FINAL REPORT

AAIU Synoptic Report No: 2010-012
State File No: IRL00909059
Published: 30/08/2010

In accordance with the provisions of SI 205 of 1997, the Chief Inspector of Air Accidents, on 14 July 2009, appointed Mr. Thomas Moloney as the Investigator-in-Charge to carry out a Field Investigation into this Serious Incident and prepare a Report. The sole purpose of this Investigation is the prevention of aviation Accidents and Incidents. It is not the purpose of the Investigation to apportion blame or liability.

Aircraft Type and Registration:	Gulfstream IV (GIV) SP, VT-MST	
No. and Type of Engines:	2 x Rolls Royce Tay 611-8	
Aircraft Serial Number:	1379	
Year of Manufacture:	1999	
Date and Time (UTC[1]):	13 July 2009 @ 08.13 hrs	
Location:	Near Killarney, Co. Kerry, Ireland	
Type of Flight:	Private	
Persons on Board:	Crew - 2	Passengers - 1
Injuries:	Crew - Nil	Passengers - Nil
Nature of Damage:	Substantial damage to No. 1 engine Windshield fractured	
Commander's Licence:	Airline Transport Pilot Licence issued by the U.S. Federal Aviation Administration (FAA)	
Commander's Details:	Male, aged 45 years	
Commander's Flying Experience:	12,500 hours, of which 1,027 were on type	
Notification Source:	Shannon Air Traffic Services (ATS) and Kerry Airport ATS	
Information Source:	AAIU Field Investigation	

SYNOPSIS

The aircraft departed from Runway (RWY) 08 at Kerry Airport (EIKY) on a flight to Luton, England (EGGW). Shortly after take-off, the left hand windshield fractured and the crew requested a return to EIKY. Kerry Tower cleared the aircraft to return using a procedure to establish on the Instrument Landing System (ILS) approach for RWY 26. The aircraft initiated the procedure but then commenced a descent, in cloud, on a track approximately parallel to the ILS but 6 nautical miles (nm) south of it. A radar controller in Shannon, who had been monitoring but not controlling the flight, intervened by phone with Kerry Tower and directed that Kerry Tower should instruct the aircraft to climb immediately.

[1] Local time = UTC + 1 hour during summertime. All times in this Report are in UTC (Universal Time Co-ordinated).

Contemporaneously, the aircraft's Enhanced Ground Proximity Warning System (EGPWS) alerted the crew. The aircraft reached a lowest height above the ground of 702 ft before commencing a climb. Kerry Tower handed it over to a radar controller at Shannon for guidance onto the ILS but the aircraft encountered further navigational difficulties before landing. On subsequent technical inspection, it was also found that the No. 1 engine had sustained serious foreign object damage and that an engine change was required.

NOTIFICATION

Notification of this serious incident was received by the Air Accident Investigation Unit (AAIU) from Shannon ATS and also from Kerry Airport ATS. Both reports referred to the cracked windshield and the aircraft's descent south of the localiser. There was no mention of engine difficulties in either report. Two AAIU Inspectors travelled to EIKY on the morning of 14 July 2009 to inspect the aircraft and to interview the crew and ATS personnel. The Directorate General of Civil Aviation (DGCA) of India appointed a non-travelling Accredited Representative (ACCREP) to the Investigation and also appointed the Managing Director of the Operator as an Adviser to the ACCREP.

1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft departed off RWY 08 at EIKY at 08.06 hrs with the intended destination of London Luton Airport (EGGW). The Captain was the pilot flying (PF). Kerry Air Traffic Control (ATC) had cleared the aircraft to depart on a CRK 1C SID[2], **Appendix A, Chart 1**. This procedure required a climb-out along a bearing of 078ºM from the Kerry non-directional beacon (NDB) to a distance of 5 nm from the airport at or above 1,300 ft, followed by a right turn to intercept the 312ºM Radial inbound to Cork VOR[3], with a maximum altitude restriction of 4,500 ft. After departure, Kerry ATC instructed the aircraft to change frequency to Shannon Centre on 124.700 MHz and the First Officer acknowledged this message.

Shortly after the aircraft had become airborne, the left-hand windshield (i.e. the windshield in front of the Captain) cracked. The crew did not contact Shannon Centre, but at 08.07:00 hrs, the First Officer transmitted to Kerry Tower, "*Sir, we have a cracked windshield. We're levelling off at three thousand, we'd like to come back to Kerry*". Kerry ATC asked the aircraft to confirm its position and received the response at 08.08:00 hrs, "*Three five miles southeast*[4] *and we'd like to maintain three thousand feet*". At 08.08:10 hrs Kerry Tower asked the aircraft, "*Do you wish to self position at INRAD*[5] *or route to the overhead*", to which VT-MST responded, "*Ok, confirm call you overhead at three thousand, Victor Sierra Tango*". Kerry responded, "*Victor Sierra Tango roger, next report overhead establishing outbound on the ILS for an ILS DME*[6] *approach runway 26*". VT-MST responded, "*Call you overhead, call you outbound for the ILS 26, Victor Sierra Tango*". The instrument approach chart for an ILS approach to RWY 26 is shown at **Appendix 1, Chart 2**.

[2] SID: Standard Instrument Departure
[3] VOR: VHF omni-range navigation beacon
[4] This position report is further discussed in Section 2 Analysis
[5] INRAD is the Intermediate Fix (IF) reporting point on the RWY 26 ILS localiser, 14.0 nm from EIKY.
[6] DME: Distance Measuring Equipment

The flight path of VT-MST is shown in **Figure No. 1**.

The aircraft, which had initially been following the CRK 1C departure procedure, levelled off at 3,000 ft and then commenced a 180º turn to the right at 08.09:20 hrs, (Point 1 on **Figure No. 1**). It rolled out onto an inbound heading towards EIKY.

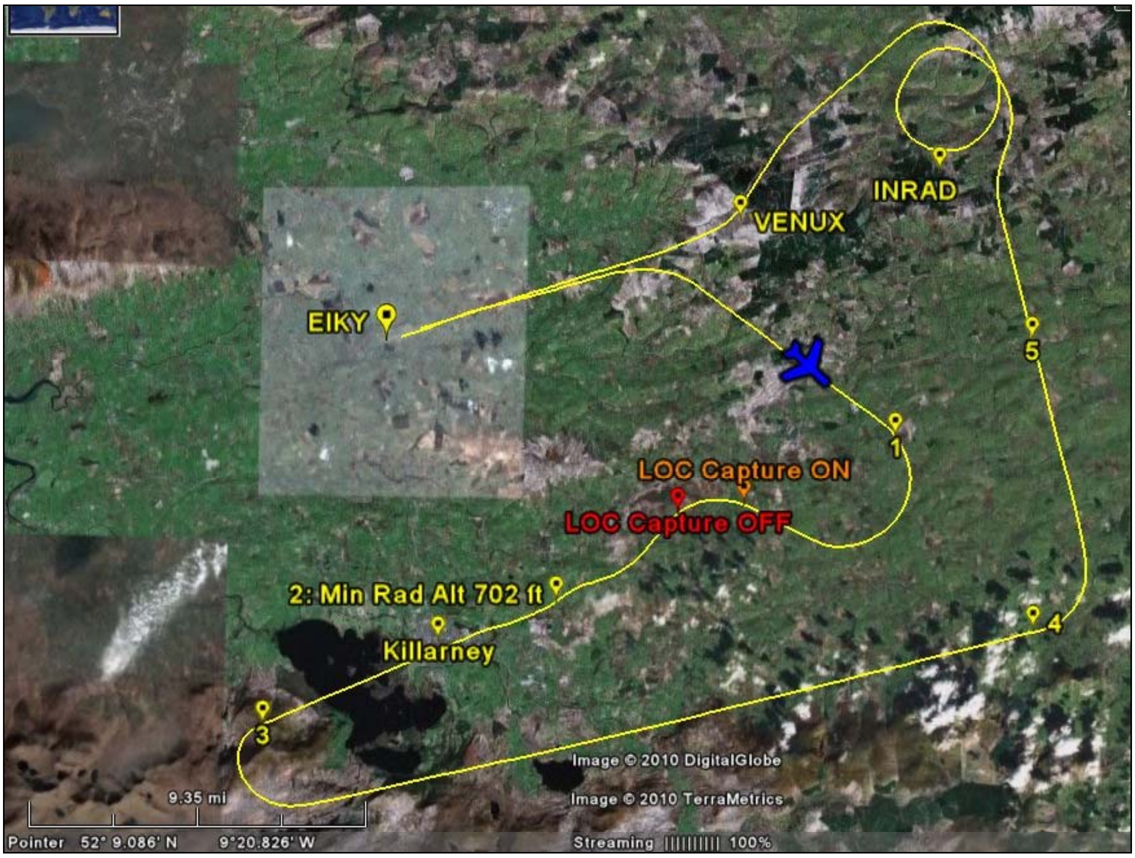


Figure No. 1: Flight Path of VT-MST

At 08.10:30 hrs, Kerry Tower asked VT-MST to confirm position and received the response, "*Ah we're turning inbound now, one zero miles inbound*". Kerry responded, "*Roger confirm you're inbound on the localiser*", to which VT-MST replied, "*Turning back on the localiser now one correction niner miles inbound now*". Kerry Tower then cleared the aircraft for the ILS approach.

Digital Flight Data Recorder (DFDR) data indicates that the aircraft navigation systems received a "false localiser" signal and generated a Localiser Capture message at a point approximately 9.4 nm southeast of EIKY. This message came ON for a time period of 64 seconds (±16 secs) and then went OFF. The approximate points where the message came ON and returned to OFF are shown on **Figure No. 1** by "*LOC Capture ON*", and "*LOC Capture OFF*". This matter is described more fully in **Section 1.11.**

At 08.11:30 hrs, at a point approximately 9 nm southeast of EIKY and in close proximity to the point where the Localiser Capture message came on, the aircraft commenced a left turn, finally rolling out on a southwesterly heading approximately 6 nm south of the localiser. The crew de-selected the autopilot (which had been engaged shortly after the aircraft had levelled at 3,000 ft) and the aircraft commenced a descent.

At 08.12:00 hrs, Kerry Tower again requested VT-MST to report position. VT-MST replied, "*Coming up on the localiser ah seven DME*[7]".

At 08.12:39 hrs, a radar controller in Shannon ATC Centre alerted the controller in Kerry Tower by phone to the fact that the aircraft was at 1,600 ft in the area of Killarney, approximately six miles south of the localiser. Kerry Tower asked the aircraft to confirm its present position and altitude to which VT-MST responded, "*Present position is six decimal eight on the localiser (RWY) 26*". The Shannon controller directed the Kerry controller to "*Climb him now please*". At 08.13:07 hrs the Kerry controller transmitted, "*Victor Tango Mike Sierra Tango, Shannon radar indicating you are six miles south of the field in high terrain. Climb immediately to 3,500 feet*". Contemporaneously, the aircraft EGPWS alerted the crew at a radio height (i.e. height above the ground) of approximately 800 ft. DFDR data indicates that the descent lasted for 1 minute 40 seconds, that the vertical speed during the first minute of this descent was in excess of 1,300 ft/min and that the aircraft reached a lowest recorded radio height of 702 feet, (Point 2 on **Figure No. 1**). The ILS Approach Chart shown at **Appendix 1, Chart 2** indicates a descent rate of 740 ft/min for a typical approach ground speed of 140 kts.

As the aircraft commenced its climb, the Kerry Tower controller handed over the aircraft to a Shannon radar controller who directed the aircraft to climb to 5,000 ft on the Kerry QNH pressure setting of 999 hPa.

Subsequently, at 08.15:45 hrs, (Point 3 on **Figure No. 1**) Shannon ATC vectored the aircraft initially on a heading of 090ºM and at 08.21:34 hrs, (Point 4 on **Figure No. 1**) onto a heading of 350ºM towards the localiser for RWY 26 at EIKY. At 08.23:42 hrs, (Point 5 on **Figure No. 1**), VT-MST confirmed that the aircraft was 4.7 nm from reporting point VENUX[8]. Shannon cleared VT-MST to turn left and route direct to VENUX to establish on the localiser RWY 26 at EIKY and, when ready, to descend to 3,300 ft. VT-MST acknowledged this instruction and stated that they would report when established on the localiser.

However, the aircraft did not turn left towards VENUX or descend but maintained the heading of 350ºM. As it passed through the localiser it commenced a right turn onto a heading of 010ºM. This was followed by a left hand orbit to the north of the localiser. At 08.26:20 hrs, VT-MST reported to Shannon that they were having problems with their Flight Management System (FMS) and requested permission to maintain position. Shannon ATC cleared the aircraft to orbit in their present position and offered to provide vectors onto finals RWY 26, an offer which the crew accepted. The aircraft was instructed to continue in the left turn onto a heading of 230ºM to intercept the localiser and to descend to 3,300 ft. At 08.30:20 hrs, VT-MST called that he was established on the localiser and at 08.30:52 hrs, Shannon instructed the aircraft to call Kerry Tower. VT-MST landed at Kerry at 08.34 hrs. The aircraft taxied to Stand 4 on the main ramp, the engines were shut down and the single passenger disembarked. The crew did not pull the Cockpit Voice Recorder (CVR) circuit breaker after the flight, although this is a requirement under DGCA of India Civil Aviation Requirements, following an accident or incident.

[7] Seven nm from the Distance Measuring Equipment (DME) station located at EIKY.
[8] VENUX is the Final Approach Point (FAP) reporting point on the RWY 26 ILS localiser, 8.9 nm from EIKY

1.2 Actions Following the Flight

At 09.32 hrs, VT-MST started engines again and taxied to remote parking on a disused runway at EIKY. At approximately 11.00 hrs, the crew commenced a number of ground runs of the No. 1 engine. The ground runs included a series of engine acceleration – deceleration actions.

1.3 Personnel Information

1.3.1 Captain

Personal Details:	Male, aged 45 years	
Licence:	Airline Transport Pilot Licence (USA FAA) Authorisation from DGCA India to fly GIV aircraft	
Medical Certificate:	Class 1, issued 9 April 2009	
Flying Experience:	Total all types:	12,500 hours
	Total all types (P1):	7,000 hours
	Total on GIV:	1,027 hours
	Total on GIV (P1):	900 hours
	Last 90 days	100 hours
	Last 28 days	31.4 hours
	Last 24 hrs	Nil

1.3.2 First Officer

Personal Details:	Male, aged 38 years	
Licence:	Commercial Pilot Licence (India DGCA) Commercial Pilot Licence (USA FAA)	
Medical Certificate:	Class 1, issued 22 April 2009	
Flying Experience:	Total all types:	3,200 hours
	Total all types (P1):	1,000 hours
	Total on GIV:	200 hours
	Last 90 days:	23 hours
	Last 28 days:	1.4 hours
	Last 24 hrs:	Nil

1.3.3 Crew Training

The Investigation requested crew-training records from the Operator through the ACCREP.

The Operator provided the Investigation with copies of the Captain's U.S. FAA Licence, medical certification, DGCA of India validation of his FAA Licence to fly Indian registered Gulfstream IV aircraft and summaries of his flying experience. The Operator also provided a copy of a certificate for GIV Recurrent PIC (Pilot-in-Command) training from a U.S. organisation dated 5 August 2008.

The First Officer had completed an Initial GIV Pilot SIC (Second in Command) training course at a U.S. training organisation in May/June 2008. The assessment for each exercise he performed in the simulator was graded as "Above Standard" by an FAA approved examiner. His training report included an entry, "*Excellent FMS and systems knowledge*". He completed a Pilot's Proficiency Check in November 2008 and a Route Check in December 2008 and he repeated the same two Checks in May 2009, all in India on VT-MST with DGCA approved examiner/instructors. All of his recurrency training was carried out on VT-MST.

1.4 Initial Inspection of the Aircraft

Two Inspectors from the AAIU arrived in EIKY at noon on 14 July (the day after the occurrence flight) to inspect the aircraft and to interview the crew. Up to that time, the Investigation had received no reports of any engine problems on the aircraft.

A maintenance crew from the aircraft manufacturer also arrived in EIKY from the UK on 14 July with a replacement windshield. The DFDR and the CVR were removed from the aircraft. An AAIU Inspector subsequently took the recorders to the UK Air Accidents Investigation Branch (AAIB) facilities in Farnborough where they were successfully downloaded. However, due to the fact that the CVR circuit breaker had not been pulled after the flight, the entire two-hour recording consisted of post-flight activity including most of the engine runs. Thus, no CVR recording of the flight, the subsequent start-up and taxi to the remote parking or the first engine run was available to the Investigation.

On initial inspection of the aircraft by the Investigation, it became clear that the No. 1 (left-hand) engine, Tay 611-8 s/n 16883, had sustained what appeared to be severe Foreign Object Damage (FOD). Many of the fan blades had V-shaped nicks in their leading edges while a boroscopic examination of the forward stages of the compressor showed significant blade damage. The Investigation and the manufacturer's maintenance crew found no evidence of a missing aircraft part, which might have been ingested into the engine.

The left hand windshield had fractured throughout its outer glass ply. Initial examination suggested that the windshield had suffered an electrical arcing failure, which had initiated the fracturing.

The Investigation examined the aircraft documentation. The aircraft was operating on a Certificate of Airworthiness issued by the DGCA of India, issued on 3 January 2008 and valid until 20 November 2009. It had been transferred onto the Indian register on 1 January 2008, having previously been on the U.S. register. The most recent Certificate of Release to Service was issued by the Operator's Chief Engineer in Luton on 10 July 2009, following which the aircraft had departed Luton for EIKY. The four documents which the crew utilised on a day to day basis were examined by the Investigation; these consisted of a Flight Sector Book, used to record flight times and incorporating an aircraft performance log; a Tech Log Record, used by the pilot to certify a pre-flight check and to record fuel uplifts; a Flight Release Certification document and a Pilot's Defect Report. Page 154 of this latter document was found to contain the following entries, "*1. Left Windshield Screen Cracked*" and "*2. Left Engine Vibration Indication Fan Guide Vanes Are Nicked*". Page 155 had four further entries recording defects on a tyre, oxygen bottle, the Auxiliary Power Unit (APU) flaming out on the ground and in the air, and a "*Display Unit*" fail message. Both of these pages were signed off by the Captain on 13 July 2009 at 09.15 hrs. The Investigation noted that the Pilot's Defect Report document present in the aircraft included the previous six sectors flown by VT-MST, going back to 17 June 2009, and that no defects had been recorded for any of those flights.

1.5 Interview With the Flight Crew

The Investigation interviewed both members of the flight crew together on 14 July 2009 at EIKY. The Captain stated that he had total flying experience of 12,500 hours on a variety of airliners and corporate jets including Gulfstream GII, GIII, GIV and GV. He had 2,600 hours on the Gulfstream family of aircraft, of which 1,027 hours were on the GIV with 900 hours as GIV Pilot in Command. He was employed by the Operator as a contract pilot. The First Officer had total flying experience of 3,200 hours of which 200 hours were on type. He was directly employed by the Operator. In the previous 28 days the First Officer had flown 1.4 hours, which was the flight from Luton to EIKY on 10 July 2009.

The Captain described how the crew had carried out normal pre-flight preparations. He said that weather was a factor as there was rain and low visibility.

The Captain described how the aircraft departed RWY 08 and that shortly after rotation the left hand windshield in front of him had "*shattered*". He was of the opinion that some FOD had impacted the windshield. He then described how, almost immediately after that, he saw a vibration level of 2.7 inches per second (ips) being registered on the No. 1 Engine Vibration Monitor (EVM). The Captain stated that he retarded the No. 1 engine throttle to idle thrust and the engine vibrations reduced to normal levels. All the other engine parameters were normal. The crew requested clearance from Kerry Tower to level off at 3,000 ft and they accelerated the aircraft to an indicated airspeed of 200 kts. The Captain stated that he was flying the aircraft manually at this point.

The crew described how there was much confusion in the cockpit at this stage and that, "*things happened very fast*". The Captain initially thought that the aircraft would be returning to land on RWY 08 at EIKY, the runway that they had used for departure. The First Officer stated that, as the aircraft flew outbound on the SID towards Cork and after they had been cleared by ATC to return to overhead Kerry and then outbound for an ILS approach to RWY 26, he initially entered "*Direct EIKY*" on the Flight Management System (FMS). However, he then programmed the FMS for an approach to RWY 26 at Luton Airport, the original intended destination, rather than RWY 26 at EIKY. He felt that the FMS might not have accepted the Direct EIKY input. At this stage of the flight both pilots had their Navigation Displays (NDs) set to weather radar mode, which meant that neither display was in EGPWS mode. Thus, neither crewmember had a visual display of high terrain in their vicinity.

The Captain stated that he was flying the aircraft and following the First Officer's navigational directions. The Captain said that the First Officer had told him that the Course Deviation Indicator (CDI) needles were "*alive*", and had "*cleared him to descend*". The Captain stated that he felt that the navigational raw data and the FMS information didn't make any sense. He stated that the First Officer had passed an incorrect position to ATC and the First Officer stated that he now[9] knew that when he had informed ATC that the aircraft was on the ILS, in fact it was not. The Captain continued, "*Since things happened very fast, and I was under basically the concern of the engine and the windshield crack, I just proceeded to continue to fly that present heading and then the GPWS came on at the same time that the controller told us (*to climb*)…*"

It was evident during the interview that there was confusion on the part of the crew regarding the sequence of events while the aircraft was airborne. For example, the Captain stated on a number of occasions that ATC had passed the crew an incorrect localiser frequency and that this was part of the confused picture. In fact, this had happened relatively late in the flight and the correct frequency was passed to the aircraft within one minute. The Captain also stated that he had decided to return to Kerry because the controller gave them a direction to return there. However, the ATC tapes indicate that the VT-MST requested a return to EIKY on the first transmission informing Kerry Tower of the windshield problem.

The Captain stated that he now thought that he should have continued to overhead Cork to give the crew more time to consider their options. He also considered that they should have had one ND on weather radar mode and one on EGPWS mode. The First Officer said that he now felt they should have continued as cleared to 4,500 ft and requested permission from Shannon Centre to hold in the area to gain more time to sort out their problems.

The Investigation asked the crew if they knew how low the aircraft had flown before the EGPWS alert and the Captain stated he thought around 3,000 ft and the First Officer was unsure. In fact, the lowest altitude return seen on Shannon radar was 1,500 feet with the aircraft still in a descent while the DFDR indicated a lowest radio height of 702 ft above the ground.

The Captain stated that, after the EGPWS alert and controller intervention, he handed flying control of the aircraft to the First Officer and he took over the programming of the FMS.

When discussing the subsequent difficulties the crew had encountered when attempting to intercept the localiser near VENUX, while under the control of Shannon Centre, the Captain said that by the time they were instructed to proceed to VENUX, they were too close to it and thus couldn't fly to it.

The Investigation asked the crew if they had carried out a pre-flight brief on what their actions would be if they encountered a serious problem on departure. The Captain replied that they had planned to go to Shannon.

In relation to the post-flight engine runs, the Captain stated that senior management of the Operator had told him to carry out a run-up with a view to establishing whether it might be possible to carry out a ferry flight to a maintenance base. The Captain said he was against the idea of such a ferry. Senior management of the Operator has stated categorically to the Investigation that no such instruction to carry out engine runs was passed by management to the aircraft Captain. The Operator provided a copy of an incident report form which had been sent to the DGCA on 14 July 2009, and which stated that a further report would be forwarded to the DGCA following investigation by the aircraft manufacturer's engineers.

[9] "Now" in this section refers to the time of the interview

The Captain stated that when he had seen the high engine vibration level during flight, all of the other engine parameters had been normal. The vibration level had been annotated in amber (caution) on the Crew Alert System (CAS) and when he had throttled back, it returned to the normal white colour.

When the crew did the engine runs, the aircraft was "*bleeding a lot of fuel*".

Both members of the flight crew agreed that the incident was "*very serious*" and that they had done a thorough de-brief after the flight. The Captain felt that there was a lot to learn from the occurrence. He felt that he was rushed and that he rushed himself to come back to EIKY. He now realised that there was no reason to rush.

In further comments made to the Investigation some months after the occurrence, the Captain submitted, "*As stated before in my report during the sequence of events that took place at the time of the incident and giving the circumstances under the high level of pressure and concern that I was under in this environment in which forced me to act as PIC flying solo as I was trying to keep the aircraft under control and in the correct FMS track.*" He also stated "*Three things that triggered the distraction that derive from this incident are: the windshield screen rupture, the engine vib. and the lack of support from my Copilot, as his situational awareness was diminished and confused by the sequence of events at the time*", and he concluded, "*In summary I was the only one there flying commanding, navigating and correcting what was erroneously compromising the safety of the flight. Making all the decisions and preventing the aircraft from a worst situation. As I managed to landed safely*".

These comments will be considered in **Section 2, Analysis**.

1.6 Airport Information

Kerry Airport (EIKY) is located in southwest Ireland at an elevation of 112 ft above mean sea level. The runway designation is 26/08 with a runway length of 2,000 m. An ILS is installed on RWY 26 while a Distance Measuring Equipment (DME) station and Non Directional Beacon (NDB) are located at the airport. The ILS approach on RWY 26 has an Obstacle Clearance Altitude (OCA) of 280 ft. An NDB approach is available on RWY 08 with an OCA of 650 ft.

Kerry Airport is certificated to provide air traffic services including a procedural ATC service within a defined block of airspace (Kerry Control Zone) in the vicinity of EIKY. Outside of the Kerry Control Zone, air traffic control is provided by Shannon ATS unit. Documented procedures governing the control of aircraft arriving and departing EIKY are agreed by both Kerry and Shannon ATS units.

The highest mountains in Ireland, reaching heights of 3,414 ft, are located approximately 12 nm southwest of EIKY. There is additional high ground to the south and to the west of the airport. A ridgeline is situated to the east of the airfield with a spot height of 1,480 ft located close to reporting point VENUX. Therefore, the minimum sector altitudes (MSAs) within 25 nm of EIKY were relatively high, being 5,200 ft in the southwest sector, 4,600 ft in the southeast sector, 3,300 ft in the northeast sector and 4,900 ft in the northwest sector.

1.7 Recordings

Recordings of all the communications between Kerry Tower and VT-MST and the subsequent communications between Shannon Centre and VT-MST were made available to the Investigation along with the telephone co-ordination communications between Shannon Centre and Kerry Tower. The Investigation found a discrepancy of 5 minutes 19 seconds in the timings of the Kerry recordings and informed Kerry ATC of that fact. In addition, the Shannon radar display of the occurrence was recorded.

Flight data information from the aircraft DFDR was available to the Investigation along with the CVR recording of much of the post-flight activity on the flight deck, commencing after the first engine run-up at the remote parking area. Parameters including door open, UTC time and radio press-to-transmit were not recorded by the DFDR. Therefore, it was not possible to precisely correlate DFDR data with other recorded data with respect to timing.

1.8 ATC Aspects

Kerry Airport has no radar infrastructure or display. Thus the ATC controllers there do not have access to a radar picture of activity in the Control Zone and must control traffic by procedural means. Controllers with radar facilities are located at Shannon Centre with the nearest radar heads situated close to Shannon and in West Cork. Aircraft can be tracked from those locations down to heights of around 1,000 ft when they are in the vicinity of EIKY. This height is dependent on the precise location of an aircraft relative to the radar head and also to high ground, which may, "*shadow*", the aircraft from the radar head. The controllers at EIKY use telephone communications with their colleagues in Shannon to co-ordinate all Instrument Flight Rules (IFR) arrivals and departures to and from EIKY.

The departure of VT-MST had been co-ordinated between Kerry Tower and Shannon Centre shortly before take-off. At 08.09:48 hrs, 2 minutes and 48 seconds after VT-MST had reported the cracked windshield to Kerry Tower, a controller in Shannon Centre who had previously worked in EIKY and who was monitoring the aircraft on radar, called Kerry by phone and asked if they required assistance with the aircraft. Kerry Tower said they would call Shannon back in a couple of minutes. At 08.12:39 hrs, the same Shannon controller alerted Kerry to the fact that the aircraft had descended to 1,600 feet, six miles to the south of the localiser. After VT-MST commenced its climb away from this descent, Kerry passed control of the aircraft to Shannon Centre.

At 08.27:37 hrs, after VT-MST had passed through the localiser to the north, Shannon Centre asked Kerry Tower to confirm the Kerry localiser frequency. An incorrect frequency was initially passed to Shannon by Kerry Tower and this was passed on to VT-MST at 08.28:16 hrs. Kerry Tower then passed the correct frequency to Shannon Centre which advised VT-MST of the correct frequency at 08.28:58 hrs.

As the aircraft turned right on the CRK 1C SID it flew into the southeast MSA sector (MSA 4,600 ft) at a height of 3,000 ft. As it descended to its lowest height to the south of EIKY, it was approaching the southwest sector, where the MSA was 5,200 ft.

1.9 Aircraft Information

The Gulfstream GIV is a twin-turbofan, long-range, business aircraft. It accommodates a flight crew of two and is certified for up to 19 passengers, although 10-12 passengers is a more typical corporate configuration. The aircraft is powered by two Rolls-Royce Tay Mk 611-8 turbofans, each flat rated at 61.6 kN (13,850 lb static thrust). The engines are rear-mounted high on the aft fuselage. Their intakes are located above and forward of the inboard trailing edges of the wing flap assemblies.

The aircraft is comprehensively equipped with avionic systems to facilitate trans-oceanic flight, including a digital Automatic Flight Control System (AFCS), Flight Management System (FMS), dual fail-operational flight guidance systems including autothrottles, etc. Crew primary instrumentation comprises six large cathode ray tube (CRT) Electronic Flight Instrumentation System (EFIS) screens, two each for Primary Flight Display (PFD), Navigation Display (ND) and Engine Instrument and Crew Alerting System (EICAS).

Navigation information is displayed to the crew on the NDs, one in front of each pilot. Each pilot can select his ND to Map, Compass or Plan modes. In Map mode, the 120º sector of the compass rose forward of the aircraft is displayed, centred on the current aircraft heading. The distance or range displayed forward of the aircraft can be varied up or down by the crew. The locations of navigation waypoints and beacons and airports can be overlaid on this display. Weather radar data can be presented on Map mode, or alternatively a terrain display showing terrain in the vicinity of the aircraft can be overlaid. However, weather and terrain may not be displayed simultaneously.

VT-MST was equipped with an EGPWS. This is a Terrain Awareness and Warning System (TAWS) providing basic GPWS functions as well as additional enhanced terrain alerting and display features. EGPWS uses aircraft inputs including geographic position, attitude, altitude, airspeed and glideslope deviation. These are used in conjunction with integral terrain, obstacle and airport databases to predict a potential conflict between the aircraft flight path and terrain or an obstacle. A conflict will result in the EGPWS providing a visual and aural caution or conflict alert to the crew, irrespective of the selected ND mode. A feature of EGPWS is the provision of a graphic display of the surrounding terrain, which in the GIV may be selected for display on the ND when in Map mode. Based on the aircraft's GPS position and the EGPWS internal database, the terrain topography (within the display range selected by the pilot) that is above or within 2,000 ft below the aircraft altitude is presented on the ND.

The Tay 611-8 is a two shaft, high-bypass ratio engine featuring a wide-chord fan with three more stages of low pressure (LP) compressor and a 12-stage high pressure (HP) compressor driven by a three-stage LP turbine and a two-stage HP turbine respectively. It has an annular combustion system consisting of ten combustors. The majority of the bypass duct is constructed in carbon fibre composite material. Cold bypass air and hot exhaust gases are combined in a forced mixer for propulsive efficiency and lower noise emissions.

An indication of LP turbine revolutions per minute (RPM) is displayed on the EICAS and on the standby engine instrument panel. This is also a measure of the LP compressor shaft speed, is displayed in percentage terms and is also known as N1. Similarly, an indication of HP turbine RPM is displayed on the EICAS and on the standby engine instrument panel.

This is a measure of the HP compressor shaft speed, is displayed in percentage terms and is also known as N2.

Engine starting is normally accomplished using pressurised air from the Auxiliary Power Unit (APU) to rotate the engine starter. The Gulfstream GIV Quick Reference Handbook (QRH) cautions, "*continued use of the starter is limited to three (3) crank cycles, with a maximum of thirty (30) seconds per cycle. Delay three minutes between start attempts*". The QRH also states that positive LP RPM must be checked and that the minimum HP reading must be 15%, prior to opening the HP fuel cock.

Each engine is equipped with an Engine Vibration Monitor (EVM) to provide the crew with continuous monitoring of the balance of the rotating assemblies in the engine. There are two outputs per engine, LP imbalance and HP imbalance. These four outputs are measured on a scale of 0 to 5 ips of vibration. The EICAS displays the readings in digital format.

Regarding engine vibration, the QRH states: "*If EVM exceeds 0.60 LP and/or 0.60 HP, retard the power lever until EVM returns to normal level. Caution: EVM indications alone should not be used as criteria for engine shutdown. In icing conditions, vibrations may exceed the alert level without other abnormal indications and are considered normal. If vibration is accompanied by other failure indication, shut down the affected engine.*"

1.10 Instrument Landing System (ILS)

An ILS is a radio navigation system that enables a suitably equipped aircraft to make a precision approach to a runway. An ILS has two main elements. They are:

a. The localiser, which provides tracking guidance along the extended centre-line of the runway, i.e. guidance in azimuth left and right of the extended centreline.

b. The glideslope, which provides vertical guidance towards the runway touchdown point, usually at a slope of approximately 3º to the horizontal, i.e vertical guidance above or below the glideslope.

The localiser antenna array, which is located at the far end of the runway with respect to a landing aircraft, transmits two overlapping lobes of radio energy on the localiser's carrier frequency (108.70 Mhz at EIKY). The lobe on the left hand side of the approach path is modulated at 90 Hz, and the lobe on the right side is modulated at 150 Hz. The localiser receiver equipment on the aircraft measures the difference in depth of modulation (DDM) of the 90 Hz and 150 Hz signals, and produces a voltage which energises the localiser indications to the cockpit crew, in accordance with the position of the aircraft relative to the centreline.

Annex 10 to the Convention on International Civil Aviation sets out specifications for radio navigation aids including ILS. The tolerances for ILS localisers provide for coverage from the centre of the antenna array as follows:-

a. Out to 25 nm within ± 10º of the centreline
b. Out to 17 nm within ± 35º of the centreline.

Published guidance cautions that attempted use of a localiser outside of these sectors may lead to false course indications being received by an aircraft crew. The phrase "False localiser capture" is commonly used within the aviation industry to refer to situations where localiser capture is prematurely attempted and does not infer any abnormality or malfunction of the ILS itself.

A GIV pilot, expecting to intercept an ILS localiser should arm Approach mode on a cockpit control panel known as the Flight Guidance Panel. The crew should then see LOC (localiser) and GS (glideslope) symbols annotated in white at the top of the PFDs, indicating that the ILS approach system has been armed. After the Course Director Indicator (CDI) becomes active the localiser is captured, the white LOC symbol turns green and the Flight Director command bars will direct the crew (or autopilot if engaged) onto the centreline of the localiser. When the glideslope is subsequently captured, the white GS symbol turns green and the flight director command bars direct the crew to descend on the glideslope.

No system deficiencies were reported for the EIKY RWY 26 ILS at the time of the occurrence.

1.11 Recorded "False Localiser" Capture

The DFDR on VT-MST records a discrete parameter[10] called "*Localiser Capture*". This parameter is recorded every 16 seconds and therefore cannot be regarded as presenting a precise timing record of the presence of a localiser capture. The Investigation identified that this discrete came ON shortly before commencement of the aircraft's initial descent towards Killarney. The discrete was ON for 64 seconds (±16 seconds) and subsequently returned to OFF. The DFDR data also indicated that during the period when the localiser capture discrete was ON, the aircraft commenced a descent, the flaps were selected to 10º and then 20º, and the landing gear was selected down. This descent continued after the localiser capture discrete returned to OFF, until the EGPWS alert and the intervention of the controller in Shannon Centre.

The DFDR data also indicates that the localiser deviation DDM value oscillated rapidly between full-scale left and right deflections during the initial period that the localiser capture discrete was ON. There was also some variation of the glideslope deviation DDM value, although it was considerably less than that of the localiser.

The co-ordinates of the position where the localiser capture discrete changed from OFF to ON were approximately 52º 06.736' N, 009º17.505' W, or 9.4 nm southeast of the localiser antenna at an angle of 43º from the localiser centreline, see **Figure No. 1,** (LOC Capture ON).

On 24 August 2009, the Investigation informed the Irish Aviation Authority (IAA) and Kerry Airport about this apparent "false localiser" capture at EIKY. At that time, the IAA were preparing an Aeronautical Information Circular (AIC) on the use of ILS facilities in Ireland. The AIC was published on 19 November 2009, with the purpose of providing guidance on the limitations of ILS and to advise pilots of precautions to be taken during operational use. The AIC sets out the tolerances for localisers as shown in Section 1.10 and states, "*The use of*

[10] A discrete parameter in this sense has two possible values, 0 or 1, and indicates the status of a given signal as being either OFF or ON.

a localiser outside these areas can lead to false course and reverse sense indications being received and such use should not be attempted." The AIC also states, "*Certain combinations of localiser beam characteristics and modern receiver/autopilot combinations can cause premature localiser capture; flight crews should be alert to this possibility. Flight deck procedures should be designed to reduce the risk of premature capture by not allowing Flight Director/Autopilot capture modes to be armed too early. Flight crews are advised to confirm the validity of ILS capture by cross-checking with other sources of navigational information when available.*"

1.12 Meteorological Information

The Investigation requested an aftercast of the weather for EIKY at the time of the occurrence from Met Éireann. The following is a summary of the aftercast.

A low pressure system dominated the weather at the time. An associated occluded front was moving eastwards across the region in a generally southerly flow. Reports from the automatic observing system show visibility at 07.50 hrs of 8 km and at 08.50 hrs of 9 km. The intensity of weather radar echoes suggest that the visibility could have dropped below these levels on occasion, possibly to the 4,000 m to 5,000 m range (if only briefly). Rain of occasional moderate intensity was present.

The cloud was scattered at 1,000 ft and broken at 1,500 ft with the likelihood of ceilings within the 800 – 1,200 ft range for a time. The atmosphere was unstable enough to justify the possibility of having convective cells embedded in the frontal system in the region of interest. It is possible that some of the more intense echoes shown on radar imagery could have been associated with this phenomenon.

The surface temperature was 14ºC with a dew point of 13ºC. The barometric pressure (QNH) was 999 hPa. The freezing level was 7,000 ft. Consequently, icing is not considered to be a factor in the reported engine vibration.

The METAR aviation weather report for 07.50 hrs gave the wind as calm, visibility 8,000m in rain, cloud scattered at 1,000 ft and broken at 1,400 ft. At 08.50 hrs, the wind was 100ºM at 3 kts, visibility 9,000 m in drizzle, cloud scattered at 1,000 ft and broken at 1,400 ft.

1.13 Damage to Aircraft

1.13.1 Damage to Windshield

Initial inspection of the damaged windshield at EIKY suggested that the fractures were initiated by an electrical fault, **(Photo No. 1)**. Since the Captain was of the opinion that an object had struck the aircraft shortly after rotation, the Investigation decided to return the windshield to its manufacturers in the United States for failure analysis under the supervision of the U.S. National Transportation Safety Board (NTSB).

The GIV windshield design incorporates an aluminium frame and retainer edge attachment system that is bonded to the inboard and outboard glass plies. The cross-section of the windshield in the pilot's vision area consists of a chemically strengthened outboard glass ply, a urethane interlayer, a central glass ply, a vinyl interlayer and an inboard glass ply. The windshield also contains a conductive anti-ice heating film applied to the inner surface of the outboard glass ply.

Photo No. 1: Damage to Windshield
(Note: The lines are cracks and the dots are raindrops)

The windshield manufacturers confirmed that the outboard glass ply failed due to electrical arcing at the interface between the inner edge of the bottom bus-bar and the conductive anti-ice heating film. The electrical arcing resulted when moisture ingress was absorbed by the interlayer and caused degradation of the bus-bar at the bottom forward corner of the windshield. The degradation of the bottom bus-bar created a potential for electrical arcing. The electrical arcing generated an excessive amount of heat that caused damage to the inner laminated surface of the outboard glass ply. The damage penetrated the surface compression and entered the centre tension layer of the chemically strengthened glass, causing spontaneous fracture.

There was evidence of degradation of the outer moisture seal due to wind and rain erosion. Cracking of the seal was observed indicating cyclic wear. There was no evidence of repair or attempted repair of the seal. There was evidence of moisture ingress and interlayer degradation around the periphery of the windshield, particularly at wire routing locations.

The manufacturers confirmed that there was no evidence of any outer glass ply fragments delaminating or separating from the laminate/interlayer surface. The entire outer glass ply remained attached to the laminate body.

It was also confirmed by the NTSB that the windshield did not sustain any birdstrike or other foreign object damage.

1.13.2 Damage to Engine

On the day following the occurrence, the aircraft manufacturer's maintenance team removed the fan blades from No. 1 (left-hand) engine to gain access to the LP compressor. Many of the fan blades had sustained V-shaped notch-like damage, between 1 and 4 mm wide on their leading edges. See **Photo No. 2**.

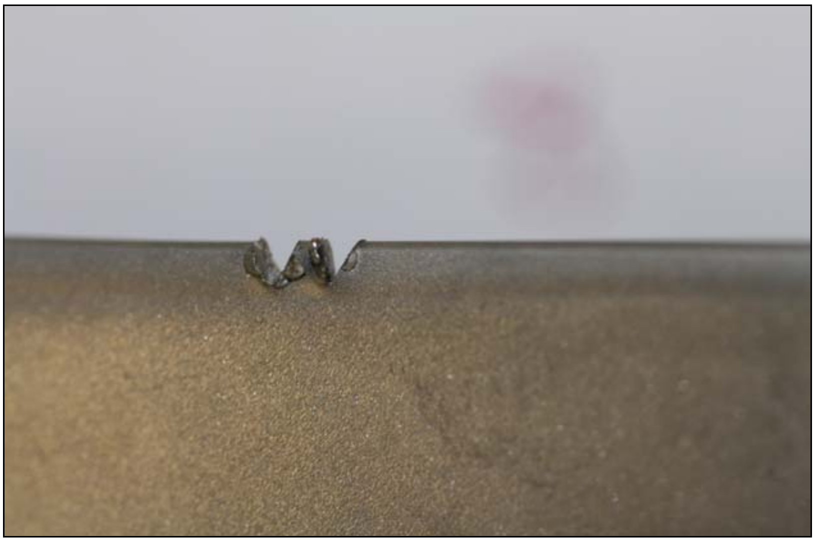


Photo No. 2: Typical Fan Blade Damage (VT-MST)

It was clear from inspection that the engine had sustained significant damage and that the aircraft required an engine change at EIKY. This was carried out over the period following the occurrence. The Operator decided to return the damaged engine to the engine manufacturer for repair and it was duly shipped to a facility in Scotland. The Investigation requested assistance from the engine manufacturer's incident investigation section and this was readily provided.

The Investigator-in-Charge (IIC) travelled to Scotland to observe the tear-down of the engine in conjunction with a member of the engine manufacturer's investigation section. The fan blades, the LP compressor blades and the HP compressor blades had all suffered significant damage. Analysis of the damage revealed that it had been brought about by impact with a hard-bodied object. Laboratory analysis of the impact sites revealed traces of residual elements consistent with a low carbon steel (typical of mild steel) object. The Investigation noted that no part in the engine intake or the engine is manufactured from low carbon steel. There was no evidence of distinguishing features, such as thread impressions, to enable the form of the impacting object to be identified. Examination of the damage to the bypass straightener vanes downstream of the fan blades revealed the presence of circumferential witness marks, with a diameter of 25 mm approximately. Similar sized rounded impact deformations (25 mm diameter) were noted on the leading edges of the 1st stage LP compressor vanes.

Significant hard body impact damage was sustained by the 1st, 2nd and 3rd stage rotor blades of the LP compressor, **Photo No. 3**. There was an arc of approximately six 2nd stage blades that had been significantly bent in a direction opposite to rotation, indicating that the engine spool speed was relatively high and that the impacting body was of significant mass. The 1st and 2nd stage stator vanes had also sustained significant damage. Three adjacent 1st stage stator vanes had sustained rounded impact damage.

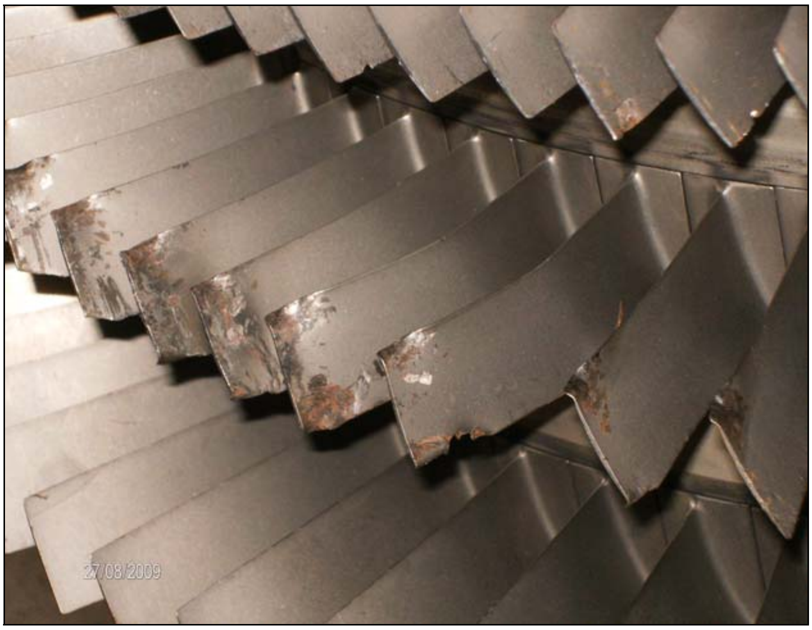


Photo No. 3: Damage to LP Compressor

There was evidence of clashing between the 2nd stage rotor blade leading edges and the trailing edges of two 1st stage stator vanes, this being indicative of a surge event.

The HP compressor also sustained varying degrees of damage. In this case it was more prevalent on the rotor stages.

There was also evidence that the engine had sustained recent bird strike events, probably during the previous two flights. Inspection confirmed that there were probably three birds ingested and that the species was the Barn Swallow. Given that the average weight of this species is 19 grams, it was not possible that three birds of this mass caused the damage.

1.13.3 DFDR Engine Data

The Investigation examined the DFDR data for the engine during the flight and during the engine runs which followed the flight. The CVR recording of crew conversations during most of the engine runs was also available. The DFDR recorder unit is connected to an electrical bus via a power relay which is energised (i.e. the recorder will operate) when either engine attains sufficient oil pressure, or via a weight off wheels circuit while the aircraft is in flight. While there are a considerable number of spikes in the DFDR data, where the values are unreliable, in general the parameters recorded during the flight and the subsequent engine runs appear to be consistent and useful.

The data points for N1, fuel flow rate, LP and HP turbine vibration levels and EGT are recorded every 4 seconds. N2 is recorded every 2 seconds while Engine Pressure Ratio (EPR) and Throttle Lever Angle (TLA) are recorded every second.

The DFDR data contains no evidence that there was a significant high vibration event on either the LP or HP turbine of the damaged No. 1 engine during the initial climb-out or during the occurrence flight. Also, the DFDR data does not show any evidence of retardation of the throttle lever position of No. 1 engine or any reduction of its fuel flow rate, when compared to the same parameters for No. 2 engine.

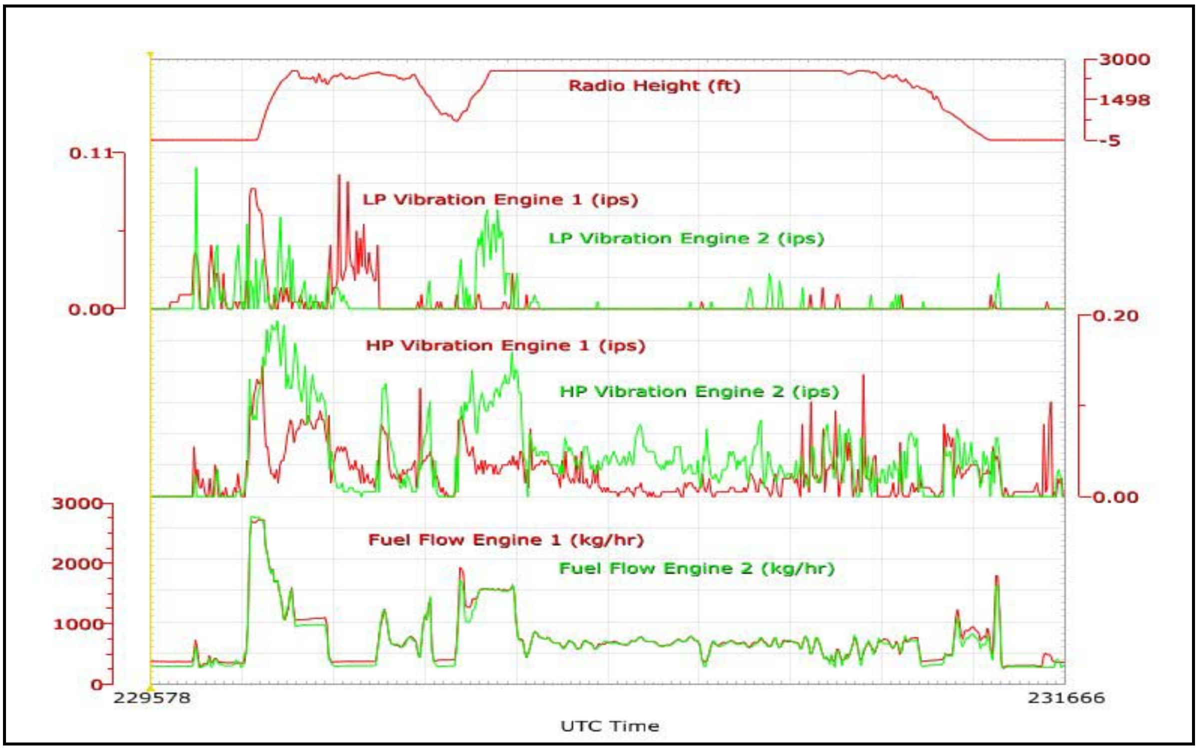


Figure No. 2: DFDR Selected Data During Flight

In **Figure No. 2**, the upper trace shows the radio height profile of VT-MST during the flight. The initial climb of the aircraft is shown on the left hand side of the upper trace, while the V-shaped notch is the unscheduled descent. The final descent to land is shown on the right hand side of the trace. This trace may be used as a timeframe for the engine parameters shown in the lower traces.

The second trace from the top shows the LP rotating assembly's vibration levels for No. 1 engine in red and No. 2 engine in green. While there is some vibration present in the early stages of the flight, the maximum value recorded is around 0.1 ips and is well within the limit of 0.60 ips. The third trace from the top shows the HP rotating assembly's vibration levels for No. 1 engine in red and No. 2 engine in green. In this case it can be seen that the No. 2 engine's vibration levels were generally higher than those of No. 1, but again the maximum levels recorded, approximately 0.2 ips, are well within limits. The fourth trace shows the fuel flows for the two engines, again No. 1 in red and No. 2 in green. It can be seen that the two fuel flows are very consistent throughout the flight and there is no evidence that No. 1 engine was particularly throttled back in comparison with No. 2 engine.

DFDR data indicates that the engine operated in a normal manner throughout the flight. There is no evidence of a significant event that might indicate that engine damage occurred during the flight.

The first indication of potential engine abnormality is indicated on the DFDR data when the aircraft has returned to the parking area immediately after the flight, just before shutdown.

The No.1 engine EGT can be seen to rise significantly while there are corresponding drops in N1 and N2. These parameters are typical of an engine compressor stall. The stall recovers almost immediately and a few seconds later the engine is shut down.

The engines were started again after approximately 57 minutes and the aircraft was taxied to a remote part of the airfield. On this engine start, the DFDR data shows that the N1 speed does not immediately accelerate as expected and as had occurred on the earlier start. N1 did not start to accelerate until N2 had reached almost 25%, whereas on the earlier start, N1 had started to rotate immediately as expected.

While parked in the remote area, the crew performed a series of ten accelerations and decelerations on No.1 engine, which are clearly indicated in the DFDR data by the throttle lever position and fuel flow rate. They can also be heard on the CVR recording, in the period between 11.10 hrs and 12.20 hrs. At each deceleration it is noted that N1 and N2 decay below the normal ground idle speeds. It may also be noted that there are a succession of engine stalls during these cycles, where the EGT is seen to rise with N1 and N2 decaying. In each of these cases the engine recovers from the stall event.

The recorded vibration levels during the engine runs are generally higher then those seen during the flight, with many HP vibration levels between 0.2 and 0.26 with a highest reading of 0.41 ips. These figures disregard several spikes seen in the data.

The final five engine accelerations were all carried out to high power settings with N2 reaching levels in excess of 90% in each case. On the final high power run, which appears to have been carried out by the First Officer, there is a very audible sound of an engine stall co-incident with rapid engine deceleration on the CVR recording, followed by the Captain saying, "*You stalled it*". Shortly after that, the engine was shut down for the final time that day.

The CVR recording indicates that the crew returned to the aircraft on the morning of 14 July and the Captain decided to do a "*quick engine start*", but said that they wouldn't accelerate it. During the first attempt to start, the First Officer can be heard to say, "*No LP, no LP*". The Captain says, "*Go ahead continue*", "*Let it run*", and, "*Let it go*". Approximately one minute after the initiation of engine start, the engine is shut down, with the Captain remarking, "*Hot start*". Almost immediately, the Captain says, "*Try that again*", and the First Officer remarks, "*I can smell the gas*". A second attempt to start is then heard on the CVR, following which the Captain remarks, "*No LP*", and the First Officer says, "*Something is blocking something*". A third start is then initiated during which the Captain remarks, "*Now you've got LP*". The engine is shut down shortly after that. Thereafter the Captain states, "*Those engine run-ups… We won't tell them that we did those…*" and "*That's why you and I need to see this happen here on the ground, I don't want to see that in the air*". Following a discussion about possible reasons for "*No LP*", the Captain says "*Go ahead and do one more run-up*". As the engine accelerates, the Captain says "*There's a noise, when I rotate that there's a noise that I'm not very happy with, like a rubbing noise*". The engine is run for approximately one minute and then shut down for the final time.

The recording indicates that the first three of these start cycles were carried out in a total time period of approximately 2 minutes and 40 seconds and that the fourth and final start was approximately 9 minutes and 30 seconds after the third attempt. The recording does not contain any evidence illustrating the use of pre-start or shutdown checklists by the crew during the engine runs.

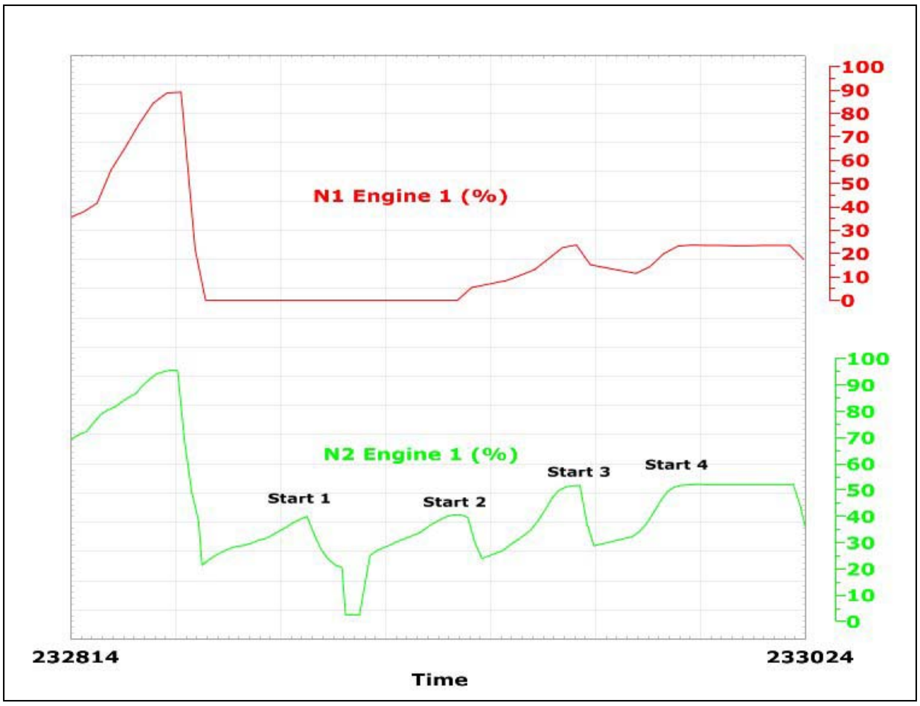


Figure No. 3: Final Engine Starts

Recorded parameters from this final sequence are shown in **Figure No. 3**. The top trace (red) is the rotational speed of the LP assembly (N1) and the lower trace (green) is that of the HP assembly (N2). The rapid engine deceleration, where the values of both N1 and N2 fall steeply during the final engine run on the 13 July, is seen on the left side of the Figure. This was co-incident with the loud engine stall sound heard on the CVR recording. The data then continues onto the attempted starts on the following morning. The period of 72 seconds when N1 remains at zero while N2 varies between a low of 2.6% and a high of 40.6% is also clearly visible. The DFDR data indicates that there were four distinct cycles where the engine stalled and tried to recover but at this stage the engine speeds were sub-idle. Following the fourth cycle, the engine tried to recover for a short period when the data came to an end.

1.13.4 Engine Maintenance History

The Investigation requested that the Operator provide the recent maintenance history of the damaged engine, Tay 611-8 s/n 16883. The engine underwent a midlife inspection in the United States, which concluded in December 2006. Since the aircraft transferred onto the Indian register in January 2008, the engine had undergone scheduled maintenance on eleven occasions. During 2009, it had completed a 9 months inspection and intermediate compressor inspection on 9 February, a 600 hrs inspection on 2 April, and a 150 hrs inspection on 22 April. The final recorded engine work, before the occurrence, was an engine starter oil change on 14 May 2009.

1.14 Other Information

A few days after the occurrence, the Captain returned to his residence in the United States. The DGCA of India suspended his authorisation to fly VT-MST on 14 July 2009. On 15 July 2009, the Operator requested that he return to New Delhi to appear before a regulatory Preliminary Investigation Board, however he did not do so. On 20 July 2009, the Captain's authorisation to fly VT-MST was withdrawn by the DGCA of India. He did not return to India thereafter.

2. ANALYSIS

2.1 Crew Aspects During the Flight

2.1.1 Initial Stages

Analysis of this serious incident was hampered by the absence of a CVR recording of crew exchanges during the flight, but most of the post-flight engine runs were recorded. Also, the DFDR data did not include many relevant parameters such as UTC time, radio press-to-transmit and door open.

It was evident to the Investigation from the interviews with the crew, carried out on the day following the occurrence, that there had been much confusion in the cockpit during the flight and that much confusion remained about the event some 24 hours later.

The confusion appears to have started immediately after the windshield fractured shortly after take-off. The Captain informed the Investigation that the crew had pre-briefed on a diversion to Shannon if they encountered difficulties after take-off. However, the First Officer requested a return to EIKY in his first transmission after the windshield fracture. Although the Captain subsequently stated that he saw excessive vibration levels on the No. 1 engine at the time, the Investigation found no evidence of this in the DFDR data, and therefore the decision to return to EIKY was reasonable.

Kerry Tower asked VT-MST to confirm their position and received the response at 08.08 hrs, "*three five miles southeast*". At this point, the aircraft had been airborne for approximately two minutes and was still well within 10 nm of EIKY. It is probable that this 35 nm was, in fact, the distance from the aircraft to Cork DME station. Thus it is likely that the loss of situational awareness commenced at this point, at least on the part of the First Officer.

2.1.2 Loss of Situational Awareness

Kerry Tower, which had no radar and could therefore not offer navigational assistance, then asked VT-MST whether they wished to self-position to INRAD or route to the overhead, i.e. to a point overhead the airport. VT-MST responded, "*OK confirm call you overhead at three thousand*", to which Kerry Tower responded, "*Next report overhead establishing outbound on the ILS for an ILS DME approach runway 26*". In this instance, it appears that the crew did not fully understand that they had been offered alternative means of initiating an ILS approach to RWY 26, and Kerry Tower interpreted their response as choosing to route first to overhead EIKY. The Captain later informed the Investigation that he understood that the aircraft was returning for an approach to RWY 08, the runway that had been used for departure. However, there is no ILS approach to RWY 08 (only a non-precision NDB approach with a much higher OCA of 650 ft) and considering the factors of the cracked windshield and the weather conditions on the day, such an approach would not have been desirable. The crew were responsible for maintaining a safe distance from the ground and therefore the decision to level off at 3,000 ft in IMC[11], beneath the Minimum Sector Altitude, was unwise.

The First Officer was navigating and programming the FMS at this stage of the flight and he informed the Investigation that he had entered, "*Direct EIKY*", and had then erroneously selected an ILS approach to RWY 26 at Luton. He thought that the Direct EIKY operation had not been accepted by the FMS. However, the radar recording shows that the aircraft did make a right hand turn rolling out on the correct track inbound to EIKY and that the aircraft held that track for about 2 nm. In this manner, the confusion of the First Officer increased, thus degrading the effectiveness of the crew.

The DFDR data indicates that, as the aircraft tracked towards EIKY, at a point approximately 9.4 nm from the RWY 26 localiser antenna and at an angle of 43º to the localiser centreline, the aircraft navigation receiver "*localiser capture*" discrete went from "*OFF*" status to "*ON*" status. The DFDR data indicates that, simultaneously, the localiser DDM commenced rapid oscillations between full-scale left and right deflection and there was also some movement of the glideslope DDM. It is considered likely that it was at this time that the First Officer told the Captain that the "*CDI was alive*" as is normal practice, in the mistaken belief that the aircraft was approaching the localiser. The Captain descended the aircraft although the DFDR data does not show that any coherent CDI localiser or glideslope commands were present. However, had the Captain properly briefed for an approach and had the crew set up the correct navigational aids as a result, they should have realised that they were not on the correct bearing to EIKY and should not have commenced a descent.

In any event, the aircraft turned left and commenced a descent, the landing gear was extended and the flaps were lowered firstly to 10º and then to 20º settings in preparation for a landing. The vertical speed during the first minute of the descent was in excess of 1,300 ft/min, which is considered to have been excessive in the circumstances and may have been as a result of the Captain assuming that the aircraft was above the glideslope. Taking into account the meteorological data, it is likely that this descent was made entirely in cloud.

Transmissions made from the aircraft stated that the aircraft was turning back on the localiser nine miles from the airport and subsequently coming up on the localiser seven miles from the airport. These were incorrect. The final position report during this phase of the flight, as the aircraft approached its lowest radio height of 702 ft was, "*on the localiser*", 6.8 miles from the airport. However, at this time the aircraft was tracking roughly parallel to the localiser but approximately 6 nm south of it and heading directly towards high ground in excess of 3,000 ft approximately six miles ahead. The fact that the descent was made in an area where the MSA was 4,600 ft and towards an area where it increased to 5,200 ft further shows that both crew members had suffered a serious loss of situational awareness.

2.1.3 "False" Localiser

The DFDR data indicates that the aircraft navigation receivers temporarily acquired a "false" localiser signal when the aircraft was flying outside the localiser specific coverage sector, which extends out to 35º on either side of the centreline. The First Officer would appear to have interpreted this "false" localiser signal as valid and thus advised the Captain that the

[11] IMC: Instrument Meteorological Conditions

CDI was active and, according to the Captain, to commence an ILS approach. However, there was no CVR recording to verify exactly what happened in the cockpit at this time. Although the Captain, who was flying the aircraft, said afterwards that he felt the navigation data was erroneous and didn't make any sense, nevertheless he initiated an "*approach*" and descended towards the ground instead of going around. It is fortunate that the descent was made over ground that was relatively low-lying in comparison to much of the terrain in the vicinity of EIKY.

It was also fortunate that a vigilant radar controller in Shannon was actively monitoring the aircraft and intervened by phone through Kerry Tower with an instruction to climb immediately, as the aircraft descended in cloud to a height of 702 feet above terrain. At the same time, the EGPWS activated and the crew responded appropriately and climbed to a safe altitude.

After Shannon Centre took over control of the aircraft and vectored it towards the ILS approach for RWY 26, it appears that further confusion arose as the aircraft approached reporting point VENUX on a radar heading of 350ºM. The crew reported that they were 4.7 nm from VENUX, and ATC directed them to turn left and route direct to VENUX and, when ready, to descend to 3,300 ft. This would have entailed a left turn through about 45º and would have set the aircraft up for a further similar left turn onto the localiser for RWY 26. However the aircraft did not turn left towards VENUX, but instead continued north through the localiser, commenced a right turn followed by a left hand orbit to the north of the localiser. This indicates that the crew had again lost situational awareness regarding the location of the aircraft with respect to the localiser and EIKY. This confusion may have been the result of the crew mistaking the reporting point INRAD for VENUX, or due to the possibility that they had never fully regained situational awareness.

After VT-MST reported having problems with their FMS, Shannon Centre provided radar vectors onto finals for RWY 26 and the aircraft made a successful approach and landing. However, no defect in the FMS was recorded after landing.

2.1.4 Crew Resource Management (CRM) Aspects

In his submissions made after the occurrence, it is clear that the Captain considered that he was "*flying solo*" during the unfolding events. He said he considered that there were three critical factors, the distraction posed by the fractured windshield, the engine vibrations and the "*lack of support from my Co-pilot, as his situational awareness was diminished and confused by the sequence of events at the time*".

The First Officer candidly stated that he had mis-programmed the FMS during the unscheduled return to EIKY and had mistakenly thought that the aircraft was on the localiser when it was not. In addition, he inaccurately reported a position of 35 nm to the southeast of EIKY when in fact he was 35 nm northwest of Cork VOR/DME station, a navigation aid he had probably had set up in advance as part of the SID procedure. The Investigation notes his relative lack of experience on type, and the fact that he had flown only 1.4 hrs in the previous 28 days. Thus, the evidence indicates that he was ill prepared to play a critical role of assisting and providing guidance to his Captain while conducting an unfamiliar approach when problems started to arise with the flight. In this respect, the Captain's assessment was correct.

However, there is no evidence that the Captain took this lack of recent flying time into account in dealing with the occurrence. Furthermore, a rushed approach was attempted without adequate preparation. The cracking of the Captain's windshield, though upsetting in itself, was not critical since the structural integrity of the windshield remained intact. The Captain reported that the No. 1 engine registered vibration levels very shortly after the windshield fracture event. The Investigation acknowledges that engine vibration is recorded only at 4-second intervals and that a momentary excessive vibration may have occurred which was not recorded by the DFDR. However, the DFDR data shows no evidence of excessive vibration or any other engine anomalies during the flight.

The Captain also said that he had retarded the No. 1 engine thrust to idle due to vibration levels on the engine following which the vibration levels returned to normal. There is no evidence of significantly differing vibration levels or thrust settings between the engines at any stage in-flight. Nor is there any evidence on the DFDR of any in-flight engine abnormality that would have required an immediate landing. Consequently, a prudent climb to an altitude above the MSA should have been conducted, and then permission should have been requested from ATC to enter a holding pattern. This would have provided adequate time to stabilise the situation, complete the appropriate checklists and prepare for an orderly approach.

The Captain subsequently submitted that he was under a, "*high level of pressure and concern*", and was forced, " *to act as PIC flying solo*". Although the cracked windshield was a matter of concern, the pressure could also have been easily reduced by engaging the autopilot and getting assistance from ATC regarding altitude and heading, as the First Officer later realised.

Although mistakes were made, it is ultimately the responsibility of the Captain to retain control of the situation, ensure that a flight is conducted safely and to manage the resources at his command: equipment, human and time.

2.2 ATC Aspects

The Kerry Tower controller was in a difficult situation during this occurrence due to his lack of access to radar data. Thus, he was dependent on the crew of VT-MST for information about the aircraft position. However, some of the information he did receive from the aircraft could not have been correct, such as the position report "*35 miles southeast*" of the airport only two minutes after departure. Also, the crew reported that the aircraft was coming up on the localiser 7 nm from the airport just 6 minutes after departure. Again, this interval was too short for the aircraft to have carried out the procedure, which the controller had cleared them to do. In addition, the crew did not comply with the controller's instruction to report overhead EIKY establishing outbound on the ILS. In fact their next report, following a position request from ATC, was turning inbound at 10 nm. These inconsistent and inaccurate position reports and non-compliance with ATC instructions were not challenged at the time by the controller. The controller informed the Investigation that he appreciated the fact that there was significant confusion in the cockpit and that the crew was under intense pressure at the time. Therefore, he did not think that it would be prudent to communicate with them regarding their non-compliance with his instructions.

A procedural controller relies on accurate and timely positional information from flight crew in order to develop his mental picture of the general situation. The failure of the aircraft to comply with instructions and provide accurate information seriously compromised the controller's situational awareness. If the Kerry Tower controller had access to radar information at the time he would have been able to verify where the aircraft was and what it was doing.

The Investigation is aware that a feed of IAA radar information is available to air traffic controllers at Weston Airport, which is located near Dublin. This information is utilised solely as an advisory aid to the controllers, so that they can verify position reports and compliance with instructions by aircraft. A similar feed of radar information to the controller in Kerry Tower would have, in all probability, averted this serious incident at an early stage.

In the circumstances, the Investigation is of the opinion that the lack of radar information at EIKY, allied to the fact that the airport is in close proximity to high ground in several directions, is a safety issue, and accordingly a Safety Recommendation is issued in this respect.

The radar controller at Shannon is to be commended for his vigilance in this case. Given the confusion of the crew of VT-MST, his direct and forceful intervention quite possibly made the difference in averting a Controlled Flight into Terrain (CFIT) accident. The fact that he had previously worked as a controller at EIKY meant that he was very familiar with the terrain around the airport and he was aware that the aircraft was descending on a heading leading towards high ground.

2.3 Engine Damage

Although the Captain reported to the Investigation that the No. 1 engine EVM had registered a vibration level of 2.7 ips very shortly after the windshield fracture event, there is no evidence of this on the DFDR. It is therefore possible that the Captain's recollection of this was confused. The examination of the windshield by the manufacturers under the supervision of the NTSB showed that the entire outer glass ply remained attached to the laminate body, i.e. that no glass was missing from the windshield. In addition, there was no evidence of any FOD impact damage. Therefore, the Investigation concludes that there was no connection between the windshield failure and the damage to the No. 1 engine.

The recorded engine parameters of the No. 1 engine were normal until a few seconds before the aircraft was shut down after the flight when the engine appeared to sustain a stall event followed by an immediate recovery and then engine shutdown. It is not possible to verify if the door of the aircraft was opened before the engines were shut down, as a door open discrete was not recorded on the DFDR. However, this stall was the first recorded evidence of a problem with No. 1 engine.

Considering the damage which was found on the No. 1 engine fan blades, the LP compressor and the HP compressor, there can be no doubt that the engine ingested a hard-bodied object. Laboratory analysis of the impact sites revealed consistent traces of debris similar to low carbon steel (typical of mild steel). Impact marks suggest that the object may have been of round shape with a diameter of 25 mm.

The first engine anomaly recorded by the DFDR was the stall event on the EIKY ramp after landing and prior to shutdown. Subsequent starts of No. 1 engine displayed different characteristics when compared to its first start of the day in that the LP assembly was seen to commence rotation later in the start sequence. The LP and HP rotational speeds also dipped below normal ground idle levels during recovery from the subsequent series of stalls. These facts suggest that the FOD ingestion may have occurred on the EIKY ramp, just before the No. 1 engine was shut down after the flight. However, the engines on the Gulfstream IV are located high on the rear fuselage with the engine intakes above and forward of the wing trailing edges in the vertical plane. This suggests that it would be very difficult for a substantial piece of steel to be ingested into the engine of a parked aircraft from ground level. Thus, it is not possible for the Investigation to say at what precise point in time the FOD was ingested into the engine.

The Pilot's Defect Report was signed off at 09.15 hrs on 13 July 2009 and included an entry "*Left engine vibration indication fan guide vanes are nicked*". This entry suggests that the crew became aware of the physical damage to the fan blades in the period between the aircraft landing back at EIKY at 08.34 hrs and the next engine start, prior to taxiing to the remote parking position at 09.32 hrs.

There was no evidence that any further technical examination of the engine, or compliance with any checklist, was carried out prior to starting or subsequent to shutting down the engine. Ten engine run-ups were conducted and were recorded on both the CVR and DFDR with a succession of engine stalls during these cycles. It is probable that the damage levels, sustained initially by the ingestion of the hard bodied object into the engine, were increasing as the condition of the compressor blades deteriorated during these run ups, resulting in a significant reduction in the surge margin of the compressors. The final five run-ups were all to high power settings and it appears from the DFDR data that the final high power run carried out on 13 July lead to significantly increased engine damage. This run ended in a very audible stall sound (recorded on the CVR) accompanied by a rapid engine deceleration.

The four attempts to start the engine the following morning were characterised by the LP assembly rotational speed (N1) remaining at zero for an extended period as the HP speed (N2) increased. Starting procedures require that positive LP RPM be seen before the HP fuel cock is opened. Although the First Officer advised that there was no LP, a first start was attempted and continued with. The core HP stage then accelerated while the LP stage showed no rotation. As would be expected, a hot start resulted, with the engine not accelerating to minimum idle speeds while EGT temperature continued to increase. Following this, further starts were attempted with the engine eventually starting but the crew hearing a rubbing noise.

The QRH clearly states that there should be a three-minute delay between start attempts. However, the crew performed three attempts to start in two minutes and forty seconds. They then carried out a fourth start nine minutes and thirty seconds after the third start although the QRH states that after three cycles, there should be a delay of at least fifteen minutes. Also there was no evidence of any use of pre-start or shutdown checklists.

Evidence of clashing between rotor blade leading edges and stator vane trailing edges, seen during the engine strip, is indicative of damage sustained from surge events. It is also probable that engine damage progressed to such an extent during the ground runs that the compressors could no longer supply sufficient air for the fuel to mix and ignite and therefore unburned fuel dripped from the aircraft, accounting for the crew report of the aircraft, "*bleeding a lot of fuel*".

In summary, it is likely that the No. 1 engine of VT-MST ingested a foreign object constituted of mild steel at some point, possibly after the aircraft landed from the flight. The FOD caused significant damage to the engine compressor, which was exacerbated by extensive and inappropriate post-flight engine runs.

2.4 Operator Oversight

The Investigation has concerns regarding the oversight of the operation of this aircraft by the Operator, in particular the standard, training and proficiency of the crew. This is evidenced by the confusion in the cockpit during the occurrence, the apparent lack of familiarity with navigational equipment, the loss of situational awareness on the part of the crew, failure to comply with DGCA of India Civil Aviation Requirements, poor crew resource management and an inappropriate series of engine starts and run-ups to a high power setting conducted on an engine which was known by the crew to be damaged.

2.5 Operator Response

In response to the contents of Paragraph 2.4, the Operator has stated the following. *"You will kindly observe that the co-pilot's training endorsement checks of instrument rating checks were carried out by the F.A.A. approved examiner and the proficiency checks, IR*[12] *renewal checks and route checks were carried out by the different pilot instructors only appointed and approved by the office of the DGCA. Therefore there has never been any oversight of the operation of the aircraft by the Operator with regard to the standard, training and proficiency of the crew."*

The Operator has also submitted *"Further we would like to apprise you of the facts that the management always emphasised on the crew to always adhere to the laid down procedures and follow the standard operating procedures. The crew has also been subjected to be checked by the instructor pilots on crew co-ordination and CRM training.*

Our operations always put a lot of emphasis on the crew to follow the laid down procedures and accomplish checklists on challenge/response methods. The complete operating procedures and laid-down rules are required to be followed by the operating crew. Each crew member has been issued with the Operations Manual for guidance and to adhere to the laid down procedures."

3. CONCLUSIONS

(a) Findings

1. The aircraft was properly certified for the flight.

2. The flight crew were properly licensed for the flight.

3. The First Officer had limited experience on type, and had flown only 1.4 hours in the previous 28 days.

4. The left hand windshield fractured shortly after the aircraft departed from EIKY.

[12] IR: Instrument Rating

5. The Captain subsequently reported excessive vibration levels on No. 1 engine during the same phase of flight. However, there is no evidence in the DFDR data of abnormal engine behaviour during the flight.

6. The controller in Kerry Tower cleared VT-MST to route to overhead EIKY and establish outbound on the ILS for an ILS DME approach to RWY 26. This instruction was acknowledged but not complied with by the crew.

7. As the aircraft tracked towards EIKY, the aircraft navigation equipment received a "false localiser" signal, resulting in an indication of Localiser Capture to the crew along with oscillations of the localiser and glideslope command bars.

8. At the location where the "false localiser" signal was received, the aircraft was outside the localiser specific coverage sector.

9. The First Officer had difficulties programming the FMS, and mis-programmed it for an approach to RWY 26 at Luton rather than EIKY.

10. The aircraft descended steeply in landing configuration on a track roughly parallel to the localiser but approximately six miles south of it, heading directly towards high ground in excess of 3,000 ft.

11. The aircraft descended in cloud to a lowest height of 702 ft above the ground.

12. The aircraft encountered further navigational difficulties as it approached reporting point VENUX while under the radar control of Shannon Centre.

13. For much of the flight, the aircraft was operated below the Minimum Sector Altitude, while not under radar control.

14. Due to non-compliance with laid-down procedures and instructions, as well as non-adherence to CRM principles, the crew lost situational awareness while attempting to return to EIKY.

15. A potential controlled flight into terrain was averted by the intervention of a controller in Shannon Centre and a simultaneous alert from the aircraft's EGPWS.

16. The failure of the crew to comply with instructions and provide accurate information seriously compromised the Kerry Tower controller's situational awareness.

17. Notwithstanding the fact that the Kerry Tower controller did not have access to radar data, he did not challenge the non-compliance of the crew with his instructions. The controller considered that such an intervention would have added to the crew's confusion and increased the pressures under which they were operating.

18. The windshield failure after take-off was caused by electrical arcing. The arcing resulted when moisture ingress was absorbed by an interlayer and caused degradation of the bus-bar at the bottom forward corner of the windshield.

19. The No. 1 engine sustained serious foreign object damage to the fan blades, the LP compressor and the HP compressor. The first indication of an engine anomaly was a stall event shortly before the engine was shut down on the EIKY ramp following the flight.

20. The foreign object was a hard-bodied object, probably of round shape, approximately 25 mm in diameter and made of mild steel.

21. There was no connection between the windshield failure and the engine damage.

22. The crew subsequently performed a series of inappropriate engine starts, accelerations and decelerations, although they were aware of foreign object damage to the fan blades. It is probable that the engine damage was exacerbated by these operations, culminating in a serious stall event on the final high power run.

23. There was inadequate oversight of the operation by the Operator.

(b) Probable Cause

1. The crew suffered a serious loss of navigational and situational awareness while attempting to return to EIKY following a windshield fracture encountered shortly after take-off.

(c) Contributory Factors

1. The crew made a number of rushed and inappropriate decisions during the flight, thus displaying poor crew resource management.

2. The First Officer's lack of recent flying hours is likely to have contributed to his loss of navigational and situational awareness.

3. A "false localiser" signal was received due to Approach mode being armed while the aircraft was outside the specific localiser coverage sector.

4. The Captain commenced a descent without having a valid ILS signal and without cross-checking other available navigation aids.

5. The situational awareness of the controller in Kerry Tower was compromised by erroneous position reports from the crew and non-compliance with his instructions, as well as a lack of direct radar information.

4. SAFETY RECOMMENDATIONS

It is recommended that:

1. The licensee of Kerry Airport, in conjunction with the Irish Aviation Authority, should review the provision of radar information to support the air traffic control service provided by Kerry ATS unit. **(IRLD2010016)**

Appendix A

Chart 1

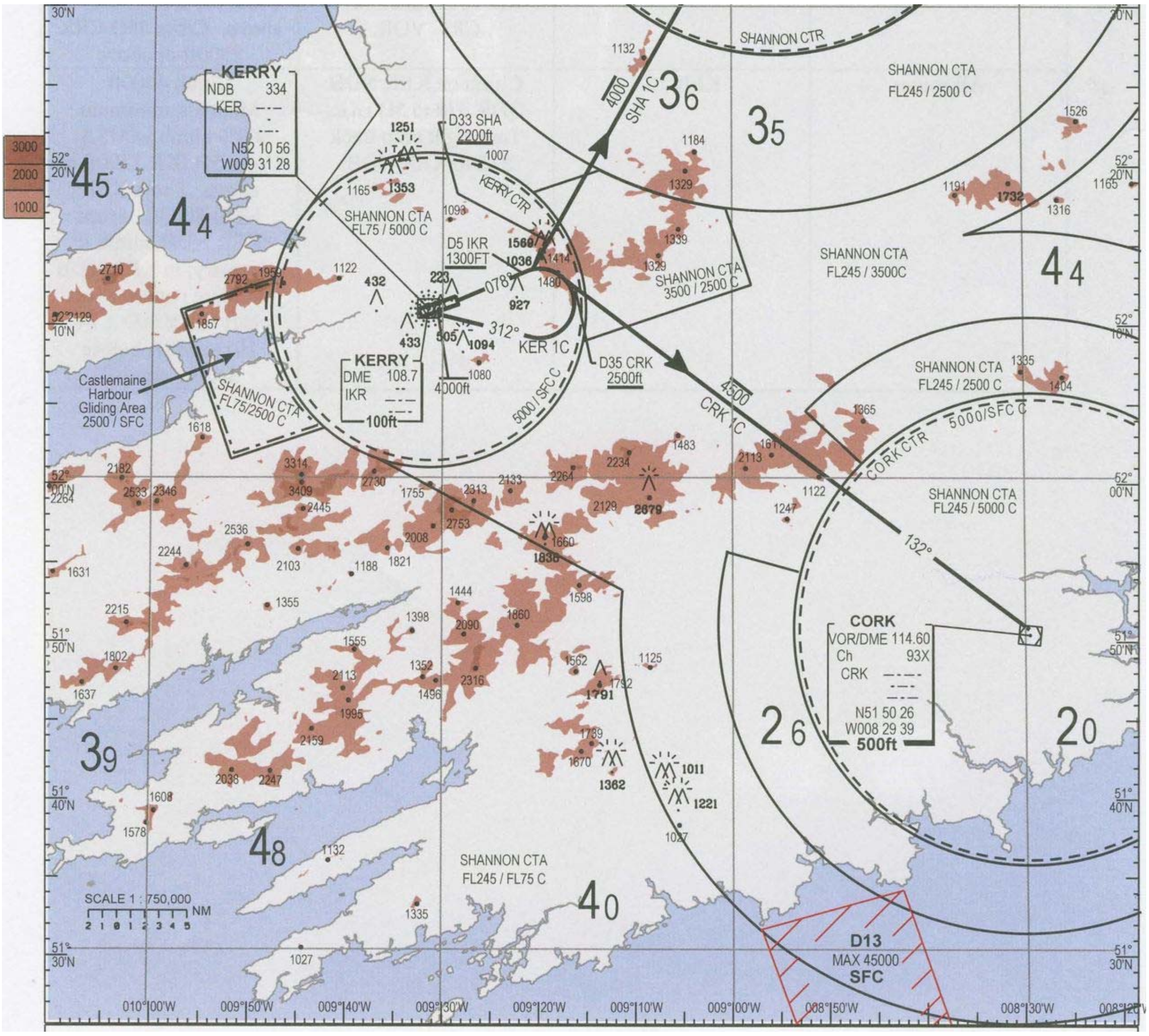
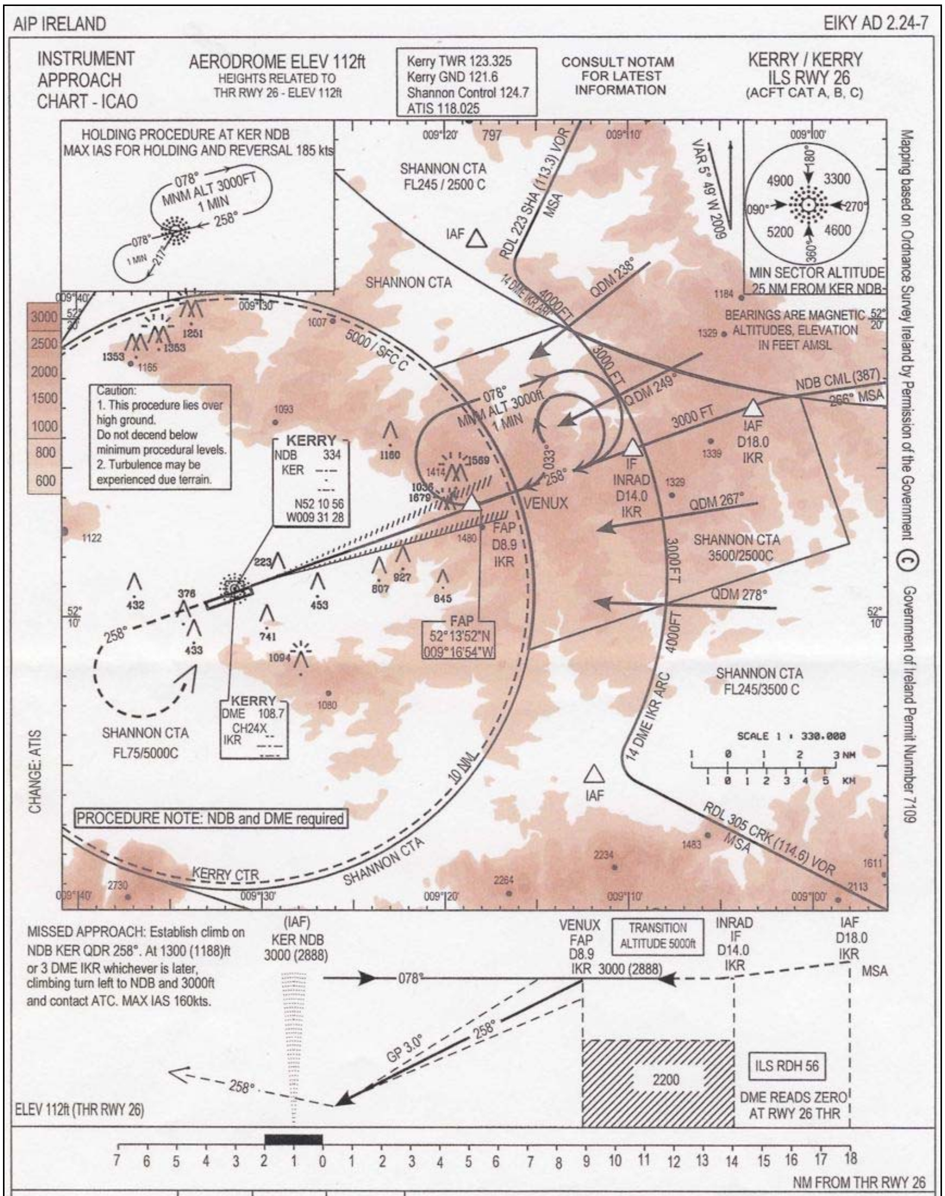


Chart 1: CRK 1C Standard Instrument Departure From EIKY

FINAL REPORT

Appendix A

Chart 2



OCA (H)		A	B	C	NOTE: INSTRUMENT APPROACHES ONLY AVAILABLE WHEN AIR TRAFFIC CONTROL ZONE IS ACTIVE UNLESS AUTHORISED BY THE OPERATING STANDARDS DEPARTMENT OF THE IAA.							
Straight - in Approach	CAT 1	260 (148)	270 (158)	280 (168)								
Visual Manoeuvring (These heights are AAL)	Total Area	1040 (928)	1140 (1028)	1500 (1388)	Ground Speed	Kts	70	90	100	110	120	140
	North of RWY only	610 (498)	610 (498)	910 (798)	Decent Rate Gradient - 5.2%	FT/ MIN	370	480	530	580	640	740

Irish Aviation Authority — Aeronautical Information 09 April 09

Chart No. 2: EIKY ILS RWY 26 Procedure