the AP/FD and/or the A/THR,
5. The STALL warning triggers, the OVERSPEED warning triggers, or the FLAP RELIEF message on the E/WD appears, and this is in contradiction to the indicated airspeeds. In this case:
   - Rely on the STALL warning. Erroneous airspeed data does not affect the STALL warning, because the STALL warning is based on Angle Of Attack (AOA) data,
   - Depending on the situation, the OVERSPEED warning may be false or justified. When the OVERSPEED VFE warning triggers, the appearance of aircraft buffet is a symptom that the airspeed is indeed excessive.
6. The barometric altitude is not consistent with the radio altitude (when the RA is displayed),

7. The aerodynamic noise reduces whereas the indicated airspeed increases, or vice versa,
8. On approach, it is not possible to extend the landing gear using the normal landing gear system.

Note:

1. *Crew coordination is important. The PNF should confirm any discrepancy:*
   - *Between the standby airspeed indication and the speed indication on his/her PFD,*
   - *Between his/her PFD and the Pilot Flying's PFD.*
2. *Because the barometric altitude may be erroneous, the aircraft may not be able to accurately maintain level flight. In addition, the ATC transponder may transmit an incorrect altitude to ATC or to other aircraft, which can lead to confusion. Therefore, the flight crew should advise ATC of the situation without delay.*

1.18.3 QRH Computer Reset Table

This table below lists the computers that had been reset in an attempt to re-engage the autopilot.

Most of the computers' reset capability is provided on the overhead RESET panel.

To reset a computer:

- Set the related normal cockpit control OFF, or pull the corresponding reset pb,
- Wait 3 s, if a normal cockpit control is used (unless a different time is indicated), or 1 s if a reset pb is used,
- Set the related normal cockpit control ON, or push the corresponding reset pb,
- Wait 3 s for the end of the reset.

WARNING	Do not reset more than one computer at a time, unless instructed to do so.

The following table lists the various computers for which manual reset capability is provided:

- On the overhead RESET panels,
- On the system control panel.

For each computer reset, the table lists the effects and/or precautions where applicable ("NIL" indicates no additional effects and/or precautions apply).

- A computer reset has to be attempted when:
  - recommended by an ECAM procedure or
  - recommended by a paper procedure.
- In all other circumstances, where a failure is suspected or detected, there is no specific recommendation as to whether a reset should be performed or not, except those where a reset is specifically forbidden.

Manual reset on ground triggers a complete power up test.

The number of reset attempts is not limited.

ATA	EQUIPMENT	REMARK
22	FMGEC	FMGEC reset results in onside AP disconnection (if engaged). It is recommended to use the FMGEC reset pb , rather than the FM reset pb.
27	FCPC and FCSC *	- FCPC/FCSC may be reset, except in the following case: • The DC BUS 2 FAULT caution is present. *Note:* *Do not attempt a reset because this would result in a loss of related FCPC/FCSC* - If a reset is performed on ground, it must be followed by a flight controls' check WARNING Do not reset more than one computer
	FCDC	NIL
31	SDAC	NIL

1.19 Useful or Effective Investigation Techniques

None

2 ANALYSIS

To be determined

3 CONCLUSIONS

To be determined

3.1 Findings

To be determined

3.2 Causes

To be determined

3.3 Contributing Factors to the Serious Incident

To be determined

4 SAFETY RECOMMENDATIONS

To be determined

5 ONGOING INVESTIGATION

The GCAA AAIS will provide updates on the investigation in line with the recommendations of ICAO Annex 13.

If no cause has been identified within 12 months of this serious incident, an Interim Report will be published to update on the progress of the investigation.

Any specific safety issues identified during the course of the investigation will be advised to all parties through the GCAA Safety Recommendations (SR) procedures.

Upon completion of the factual data collection, analysis, determination of the findings, causes and contributing factors associated with the investigation's conclusions, the Air Accident Investigation Sector will determine which safety recommendations are required. These will be detailed in the Final Investigation report which will be published.