Contents

Air Accidents Investigation Branch

Aircraft Incident Report No: 5/2007 (EW/C2005/03/02)

Aircraft Operator:	British Mediterranean Airways Limited (known as BMED)
Aircraft Type and Model:	Airbus A321-231
Registration:	G-MEDG
Location:	On final approach to Runway 36, Khartoum Airport, Sudan
Date and Time:	11 March, 2005 at 0033hrs
	All times in this report are UTC

Synopsis

The incident was notified to the Air Accidents investigation Branch (AAIB) on 14 March 2005. By that time the aircraft had returned to the UK where the aircraft's Flight Recorders were interrogated. The AAIB investigation team comprised:

Mr J J Barnett	(Investigator-in-Charge)
Mr N C Dann	(Operations)
Mr P Wivell	(Flight Recorders)

The aircraft was attempting to land at Khartoum by night in conditions initially reported as blowing sand but which were in fact consistent with a forecast dust storm. Runway 36 was in use but the ILS on this runway was out of service. The commander assessed the weather conditions passed to him by ATC and believed that he was permitted, under his company's operations policy, to carry out a Managed Non-Precision Approach (MNPA) to Runway 36. This type of approach requires the autopilot to follow an approach path defined by parameters stored in the aircraft's commercially supplied Flight Management and Guidance System (FMGC) navigation database.

On the pilot's approach chart, which was also commercially supplied but from a different supplier, the final descent point was depicted at 5 nm from the threshold of Runway 36 whereas the FMGC's navigational database had been correctly updated with a recent change to this position published by the Sudanese CAA which placed it at 4.4 nm from the threshold. The discrepancy amounted to a difference in descent point of 0.6 nm from the Khartoum VOR/DME beacon, the primary navigation aid for the non-precision approach.

The pilots commenced the approach with the autopilot engaged in managed modes (ie the approach profile being determined by the FMGC instead of pilot selections). The aircraft began its final descent 0.6 nm later than the pilots were expecting. Believing the aircraft was high on the approach, the handling pilot changed the autopilot mode in order to select an increased rate of descent. The approach became unstable and the aircraft descended through 1,000 ft agl at an abnormally high rate. The aircraft then passed through its Minimum Descent Altitude (equivalent to a height of 390 ft agl) with neither pilot having established the required visual references for landing. Instead each pilot believed, mistakenly, that the other pilot was in visual contact with the runway approach lights.

When the confusion between the two pilots became apparent, the aircraft had descended to approximately 180 ft agl and the handling pilot commenced a go-around. Between 3.4 and 5.1 seconds later, with the aircraft at a radio altitude of approximately 125 ft agl, in a position approximately 1.5 nm short of the runway, the Enhanced Ground Proximity Warning System (EGPWS) "TERRAIN AHEAD, PULL UP" audio warning was triggered. The correct emergency pull-up procedure was not followed in full, partly because the handling pilot had already initiated a go-around. The minimum recorded terrain clearance achieved during the recovery manoeuvre was 121 ft.

One further non-precision approach to Runway 36 was attempted using selected autopilot modes. The crew were attempting a third approach when they received visibility information from ATC that was below the minimum required for the approach. The aircraft then diverted to Port Sudan where it landed without further incident.

The following causal factors were identified:

1. The pilots were unaware of a significant discrepancy between the approach parameters on the approach chart and those within the navigation database because they had not compared the two data sets before commencing the approach.

2. Confusion regarding the correct approach profile and inappropriate autopilot selections led to an unstable approach.

3. The unstable approach was continued below Minimum Descent Altitude without the landing pilot having the required visual references in sight.

4. The UK CAA's guidance and the regulatory requirements for approval to conduct MNPA were fragmented and ill-defined.

5. The operator's planning and implementation of MNPA (Managed Non-Precision Approaches) procedures included incomplete operational and written procedures and inconsistent training standards.

6. The ability of the installed EGPWS to provide sufficient warning of inappropriate terrain closure during the late stages of the approach was constrained by the lack of a direct data feed from the GPS navigation equipment.

Following this serious incident, significant safety action was taken by the operator and the UK CAA. The AAIB made four safety recommendations.

1. Factual Information

1.1 History of the flight

The crew reported for duty at 1930 hrs (2130 hrs local) for a scheduled return flight from Amman, Jordan to Khartoum, Sudan. The flight departed at 2130 hrs with the commander acting as handling pilot.

The weather forecast for Khartoum, obtained before departure, had reported gusting northerly winds and reduced visibility in blowing sand. During the cruise, and once they were in Sudanese airspace, the co-pilot asked ATC for the latest weather report for Khartoum. ATC reported blowing sand with a northerly 20 kt wind and visibility of 1,000 m. Neither pilot had previously operated in blowing sand and both were concerned about the possible implications. They stated that they referred to the company Operations Manual but could find no reference to flying in blowing sand. Instead, they decided to refer to the section on volcanic ash as the closest equivalent source of information. As a result, the pilots discussed various possible actions and the commander chose to select continuous ignition on both engines for the approach.

The commander briefed a GAILY 1 standard arrival for a VOR/DME approach to Runway 36. He decided to fly the approach with the autopilot engaged, coupled to the Flight Management Guidance System (FMGS); this configuration is known as flying a 'managed approach'. At that time a managed approach required the aircraft to be in VMC, a situation the commander believed existed from his interpretation of the information he had available. The published minima for the approach, as provided by the chart supplier and used by the pilots (see Figure 1), were an RVR[1] of 1,600 m and a Minimum Descent Altitude (MDA) of 1,600 ft, (340 ft above the runway elevation of 1,260 ft amsl). Because it was a non-precision approach, the operator's standard procedures required an additional 50 ft to be added and so the pilots entered this revised MDA of 1,650 ft into the FMGS (Flight Management and Guidance System).

The commander stated that a further weather check was made with ATC who reported an improved visibility of 3,000 m. After the commander's briefing to the co-pilot was complete, the aircraft was cleared by ATC to descend. On passing overhead the Khartoum (KTM) VOR the aircraft was cleared for the VOR/DME approach to Runway 36.

1 Runway Visual Range which is the maximum distance along the runway at which the runway lights are visible to a pilot during takeoff or after touchdown.

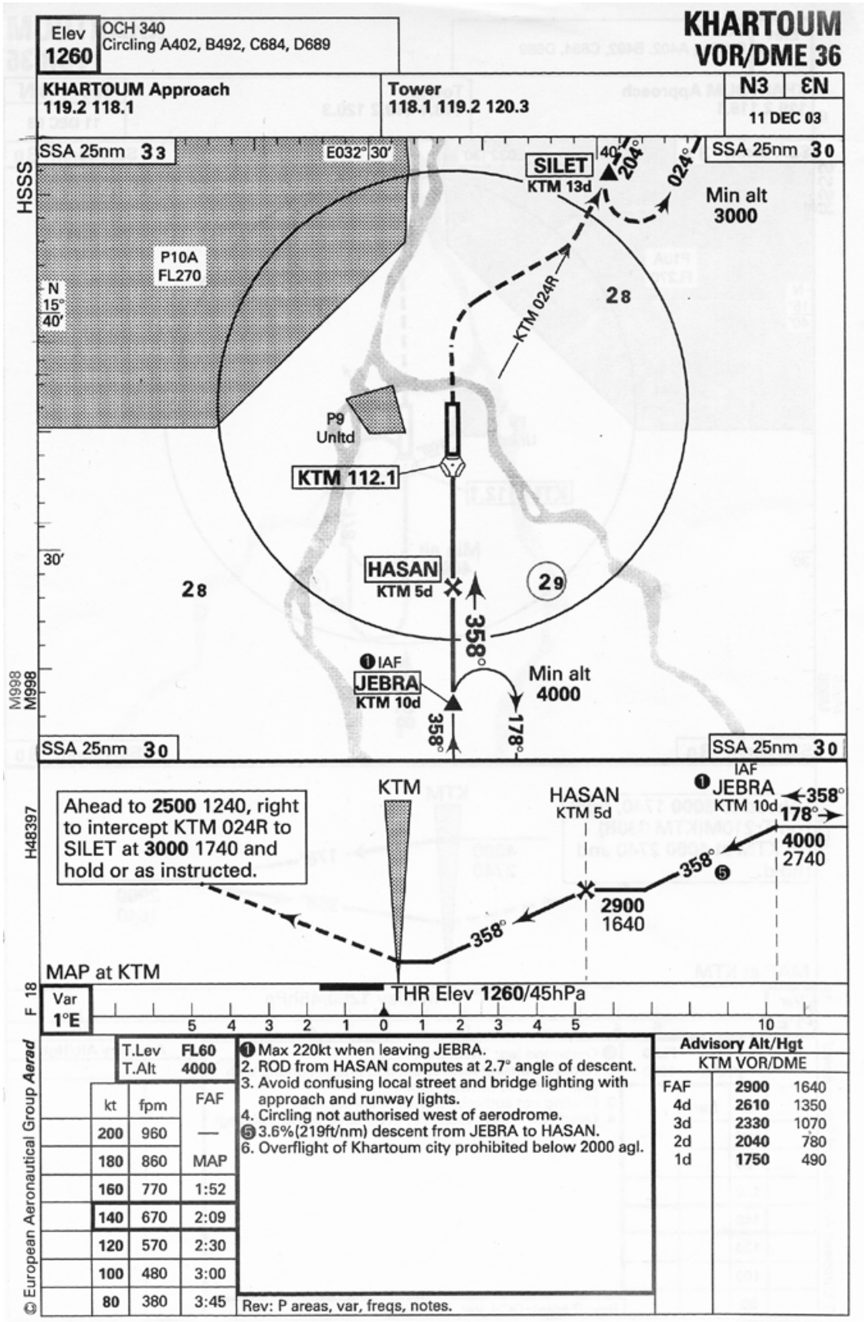

Figure 1

VOR/DME 36 Approach Chart

The pilots followed the procedure and stated that upon reaching the Final Approach Fix (FAF) shown on their chart and identified by the waypoint HASAN at KTM 5 DME[2], the aircraft was level at 2,900 ft QNH, fully configured for landing, and stabilised at the appropriate airspeed. They also checked the latest

2 KTM 5 DME means a distance of 5.0 nm from the KTM (Khartoum) VOR/DME beacon.

visibility with ATC which was reported to be between 1,000 m and 1,200 m. The commander had programmed the autopilot to intercept and capture the final approach course and to descend in accordance with the final descent path. On the chart the final descent path is shown as commencing at 5 DME from the KTM VOR.

The commander was aware of the descent path shown on the chart and therefore expected to see the autopilot command a descent at KTM 5 DME but instead the aircraft continued to fly level. The commander stated that, at the time, he mistakenly thought the Flight Control Unit (FCU) was set to TRK/FPA[3]. He stated that as the aircraft passed through KTM 5 DME, he set the autopilot to commence what he believed was a flight path angle of 3.0º down, whereas he later realised that he had commanded a descent at 300 ft/min[4].

The aircraft began its descent and entered blowing sand with forward visibility reducing rapidly. The commander described the effect of the sand as like watching iron filings flying past the windscreen. The aircraft continued its descent and the co-pilot stated that the altitude check at 4 DME revealed the aircraft was about 200 ft above the published descent profile. The commander stated that as the aircraft approached 3 DME it became apparent that it was not closing with the vertical profile and so he increased the rate of descent to about 2,000 ft/min.

The aircraft then reached the Minimum Descent Altitude (MDA). It has not been possible to establish exactly what was said between the pilots at this time. However, it is apparent that at some stage late in the approach the commander asked the co-pilot if he could see the approach lights. The co-pilot mistook this question to be the commander stating that he could see the lights. As a result, the co-pilot informed ATC that they could see the approach lights and requested confirmation that they were cleared to land. The commander, hearing the co-pilot's transmission, took this to mean that the co-pilot had got the approach lights in sight and looked up to see 'running rabbit' strobe lights and some other lights in his one o'clock position. The confusion between the two pilots then became apparent and it was quickly realised that the lights seen just to the right of the aircraft were not the approach lights. This, combined with the disorientating effect of the aircraft's landing lights reflecting off the blowing sand, caused the commander to order a go-around.

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3 For an explanation of this term refer to section 1.6.2.

4 A 3º descent path at approach speed equates to a rate of descent in the order of 800 ft/min so with only 300 ft/min commanded, the aircraft will very quickly rise above the desired vertical profile.

The commander stated that with the autopilot still engaged, he selected the thrust levers to TOGA[5] and that almost simultaneously the EGPWS (Enhanced Ground Proximity Warning System) sounded a "PULL UP" warning. The commander reported that he noted the aircraft's attitude was 5º nose-up and so he pulled back on his sidestick with sufficient force to disengage the autopilot and increase the pitch attitude to between 17º and 20º nose-up. Thereafter he relaxed the back pressure once he was sure the EGPWS warning had stopped. He then instructed the co-pilot to re-engage the autopilot.

The pilots flew the published go-around procedure towards waypoint SILET climbing to 3,000 ft QNH and the commander briefed for a further VOR/DME approach to Runway 36, this time to be flown without reference to the FMGS but using raw VOR/DME data and autopilot commands on the FCU instead of a managed approach. The pilots also decided to leave the landing lights off for this second approach to prevent the disorientating effect of light scattering off the sand.

The second approach was flown with the autopilot engaged, this time using the TRK/FPA mode for guidance. Neither pilot saw the running strobe or other approach lights and on reaching MDA, the commander stated that again he ordered a go-around. Whilst carrying out the go-around the commander could make out the running strobe lights below and stated that the aircraft passed slightly to the right of them.

On this occasion ATC cleared the aircraft to fly to SILET at FL080. Soon afterwards the two pilots realised that another aircraft had recently landed on Runway 36 from an ILS approach. Thinking the ILS might have become serviceable they tuned its frequency and tried to identify it. They discovered that it was still transmitting a test code meaning that the ILS must not be used for an approach.

The commander decided to carry out a third approach and the aircraft was cleared by ATC to position for an approach to Runway 36. Whilst manoeuvring they heard the pilots of another inbound aircraft ask Khartoum Tower to confirm that the visibility was now 200 m. When this reported visibility was confirmed, the co-pilot immediately questioned the Tower controller about the current visibility at Khartoum. The initial reply from the controller was that the visibility was 900 m followed quickly by a correction to 800 m and then a further correction by the controller to 200 m.

5 Take Off/Go Around – in this position the engines produce maximum thrust and the autopilot/flight director systems automatically enter the go-around mode and provide guidance for the missed approach manoeuvre.

On hearing this information the commander decided to divert to Port Sudan. The aircraft landed there without further incident at 0214 hrs and was met by a member of the airline's staff. The staff member reported that a SIGMET for Khartoum had been received by him at Port Sudan reporting reduced visibility of 200 m in blowing sand valid until 0800 hrs, subsequently extended to 1100 hrs on 11 March 2005.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor/None	8	19	0

1.3 Damage to the aircraft

Nil

1.4 Other damage

Nil

1.5 Personnel information

1.5.1 Commander

Age:	46 years	
Licence:	Airline Transport Pilot's Licence	
Aircraft Ratings:	Airbus A319/A320/A321	
Last Licence Proficiency Check:	07/12/2004	
Last Instrument Rating Renewal:	07/12/2004	
Last Line Check:	10/01/2005	
Last Medical:	05/01/2005	
Emergency and Safety Equipment Check:	14/12/2004	
Flying Experience:	Total all types	7,400 hours
	On Type:	3,700 hours
	Last 90 days:	131 hours
	Last 28 days:	25 hours
	Last 24 hours:	3 hours
Previous rest period:	74 hours	

1.5.2 Co-pilot

Age:	39 years	
Licence:	Airline Transport Pilot's Licence	
Aircraft Ratings:	Airbus A319/A320/A321	
Last Licence Proficiency Check:	28/01/2005	
Last Instrument Rating Renewal:	27/01/2005	
Last Line Check:	10/10/2004	
Last Medical:	29/06/2004	
Emergency and Safety Equipment Check:	22/11/2004	
Flying Experience:	Total all types	4,700 hours
	On Type:	3,200 hours
	Last 90 days:	118 hours
	Last 28 days:	40 hours
	Last 24 hours:	3 hours
Previous rest period:	74 hours	

1.6 Aircraft information

1.6.1 General information

Manufacturer:	Airbus
Type:	A321-231
Aircraft serial number:	MSN 1711
Date of construction:	05/04/2002
Powerplant:	2 x IAE V2533-A5 turbofan engines
Total airframe hours:	12,137 hours
Total airframe cycles:	3,059
Certificate of Airworthiness:	No: 053243/001 expiry 04/04/2008
Certificate of Release to Service:	Ref 01/0986/51 dated 10/03/2005

1.6.2 Control of flight path

There are three methods of controlling the aircraft's flight path: manual control, autopilot control following a pilot selected instruction and autopilot control managed by the FMGS.

Manual control involves either pilot using a sidestick to command pitch and roll and the rudder pedals to command yaw. When engaged, one of two autopilots automatically controls pitch, roll and yaw to maintain various parameters such as heading, track, speed, vertical speed, flight path angle and altitude. Parameters may be manually controlled by the pilot via selections on the FCU

(Flight Control Unit), (see Figure 2). The autopilot then attempts to satisfy these demands which are known as 'selected' modes. Alternatively, the flight parameters may be managed automatically by the FMGS, in which case they are termed 'managed' modes. Engine thrust, an integral part in maintaining a chosen flight path, is controlled either manually using the thrust levers or automatically by use of the autothrust facility which is partly a function of the FMGS.

There are two combinations of lateral and vertical autopilot/flight-director modes available for a pilot to select: HDG/VS meaning heading and vertical speed or TRK/FPA meaning track and flight path angle.

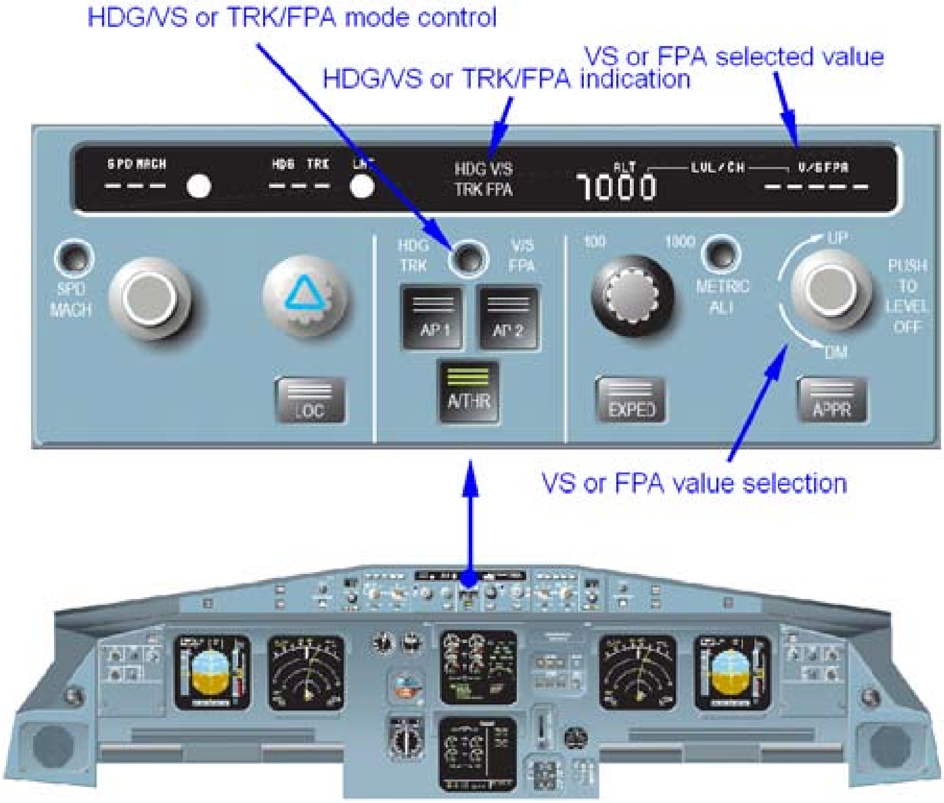

Figure 2

Controls and displays for selecting and managing the vertical path of the aircraft using the flight control unit

When the aircraft is in the fully managed mode it relies upon the navigation waypoints stored within the FMGS for both lateral and vertical guidance. The pilot selects the chosen approach from information stored in the navigation database and controls the autopilot to ensure the appropriate lateral and vertical modes are engaged to allow the FMGS to manage the aircraft's flight path.

Whilst the autopilot may be capable of automatically flying different types of approaches, the procedure may only be flown if the other aircraft equipment, the ground facilities, the operating procedures and the pilots' training meet required standards.

1.6.3 Managed non-precision approach

Khartoum Airport was equipped with an ILS which, had it been serviceable, would have allowed the aircraft to conduct a precision approach. In this instance the ILS was not serviceable and the crew had to carry out a VOR/DME approach. This type of approach is termed a non-precision approach as no external vertical beam guidance is provided to guide the aircraft. Because the approach is less precise the aircraft can not descend as low as it might on an ILS approach before either adequate visual reference is achieved or the aircraft goes around. This altitude is termed the Minimum Descent Altitude (MDA).

Whilst no physical vertical guidance is provided to the aircraft, the approach charts available to the pilots provide target altitudes at various ranges from touchdown for the aircraft to achieve in order to maintain the correct vertical profile whilst flying the approach. The A321's FMGS is able to calculate both the lateral and vertical path the aircraft must fly in order to maintain both the correct vertical and lateral flight paths. This calculation is based upon information contained in the aircraft's navigation database. The aircraft's position is determined by the FMGS which uses inputs from GPS, IRS or VOR/DME or VOR beacons that might be in range. The combination of aircraft position and FMGS generated guidance can then be used to fly an automatic approach, this being termed a managed non-precision approach, (MNPA). The pilots are able to check that the aircraft is being flown on the correct lateral approach path by reference to the external ground-based navigation aid upon which the approach is based, in this case the KTM VOR beacon. This 'raw data' from the ground-based approach aid should be monitored throughout the approach to ensure the aircraft remains on track and that the FMGS defined position corresponds with the raw data position. The pilots are able to ensure the correct vertical path by cross-referencing the aircraft's altitude and DME distance from the relevant navigation aid with that published in their charts, in this case the KTM DME beacon.

1.7 Meteorological information

1.7.1 Obscuration by particles in the atmosphere

There are two kinds of airborne particles which can obscure visibility: hydrometeors which are water particles of varying sizes and lithometeors which are solid particles such as, haze, smoke, dust, sand and volcanic ash. Of these, the last three can be the most problematic but sand and dust particles are more frequently encountered than volcanic ash.

The conventional difference between sand and dust is particle size, dust being much finer than sand, but both originate from dry land surfaces. During a dust or sand storm smaller particles can be carried high into the atmosphere, sometimes above 10,000 ft.

Aviation weather forecasts and reports are coded such that dust is represented by the letters DU and sand by the letters SA. These can be modified by descriptors such as DR for drifting and BL for blowing. Thus blowing sand would be encoded as BLSA and low drifting sand would be coded as DRSA. There are also codes for a dust storm (DS) or a sand storm (SS).

ICAO Annex 3, '*The Meteorological Service For International Air Navigation*', makes frequent reference to sand and dust storms in its 15^{th} edition of 2004 but it but does not define these conditions in terms of visibility. Sometimes the term sand storm or dust storm is used to describe visibility of less than 1,000 m due to airborne particles but there are varying national practices for reporting and categorising these hazards.

Other meteorological reference documents suggest that drifting sand is associated with light to moderate winds which keep the particles close to ground level. Blowing sand is associated with stronger winds which raise the particles above ground level but no higher than 2 m. Dust and sand storms are usually associated with strong or turbulent winds that raise particles much higher than 2 m. The Sudan is an area particularly prone to dust storms. The arrival of a dust storm is characterised by a sudden increase in wind speed and a rapid deterioration in visibility.

1.7.2 Synoptic situation

The synoptic situation at 0001 hrs on 11 March 2005 showed an area of low pressure over the Sudan with a fresh to strong north-easterly flow over the Khartoum area. The published forecast (TAF) and actual (METAR) weather conditions for Khartoum International Airport (HSSS) during the period leading up to, and following, the incident were as follows:

TAF
HSSS 101900Z 102106 34005G15KT 6000 TEMPO 2124 3000 BLSA PROB30 TEMPO 0006 0800 DS=

METAR
2300Z 10/03/05 HSSS 102300Z 33014KT 1000M SA 29/07 Q1006=
0000Z 11/03/05 HSSS 110000Z 33015KT 4000M SA 29/09 Q1006=
0050Z 11/03/05 HSSS 110050Z 34011KT 1000M DS 26/08 Q1008=

These codes generally indicate a forecast northerly surface wind of 5 kt gusting up to 15 kt with reported northerly surface wind conditions of about 15 kt at the time of the flight. The forecast also gave a visibility of 6,000 m, temporarily reducing to 3,000 m between 2100 and 2400 hrs in blowing sand with a 30% probability of further reducing to 800 m between 0000 hrs and 0600 hrs in a dust storm. The actual report for 2300Z gives a visibility that borders on the accepted visibility criterion for a sand storm whereas the 0050Z report gives the same visibility but attributes the obscuration to dust.

1.7.3 Runway visual range (RVR)

Khartoum Airport was not equipped with transmissometers[6] although it would have been possible to provide runway visual range (RVR) information by visual assessment in accordance with ICAO Document 9328 '*Manual for RVR Assessment*'. However, before starting their approach, the pilots had been required to convert the reported 'met' visibility into an RVR by reference to a conversion factor table in their company's operations manual (see Figure 3).

Table 8 Converting Reported Met Visibility to RVR

Lighting Elements in Operation	RVR = Met Visibilty x	
	Day	Night
HI Approach and Runway Lighting	1.5	2.0
Any Type of Lighting Installation Other than Above	1.0	1.5
No Lighting	1.0	N/A

a. Table 8 may not be used for calculating take-off minima or Cat II/III minima.
b. Table 8 may not be used when a reported RVR is available

Figure 3

Table for converting reported met visibility to RVR

6 A transmissometer is an optical instrument, sited alongside a runway, for measuring Runway Visual Range.

They multiplied the met visibility by a factor of two which was the factor applicable for operations at night when high intensity approach and runway lighting are in use. Thus, with the stated visibility of 1,000 m they calculated an RVR of 2,000 m. They determined that this calculated RVR exceeded the published company minimum for the approach of 1,600 m RVR. The subsequent weather update from ATC giving an increased visibility of 3,000 m effectively increased the RVR, as calculated by the pilots, to 6,000 m. Neither visibility exceeded the 5,000 m minimum visibility for Visual Meteorological Conditions (VMC) to exist within Class B Airspace[7].

It has not been possible to obtain a copy of the SIGMET obtained by the operator's staff member in Port Sudan.

1.8 Aids to navigation

The KTM VOR/DME beacon is positioned 0.6 nm south of the Runway 36 threshold, in line with the runway centreline. It acts as the only area navigation aid within the vicinity of the airfield. The runway is also equipped with an ILS, although this had been out of service for some months prior to the incident. The ILS signal for Runway 36 was radiating on the night of the incident but the identifier signal was transmitting the test code and a NOTAM declared the ILS as being out of service.

1.9 Communications

All communications between the aircraft and air traffic control services were by VHF radio. Attempts to recover recordings of these communications from the relevant authorities were unsuccessful.

1.10 Aerodrome Information

Khartoum Airport has a single runway 2,980 m (9,777 ft) in length, aligned on a north – south axis. Runway lighting consisted of threshold lights, centreline lights, high intensity edge lights and two bars of approach lights. No mention was made in the pilots' charts of the running strobe lights that exist along the final approach, although notes did warn of other lighting in the vicinity of the runway which may be confused with the approach or runway lighting.

Khartoum Airport is situated in Class B airspace which, at altitudes below FL100, requires 5 km in-flight visibility for visual meteorological conditions and hence visual flight rules to apply.

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7 See section 1.10.

1.11 Flight recorders

The aircraft was fitted with a mandatory Cockpit Voice Recorder (CVR), a mandatory Flight Data Recorder (FDR) and a non-mandatory Digital AIDS Recorder (compounded acronym referred to as the DAR where the 'A' refers to AIDS which stands for Aircraft Integrated Data System).

By the time the AAIB were notified of the incident, the CVR had been overwritten. The FDR captured 54 hours of data, including the event, recording 179 parameters. The DAR recorded additional parameters over a period of 44 hours, including the event, and was downloaded as part of the investigation.

The aircraft was also fitted with an EGPWS which was also downloaded as part of the investigation and provided additional information regarding the "PULL UP" warning.

The following data summary is derived from an amalgamation of all these sources.

1.11.1 Recorded Flight Data

The data recorded the aircraft taking off at 2142 hrs on 10 March 2005. Figure 4 shows an overview of the basic flight data when in the vicinity of Khartoum. This shows the aircraft approached the airfield from the GAILY waypoint to the north-east of the airfield, following the GAILY1 approach with the autopilot flying the aircraft under the control of the FMGS. The aircraft then remained in fully managed mode, initially following the VOR/DME 36 approach profile (pre-HASAN).

Figure 5 provides a more detailed view of the vertical profile during the first approach. The aircraft acquired and then descended from the initial approach fix (waypoint JEBRA) at 4,000 ft amsl. The Final Approach Fix (FAF) altitude of 2,900 ft amsl was acquired some 6 nm from the runway and maintained. The autopilot entered the final descent managed mode at the HASAN FAF waypoint stored in the navigation database and commenced a smooth descent towards the runway threshold.

Approximately 4 nm from the threshold the vertical speed / flight path angle knob on the FCU was pulled. This disengaged the managed final descent autopilot mode, in which the rate is controlled by the FMGS, and engaged the Selected Vertical Speed mode, in which the rate is controlled by the VS/FPA selector knob on the FCU. The vertical speed selected at the time was 500 ft/min[8] but this was changed immediately and within the next 3 seconds it reached 2,000 ft/min, briefly overshooting this figure before returning to it. Approximately 3 seconds later this selected rate was reduced on the FCU knob, finally reaching 1,200 ft/min. During this period the aircraft descent rate peaked at 1,728 ft/min. Subsequently the selected vertical speed was varied and the aircraft's descent rate varied between 864 ft/min and 1,280 ft/min.

The aircraft passed through 1,650 ft amsl (the operator's MDA for the approach) about 2.2 nm from the threshold, at which point it was about 400 ft below the correct approach path with a descent rate of approximately 1,200 ft/min.

Figure 6 provides a timeline and terrain clearance information for the last part of the first approach. The terrain closure rate was approximately 1,200 ft/min before the thrust levers were advanced. The thrust levers were set to TOGA power when the aircraft was between 220 and 200 ft above terrain, approximately 210 ft below the operator's MDA. Within two seconds of setting TOGA power, the commander's sidestick was pulled back to 68% of its full rearwards travel position. This sidestick position was then reduced slightly over the next two seconds. Between 3.4 and 5.1 seconds after setting TOGA power, with the aircraft at a radio altitude of approximately 125 ft agl, the EGPWS terrain awareness warning, "TERRAIN AHEAD, PULL UP", was triggered. At this point the commander's sidestick was at about 40% rear deflection. The sidestick position was then briefly moved forward to 54% forward deflection before being moved rearwards to 55% rearwards stick deflection.

In the 4.5 to 5.5 seconds after TOGA power was set, the aircraft lost 80 to 100 ft in height before the descent was halted, resulting in a minimum recorded terrain clearance of 121 ft. The EGPWS warning ceased on passing about 250 ft agl in the climb, about 5 to 7 seconds after being triggered.

The first go-around occurred at 0032 hrs. The aircraft levelled off from the go-around manoeuvre at 3,000 ft amsl. Just before the aircraft was turned around for the second approach, the flightpath reference mode was changed from HDG/VS to TRK/FPA. The second approach was flown with TRK/FPA selected, autopilot engaged with vertical and lateral guidance selected by the pilots. TOGA was set at 1,580 ft amsl, 70 ft below the company MDA, and a second go-around commenced at 0049 hrs. The aircraft climbed to 8,000 ft amsl and flew outbound to the SILET waypoint before turning back in preparation for a third approach.

8 The selected vertical speed parameter has a resolution of 64 ft/min. Crew selection is limited to hundreds of ft/min. In this case a selected vertical speed of 512 ft/min was recorded but associated with an actual selection of 500 ft/min.

On the third approach, the aircraft descended to 4,000 ft amsl before it climbed away and diverted to Port Sudan, landing approximately one hour later at 0214 hrs.

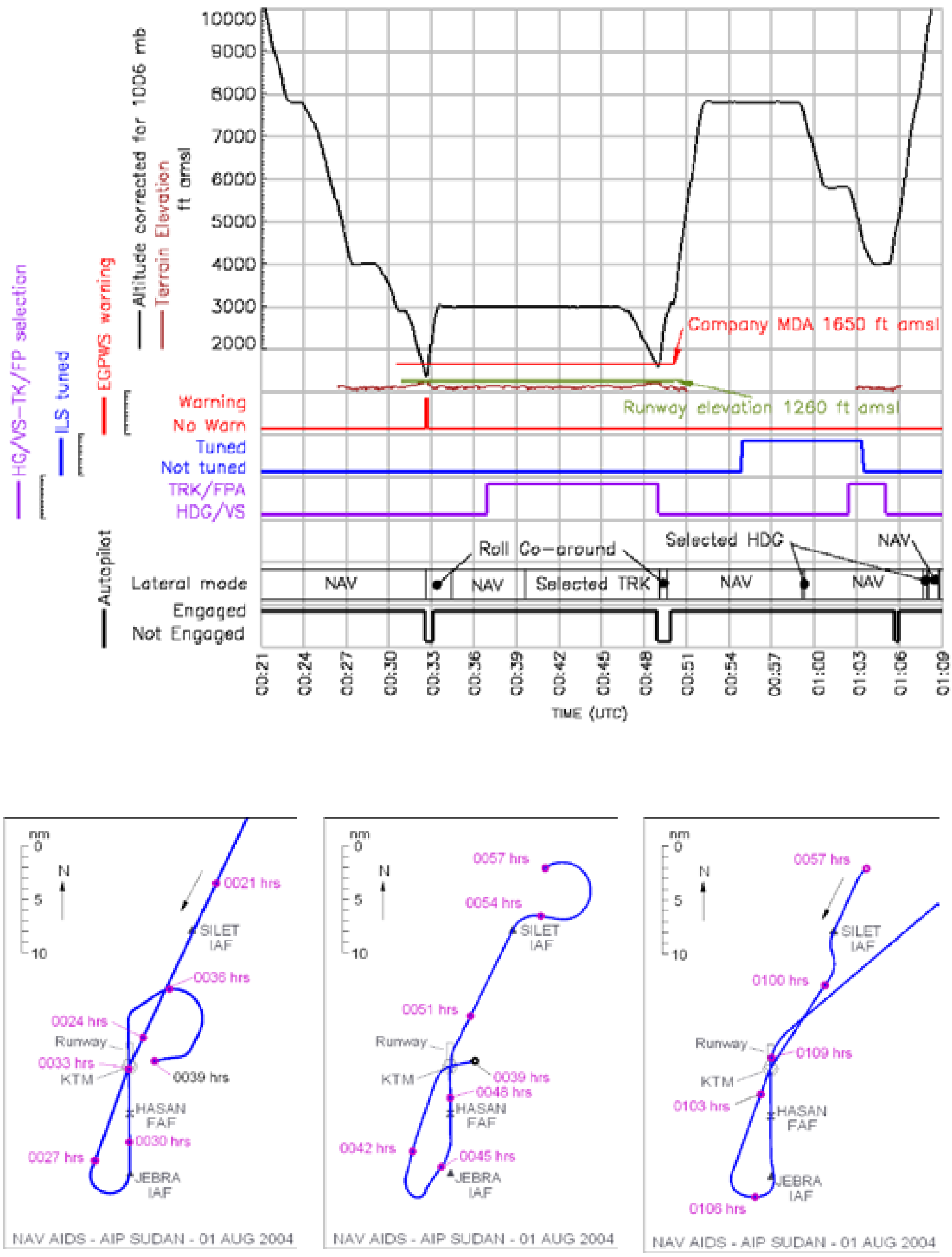

Figure 4

General overview of the flight path in the vicinity of Khartoum

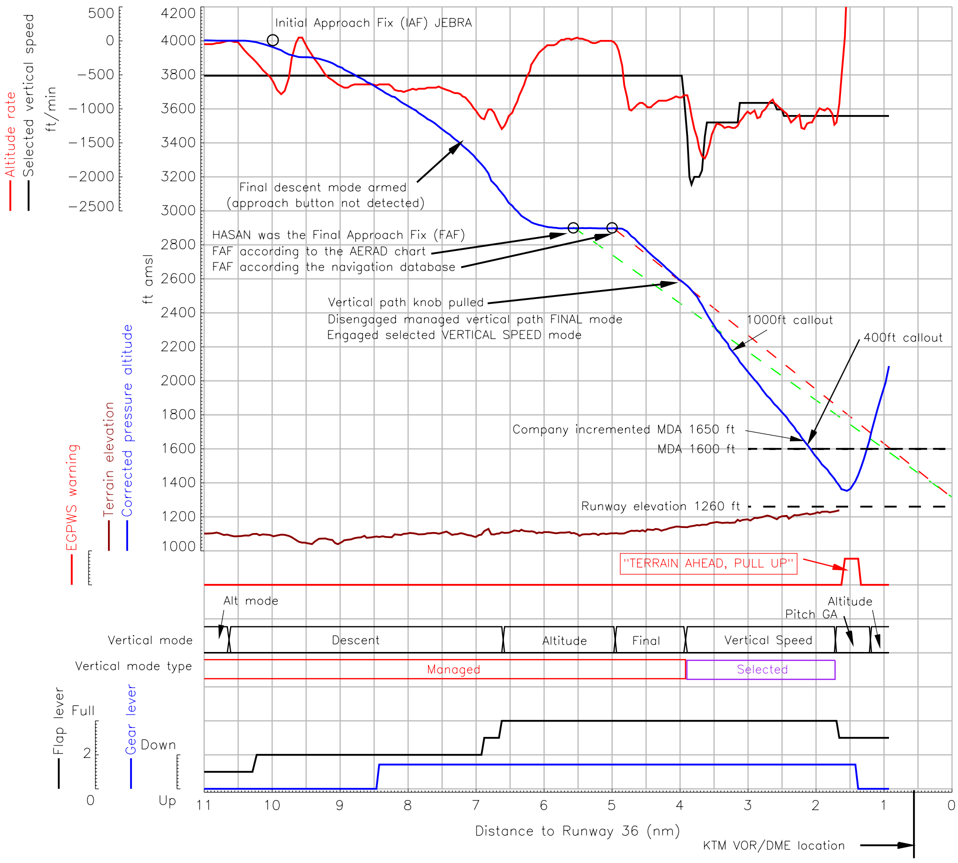

Figure 5

First approach shown relative to distance to the runway threshold, KTM VOR/DME and different reference points for the final approach fix

1.11.2 Recorded Navigation Data

The aircraft position was recorded from a number of sources: the left and right Inertial Reference System (IRS), GPS, GPIRS (blend of GPS and IRS) and the FMGS. These sources, sensed or generated by different methods, correlated very well.

The recorded data included DME range from the KTM VOR/DME. Comparing the DME detected distance from the aircraft to the DME beacon with the calculated distance between the FMC position and the DME beacon according to the AIP Sudan dated 01 AUG 2004 showed a difference of less than 0.05 nm.

1.11.3 Recorded EGPWS data

The EGPWS download correlated with the other sources of recorded data and also showed that the system was fully operational.

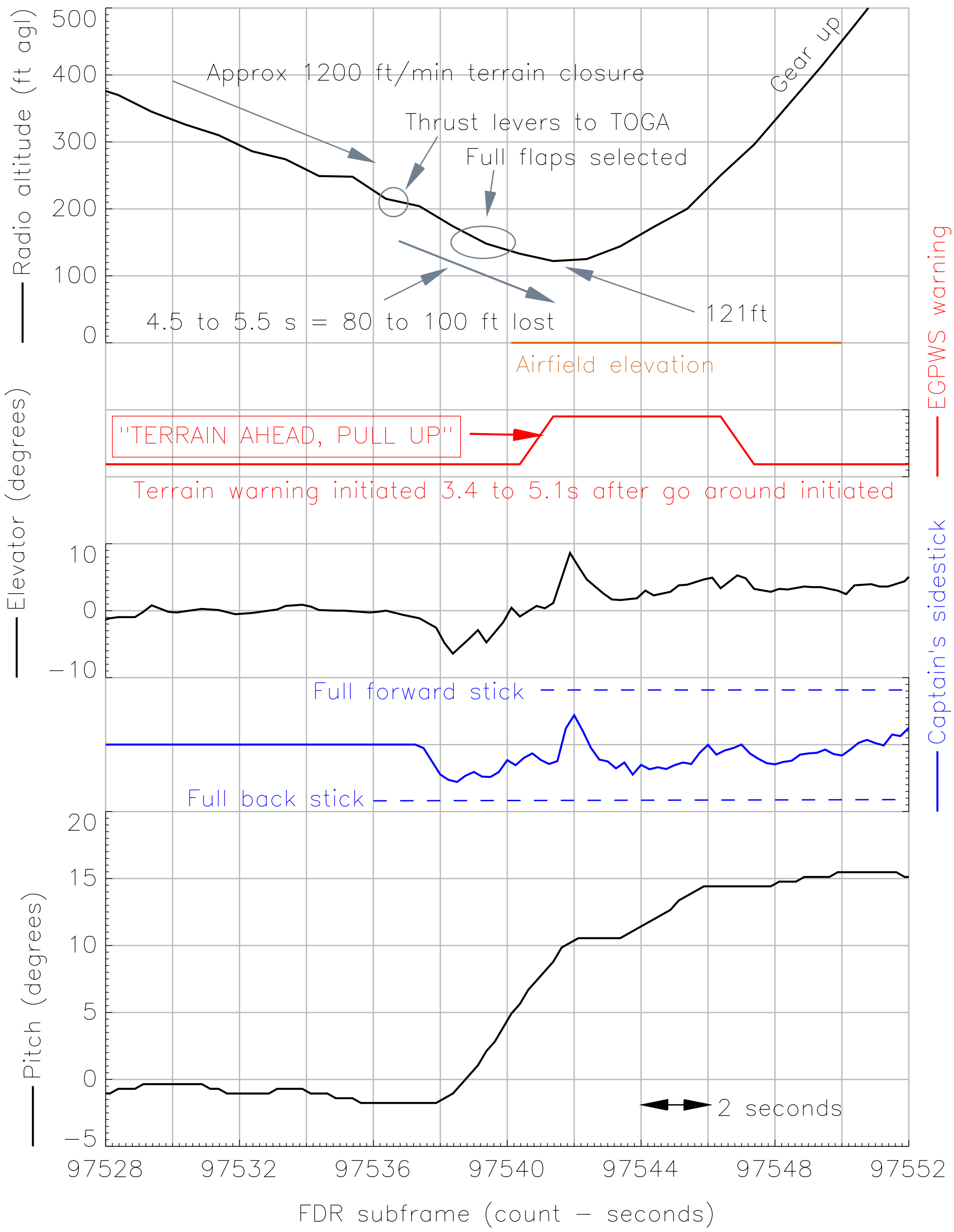

Figure 6

EGPWS warning during the first go-around

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

Not applicable

1.17 Organisational and management information

At the time of the incident, flying operations within the company were the responsibility of the Director of Flight Operations (DFO). Reporting directly to him was the Chief Pilot who in turn oversaw the Flight Operations Manager and Training Manager. The operator's interface with the CAA was through a CAA Flight Operations Inspector.

Implementation of MNPA operations in VMC had been the result of meetings involving some or all of these five individuals. As a result the Training Manager had developed a programme to train pilots to operate MNPA in accordance with the Airbus Standard Operating Procedures (SOPs) contained in Airbus FCOM Bulletin 826/1, *'Use of Managed Guidance in Approach and Nav Database Validation'*. The Chief Pilot was responsible for the implementation of MNPA operations on the line after pilots had been trained. He was also responsible for collecting feedback with the intention of compiling company specific procedures although this task had not been completed when the incident occurred.

The operator was a CAA authorised Type Rating Training Organisation (TRTO). The TRTO status required a head of type training with responsibility to the CAA to ensure training was carried out in accordance with CAA requirements. This head of type training also reported to the operator's Training Manager.

1.18 Additional information

1.18.1 Operator's history of MNPA

The operator began attempts to introduce MNPA operations in the summer of 2002 but was thwarted by a lack of guidelines of how to gain CAA approval. The operator attempted to resolve this position by using the JAA document Temporary Guidance Leaflet (TGL) 10: *'Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace'*, as a framework on which to base their training. The Airbus SOPs for MNPA were adopted and pilot training was started during the 2003 recurrent simulator training programme. The operator has no record of the CAA being consulted about this training program before its introduction.

The Training Manager issued a memorandum to training captains on 22 April 2003 detailing the training required to be carried out and the reference material to be consulted. He issued another memorandum to line pilots the next day explaining the training program and stating the reference material that pilots needed to study. Copies of the Airbus SOPs were also distributed to all training captains and pilots. The operator intended to publish its own specific SOPs as part of the approval process at a later date, developed from the experience gained during this training.

The co-pilot was employed by the operator during this period of training and so he received notification of the required references and a copy of the Airbus SOPs whereas the commander, who had only recently joined the operator, had not been given any of this information. The commander had, however, conducted MNPA operations on the same aircraft type with his previous company. The operator stated that on joining them the commander had received a brief on the MNPA procedures to be adopted as part of his induction training. Having had one approach demonstrated to him and after flying a satisfactory approach himself during the induction training, he was awarded a certificate of approval to conduct MNPA operations.

The FMGS database validation process, required as part of the CAA approval process for conducting MNPA, was agreed at a Training Standardisation and Policy meeting held on 8 June 2004, attended by the operator's CAA Flight Operations Inspector (FOI). Approval was given by the FOI for the operator to fly MNPA subject to limitations laid out in a memorandum from the operator (Training Memorandum OPS Notice 32/04), issued to pilots on 13 August 2004. Principal amongst these limitations was the requirement that MNPA approaches were only to be flown in VMC and whilst ground contact could be maintained throughout the final approach.

In order to start collecting data for use during the validation process, on 2 December 2004 the operator issued Admin Memo 135/04 providing a feedback form for comments on MNPA's flown. Completed forms were stored on receipt to be processed at a later date, prior to full MNPA approval being granted. At the time of the incident no processing or action had been taken to assimilate the feedback information.

Subsequent investigation by the operator revealed that five feedback forms were received prior to the incident relating to MNPA to Runway 36 at Khartoum. The feedback form required notification of the point at which the final approach descent commenced. One described it commencing at 'HASAN', another at 4.4 DME from 'KRT' and the remaining three at 5 DME from the KTM VOR. The same forms asked if the 'down arrow' on the navigation display corresponded to the 'plate FAF'[9]. All replies stated 'yes' with the exception of the form stating that the descent commenced at 4.4 DME from 'KRT' which stated 'no'. Three of the five reports stated that the aircraft's altitude during the final approach did not correspond with the published check altitudes; discrepancies varied from 150 to 210 ft high at 4 DME from the KTM VOR closing to between 70 and 90 ft high at 1 DME. The other two reports both recorded altitudes which were again above the corresponding published check altitudes but without specifically noting the amount of deviation. None of the reports noted a difference between the information relating to the approach descent point and flight path angle published in the charts and those appearing in the FMGS database.

An audit carried out early in 2005 by the operator of a simulator detail during one of their type conversion courses identified that the crew procedures for MNPA were not being taught in accordance with the appropriate Airbus FCOM Bulletin 826/1.

A non-conformance report, reference AWA/A/4/04, was raised on 23 February 2005 addressed to the operator's head of type rating training. This included a comment that the suggested corrective action might more appropriately lie with the operator's Training Manager. A later comment attached to the non-compliance report indicates that responsibility for corrective action was transferred to the Chief Pilot on 16 March 2005.

9 The Final Approach Fix illustrated and defined on the Approach Chart.

1.18.2 Provision of Aeronautical Navigational Charts and Databases

Flight Management System[10] (FMS) databases and navigation charts are provided by various commercial organisations, or 'datahouses', worldwide but the market is dominated by three main producers.

Each datahouse maintains its own library of national Aeronautical Information Package (AIPs). These documents are produced by State authorities detailing all aspects of that State's airspace infrastructure in accordance with ICAO Annex 15. Amendments to a State's AIP should be promulgated in accordance with Chapter 6 of the Annex, under the Aeronautical Information Regulation and Control (AIRAC) system[11]. These amendments should then be sent to any organisation paying a subscription to the publishing state.

AIPs form the main source document for the production of the original charts and aeronautical facility databases. Notified amendments are then used to update both as required every 28 days in compliance with the AIRAC system. At the time of this incident, datahouses were producing charts in accordance with the international standards and recommended practises as laid down in ICAO Annex 4.

Aeronautical facility databases are produced in accordance with guidance laid down in the European Organisation for Civil Aviation Equipment (EUROCAE) document ED-76: '*Standards for Processing Aeronautical Data*' (published in October 1998) or the American equivalent: '*Requirements and Technical Concepts for Aviation Inc (USA) (RTCA)*' document DO-200A.

The datahouses process the aeronautical information received into the required format for charts to be sent for printing and distribution direct to customers. The same source information is also used to generate data in compliance with Aeronautical Radio Inc (ARINC) Specification 424 to be passed to FMS manufacturers for processing in compliance with the individual manufacturer's system requirements. This processed information is then distributed to end users to update their aircraft systems.

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10 The generic name for an avionics component found on most commercial and business aircraft to assist pilots with navigation, flight planning, and aircraft control functions. The FMGS fitted to the A320 is a version of the equipment generically known as FMS.

11 This is an international system which controls and regulates the operationally significant changes worldwide requiring amendments to aeronautical information such as charts and route-manuals, so that such changes whenever possible, will be issued on predetermined dates.

In order to allow sufficient time for database processing, chart printing and distribution, the datahouses impose a deadline for amendments to be incorporated. These deadlines vary slightly between producers and are affected by the time required to print charts and for the different FMS database producers to process the data. Thus, for example, for incorporating amendments into the database for one major FMS manufacturer, one producer has a deadline of 15 days prior to the AIRAC cycle effective date. The same producer has a deadline of 21 days for another major FMS supplier and 14 days for chart production.

The variation in deadline dates might potentially result in more up to date information being included by one supplier than another. Also, differences may emerge between the FMS databases and approach charts provided by one datahouse. This possibility is minimised by rigorous in-house quality assurance to ensure that there are no discrepancies of importance between databases and charts. Further protection is provided by the ICAO requirement for States to provide a minimum of 28 days notice prior to any minor airspace changes being made and 56 days notice prior to any major changes. These notice periods relate to the AIRAC cycle dates.

1.18.3 Operator's navigational charts and databases for Khartoum

At the time of the incident the operator used charts supplied by one datahouse and databases supplied by another datahouse. The database on the incident aircraft was LAJ1050201 which was the appropriate database for the date of the flight.

For its source material, the datahouse supplying the charts used the AIP for Khartoum dated 1 November 2002 (see Appendix 1). This was the most recent version of the AIP held by their library and no later amendments had been received from the Sudanese authorities under the subscription service that was in place at the time. The AIP entry for the VOR/DME approach to Runway 36 contained various anomalies which the datahouse had to resolve. Of note was the position of the final approach fix 'HASAN'. The displayed latitude and longitude co-ordinates for this point were incorrect and the reference distances used on the vertical profile were inconsistent. These showed that HASAN was equidistant at 5 nm from both the KTM VOR and the runway threshold, despite the same vertical profile showing the KTM VOR was some 0.6 nm short of the runway threshold. By interpolating the depicted final approach gradient, the datahouse determined that HASAN was actually 5.6 nm from the runway threshold. This coincided with the KTM 5 DME position. The confirmed position of the KTM beacon gave a corresponding flight path angle, appearing on their chart, of 2.7º on the final approach (see Figure 1).

The datahouse supplying the FMS database for the operator was, however, in possession of an amendment to the Sudanese AIP for Khartoum, dated 1 August 2004 (see Appendix 2). This amendment depicted the final descent point at 5 nm from the threshold to Runway 36, coincident with KTM 4.4 DME. It also indicated a final approach flight-path angle of 3º.

The amended information was passed to various FMS manufacturers for processing. The operator's fleet used FMGC units from two different manufacturers. Each manufacturer structured the navigation data in a proprietary format to suit its product. Subsequent examination has shown that despite being supplied with identical information after processing, there were differences in the information contained in the navigation databases of the two types of FMGC. One FMGC database gave a flight path angle of 3º to be flown from the FAF at HASAN whilst the other gave the same flight path angle required from the initial approach fix at JEBRA, (see Table 1, Table 2 and Figure 7).

	Lat/Long (ddºmm'ss.ss")
KTM	N15º33'57.87" E032º33'12.11"
JEBRA	N15º23'55.37" E032º33'17.62"
HASAN	N15º29'32.46" E032º33'14.57"
SILET	N15º46'42.45" E032º39'19.86"
RW36	N15º34'33.72" E032º33'11.71" Elevation 1,260, Bearing 358º, length 9,800, Threshold crossing height 49 feet

Table 1

FMGC navigation database locations - LAJ1050201

Location	**Altitude**	**Vertical angle**
JEBRA	4,000	
HASAN	2,900	
RW36	1,310	3.00

Table 2

Part of the FMGC navigation database
defining the HSSS V36 approach - LAJ1050201

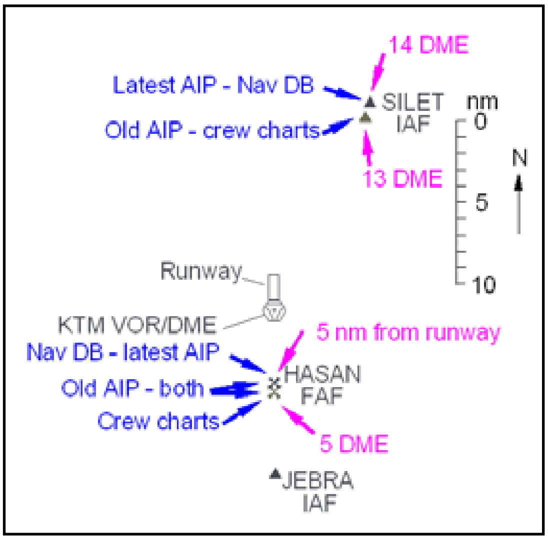


Figure 7

Comparison of waypoint locations as shown in the
Sudanese AIPs, the Navigation database and the crew charts

1.18.4 Visibility minima

The different AIP versions used by the two datahouses both declared a required minimum of 1,600 m visibility for the approach. Using the JAR-OPS 1 conversion tables the RVR equivalent to 1,600 m visibility would be 2,400 m by day and 3,200 m by night (see Appendix 3).

The minima page associated with the operator's charts for Khartoum displayed this as a minimum RVR of 1,600 m, as opposed to a minimum visibility. JAR-OPS1 classified the facilities for this non-precision approach as 'basic', the aeroplane was Category C and the published MDA was 340 ft. These parameters mean the JAR-OPS1 minimum RVR for the approach was 1,600 m (see Appendix 4), but this RVR represented a lower limit than the 1,600 m visibility specified by the Sudanese authorities on their State chart. The datahouse producing the charts however made no differentiation between RVR and visibility when transcribing information from any AIP into their charts, referring to all figures as RVRs.

1.18.5 Terrain Awareness and Warning Systems

1.18.5.1 Background

Historically, the most significant cause of civil aviation fatalities has been the inadvertent flying of a serviceable aircraft into terrain due to a lack of situational awareness of where the aircraft was in relation to terrain. This type of accident is called Controlled Flight Into Terrain (CFIT).

To combat CFIT, Terrain Awareness and Warning Systems (TAWS) provide terrain displays for the pilots to improve awareness of where the local terrain is and also provide alerts when a terrain proximity hazard is detected. The system works by comparing aircraft position, speed and other parameters against a model of the terrain held in its memory, generating the relevant terrain displays and hazard alerts. During an approach the system must allow touchdown on terrain (the runway) whilst still providing protection against terrain hazards before the landing. To do this, TAWS also has a stored database of all usable runways so that it can allow the aircraft to approach terrain when appropriate ie landing.

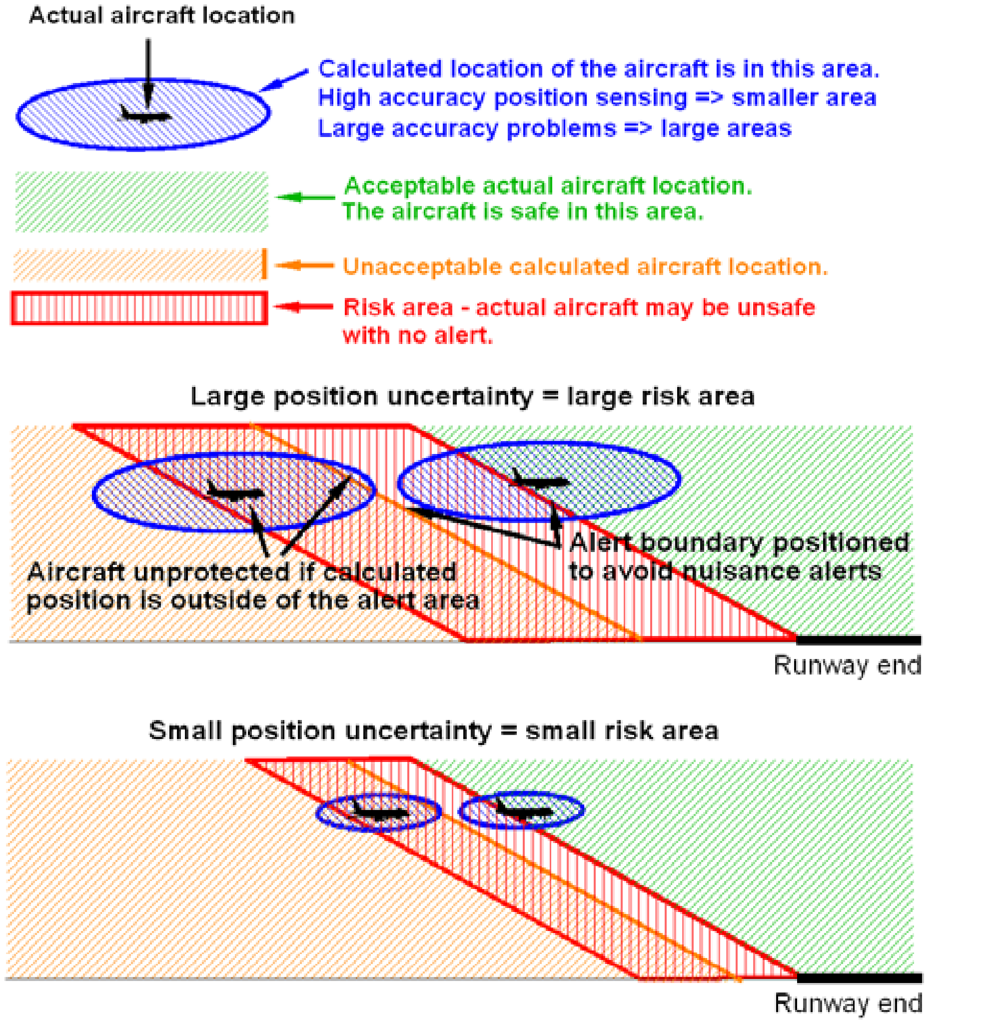
The system is only as good as the accuracy of terrain and runway data stored in the equipment coupled with the quality of the aircraft position data provided by the aircraft systems. Inappropriate 'nuisance' alerts have the effect of eroding flight crew confidence in the effectiveness of the system and so must be avoided. Ultimately a compromise must be made between the timeliness of the alerts and the number of nuisance alerts generated. The closer the aircraft is to the runway, the more difficult this compromise becomes. If there is uncertainty in the aircraft position then the alerting envelopes must be relaxed to keep the number of nuisance alerts to a minimum, resulting a volume of airspace in which the aircraft will be in danger of undershooting the runway without any alert to the hazard. This is illustrated in Figure 8**.**

From the start of the TAWS development it was established by the equipment manufacturers that the aircraft position was best supplied by a direct GPS source. GPS data from onboard receivers include position data quality information allowing TAWS to adjust system performance according to the GPS equipment's estimate of its accuracy.

1.18.5.2 TAWS certification

The minimum performance standards of the TAWS equipment were originally covered by Federal Aviation Administration (FAA) document Technical Standard Order (TSO)-C151b . Subsequently the Joint Aviation Authorities (JAA) issued a virtually identical document, JTSO-C151 and later the European Aviation Safety Agency (EASA) followed suit with ETSO-C151a. These standards stipulate minimum alert times for given scenarios and stress the need to avoid nuisance alerts. There is little difference between these three documents and so they will be referred to as 'the TSO' for the purpose of this report.

The certification of the TAWS aircraft installation was guided by the JAA document '*Section One: General Part 3: Temporary Guidance Leaflets LEAFLET NO 12: Certification Considerations for the Terrain Awareness*



Illustrative only. In reality the differences between poor navigation systems and GPS position are much more marked especially at low altitude.

Figure 8

Risk Area

An illustration of how position uncertainty affects the alert boundaries to avoid nuisance alerts and therefore affects the area in which there is a risk that no alert will be given despite the aircraft being in a dangerous location.

Warning System: TAWS.' – referred to as TGL12. This guidance allowed the use of the aircraft navigation system, designed for area navigation, as the source of position information for the TAWS. The capabilities of these area navigation systems vary from very poor to very good. There is no requirement to have GPS as a source. There are no minimum positional accuracy requirements imposed on the source for TAWS, other than by reference to relatively relaxed area navigation requirements, and no requirements to supply TAWS with relevant indicators of data quality.

1.18.5.3 TAWS alerts

There are two ways in which TAWS provide alerts that are relevant to premature descent on final approach with the aircraft fully configured for landing.

The first relevant TAWS alert function is the Forward Looking Terrain Avoidance (FLTA) alert function which scans the terrain model data for hazards ahead of the aircraft. This includes protection against drifting down into relatively flat terrain but must allow landings on runways. The requirements are listed in TGL12 Appendix 3, para 1.6 (Final Approach Segment Descent Requirements), Table E.

The pertinent TSO requirements for the FLTA when in the approach phase are shown in Table 3.

Vertical speed (ft/min)	Minimum TAWS warning alert height - above terrain (ft)
500	112
750	122
1000	135
1500	164

Table 3

FLTA TSO requirements

The second relevant TAWS alert function is called the Premature Descent Alert (PDA) function. There are no required PDA test conditions defined in the TSO. Instead, the document highlights the opposing needs for CFIT protection. This is illustrated by the fact that a third of CFIT accidents occurred with the aircraft fully configured in the approach; the same stage of flight in which nuisance alerts need to be avoided.

1.18.5.4 TAWS installation

The TAWS fitted to this aircraft was the Honeywell Enhanced Ground Proximity Warning System (EGPWS), part number 965-0976-003-206-206. The actual performance of the system fitted is given in the Honeywell document, '*Product Specification for the Enhanced Ground Proximity Warning System*', DWG No. 965-0976-6093 rev M.

This equipment interfaced with the aircraft Flight Management and Guidance Computer (FMGC) for navigational information which used GPS as part of its navigation solution. However it did not feed GPS data direct to the EGPWS and so provided only limited navigational quality indicators to the EGPWS. Under these conditions, the EGPWS must allow for the possibility that the FMGC data is not based on high accuracy GPS data and so it must reduce the sensitivity of the alerting modes near the runway.

The EGPWS Terrain Look Ahead Alerting function fulfils the role of the TAWS FLTA alert and is shown in Figure 9.

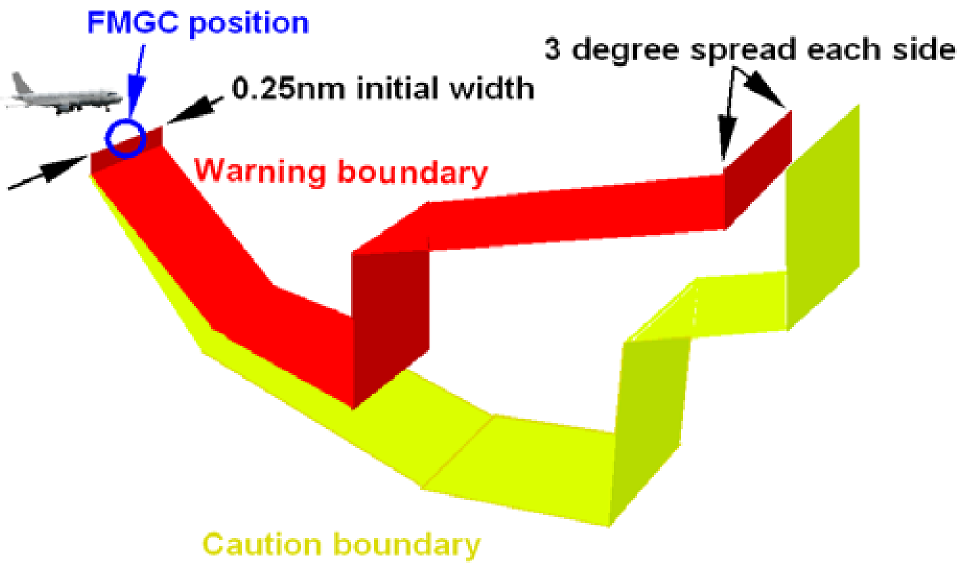


Figure 9

Illustration of the EGPWS algorithms for FLTA that move with the aircraft.

(Not to scale. The geometry varies by aircraft type, configuration and flight parameters.)

In the EGPWS virtual model, the alert envelopes travel with the aircraft. If terrain data penetrates the caution boundary a "TERRAIN AHEAD, TERRAIN AHEAD" caution is triggered. If terrain data penetrates the warning boundary a "TERRAIN AHEAD, PULL UP" warning is triggered.

The EGPWS alert envelope that covers the PDA requirement is called the Terrain Clearance Floor (TCF). This alerts against insufficient terrain clearance for any given distance from the runway. The TCF alert envelope for the installed system is illustrated Figure 10. Penetration of this stationary envelope by the aircraft results in a "TOO LOW TERRAIN" caution.

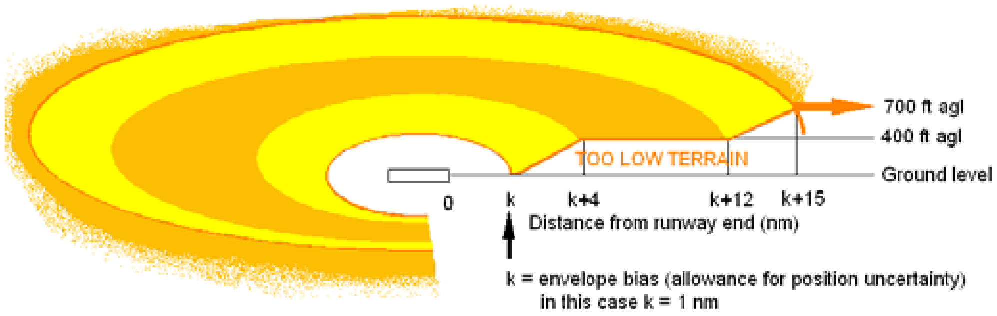


Figure 10

The TCF alert envelope for the standard of EGPWS fitted.

The actual boundary is shown in more detail in Figure 11 together with the alert envelope that would have been active had the latest software and a GPS direct link been installed in G-MEDG. These were not current requirements and were not available at the time of initial installation. Penetrating below these alert envelopes would result in a "TOO LOW TERRAIN" alert.

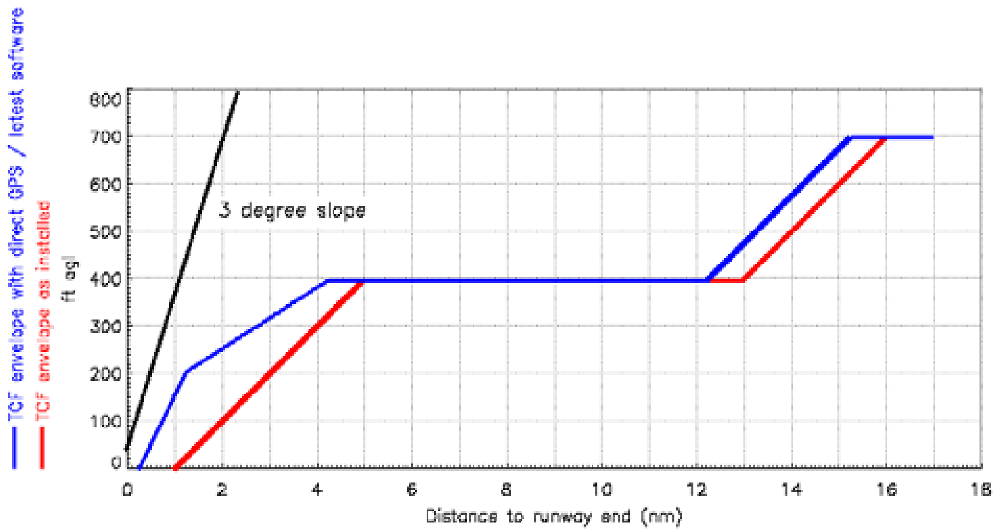


Figure 11

The TCF alert envelope.

1.18.5.5 EGPWS experience

Data downloads of EGPWS units involved in CFIT incidents and accidents are reviewed by the equipment manufacturer. One study looked at the CFIT risk to Airbus aircraft. This showed that approximately 25% of the CFIT risk exposure was within 3 nm of the runway associated with insufficient alert times. This large proportion of the risk contrasts with the small proportion of time an aircraft is within this zone. The study highlighted the following causal factors:

- Lack of GPS.
- Lack of accurate runway position data.
- Lack of latest EGPWS software.
- Lack of accurate terrain data.
- Lack of man made obstacle data.

The EGPWS manufacturer expressed concern about the sub-3 nm CFIT risks. The company advised of the need for a direct link between the GPS and the EGPWS, the benefits of which are concentrated in this risk area.

A direct data link from the GPS would allow alert/warning boundaries to operate up to ¼ nm from the runway instead of the 1 nm in use on non-GPS aircraft. Using an FMS as the EGPWS positional sensor, even if the FMS is using a GPS feed, does not provide uniform results across the large spread of FMS products being flown and is subject to the vagaries of the many different radio aid environments at airfields. Other solutions that feed GPS data to the EGPWS via other systems also increase the chances of data being corrupted and a common mode sensor failure proliferating errors across the aircraft systems. Non-GPS installations are more prone to nuisance alerts due to lateral and vertical positional errors. This provides a higher rate of nuisance warnings to flight crews, potentially resulting in a lack of appropriate reactions to alerts and/or routine inhibiting of the look-ahead functions. Both issues negate the benefits that TAWS has to offer.

Both Boeing and Airbus use a GPS source for the EGPWS as standard on aircraft they currently manufacture. The detail of how GPS data is used is so important that Airbus recently changed and re-certified the architecture of its standard GPS/EGPWS installation to ensure that pure GPS data, including the GPS quality information, is routed directly to the EGPWS.

1.18.6 Operator's EGPWS warning procedures

The operator's procedures for reacting to an EGPWS warning appear in the aircraft's Quick Reference Handbook (QRH), reproduced at Appendix 5. The procedures listed are identical to those issued by the aircraft manufacturer. The initial actions (which appear shaded in the QRH) are items required to be memorised and carried out by the flight crew without delay and without reference to any other material.

1.18.7 Operations in sandstorms

Section 8.3.8.8 of the operator's operations manual stated the following:

> '**Sandstorms** *Avoid flying in active sandstorms whenever possible. When on the ground, aircraft should ideally be kept under cover if dust storms are forecast or in progress. Alternatively, all engine blanks and cockpit covers should be fitted, as well as the blanks and 'gloves' for the various system and instrument intakes and probes. These should be carefully removed before flight to ensure that accumulations of dust are not deposited in the orifices which the covers are designed to protect.'*

1.18.8 Operator's stabilised approach criteria

Section 2.4.1 of the operator's operations manual stated the following:

> '**Stabilised Approach Criteria** *On all approaches, at 1000feet radio, the configuration must be at least flap 2 with gear down and speed less than 185kts. Furthermore, by 500feet radio (1000feet radio if the approach is made in IMC conditions), the aircraft must be stabilised in the planned landing configuration, the glide slope or correct vertical profile established, approach power set and indicated air speed no more than 10kts above V app (or GS mini). If these criteria are not achieved, then an immediate go-around must be carried out. Where an approach is made over terrain which results in a significant difference between radio height and the height above runway threshold, e.g. an approach over sea to a cliff top aerodrome, an appropriate adjustment should be made to the 500feet radio decision point.'*

2. Analysis

2.1 Implementation of MNPA operations

The investigation was unable to identify any formal CAA policy, in place prior to the incident, regarding the implementation of MNPA operations. Instead, agreement was reached between individual operators and their respective CAA Flight Operations Inspector on how they might implement such operations. This approach led, at least in part, to a lack of clear objectives on how this procedure was to be carried out. In turn, this partly led to the operator in this incident producing inconsistent training standards and incomplete operational and written procedures. This lack of standardisation resulted in the commander receiving inadequate training in the operator's MNPA procedures during his induction training. There was also a lack of clear written procedures available to both the commander and the co-pilot on how to conduct MNPA approaches. The absence of clearly explained procedures probably contributed to their fundamental omission of failing to compare the information contained in the approach chart with that in the FMGC navigation database. Had they done so they should have identified the difference between the approach descent points and final approach path angles contained in the two sources and the approach should not have been attempted. The fact that none of the feedback forms received relating to the same approach had identified these differences is symptomatic of a widespread lack of understanding of the correct procedures within the operator at the time.

The operator was collecting feedback on the MNPA approaches flown by its pilots, but at the time of the incident, the management had neither implemented a system to check the information received nor had they acted upon any of it. The lack of such a system was not due to an oversight by the operator; the management's intention was to introduce a system at a later date as part of the approval process for conducting MNPA in IMC. It was considered that as the approaches were initially being flown only under VFR conditions, the implementation of a review system was not a priority. This decision represented another missed opportunity to identify the differences between the chart and the database.

Shortly after the incident the operator decided to suspend its attempt to gain approval to conduct MNPA operations in IMC. In August 2005 the CAA published a Flight Operations Standards Communication containing information on MNPA (FOSCOM Number 5). A FOSCOM is an internal document produced by the CAA Flight Operations Inspectorate (Training Standards) Section intended to provide Flight Operations Inspectors with guidance on issues where their assigned operators might seek advice. In addition, the CAA formed a working group to examine all aspects of FMS navigation and in particular, to revise all relevant guidance and policies. These initiatives may eliminate what might be considered the first link in the chain of events leading up to this incident.

2.2 Conduct of the flight

The commander made his decision to carry out a managed non-precision approach in order to reduce the workload under the prevailing conditions. He had operated MNPA with his previous company and therefore did not consider it would be a problem, despite the fact that the reported visibility was below VFR limits and therefore did not comply with the restrictions imposed by his current employer. The co-pilot's acceptance of this decision illustrates that neither pilot appreciated that the reason MNPA were limited to VFR conditions was that not all the necessary safeguards were in place to conduct such approaches safely in IMC.

The approaches were made with reference to the Khartoum VOR/DME 36 procedural chart at Appendix 2. The approach profile required a final descent from 2,900 ft at the Final Approach Fix (FAF) called HASAN. The navigation database in the FMGC was in accordance with the latest Sudanese AIP which placed HASAN at 4.4 DME. Consequently, with the lateral and vertical profile being managed by the FMGC, the aircraft initiated descent at KTM 4.4 DME. It correctly followed the AIP prescribed descent profile whilst its vertical path was managed by the FMGC but the pilots were comparing the accuracy of the achieved descent path to the chart which showed HASAN 0.6nm further out at KTM 5 DME. Therefore, they perceived that the aircraft had started its descent 0.6 nm late and was too high on the descent profile. Despite this apparent and significant discrepancy the flight data shows that the approach was continued in the managed mode for several seconds. The aircraft had already started its descent by the time the commander interrupted the managed descent by selecting a rate of descent on the autopilot FCU. This sequence of events suggests the pilots either did not monitor the FMGS or did not understand what the aircraft was doing. Had they monitored the descent profile they would have realised that the aircraft was descending on the approach profile in its database and this would have acted as a second cue that the approach chart and navigation database were not in agreement.

When the commander switched the autopilot from managed vertical navigation under the control of the FMGS to a selected vertical path mode, HDG/VS was active and not TRK/FPA. So, instead of the vertical path dial selecting a flight path angle in accordance with the operator procedures, the dial generated a vertical speed command.

The vertical speeds subsequently dialled into the FCU, which varied between 500 ft/min and 2,000 ft/min, are not consistent with mistaking the vertical path figures displayed on the FCU as a reasonable flight path angle. Therefore, the vertical path was probably being dialled without reference to the numbers displayed but with reference to another cue. The pilot's selections resulted in a varying flight path angle that averaged about 4.5º.

The result was a maximum descent rate achieved of 1,728 ft/min at a point where the aircraft was 1,100 ft aal, less than 4 nm from the runway and in IMC. At 1,000 ft agl the aircraft was about 80 ft below the descent profile according to the approach chart and about 180 ft below the descent profile according to the navigation database. At 500 ft agl the aircraft was about 230 ft below the descent profile according to the approach chart and about 280 ft below the descent profile according to the navigation database, descending at about 1,200 ft/min.

The Operations Manual specified the criteria for an approach to be considered stable[12]. These require the aircraft to be on the correct descent profile by 1,000 ft RA (Radio Altitude) when in IMC. The flight data clearly shows that the approach was far from stable and a go around should have been initiated at 1,000 ft RA.

Irrespective of the conduct of the approach, the aircraft should not have been flown below MDA unless there were sufficient visual references to complete a safe landing. The lack of CVR information denied the investigation a clear understanding of exactly what happened when the aircraft reached MDA. On this aircraft there was no automatic voice alert when passing through MDA but the FMGS entry of the company MDA marked 1,650 ft MDA on the pressure altitude strip of the pilots' Primary Flying Displays (PFDs) as a reminder. However, the pilots' statements suggest that the required calls and responses were not made on the flight deck as the aircraft neared and then flew through the MDA. These standardised calls are intended to leave no doubt between the two pilots that either the required visual references have been achieved or a go-around is necessary. Timely calls are required so that should a go-around be required, the aircraft can transition from descent to climb without flying below MDA.

The aerodrome chart warned of lights in the vicinity which might be confused with the approach or runway lighting. Had appropriate calls been made at the critical moments, they would have almost certainly prevented the confusion that allowed the aircraft to continue below MDA without the required visual references.

12 See paragraph 1.18.7.

The commander made the decision to go-around when he realised that the lights he could see were not the approach lights and that he was becoming disorientated due to the blowing sand. The aircraft had descended 210 ft below MDA when he commenced the go-around by selecting the thrust levers to TOGA. The time taken for the engine power to increase and for the aircraft to transition from descent to climb allowed it to descend a further 80 to100 ft. This resulted in the aircraft descending to 121 ft agl, triggering the EGPWS warning. Had the go-around been commenced as required by the operator's procedures, the EGPWS would not have been triggered because the aircraft would have had sufficient altitude remaining to safely commence its climb without descending below MDA.

When the EGPWS terrain awareness warning, "TERRAIN AHEAD, PULL UP", was triggered the thrust levers were already at TOGA and the commander's sidestick was at about 40% rear deflection. He then made a forward deflection briefly before again making a rearwards deflection of 54%. This was contrary to the memory drill listed in the QRH which requires full back stick to be applied. The commander explained he had not selected full back stick as he considered he was already over pitching the aircraft during the go-around manoeuvre he had just commenced.

Omitting to select full back stick promptly and positively was inappropriate and inconsistent with the pilots' training and the published QRH procedure issued by the aircraft manufacturer. By nature, any EGPWS terrain warning requires prompt and decisive action and the protections built into the aircraft's flight control system allow for the application and maintenance of full back sidestick until the warning ceases. However, the QRH instructs the pilot to '*pull up to full back stick and maintain*'. This phrase can be interpreted in two ways. The placing of commas is used to illustrate the ambiguity. It could be read as:

> ***'pull up, to full back stick, and maintain'***,

or alternatively, it could be interpreted as:

> ***'pull, up to full back stick, and maintain'***

The second interpretation infers that any amount of back stick is acceptable, rather than the full deflection that is intended and taught. The word *'up'* could be deleted so that the instruction reads '*pull to full back stick and maintain*'. Therefore it was recommended that:

> Airbus should revise the expanded information *'Pull up to full backstick and maintain'* of the A320 Emergency Procedure for the EGPWS Alert "TERRAIN TERRAIN PULL UP" to remove any ambiguity about the amount of rearwards sidestick that should be applied. (Safety Recommendation 2007-041)

2.3 Operations in blowing sand and dust

Neither pilot had previously encountered blowing sand so they sought guidance from the Operations Manual. The commander stated he was unable to find suitable guidance and instead adopted the procedures for encounters with volcanic ash. However, the operator's Operations Manual did contain guidance on operating in sandstorms in the section which preceded volcanic ash; it advised that flight in an active sandstorm should be avoided whenever possible.

Whilst the demarcation between blowing sand and a sandstorm is somewhat subjective, there was written guidance available to the pilots, in the appropriate document, about the problems associated with sand encounters. In the absence of more detailed knowledge, a diversion would have avoided possible damage to the aircraft, incurred either by flying through the sand or subsequently on the ground, had the appropriate blanks and covers not been available. They were not carried on the aircraft and they were not available from the operator's contracted staff at Khartoum.

Enquiries by the AAIB have revealed little published information available on operations in blowing sand. The aircraft manufacturer did not publish any specific procedures for in flight operations in blowing sand, although they did published limited information for ground operations at airports covered with ash or dust.

The aircraft manufacturer stated in correspondence to the AAIB in July 2005 that flight in these conditions was possible and that they were now working on a new procedure for use both on the ground and in the air. This was likely to be published as a separate Supplementary Techniques chapter in the FCOM (Flight Crew Operations Manual) entitled 'Operations from/to airports contaminated with loose/abrasive particles'.

This amendment was not in place by the end of 2006. When a progress report was sought by the AAIB, the aircraft manufacturer advised that the procedure for sand encounters will be introduced with next FCOM Volume 3 revision which is planned for September 2007. In view of the continuing delay in producing this important guidance, the AAIB made the following Safety Recommendation:

> Airbus should expedite publication of guidance material relevant to flight and ground operations by Airbus aircraft types in conditions of blowing sand or low drifting sand. (Safety Recommendation 2007-042)

Because this operator frequently conducts operations in areas prone to blowing sand it seems prudent that they ensure their pilots are familiar with flight restrictions imposed and if necessary expand upon the guidance available in the Operations Manual. Since this incident, the operator has stated that "additional advice on operations in sand has been subsequently included in the BMED Operations manual though there is no guidance from the aircraft or engine manufacturers for such operations".

2.4 The conversion of reported visibility to RVR

Another aspect of operating in blowing sand was the validity of the calculation used by the pilots to convert meteorological visibility into an RVR. The investigation sought to establish whether the conversion took into account the different characteristics of sand and dust, as opposed to water droplets, when the conversion procedure was introduced. No authoritative answer was identified and it seems much of the definitive work in this area was conducted some years ago with few records now being available. However, the UK CAA stated that visibility is restricted to some extent by the effect of light being scattered and absorbed by atmospheric particles (eg microscopic salt crystals, dust or soot particles and water droplets), whether suspended in or falling through the atmosphere. Even in the absence of particles, molecular scattering (known as Rayleigh scattering) limits the visibility. The ICAO Manual of Runway Visual Range and Reporting Practices (ICAO Doc 9328, 3rd Ed. 2005) notes that in a sandstorm, a strong and turbulent wind is required to carry and maintain sand suspended in the atmosphere. Typically, in these events, the particles are of the order 0.08 to 1 mm in diameter. The CAA also stated that it is known that dense and widespread drifting sand may partially or totally prevent a pilot from seeing the runway lights, although the reported meteorological visibility may suggest that he ought to be able to see the lights. It has not, however, been possible to ascertain if the effect of suspended solids on visibility, particularly slant visibility at night, has ever been subjected to any scientific research.

The investigation could not determine why inaccurate visibility figures were passed to the pilots nor why the SIGMET regarding the blowing sand had not been made available to them. Both these factors were unhelpful to the pilots in being able to make timely decisions about the conduct of the flight. Certainly, had the pilots been informed that the visibility at Khartoum was only 200 m, they would have been able to determine that this was insufficient to attempt an approach. However, the inaccurate reporting of visibility had no relevance to their descent below MDA. If, at MDA, the landing pilot did not have the required visual references clearly in view, he should have called for or executed a go-around in sufficient time for the aircraft not to have descended below MDA.

2.5 TAWS effectiveness

During the first approach the aircraft came hazardously close to the ground. The installed TAWS failed to alert the pilots to the threat before they initiated a go-around.

As the go-around was initiated the aircraft terrain closure rate was approximately 1,200 ft/min. Given that the minimum recorded terrain clearance achieved was 121 ft (and assuming that the terrain in the area is flat with no significant buildings) it is reasonable to assume that had the go-around decision been delayed by 6 seconds, the aircraft could have impacted the ground roughly 1.5 nm short of the runway.

The EGPWS warning triggered between 3.4 and 5.1 seconds after the initial go-around action was taken and would not have been triggered significantly earlier had the 1,200 ft/min closure rate been maintained. Given that procedural triggers to go-around had not been effective it is of concern that the warning system may not have provided sufficient alert time to prevent an impact with the ground.

The fact that the GPS, GPIRS and FMC positions were close and correlated with the recorded DME distance showed that navigational accuracy was not a factor in the ineffectiveness of the EGPWS in this instance. No anomalies with other sources of data were identified and the EGPWS was fully operational as established by analysis by the manufacturer. The lack of a timely alert was a factor of the design of the system.

The navigation system as installed included a GPS source and so provided accuracy that exceeded the applicable TAWS requirements even though the GPS did not directly feed the EGPWS. Further manufacturer analysis of the data highlighted that had a direct link between the GPS and the EGPWS been installed and the latest software used, the TCF alerting envelope would have triggered a "TOO LOW TERRAIN" with a radio altitude of approximately 240 ft as show in Figure 12. The "PULL UP" warning trigger point would not have changed. The alert at 240 ft radio altitude would have served as an earlier, systematic alert whereas none was given by the system installed at that time.

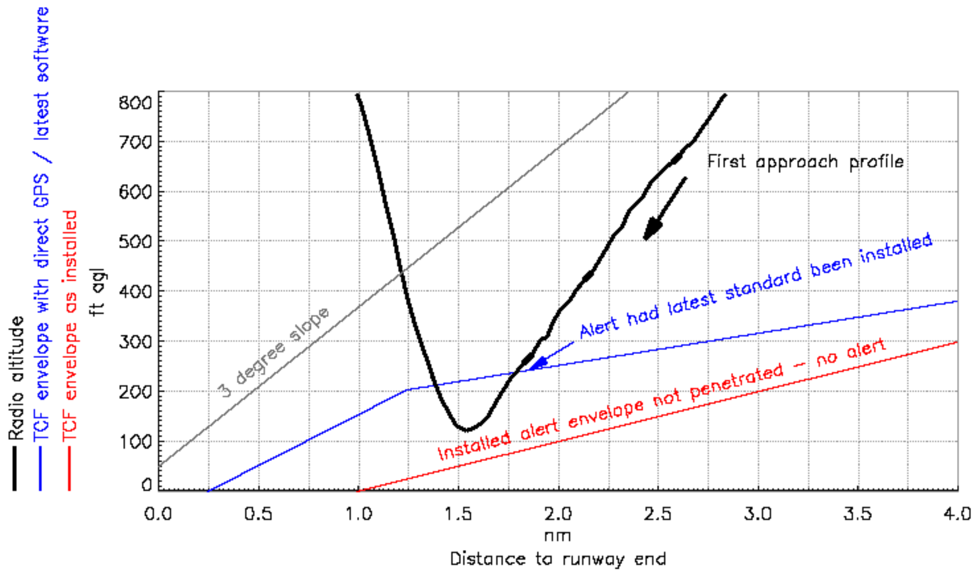


Figure 12

The TCF alert envelope as fitted compared to the latest certified alert envelope with a direct GPS feed to the EGPWS

Whilst it is doubtful that an improved alert time would have resulted in a terrain clearance better than was achieved, it does suggest that a comparable terrain clearance could have been achieved had the pilots decision to go-around not been taken at the point that it was.

Given that the ineffective alert timing satisfied the certification requirements applicable at the time and that currently available technology would have improved this alerting time, it is considered appropriate to strive for improved TAWS certification requirements in this area.

The current TAWS standards undoubtedly were appropriate at the time of implementation and the statistics show that they have significantly reduced the CFIT risks, (most likely saving many lives). However, operational experience of indirect GPS installations that do not directly feed GPS quality data to the TAWS (and even non-GPS installations) has highlighted problems that have been addressed by the TAWS manufacturers but that are not required to be implemented. In essence, the CFIT protection technology has improved but the required minimum TAWS standards have not. Thus significant improvements in aviation safety in this area are available but not mandated. Consequently, the following Safety Recommendation was made:

The European Aviation Safety Agency, in conjunction with industry, should review the current TAWS system design criteria (ETSO-C151a), and installation certification criteria, with particular emphasis on the timeliness of alerting when close to the runway. Revisions to these standards arising from this review should apply retrospectively to all aircraft currently covered by the TAWS mandate. (Safety Recommendation 2007-044)

2.6 Navigation data

The provision of navigation information for use in aviation is complex. Considerable work has been undertaken by regulating authorities to set standards in the hope of ensuring accurate information for use around the world by a multitude of operators and aircraft types. This investigation has revealed that despite such steps the system is still vulnerable to error.

Reference by the datahouse only to RVR figures, as opposed to visibility, when publishing minima for all but circling approaches complied with JAR-OPS convention. However, by not converting the visibility requirement quoted in the AIP into an equivalent RVR on their charts, the datahouse would not necessarily have been complying with the limits laid down by the relevant state or appropriate regulator. In this case it was purely co-incidence that the published minima complied with the JAR-OPS requirement for the approach, but it did not comply with the more restrictive Sudanese requirement.

Since this incident the datahouse responsible for producing the approach chart has changed its own in-house quality assurance procedures to try and prevent a repeat of the circumstances leading to use of out of date information in this incident. The datahouse has also implemented a more rigorous procedure for ensuring that appropriate approach minima are published on all approach charts. This procedure is also designed to ensure that published approach minima properly reflects either the more restrictive minima, or all minima promulgated by the State AIP.

It is apparent that all datahouses remain vulnerable whilst countries apply the published standards with differing effectiveness and whilst each datahouse is responsible for collating and interpreting its own data. Sufficient regulation probably exists to provide the aviation industry with accurate data but only if all nations adhere to the requirements as intended.

2.7 Residual differences between charts and databases

It seems likely that there will be future encounters where pilots and their aircraft are qualified for a managed non-precision approach but the chart and the FMS database parameters differ, as in this case. Pilots are then faced with a dilemma:

Do they:

a. Fly the MNPA using the FMS database parameters?
b. Carry out a normal non-precision approach according to the chart parameters using selected autopilot modes?
c. Use an alternative approach which has no data discrepancies?
d. Divert?

They may be tempted to abide by the data set (be it chart or FMS database) bearing the most recent amendment date but this may not be the safest option. Charts bear an amendment date relating to changes relevant to the specific approach procedure whereas FMS databases are routinely and regularly updated even though the majority of stored approach parameters may remain unchanged. Consequently, a recently amended FMS database may not necessarily contain the most recent changes to a specific approach procedure. Therefore it was recommended that:

> The UK CAA should publish guidance to pilots regarding the appropriate action when faced with a conflict in approach parameters between their approach charts and an FMS database authorised for managed non-precision approaches. (Safety Recommendation 2007-046)

3. Conclusions

(a) Findings

1. The UK CAA had no official policy in place at the time of the incident which adequately described all the requirements for MNPA operations.

2. The pilots had not received all the appropriate training in MNPA operations from the operator.

3. The operator had received five feedback forms relating to issues associated with MNPA to Runway 36 at Khartoum.

4. The operator had not processed any MNPA feedback forms received prior to the incident.

5. The operator's Operations Manual recommended avoiding flight into sandstorms.

6. The aircraft was operated into conditions reported as blowing sand.

7. The pilots were passed incomplete or inaccurate information on the visibility at Khartoum.

8. The JAR-OPS1 minimum RVR for the approach was 1,600 m but this was inconsistent with the 1,600 m visibility specified by the Sudanese authorities on the State chart.

9. No check was made that the approach information on the chart agreed with that in the navigation database.

10. MNPA's were only authorised in VMC.

11. An MNPA was commenced to Runway 36 at Khartoum in IMC.

12. At the time of the incident, the operator used charts and databases supplied by different commercial organisations.

13. The FMGC navigation database correctly reflected the most recent revision of the Sudanese AIP which placed the FAF at 4.4 DME from the KTM VOR/DME beacon.

14. The approach charts showed the FAF at 5 DME from the KTM VOR/DME beacon; this position did not reflect the latest Sudanese AIP revision.

15. The autopilot flew the managed approach in accordance with the parameters stored in the FMGC navigation database.

16. The aircraft started its descent in a managed approach mode at KTM 4.4 DME.

17. The commander changed to selected descent mode at KTM 4 DME, believing the aircraft was high on the approach profile.

18. The maximum descent rate achieved during the final approach was 1,728 ft/min at a point where the aircraft was 1,100 ft aal, less than 4 miles from touchdown and whilst in IMC.

19. The approach was unstable as the aircraft passed through 1,000 ft agl.

20. The operator required that a go around be flown for any unstable approach in IMC when passing 1,000 ft agl.

21. As MDA was reached, each pilot mistakenly believed that the other pilot was visual with the runway approach lights.

22. No decision calls were made in accordance with the operator's procedures when approaching or at MDA.

23. TOGA power was selected approximately 160 ft below the published MDA, equating to 210 ft below the company MDA.

24. The minimum terrain clearance recorded was 121 ft agl at a position more than 1.5 nm from the runway threshold.

25. Between 3.4 and 5.1 seconds after the go-around manoeuvre had been initiated, an EGPWS pull up warning was triggered.

26. The EGPWS worked in accordance with its design and contemporary certification requirements.

27. It is likely that the EGPWS alert would not have provided sufficient warning time to prevent a CFIT accident.

28. During the EGPWS alert, the sidestick was not maintained in the fully aft position as required by the Emergency Procedure.

29. Since the initial TAWS certification requirements were drawn up, the EGPWS manufacturer has improved the system's design to reduce the CFIT risk areas.

30. A direct feed to the EGPWS of GPS position and accuracy data is necessary to improve EGPWS performance during the late stages of an approach.

31. Recent aircraft manufacturer's revisions to the integration procedures for EGPWS into Boeing and Airbus aircraft require pure GPS data, including GPS accuracy information, to be routed directly to the EGPWS.

32. In this incident, currently certified but not mandated EGPWS integration improvements could have yielded an earlier "TOO LOW TERRAIN" alert.

(b) Causal factors

The following causal factors were identified:

1. The pilots were unaware of a significant discrepancy between the approach parameters on the approach chart and those within the navigation database because they had not compared the two data sets before commencing the approach.

2. Confusion regarding the correct approach profile and inappropriate autopilot selections led to an unstable approach.

3. The unstable approach was continued below Minimum Descent Altitude without the landing pilot having the required visual references.

4. The UK CAA's guidance and the regulatory requirements for approval to conduct MNPA were fragmented and ill-defined.

5. The operator's planning and implementation of MNPA (Managed Non-Precision Approaches) procedures included incomplete operational and written procedures and inconsistent training standards.

6. The ability of the installed EGPWS to provide sufficient warning of inappropriate terrain closure during the late stages of the approach was constrained by the lack of a direct data feed from the GPS navigation equipment.

4 Safety Recommendations

The following Safety Recommendations have been made:

4.1 **Safety Recommendation 2007-041**: Airbus should revise the expanded information *'Pull up to full backstick and maintain'* of the A320 Emergency Procedure for the EGPWS Alert "TERRAIN TERRAIN PULL UP" to remove any ambiguity about the amount of rearwards sidestick that should be applied.

4.2 **Safety Recommendation 2007-042**: Airbus should expedite publication of guidance material relevant to flight and ground operations by Airbus aircraft types in conditions of blowing sand or low drifting sand.

4.4 **Safety Recommendation 2007-044**: The European Aviation Safety Agency, in conjunction with industry, should review the current TAWS system design criteria (ETSO-C151a), and installation certification criteria, with particular emphasis on the timeliness of alerting when close to the runway. Revisions to these standards arising from this review should apply retrospectively to all aircraft currently covered by the TAWS mandate.

4.5 **Safety Recommendation 2007-046**: The UK CAA should publish guidance to pilots regarding the appropriate action when faced with a conflict in approach parameters between their approach charts and an FMS database authorised for managed non-precision approaches.

J J BARNETT
Principal Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport
November 2007

GLOSSARY AND ACRONYMS USED IN THIS REPORT

AIP	Aeronautical Information Package. A state publication detailing the aeronautical information necessary for flying in that state, including charts and approach.
CFIT	Controlled Flight Into Terrain. This is effectively flying a controllable aircraft into terrain because of a lack of awareness of the terrain. This is the single largest cause of civil aviation fatalities.
DAR	Digital AIDS Recorder (AIDS = Aircraft Integrated Data System). This records aircraft parameters as per the FDR.
EASA	European Aviation Safety Agency. The relatively recently formed (forming) body responsible for generating and enforcing a common set of airworthiness codes that is mandatory to all member states of the European Union.
EGPWS	Enhanced Ground Proximity Warning System - Honeywell TAWS product.
ETSO	See TSO.
FAA	Federal Aviation Administration.
FAF	Final Approach Fix.
FCU	Flight Control Unit. The pilots use this unit to engage the autopilot and the autothrust and to enter commands to these units.
FDR	Flight Data Recorder.
FLTA	Forward Looking Terrain Avoidance – a required function of TAWS to look ahead of the aircraft and assess terrain hazards by comparing the aircraft projected flight path with a terrain database. This is covered by the Honeywell Terrain Look Ahead Alerting function.
FMGC	Flight Management and Guidance Computer(s).
FMGS	Flight Management and Guidance System.
FMS	Flight Management System. Part of the FMS function is the calculation of the aircraft position and motion using multiple sensor inputs. On the A321 the FMS processing resides in the FMGC.

GLOSSARY AND ACRONYMS USED IN THIS REPORT (Cont)

GPIRS	Blend of GPS and IRS position information.
GPWS	Ground Proximity Warning System - sometimes used in industry to refer to the older alert modes, and sometimes used to include the new alert modes as well. In this document the term 'classic GPWS' is used to refer to the older alert modes.
GPS	Global Positioning System. A system that calculates its position on/above the earth by processing signals from a constellation of satellites that orbit the earth.
IAF	Initial Approach Fix.
ICAO	International Civil Aviation Organisation.
IRS	Inertial Reference System.
JAA	Joint Aviation Authorities. A European body established by a collection of European countries to generate common airworthiness requirement codes which could be adopted by a country if they decided to do so. The JAA role is being overtaken by the formation of EASA.
JTSO	See TSO.
MDA	Minimum Descent Altitude.
MNPA	Managed Non-Precision Approach.
Navigation database	A computerised database containing aeronautical data regarding runway, navigational aid and waypoint locations and standard flight paths.
Radio Altitude	Also referred to as terrain clearance for the purpose of this investigation. This is the vertical separation between the terrain and the aircraft.
TAD	Terrain Alerting and Display – A proprietary term referring to a new forward looking alerting mode and terrain display.
TAWS	Terrain Awareness and Warning System – sometimes used in industry to refer to the newer alert modes, but the specification also includes the classic GPWS alert modes.

GLOSSARY AND ACRONYMS USED IN THIS REPORT (Cont)

Terrain Clearance	See Radio Altitude.
TCF	Terrain Clearance Floor – A proprietary alerting mode for the TAWS PDA requirement incorporated into EGPWS.
TGL12	Short reference used in these documents to refer to JAA document "*Section One: General Part 3: Temporary Guidance Leaflets LEAFLET NO 12: Certification Considerations for the Terrain Awareness Warning System: TAWS*."
TSO	Technical Standard Order – a document detailing the minimum performance standard of a system. TSOs are produced by the FAA. The JAA version is called a JTSO and the EASA version is called an ETSO.
PDA	Premature Descent Alerting. This is intended to protect the aircraft from landing short of the runway (or to the side) even when in full landing configuration. EGPWS satisfies this alert mode requirement with TCF alerting.
QAR	Quick Access Recorder. A data recorder on an aircraft that is not crash protected but records data for the purpose of quality management.
VOR/DME	A co-located pair of navigation aids that enable an aircraft to establish where it is relative to a ground station by virtue of detecting the relative bearing from the ground station and distance to the ground station.