Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT
BOEING 737-800, EI-DHI
Riga Airport, Latvia
7 January 2012

An Roinn Iompair Turasóireachta agus Spóirt
Department of Transport, Tourism and Sport

Foreword

This Report is a technical document that reflects the opinion of the AAIU regarding the circumstances of this occurrence and its probable causes and consequences.

In accordance with the provisions of Article 5.4.1 of Annex 13 of the International Civil Aviation Convention, and with Article 5.5 of Regulation (EU) No 996/2010 of the European Parliament and the Council, and with Regulation 8 (3) of S.I. No. 460 of 2009, the sole objective of this Investigation is the prevention of future accidents and incidents.

Accordingly, this Investigation is exclusively of a technical nature, is separate from any proceedings that may apportion blame or liability and should only be used for the advancement of aviation safety. The Investigation has been conducted in accordance with the above norms and regulations using procedures that are not subject to the admissibility of evidence requirements and safeguards in a judicial process.

Consequently, any use of this Report for purposes other than that of preventing future accidents and incidents may lead to unreliable conclusions or interpretations.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010 and the provisions of S.I. 460 of 2009, the Chief Inspector of Air Accidents, on 13 January 2012, appointed Mr. Paddy Judge as the Investigator-in-Charge to carry out an 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:	BOEING 737-800, EI-DHI
No. and Type of Engines:	2 x CFM56-7B26
Aircraft Serial Number:	33818
Year of Manufacture:	2005
Date and Time (UTC):	07 January 2012 @ 19.05 hrs
Location:	Approach to Riga Airport (EVRA), Latvia
Type of Operation:	Commercial Air Transport – Passenger
Persons on Board:	Crew - 6 Passengers - 140
Injuries:	Crew - 0 Passengers - 0
Nature of Damage:	Nil
Commander's Licence:	Airline Transport Pilot Licence issued by CAA UK
Commander's Details:	Male, aged 46 years
Commander's Flying Experience:	11,500 hours, of which 5,570 were on type
Notification Source:	Operator
Information Source:	AAIU Investigation

SYNOPSIS

While descending towards Riga, in poor weather conditions with moderate snow, the indicated airspeed (IAS) readings began to diverge. The Flight Crew decided, following evaluation, that the IAS displayed on the First Officer's (F/O) side was incorrect. Airspeed disagreement and other warnings then activated. Following completion of checklists an ILS approach to Runway (RWY) 18 was commenced with Air Traffic Control (ATC) actively monitoring the aircraft. During the approach both the autopilot and autothrottle disconnected and the approach was continued hand flown. During the later stages of the approach the stall warning (stick shaker) activated on the F/O's side and this continued until after the landing.

Subsequent maintenance action found that, although the pitot heater on the F/O's side had failed due to a short circuit, the pitot heater failure warning had not activated because the design of the warning system may not detect failures of this nature.

As a result of the Investigation, two Safety Recommendations are issued to the aircraft's Manufacturer regarding the design of the pitot heater failure warning system and the guidance provided to flight crew. A further Safety Recommendations is issued to the Federal Aviation Administration (FAA) regarding the Failure Modes and Effects Analysis (FMEA) of the B737-800.

NOTIFICATION

The Operator filed a Mandatory Occurrence Report (MOR) through the Irish Aviation Authority's (IAA) Safety Occurrence Tracking System (SOTS). Following receipt of the occurrence report the AAIU notified the Transport Accident and Incident Investigation Bureau (TAAIB) of the Republic of Latvia, which was the State of Occurrence.

The TAAIB on the 13 January 2012, in accordance with ICAO Annex 13, Section 5.1.2, delegated the Investigation of this serious incident to the AAIU as the Safety Investigation Authority (SIA) of the State of Registration and of the Operator. The TAAIB and the National Transportation Safety Board (NTSB) of the USA (the State of manufacture) appointed accredited representatives (ACCREPs).

1. FACTUAL INFORMATION

1.1 History of Flight

EI-DHI took off from East Midlands Airport (EGNX), United Kingdom, at 16.52 hrs with Riga Airport (EVRA), Latvia as its destination. The evening flight was normal throughout its climb, cruise and the initial descent into EVRA where the weather conditions were poor with moderate snow.

During the initial approach, while descending from 6,000 ft, the IAS on the F/O's side gave erroneous information. The aircraft was levelled at 4,000 ft and the approach was delayed while checklists were completed and the problem assessed. The approach was later continued with the aircraft landing at its destination at 19.17 hrs.

1.2 Interview with the Flight Crew

Both pilots were interviewed by the Investigation. They stated that the flight was operated with the Commander acting as Pilot Monitoring (PM) while the F/O was the Pilot Flying (PF) the aircraft. They said that the flight had been normal and that during descent, through approximately 15,000 ft, the wing and engine anti icing had been selected on. Later, while descending from 6,000 ft with autopilot 'B' engaged in Level Change mode (LVL CHG) and 250 kts selected on the Mode Control Panel (MCP), the aircraft entered a layer of cloud. Approximately 6 seconds later the PF noticed the IAS on his Primary Flight Display (PFD) decreasing with the rate of descent increasing. In the meantime the IAS on the captain's side was increasing to about 280 kts or possibly in excess of that. The PF stated that he disconnected the autopilot and autothrottle, as he felt something was wrong since the rate of descent was too high. He levelled the aircraft at 4,000 ft and applied power. When the Flight Crew crosschecked they noticed 'IAS DISAGREE' warnings on the PFDs and that the F/O's altimeter read 250 ft higher than the Commander's. At that time "ALT[1] DISAGREE" also illuminated intermittently on both PFDs; later it was continuously on.

The Flight Crew stated that initially they completed memory action drills. The QRH[2] checklist for IAS DISAGREE was then completed during which they checked that the pitot heaters were selected on and confirmed that the pitot heater failure warning lights were not illuminated. The standby airspeed indicator and standby altimeter were checked and indicated that the captain's instrumentation was probably correct. The captain's IAS, which showed a speed close to 250 kts, was crosschecked with the Inertial Reference System (IRS), which showed a groundspeed of 240 kts.

An engine warning also illuminated on the Master Caution annunciator and this was traced to the right hand Electronic Engine Control (EEC) defaulting into alternate mode. As the EEC push buttons are on the aft overhead panel behind guards, the Flight Crew commented that this warning was initially quite difficult to see.

[1] **ALT:** Altitude
[2] **QRH:** Quick Reference Handbook

The QRH checklist for EEC Alternate Mode was consequently completed following which the EEC entered the required mode. While evaluating the situation they held over the sea at 4,000 ft in an elliptical holding pattern to the north of the ILS while the aircraft was hand flown without Flight Director vertical guidance. ATC and the cabin were advised of the problem following which ATC volunteered and helpfully gave groundspeed readouts.

The Flight Crew said that in the meantime the weather had been deteriorating with low cloud and sleet; the braking action on the runway was reducing towards CAT I[3] minima conditions in moderate snow. As the captain's instrumentation appeared to be correct the Flight Crew switched roles with the Commander becoming PF and the F/O PM; autopilot 'A' and autothrottle were selected, as these are supplied with data from the captain's side. They descended over the sea to 2,300 ft and the radio altimeter (RADALT) crosschecked correctly with the captain's altimeter.

The Flight Crew stated that when they subsequently selected flaps and decelerated for the approach the stall warning (stick shaker) activated on the F/O side. As the stick shaker continued until the aircraft had landed the crew commented that they found this very distracting and the noise made communications difficult. Although they commented that the circuit breaker for the stick shaker could have been pulled, they felt that it was unwise to look for the particular circuit breaker in a dark cockpit and in the prevailing circumstances. Due to workload in the cockpit the Cabin Crew were briefed over the interphone.

They said that during the approach the autopilot self-disconnected at about 7 nautical miles
5 (nm) and that the autothrottle kept tripping out. The approach to RWY 18 was therefore continued manually and, following visual acquisition of the runway at about 300 ft, the aircraft landed.

The Cockpit Voice Recorder (CVR) was protected after landing by the Commander pulling the circuit breaker.

1.3 Maintenance

Maintenance action subsequent to the occurrence consisted of replacing the F/O pitot probe and associated leak checks. The Operator informed the Investigation that the pitot probe was installed on the aircraft during manufacture in April 2005 and that it had not been replaced since the delivery of the aircraft. It further stated that the pitot probe had been subjected to inspections at the intervals prescribed by the Manufacturer which take account of the wear and tear that occurs between inspections that do not affect the performance of the pitot probe.

This Goodrich (Rosemount Aerospace Inc.) pitot probe, BAC Part Number: S232N911-6, Serial number 237597, which had completed 23,618 hours on the aircraft, was sent to a maintenance facility for examination. This reported "*Heater shorted. Nose heavy corrosion. Pitot nose tip damage beyond serviceable limits. Overhaul required*".

[3] **CAT 1:** Category One ILS

1.4 Pitot Probe Examination by Manufacturer

Following receipt of the maintenance facility's report the pitot probe was sent to the Manufacturer for further examination. The Manufacturer reported that:

1. Heater is confirmed to be shorted to case
2. One leg of short is more affected by localized temperature (aerosol coolant or heat gun) than the other.
3. The short junction is affected by localized temperature (aerosol induced cold causes resistance to rise / heat gun induced heat caused resistance to drop).

1.5 Further B737-800 Events Reported by the Operator

Similar pitot heat problems were reported on 11 March 2011 by another of the Operator's B737-800 aircraft. "IAS DISAGREE" warnings were observed on both the captain's and F/O's PFDs during the descent approaching Flight Level (FL) 170. The F/O's IAS steadily decreased to 170 kts with the standby IAS indicating 270 kts. The Flight Crew carried out the 'IAS DISAGREE' and 'AIRSPEED UNRELIABLE' checklists and confirmed that both pitot probe heaters were selected to on and that the pitot heater failure warning lights were not illuminated. They reported that both EEC ALT mode lights also illuminated and later 'ALT DISAGREE' was observed on both PFDs with the F/O's altimeter showing 400 ft lower than the captain's and the standby altimeters. A hand flown approach was commenced using the captain's IAS and when Flaps 1 was selected at 230 kts, the airspeed was reduced. The F/O's stick shaker activated when his IAS reduced to 113 kts. Thrust was then increased until the F/O's IAS reached approximately 230 kts and the approach was continued using the F/O's IAS as reference. At about 700 ft the warnings disappeared and airspeed and altitude matched on both sides of the cockpit. An evaluation carried out by the Operator found that the computed airspeed had reached 298.5 kt during this occurrence with the flaps at position 1. A subsequent post event engineering examination found that both of the F/O`s pitot probe pins had shorted to ground.

On 06 November 2012, during descent through approximately 14,000 ft, the flight crew of a different aircraft reported that the 'IAS DISAGREE' warnings illuminated with 'ALT DISAGREE' shortly thereafter. The F/O's side was confirmed as reliable by the standby IAS and by groundspeed from radar. The outside temperatures became positive at about 4,000 ft and the problems disappeared.

On a flight on 3 December 2012 flight crew reported that, during descent at FL220, the 'IAS DISAGREE' warnings appeared followed shortly afterwards by 'ALT DISAGREE' and Master Caution ENG (engine) warning due to both EECs changing to alternate mode. When later descending through FL120, the IAS on the F/O's side recovered and eventually both the IAS and ALT disagree warnings disappeared. Subsequent maintenance action recovered approximately 15-20 ml of water from the F/O`s pitot probe, which was replaced and its heater found to be unserviceable.

On 04 February 2013 another of the Operator's aircraft, descending through FL 80 suffered an airspeed disagreement, in this case the captain's IAS being 220 kts and the F/O's 320 kts. In addition the EEC went to ALT mode.

The three flight crew (on that occasion) confirmed that there were no cockpit warnings associated with pitot heaters and that the stick shaker activated during the approach. The fault was traced to a short in the captain's pitot probe heater element.

The Operator reported that it had 20 events in 2012 of unannounced pitot heat failures. It stated that the life analysis of these failures indicated that the pattern of pitot tube failures showed no trend that would allow determination of the life of pitot probes. The Operator commented that unannunciated failures are a fleet-wide problem that has occurred on all makes of the Boeing 737NG aircraft. It further stated that at that time the Manufacturer had informed the Operator that it had no solution that would annunciate heater failure at a different current value.

The Operator informed the Investigation that it and other operators had brought the failure of the pitot probe heater warning system to the attention of the Manufacturer. It stated that the Manufacturer had consulted with the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) who agreed in 2011 that the current rate of unannounced pitot probe heater failures met the FAR-25 requirements and that it was not therefore a safety of flight issue.

1.6 Further Operator Information

On 19 January 2012 the Operator provided additional training material and information to its pilots regarding flight with unreliable airspeeds. The Operator stated that this training was conducted as a response to a trend identified in the Operator's Safety Management System (SMS) regarding 'pitot tube failure or partial failure'. The documentation stated, inter alia, that:

7

'Early recognition of erroneous airspeed indications requires familiarity with the interrelationship of attitude, thrust setting, and airspeed. A delay in recognition could result in loss of airplane control.'

The training material advised flight crew that they should expect to fly three unreliable airspeed exercises in the simulator including one with a complete loss of reliable airspeed.

1.7 Flight Crew

The Captain, aged 46, was the holder of a valid Airline Transport Pilot Licence (ATPL) issued by the Civil Aviation Authority (CAA), UK. His Aeroplane type rating (issued on 26 February 2011) and his Class One medical (issued on the 27 April 2011) were also valid. He had accumulated 11,500 hours flying of which 5,570 hours were on the aircraft type.

The First Officer, aged 35, was the holder of a valid Commercial Pilot Licence (CPL) issued by the Irish Aviation Authority (IAA). His Aeroplane type rating (issued on 06 March 2011) and his Class One medical (issued on the 23 November 2011) were also valid. He had accumulated 2,300 hours flying of which 2,100 hours were on the aircraft type.

1.8 Meteorology

The Terminal Area Forecast (TAF) for Riga Airport for the time of the occurrence was as follows:

TAF EVRA 071403Z 0715/0815 20007KT 9999 SCT006 BKN015 TEMPO 0715/0718 BKN006 BKN012 BECMG 0718/0719 5000 -RASN BR OVC004 TEMPO 0800/0815 2500 SN BECMG 0804/0806 14007KT SCT004 BKN012=

The Actual meteorological conditions reported (METARs) at Riga about the time of the occurrence were:

METAR EVRA 071850Z 18006KT 9999 -RASN OVC005 01/01 Q1001 R18/290158 NOSIG=
METAR EVRA 071920Z 19006KT 9999 -RASN OVC005 01/01 Q1001 R18/290158 NOSIG=
METAR EVRA 071950Z 17005KT 9999 -SNRA OVC005 01/01 Q1001 R18/290158 NOSIG=

1.9 Airspeed Unreliable Checklist

The Manufacturer's checklists for an airspeed disagreement (**Graphic No. 1**) and an unreliable airspeed (**Graphic No. 2**) are published as memory items in the aircraft's QRH.

IAS DISAGREE

Condition: The IAS DISAGREE alert indicates the captain's and first officer's airspeed indications disagree by more than 5 knots for 5 continuous seconds.

Accomplish the AIRSPEED UNRELIABLE checklist.

Graphic No. 1: IAS Disagree Checklist

AIRSPEED UNRELIABLE

Condition: Pitch attitude not consistent with existing phase of flight, altitude, thrust, and weight, or noise and/or low frequency buffeting.

Crosscheck ground speed and winds provided by the IRS and FMC to determine airspeed accuracy if indicated airspeed is questionable.

Note: Erroneous or unreliable airspeed indications may be caused by blocked or frozen pitot-static system(s), or a severely damaged or missing radome.

Airplane attitude/thrust . . . . . .Adjust

Maintain airplane control. Attitude and thrust information is provided in the Performance-Inflight section.

PROBE HEAT . . . . . .Check ON

MACH/AIRSPEED indicators . . . . . .Cross check

Graphic No. 2: Airspeed Unreliable Checklist

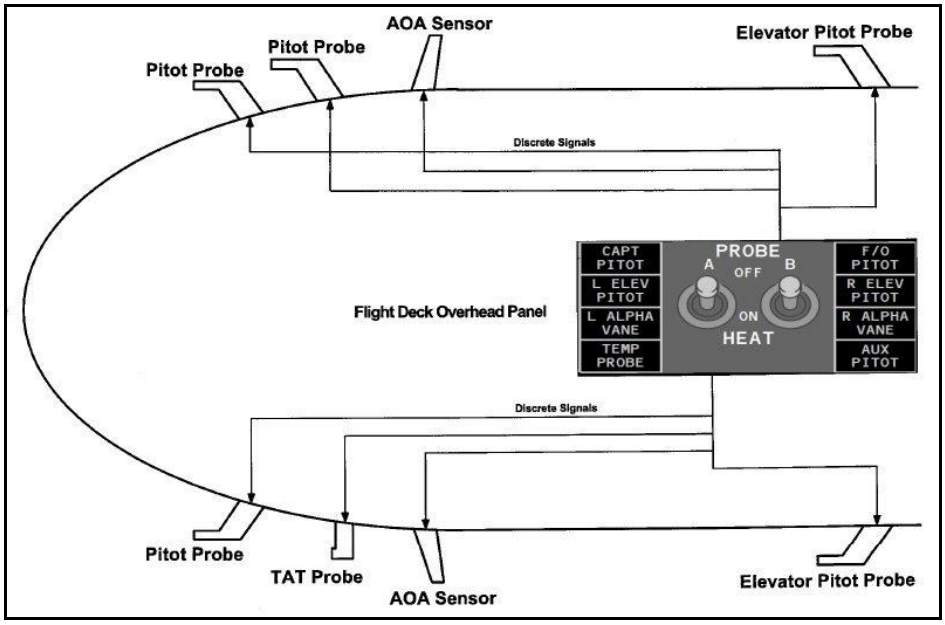
1.10 Pitot Probe Heat Systems

The pitot probe anti-icing system on the B737-800 prevents ice forming on the air data pitot probes and thus the false air data signals that can arise. The pitot probes have integral heaters that use 115V AC electrical power.

The pitot probe heaters on early models of the B737 – 600/700/800/900 (B737NG) types had reliability issues and the heater element of the probe was redesigned by its manufacturer, Goodrich Sensor Systems. The pitot probe fitted to EI-DHI was the redesigned version.

The Manufacturer advised the Investigation that its experience with the revised version of the probe indicated a life of around 18,000 - 22,000 hours depending on environmental conditions, etc. The Manufacturer stated that pitot probes are not life restricted and are replaced on condition.

There are 5 identical pitot probes on the B737-800 (**Graphic No. 3**), 2 located on the fin and the three on the nose.



Graphic No. 3: Air Data Sensor Heat System Schematic

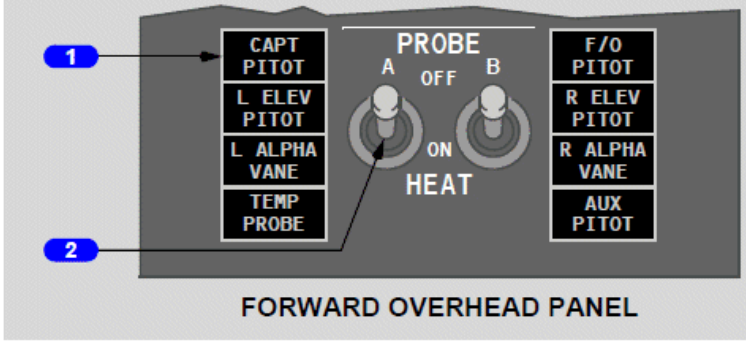
The pitot probe heaters are controlled by two PROBE HEAT toggle switches on the window/pitot heat module (**Graphic No. 4**). This module is located on the forward overhead panel. PROBE HEAT A controls the captain's pitot, the left elevator pitot, the left AOA sensor (alpha vane) and the temperature probe. PROBE HEAT B controls the F/O pitot, the auxiliary pitot, the right alpha vane and the right elevator pitot.

The pitot probe utilises a thin wire heating element wound around inside the probe. This wire is connected in series with a ceramic element located inside the base of the probe. The resistance of the ceramic element changes proportionally with local ambient probe temperature.

On the ground with no wind blowing, the ceramic element has increased electrical resistance which limits the current to the heating element wire. During the take-off roll, the ceramic element cools and decreases its electrical resistance thus allowing more current to the heating wire and more heat to the probe.

Normally, the heater draws approximately 1.5A, circuit protection being provided by a 2.5A, 115V AC circuit breaker (c.b.). On activation the probe heats to about 214° F. On reaching this temperature the probe reduces power consumption to about 200 mA.

Probe Heat Panel



FORWARD OVERHEAD PANEL

1 Probe Heat Lights

Illuminated (amber) – related probe not heated.

Note: If operating on standby power, probe heat lights do not indicate system status.

2 PROBE HEAT Switches

ON – power is supplied to heat related system.

OFF – power off.

Graphic No. 4: Pitot Probe heater panel

The probe heaters are monitored by a current detection system. This uses 28 V dc power and has two system indication light banks on the module associated with the switches, one per switch. The amber probe heat lights are press-to-test and illuminate if the associated probe heater does not draw sufficient electrical current. Current monitoring is achieved by a circuit card in a control panel (**Appendix A**). If the current drawn by the heater is less than 60 mA +/- 30 mA, the current monitor system activates the amber probe heat warning light for that heater. Illumination of a probe heat light will cause the "Master Caution" and "Anti-Ice" system annunciator lights in the cockpit to be illuminated.

1.11 Pitot Probe Heat Failure Modes

Information provided by the Manufacturer states that pitot probe heat failure modes may be either 'Annunciated', where the warning lights illuminate due to power loss/failure, or 'Un-annunciated' where insufficient current flows to the pitot heater and the probe warning system does not detect a failure.

In the latter case, a partially heated or unheated pitot probe can result in ice accumulation with a resulting incorrect display of IAS. An IAS disagreement is announced by an 'IAS DISAGREE' message displayed on both PFDs if there is a 5 kts or greater airspeed difference between the captain's and F/O's airspeeds for 5 consecutive seconds.

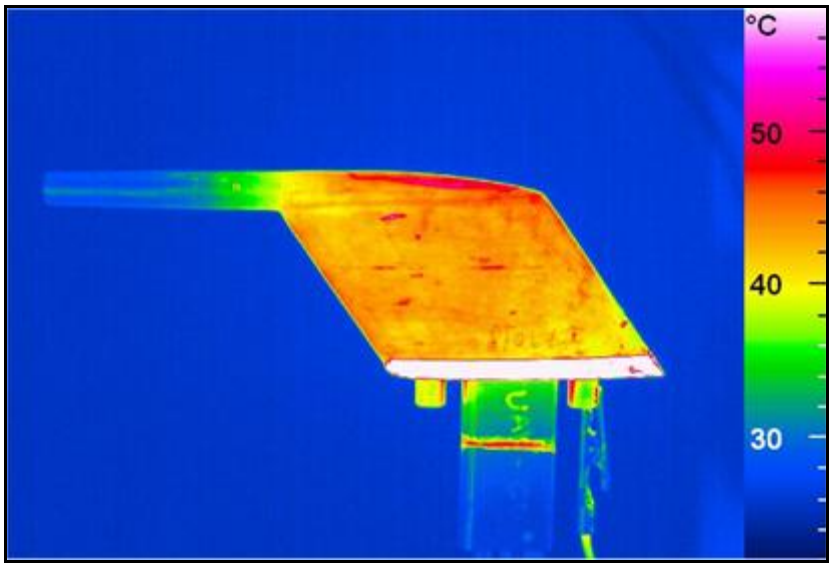
A failed probe heater only affects the airspeed indicating system associated with that probe. With three independent IAS systems a suspect system can normally be identified by comparison of the three IAS indicators; captain's, F/O's and standby. The Manufacturer cautioned that pulling an aural warning c.b. would eliminate a possible level of safety.

The Minimum Equipment List (MEL) allows dispatch in day Visual Meteorological Conditions (VMC) with a heater inoperative in clear air/non-icing conditions.

1.12 Pitot Probe Manufacturer's Report

The manufacturer of the pitot probe[4] stated that it had examined 12 pitot probes that were returned due to un-annunciated heater failures. These probes varied between 4 and 8 years old, with the exception of one which was 1.5 years old.

Typically, un-annunciated pitot heater failures were detected as the result of an "IAS Disagree" message. The manufacturer stated that this IAS disagreement is believed to be caused by partial heating of the pitot probe (**Thermal Image No. 1**) thus allowing ice to accumulate on the probe and causing an airspeed disagreement. Partial heating in all cases examined was caused by a short circuit within the pitot probe.



Thermal Image No. 1: Pitot probe heater tip not heated

[4] Goodrich, the original manufacturer, was subsequently acquired by United Technologies Corporation.

In addition the manufacturer identified that:

- The locations of the short circuits varied among the probes:
  - 3 in the nose
  - 3 in the region of the drain hole/head-strut interface
  - 3 at the base of the strut
  - 3 at the end of the heater sheath (connector area)

- All of the shorts resulted from a dielectric breakdown event through the insulation (i.e. electrical arcing inside the heater).
- If the short was between the power input pin and the tip, then the tip did not heat properly.
- If the short was between the tip and the power return pin, then the tip heats.
- All the shorted heaters still drew current, which prevented the aircraft from detecting a failure.

The pitot probe manufacturer concluded that:

- Testing demonstrated that when the heater is shorted it can still draw current and not be detected as a failure, yet it will not heat properly which could lead to pitot icing in flight.
- Failure Analysis showed that the cause of the heaters becoming shorted was corrosion through the heater sheath that resulted in electrical arcing and shorting.

1.13 Federal Aviation Regulation (FAR) 25.1326

FAR 25.1326, Pitot Heat Indication Systems, under which the B737-800 is certified, requires that heated air data sensors are monitored and that such a system is able to annunciate a heater failure. It states:

If a flight instrument pitot heating system is installed, an indication system must be provided to indicate to the flight crew when that pitot heating system is not operating. The indication system must comply with the following requirements:

(a) The indication provided must incorporate an amber light that is in clear view of a flight crewmember.
(b) The indication provided must be designed to alert the flight crew if either of the following conditions exists:

(1) The pitot heating system is switched "off".
(2) The pitot heating system is switched "on" and any pitot tube heating element is inoperative.

1.14 Failure Modes and Effects Analysis (FMEA[5])

The FMEA for the B737NG is issued in accordance with approval of the FAA. The Manufacturer of the aircraft provided the Investigation with a copy of the relevant sections of the FMEA, which cover a pitot head (probe) heating failure and its warning system. This showed that initial qualification tests on the earlier pitot probe, which is similar to that installed on the B757, were successfully completed by the probe manufacturer on 3 September 1996.

Flight testing was conducted on 3 October 1997 using the probe heat switches manually with icing conditions within FAR 25 Appendix C continuous maximum icing envelope. Following this, a Hazard Assessment and a FMEA were drawn up. The failure modes evaluated for the probe heater were:

- Heating element fails open, or shorts with resultant circuit breaker trip.
- Heating element fails shorted and circuit breaker does not trip.

The failure mode evaluated for the probe heater annunciator (**Appendix B**) were:

- Fails to turn-on and there is a failed probe heater.
- Fails on.

The hazard classification was "Minor".

13

The FMEA commented that *"The loss of anti-ice functions for all pitot probes or a latent loss of the anti-ice function for two or more pitot probes could result in a catastrophic event; therefore the probability of loss of this function must be of the order of 10^{-9} or less per flight hour"*. It noted that "*The 757 system has experienced no failures of the anti-ice function for all pitot tubes, and no latent failures of the anti-ice function for two or more pitot probes, resulting in an air turnback or diversion in over 13,800,000 flight hours***".**

1.15 Reporting of Occurrence

The Operator classified the occurrence as an Incident and submitted a SOTS occurrence report on 9 January 2012, within the 72 hours required by EU OPS. Following evaluation of the SOTS Report the AAIU re-classified this occurrence as a Serious Incident, in accordance with the guidance issued in the Annex to Regulation (EU) 996/2010:

— multiple malfunctions of one or more aircraft systems seriously affecting the operation of the aircraft,

[5] **FMEA:** "..a formal and systematic approach to identifying potential system failure modes, their causes, and the effects of the failure mode occurrence on the system operation…FMEA provides a basis for identifying potential system failures and unacceptable failure effects that prevent achieving design requirements from postulated failure modes…FMEA is used in many system design analyses including assessing system safety, planning system maintenance activities, defining provisions for fault recovery, fault tolerance, and failure detection and isolation, and identifying design modifications and corrective actions needed to mitigate the effects of a failure on the system." (Society of Automotive Engineers (SAE) International Aerospace Recommended Practice (ARP) 558).

The AAIU then advised the TAAIB of the occurrence in accordance with the reporting requirements of a serious incident.

The TAAIB reported that the Operator's technicians had arrived into EVRA on the morning of the 8 January 2012, the day after the occurrence, and that following maintenance EI-DHI had departed Latvia as a non-revenue flight later that day. Consequently, the TAAIB requested the AAIU on the 13 January 2012, as State of the Operator and Registration of the aircraft, to conduct an investigation and delegated the Investigation to the AAIU.

The Operator, when contacted by the Investigation, on the 9th January 2012, stated that the aircraft had already been returned to service and that the data on the CVR had been overwritten and was no longer available. Nevertheless, the Digital Flight Data Recorder (DFDR) was available and this was provided to the AAIU for download. The data obtained from the DFDR was of good quality and was consistent with the Flight Crew's recollection of events.

1.16 Manufacturer's Response to the Draft Final Report

Following issuance of the Draft Final Report the Manufacturer informed the Investigation that it had undertaken a study on how to improve the reliability of the indicating system for the probe heaters. It found that by reversing the connection polarity of the probe heat wiring, a partially shorted probe continues to provide adequate heat until the short burns through the wire element thus causing an open circuit (and associated indication). This has been verified via analysis and testing of a shorted probe. The Manufacturer stated that new airplanes now have the opposite polarity incorporated into production and that it expects to release a service bulletin for the existing B737NG in the first quarter of 2014.

In addition, the Manufacturer is also in the process of updating and reformatting the QRH checklists for all airplane models including the checklist for unreliable airspeed. Furthermore, it stated that a Flight Operations Technical Bulletin has been released to all operators noting the changes to the unreliable airspeed checklist.

In response to the third draft safety recommendation, the Manufacturer stated that an amended checklist will include various symptoms of possible unreliable airspeed including the activation of stick shaker. This new checklist is expected to be released in June, 2014 for the 737NG airplanes.

2. ANALYSIS

2.1 General

The aircraft entered cloud at 6,000 ft during its descent into EVRA. Shortly afterwards, the Flight Crew noticed that IAS indications were diverging and that IAS Disagree warnings illuminated on both PFDs. The Flight Crew then stabilised the aircraft while the situation was assessed. They found no obvious reason for the airspeed discrepancy since the pitot heaters were on and none of the pitot heater failure warning lights were illuminated.

The Flight Crew then conducted appropriate checklists and determined, by reference to the standby IAS and the groundspeed on the IRS, that the F/O's IAS was incorrect.

A further engine warning was eventually traced to the right EEC on the aft overhead panel and this too was addressed. Later, during the approach in poor weather, the autopilot and autothrottle unexpectedly dropped out and afterwards the F/O stick shaker/stall warning activated continuously. They continued the approach, having correctly diagnosed the problem and the outcome was a safe landing.

The response of a different flight crew, who encountered similar problems during an occurrence on 11 March 2011 (**Section 1.5**), was initially similar with the aircraft being stabilised and the appropriate checklists completed. The F/O's IAS was also correctly diagnosed as being faulty. However, on selection of Flap 1 and reduction of airspeed, the stick shaker activated. This confused the flight crew who immediately increased power until the stall warning ceased, thus ensuring that the aircraft was at a safe airspeed. Although this was achieved, it resulted in a significant exceedance of the maximum speed for flap extension. As the increased airspeed coupled with a decreased altitude caused a rise in temperature, the F/O's pitot probe evidently de-iced, since the airspeeds and altitudes returned to normal and the approach resulted in a normal landing.

Most of the 20 un-annunciated pitot probe heater failures reported by the Operator were identified due to airspeed divergences being observed during flight. In the majority of the cases reported, the airspeed divergences returned to normal as the probe ice melted during the descent into the warmer temperatures at lower altitudes.

The Investigation notes that the Operator subsequently issued guidance and provided simulator training to its flight crew regarding unreliable airspeed indications.

2.2 Un-annunciated Failures

The pitot probe heater failure warning system was designed to detect and provide warnings of a power supply failure and does so in the following circumstances:

- If the pitot probe heater fails in an open circuit mode (i.e with no further current draw) or;

- If the pitot probe heater shorts directly to ground (i.e. the c.b. opens and the probe heat light illuminates since there is no current draw).

However, as evidenced by the failures reported by the Operator to the Manufacturer and confirmed in testing by the pitot heater manufacturer, the failure can be un-annunciated. In this case the pitot probe can be partially heated, as in **Thermal Image No. 1**, due to:

- A short to the case that is not a dead short (i.e. it does not trip the c.b.)
- The heater continuing to draw current at a level that is too low to fully heat the pitot probe but high enough not to activate the monitoring circuit (i.e. the probe heat light does not illuminate since there is still a current draw). Thus the pitot probe is not protected from icing, but the flight crew are not aware of this.

Equally, it is possible in non-icing conditions that a potential un-annunciated pitot heater failure might exist on an aircraft for some time without being detected. Furthermore, as there is no independent maintenance check that each pitot probe is heating, this condition could exist in more than one pitot heater at the same time.

In the latter case, should pitot probe icing be encountered the only reliable indication of which airspeed is correct might be groundspeed from the aircraft's IRS/FMC systems.

With unreliable airspeed indications the aircraft would require to be stabilised and flown in accordance with the power/pitch attitude tables, as recommended in the Manufacturer's Performance tables, an activity infrequently practised in training. The Investigation notes that, subsequent to the event, the Operator increased flight crew training in this area.

2.3 Failure Modes and Effects Analysis (FMEA)

The Investigation notes the Manufacturer's FMEA considers that the latent loss of anti-ice function of two or more pitot probes could be a catastrophic event. The relevant evaluation in **Appendix B** shows that a 'Master Caution Anti-Ice Indicator' will provide indication of the latent failure, which did not occur during this event. The FMEA does not appear to have fully considered the failure of the pitot probe heater warning system to provide a warning annunciation in the event of an internal short circuit, as identified during this and other occurrences. In addition, the FMEA in the 'Failure Effects, Airplane' does not identify the consequential multiple failures experienced by the crew, including the stall warning/stickshaker activation. Consequently, the Investigation considers the FMEA should be reviewed and issues a Safety Recommendation to the FAA, which is the regulatory authority that issued the Type Certificate for the B737NG.

2.4 Pitot Heat Indicator System

FAR 25.1326, Pitot Heat Indicator Systems, under which the aircraft is certified requires that heated air data sensor or pitot probes are monitored and that an indication must alert the flight crew if "t*he pitot heating system is switched "on" and any pitot tube heating element is inoperative".* It is clear that in the case of un-annunciated failures, the pitot heater failure warning system installed in the aircraft fails to meet these criteria.

The Investigation therefore does not consider that the warning system meets this certification requirement, as it may not provide reliable warnings when the heater is shorted since it can still draw current but not be detected as a failure. In these circumstances the heater does not heat the pitot probe properly and this could lead to pitot probe icing in flight with the loss of critical airspeed information without a warning being annunciated.

The Investigation therefore issues a Safety Recommendation to the Manufacturer that the Pitot Heat Indicator System should be addressed in order to provide flight crew with reliable warnings of pitot heater failure as required by the certification specification FAR 25.1326 (b)(2).

2.5 Aircraft Checklists

Activation of the stall warning stickshaker during a final approach, following other unanticipated failures such as the autothrottle and autopilot self-disconnecting, would be particularly disconcerting in the circumstances where the flight crew is aware that an IAS is unreliable, although there is no obvious cause.

While the Manufacturer's QRH contained checklists for both IAS disagreement and airspeed unreliable, the checklists do not contain any caution regarding the known issue of some pitot heater failure modes not resulting in activation of the pitot heater failure warning. Furthermore, no guidance is given regarding further operational consequences that may be the consequence of a faulty airspeed indication, such as spurious stall warnings.

To that extent the Investigation considers that the relevant Manufacturer's QRH checklists should provide guidance for flight crew specifying the systems that might be lost and the possible warnings generated as a consequence of such encounters. This would reduce the uncertainty that pilots face when seemingly unrelated warnings and cascading system losses stem from an un-annunciated failure of a pitot probe heater. Accordingly, it issues a Safety Recommendation recommending that the Manufacturer should consider reviewing the AIRSPEED UNRELIABLE checklist to include such guidance.

3. CONCLUSIONS

(a) Findings

1. During the descent into Riga the Flight Crew noticed that the IAS indications were diverging.
2. The aircraft was stabilised while the situation was assessed.
3. 'IAS DISAGREE' and 'ALT DISAGREE' warnings activated.
4. The pitot probe heaters were on and their failure warning lights were not illuminated.
5. Following evaluation the F/O's airspeed was determined to be giving incorrect information.
6. The right hand engine EEC defaulted into an alternate mode.
7. Following completion of the appropriate checklists the aircraft commenced an approach.
8. During the approach the autothrottle and autopilot unexpectedly disconnected.
9. On selection of flaps and deceleration, the F/O's stickshaker activated. This continued during the final approach and landing.
10. The Flight Crew reported that the noise from the stickshaker was distracting and that it made communications difficult.
11. The Flight Crew were properly licensed with valid medicals.
12. Maintenance found that the F/O's pitot probe heater had shorted.
13. The pitot probe heater failure warning system did not warn of the heater failure.
14. The Operator reported that 20 other pitot probes had suffered un-annunciated pitot heater failures on its fleet of B737-800 aircraft.
15. The pitot probe was installed on the aircraft at manufacture and had completed 23,618 hours operations.
16. The pitot probe had no life limit/time limitation as it was '*on condition*'.
17. The pitot heater failure warning system design did not comply with FAR 25.1326 (b)(2).
18. The FMEA did not fully take account of un-annunciated pitot heater failures and their consequences.
19. The QRH checklists did not provide guidance regarding further failures that were the consequence of a faulty pitot probe heater.

(b) Probable Cause

1. Failure of the First Officer's pitot probe heater.

(c) Contributory Cause(s)

1. Failure of the pitot probe heater warning circuit to detect and annunciate the heater failure.

4. SAFETY RECOMMENDATIONS

No.	It is Recommended that:	Recommendation Ref.
1.	The Federal Aviation Administration (FAA) reviews the Failure Modes and Effects Analysis (FMEA) of the B737NG regarding latent failures of the pitot heat indicator warning system.	IRLD2013029
2.	The Boeing Aircraft Company reviews the B737NG Pitot Heat Indicator System in order to provide flight crew with reliable warnings in the event of a pitot heater failure.	IRLD2013030
3.	The Boeing Aircraft Company B737NG QRH checklists should provide guidance for flight crew specifying the systems that might be affected and the possible warnings generated as a consequence of a pitot failure.	IRLD2013031

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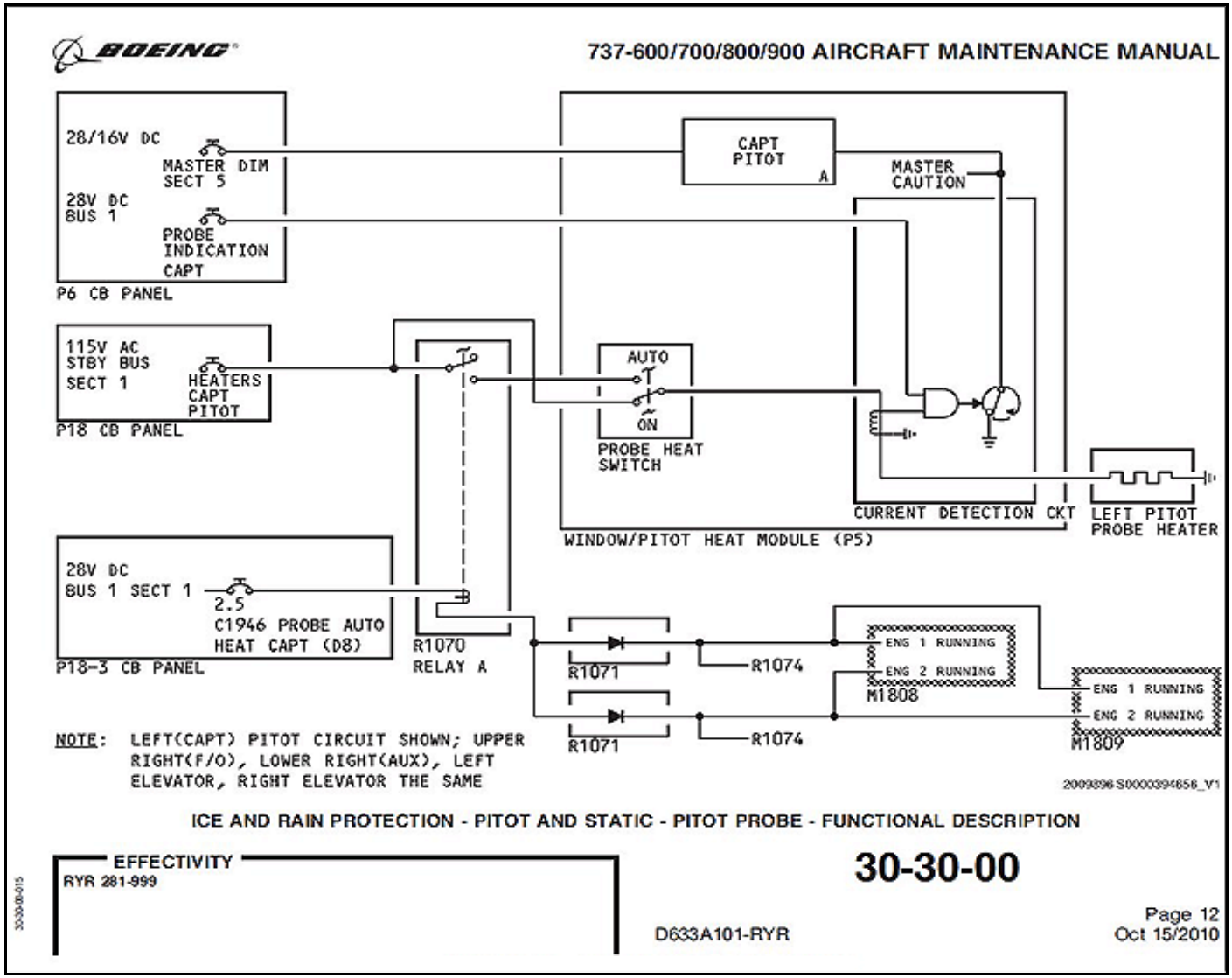
Appendix A



Pitot Probe Electrical Schematic

Appendix B

Rev. B

D218A018-2

Component/ Subassembly Nomenclature	Function	Failure Mode	Flight Phase	Failure Effects		Haz Cls	Failure Detection Method	Compensating Provision	Indication/ Remarks
				System	Airplane				
Probe Heat Control Switch	Enables anti-ice and evaporative heating to the TAT, AOA, and Pitot Probes	Fails to turn on.	ALL	Unable to provide heat to the affected probe(s).	No affect for AOA and Pitot Probes.	IV	P5-9 and Master Caution indication	Redundant AOA and Pitot Probes will provide required data	P5-9 "CAPT PITOT" or "L ELEV PITOT" or "L ALPHA VANE" or "TEMP PROBE" or "F/O PITOT" or "R ELEV PITOT" or "R ALPHA VANE" or "AUX PITOT" and Master Caution Anti-Ice Indicator
Probe Heat Annunciator	Provides indication of probe heater operation	Fails to turn-on and there is a failed probe heater	ALL	Unable to provide heat to the affected probe.	Erroneous data from TAT probe. Redundant AOA and Pitot Probes.	IV	Master Caution indication	Redundant AOA and Pitot Probes will provide required data. Dual lamps in indicator.	Master Caution Anti-Ice Indicator
		Fails on.	ALL	None.	No affect for AOA and Pitot Probes.	IV	P5-9 and Master Caution indication	Redundant AOA and Pitot Probes will provide required data	Master Caution Anti-Ice Indicator
Hazard Classification I - Catastrophic II - Hazardous III - Major IV - Minor	Notes:			LRU Nomenclature - Probe Heater System - Environmental Control System Airplane Model - 737				Date: 3/26/96 Rev A: 1/26/97	

Extract from Table 6.4.3.1, Air Data Sensor Heat System FMEA

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

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