BAe 146-200, G-JEAX

AAIB Bulletin No: 2/2004	**Ref: EW/C2002/12/02/03**	**Category: 1.1**
Aircraft Type and Registration:	BAe 146-200, G-JEAX	
No & Type of Engines:	4 Lycoming ALF502R-5 turbofan engines	
Year of Manufacture:	1989	
Date & Time (UTC):	12 December 2002 at 1309 hrs	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew -5	Passengers - 36
Injuries:	Crew - 2 (Serious)	Passengers - 1 (Minor)
	1 (Minor)	
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	37 years	
Commander's Flying Experience:	5,728 hours (of which 2,778 were on type)	
	Last 90 days - 51 hours	
	Last 28 days - 43 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft was carrying out a scheduled passenger flight from Birmingham to Belfast City. During the climb, it appeared to hunt in pitch more than usual whilst the autopilot was engaged and it seemed to the flight crew that it would fail to maintain FL240, their cleared cruising level. When the autopilot was disconnected, the aircraft pitched up and the elevator control forces to counteract this were found to be very heavy. Nose down trim was applied, which caused the aircraft to pitch down. In an attempt to level the aircraft, both pilots then pulled back on the control columns with considerable force. The controls suddenly freed causing the aircraft to pitch up rapidly, resulting in a large excursion in normal acceleration which caused serious injuries to two cabin crew members.

The investigation determined that the accident was probably caused by icing of the elevator servo tabs, coupled with the crew's response to the situation for which they had not been trained.

There have been a number of previous occurrences of suspected servo tab icing on the BAe 146/RJ aircraft series. This report makes a number of safety recommendations calling for maintenance and inspection actions to reduce the probability of this occurring and for the introduction of an emergency procedure to enable flight crews to respond to such an event in a manner that minimises the risk to the aircraft and its occupants.

Pitch oscillation

There are a number of references within this report to low frequency pitch oscillations. These oscillations had a periodicity of about 12 seconds and were distinct from the higher frequency pitch oscillations of four to six cycles per second, which have been encountered in this aircraft type in the past and for which there is an approved abnormal procedure.

History of the flight

The aircraft had been parked overnight on the apron at Belfast City Airport. At 0200 hrs it was treated with Type II+ anti-icing fluid in preparation for a departure to Birmingham at 0655 hrs. According to the operator, the aircraft had not been de-iced or anti-iced with fluid since the previous winter season. At 0555 hrs the crew reported at Belfast City for a four sector duty, shuttling between Belfast and Birmingham.

The first three sectors proceeded without incident and the aircraft arrived at Birmingham, for the second time, at 1145 hrs. The aircraft remained on stand at Birmingham for 55 minutes. During this period a mixture of rain, sleet and snow fell. The commander and co-pilot discussed the need to de-ice the aircraft but, together, decided that the snow and sleet were not settling on the visible parts of their aircraft or neighbouring aircraft. (There is a record of one aircraft belonging to another operator being de-iced during the early part of the time that G-JEAX was parked on stand, and in the hour after G-JEAX took off a number of aircraft were de-iced.) The aircraft pushed back off the stand at 1240 hrs. During the full and free check of the flight controls, prior to takeoff, the control column was held fully back for about 25 seconds to allow any water to drain from within the elevator. This was in accordance with a company operating procedure introduced in a Notice to Aircrew, which was valid for six months until 15 October 2002 but had not been superseded before this accident.

The aircraft took off at 1252 hrs and followed the Whitegate 3E Standard Instrument Departure. (The previous aircraft departure from Birmingham had been at 1229 hrs and the next was at 1305 hrs. Neither of these aircraft were included in the records of those aircraft, mentioned earlier, which had been de-iced.) The commander flew the aircraft manually until it had reached approximately 3,000 feet altitude whereupon he engaged the autopilot. ATC instructions enabled the crew to maintain a continuous climb and they activated the aircraft's anti-icing and de-icing systems as appropriate. The crew were not aware of any significant accumulations of ice during the climb and the aircraft cleared the tops of the clouds at about 18,000 feet altitude.

During the climb, the flight crew noticed that the aircraft was hunting in pitch more than was customary. Minor, low frequency pitch oscillations with the autopilot engaged are not an unusual feature of the aircraft type but the oscillations on this aircraft were unusually pronounced on this sector. Investigation by the commander revealed that the low frequency oscillations were more apparent when the vertical profile was maintained using the autopilot vertical speed or speed modes, rather than pitch mode. The autopilot remained engaged for most of the climb. It was briefly disengaged early in the climb and twice when the aircraft was above Flight Level (FL) 200. The flight crew reported that it was re-engaged before the aircraft approached its final cleared level of FL240. They did not recall seeing any autopilot or pitch trim system fault indications at any time.

The flight crew reported receiving the normal visual and aural 'alerts' in the final 1,000 feet of the climb, but stated that the aircraft did not level off at FL240. Instead it appeared to pitch more nose-up and continued to climb. The commander disengaged the autopilot whereupon he was immediately aware of a strong pitch-up tendency. He applied increasing forward pressure on the control column and supplemented this with electric elevator trim using his control wheel mounted thumb switches. At FL242 the aircraft pitched down at a marked rate. Having pitched to below the straight and level attitude, the commander then tried to counter this with a progressive rearwards force on the controls. He described the feel of the control forces as very heavy but did not regard the controls as jammed. Unable to arrest the aircraft's rate of descent, the commander instructed the co-pilot to assist him on the controls. They both pulled back with considerable force. The control columns suddenly moved aft, the aircraft pitched up and the flight crew felt a violent shudder through the whole airframe that lasted for two or three seconds. After this, the crew stated that the control forces returned to normal and they were able to level the aircraft at FL240. During the pitching manoeuvres, two of the three cabin crew had fallen in the cabin aisle. One had sustained a broken leg and the other had a suspected sprained ankle; this latter injury was subsequently diagnosed as a fracture. The third cabin attendant and a passenger, who were both seated, had suffered minor head injuries. Two doctors, who were among the passengers, attended the cabin attendant with the broken leg.

The crew transmitted a PAN call, requesting gentle turns and a continuous shallow descent. Control of the aircraft was handed to the co-pilot while the commander managed the aftermath of the event. At 10 nm on final approach to Belfast City Airport the commander resumed control of the aircraft. The landing on Runway 04 was completed without further incident and the aircraft was met by the Emergency Services.

From the time that the crew felt the control forces return to normal at FL240 the aircraft had been flown manually. Both pilots described the control forces and aircraft response as normal for the remainder of the flight.

Despite the manoeuvres, the aircraft did not deviate sufficiently from its cleared flight level to constitute a 'level bust'.

Pitch control system

The BAe/Avro 146/RJ series aircraft possess manually operated elevators with mechanical control circuits which operate the left and right elevators independently (see Figure 1). Control column inputs are transmitted via cables, pulleys and rods to a servo tab mounted on each elevator, which provides aerodynamic force to move the elevator. Torsion bars on the inputs to the tabs limit the aerodynamic forces that can be applied to the tabs. If sufficient control force is applied, the torsion bars will contact stops and the control columns will then move the elevators directly, with significantly higher control forces required. A mechanical elevator feel system provides artificial feel which helps prevent excessive control deflection at high speed.

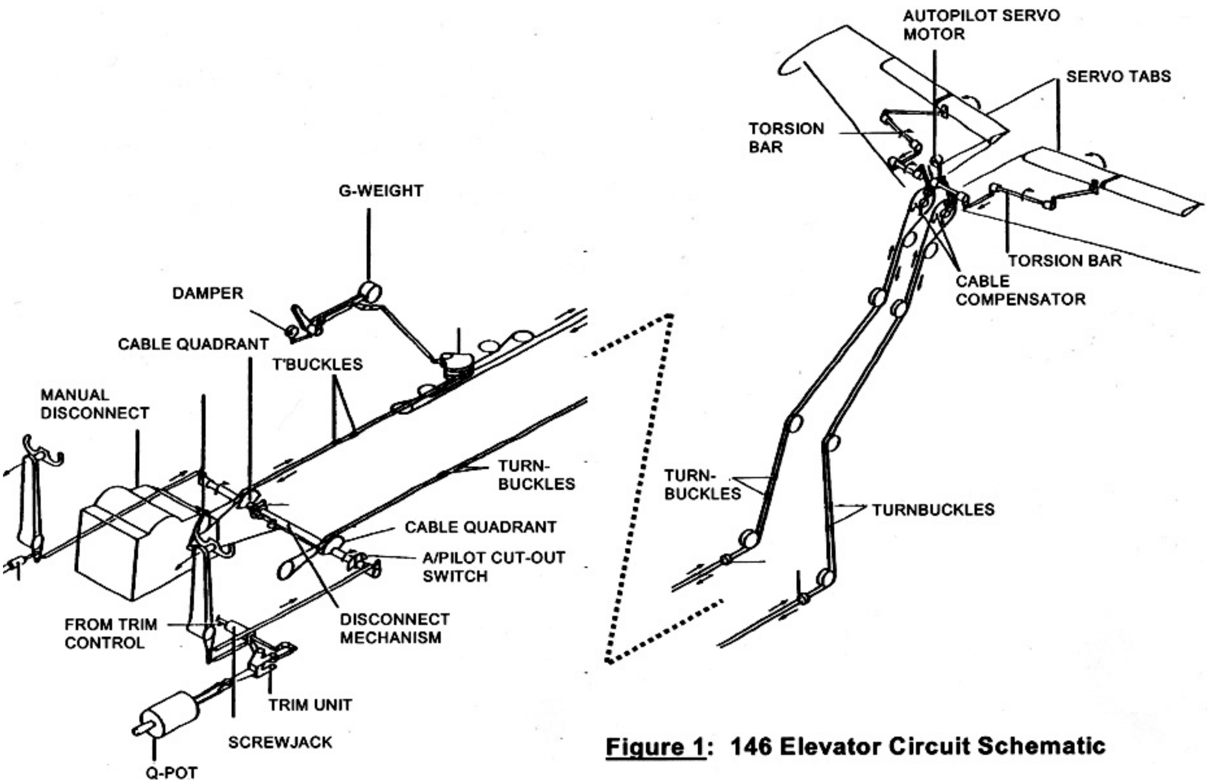


Figure 1: 146 Elevator Circuit Schematic

The two control columns are interconnected such that in normal operation, movement of either control column operates both servo tabs and thus both elevators. A manually-operated disconnect device allows the control columns to be mechanically isolated from each other in the event of a jam occurring in either elevator control circuit. Operation of the elevator manual disconnect handle will allow the pilot on the non-jammed side to retain control of the elevator on that side.

The elevators sit in the trailing edge up position when the aircraft is parked as a result of the control mass balance. The elevators, the servo tabs and the trim tabs have numerous drain holes to allow any accumulated water within the control surfaces to drain out. The gaps between the elevator and the servo and trim tabs are by design, quite small (approximately 5 mm).

Pitch trim is effected by means of a trim tab on each elevator. The trim tabs are connected to trim screw jacks, which receive manual, electric or autotrim (trimming signalled by the autopilot) pitch trim inputs via a trim torque shaft and a series of cables and pulleys. Manual trim inputs may be made using trim hand wheels mounted on the centre console. The hand wheels are connected by chain drives to the trim torque shaft. Electric trim is operated via thumb switches on the control wheels. These command the autotrim servomotor to trim at a fixed speed in the selected direction. The servomotor is connected to the trim torque shaft and backdrives the hand wheels.

Autotrim is provided whenever the autopilot is engaged, to relieve any steady load being held by the autopilot pitch servomotor and to ensure that the pitch axis of the aircraft is in trim when the autopilot is disengaged. The autotrim servomotor is automatically commanded to re-trim the aircraft when the pitch servomotor current duration exceeds a threshold of 1.5 seconds. The trim rate in autotrim is slower than that for manual electric trim. Autotrim system malfunctions (eg a failure to trim when commanded or trimming in the wrong direction) are detected by monitors that illuminate the 'EL TRIM' legend on the mode annunciator panels on the instrument panel.

Meteorological conditions

The synoptic situation at 1200 hrs showed high pressure centred over Norway with a light south-easterly flow over the route between Birmingham and Belfast. Frontal systems affected the southern half of the UK producing a mixture of rain and snow over the Midlands. This precipitation was falling from multiple layers of cloud, which had a base at about 1,000 feet. The UK Low Level Forecast for the route warned of severe icing in freezing rain and moderate icing in cloud.

The METARs for Birmingham Airport for the periods when G-JEAX was on the ground were:

0750Z 06007KT 4500 BR OVC010 01/M01 Q1017=

0820Z 05007KT 3300 DZ OVC009 01/M01 Q1017 RERA=

0850Z 05006KT 3400 DZ OVC009 01/M01 Q1017=

1150Z 06006KT 010V080 2100 -RASN SCT008 BKN009 01/M00 Q1017=

1220Z 05005KT 1600 R15/1400 -SN SCT008 BKN009 01/M00 Q1017=

1250Z 05004KT 1700 -SN FEW007 SCT008 BKN010 00/M00 Q1017=

1320Z 04005KT 1500 R15/P1500 R33/P1500 -SN FEW007 BKN009 00/M00 Q1017=

1350Z 05005KT 1700 -PE FEW005 BKN008 00/M00 Q1017=

The METARs for Belfast City Airport when G-JEAX was on the ground there were:

0620Z 09010KT 9999 FEW019 SCT030 BKN130 04/01 Q1018=

0650Z 09009KT 9999 FEW019 SCT030 04/00 Q1018=

1020Z 08010KT 9999 BKN024 04/00 Q1018=

1050Z 08011KT 9999 SCT025 BKN093 04/00 Q1018=

Note: METARS take the following form:

Observation time in UTC (eg 0750Z); wind direction and speed (eg 06007 = direction 060° at 07 kt); visibility in metres (R15/1400 = Runway 15/ touch down zone runway visual range = 1400 metres, and P1500 = greater than 1500 metres); weather code (eg BR =mist DZ=drizzle RASN=rain and snow PE = ice pellets), cloud cover (eg OVC=overcast BKN=broken SCT=scattered); cloud base above the surface in hundreds of feet (eg 008=800 feet); air temperature and dew point (eg 01/M01 = temp +1° dew point -1°) and altimeter pressure setting for altitude (eg Q1018 = QNH 1018 Hpa).

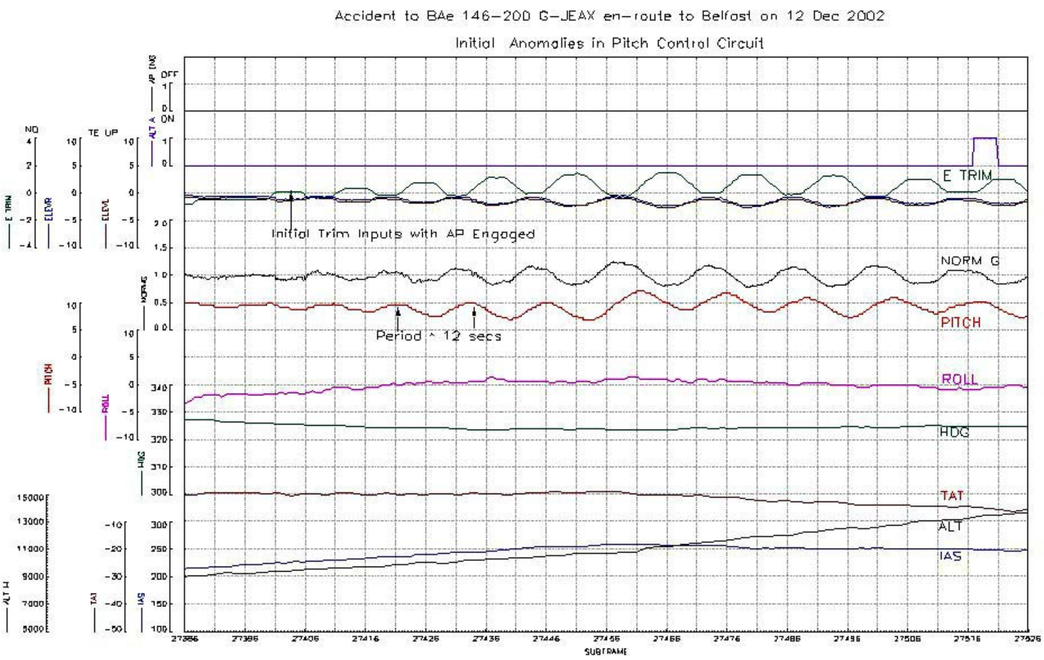
Cockpit Voice Recorder

The aircraft was fitted with an A100 Cockpit Voice Recorder (CVR) which recorded the commander's, co-pilot's and cockpit area microphones on a continuous 30-minute loop when electrical power was applied. Unfortunately, the sound recordings of the accident sequence had been over-written by the time the aircraft had been shut down at Belfast.

Flight Data Recorder information

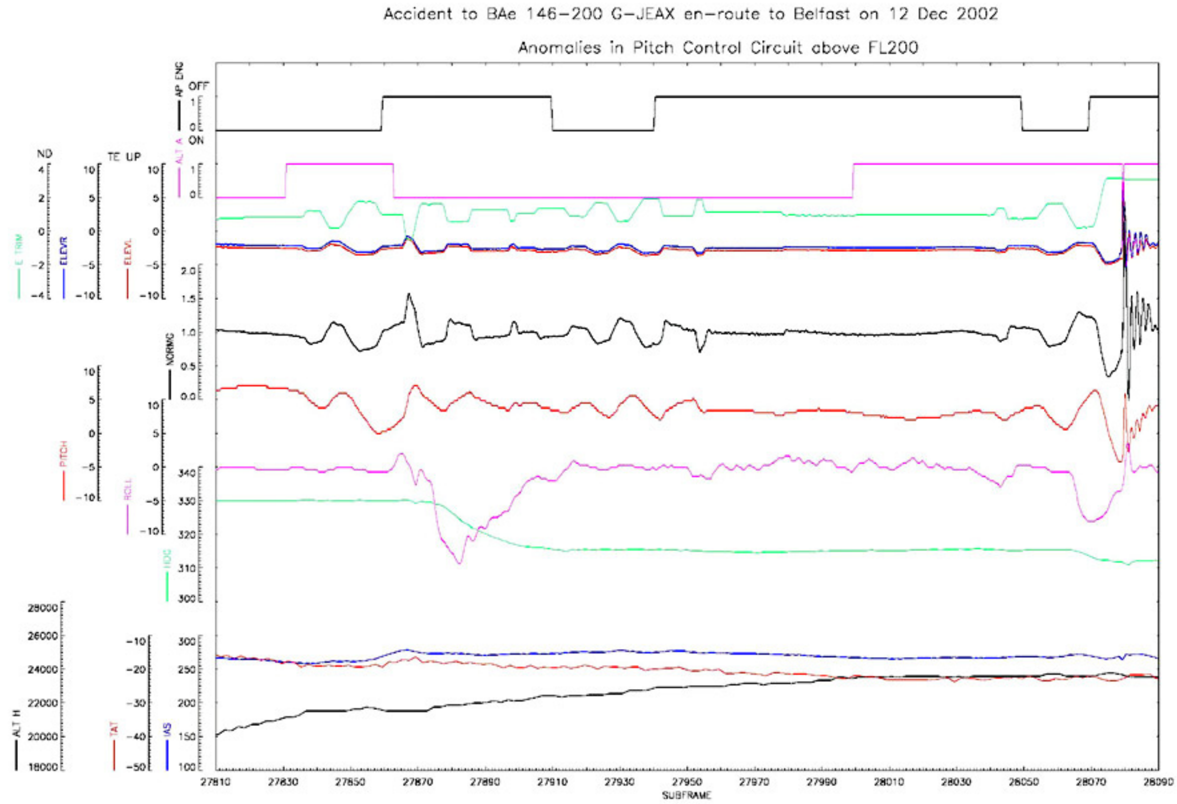
The aircraft was fitted with a Plessey 1584 Flight Data Recorder (FDR) which recorded about 60 parameters on a 25-hour continuous loop.   All the data were recovered from the FDR, although there were data dropouts throughout the recording. Nevertheless, it was possible to extract all the relevant parameters at the time of the accident.

A time history of the relevant parameters during the climb to FL140 is shown in Figure 2. The 'E TRIM' parameter indicates the elevator trim tab position. It can be seen that, with the autopilot engaged, the elevator trim started to provide trim inputs to the pitch control system on a 12 to 15 second cycle beginning at about FL90. The elevators appeared to respond correctly to the applied trim, and the aircraft also responded in the conventional sense, describing a 'phugoid' motion also of period 12 to 15 seconds.



The Total Air Temperature (TAT) at which the trim started to operate was about +1° C. At the prevailing flight conditions, this equates to an Outside Air Temperature (OAT) of about minus 8° C. The cyclic trim inputs appear to be present throughout those climb phases where the autopilot was engaged, but not when the autopilot was disengaged.

A time history of events which took place during the climb between FL200 and FL242 is presented in Figure 3.



This graph illustrates differences in the aircraft's behaviour with the autopilot engaged and disengaged. An expanded view of the pitch upset event is presented in Figure 4.

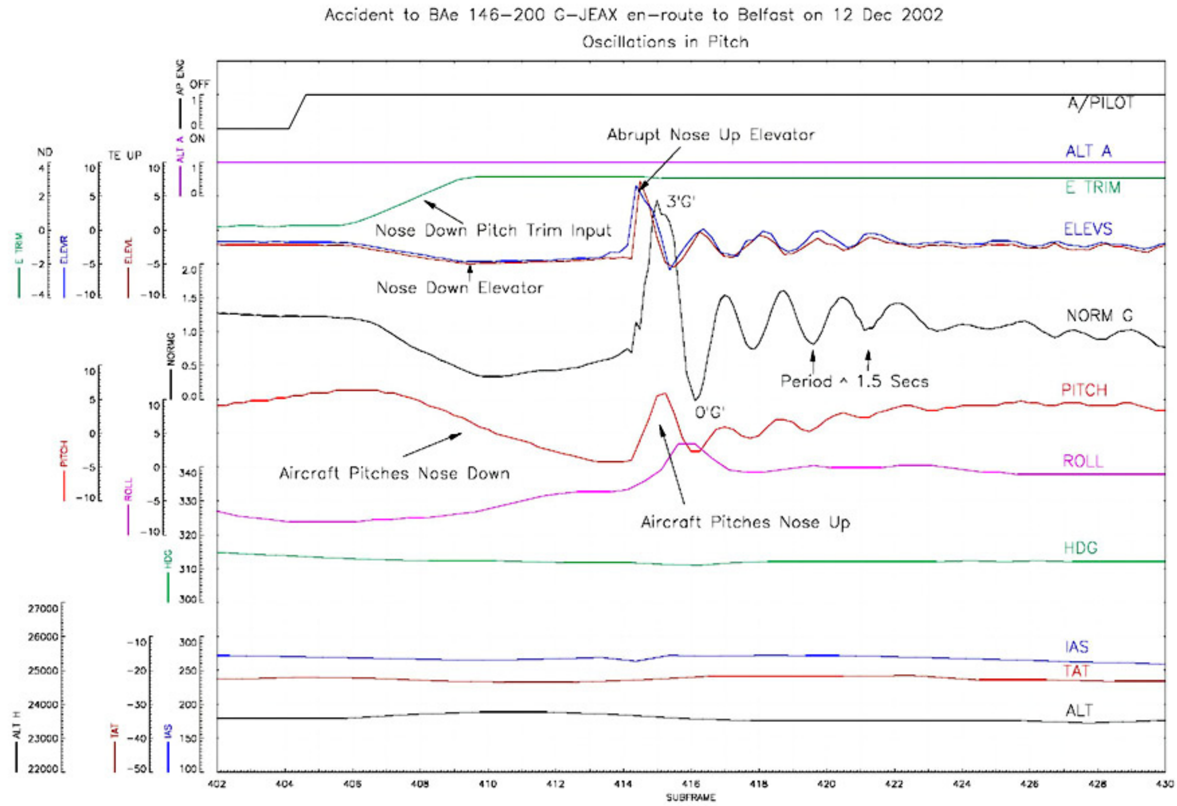
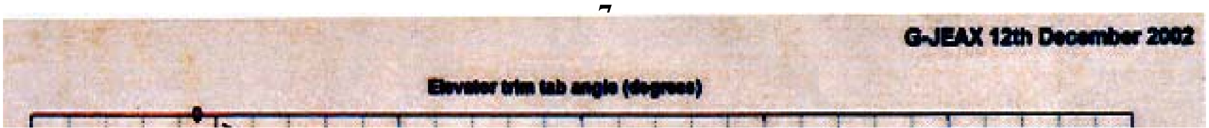


Figure 5 shows a graph of the relationship between the trim tab angle and the mean elevator angle at various points in the accident flight, as compared with previous flights. This graph was prepared by the aircraft manufacturer using the FDR data.



The aircraft was inspected by the AAIB at Belfast City Airport on the morning after the accident, with the assistance of a technical representative from the aircraft manufacturer. A visual inspection of the pitch control system did not highlight any defects and no evidence was found of foreign objects having interfered with the controls. The elevator full and free checks were also normal. Functional checks of the autopilot and pitch trim systems were completed satisfactorily. Notwithstanding these results, as a precaution, the autopilot computer, electric trim switches, trim screwjacks, autotrim servomotor, and autopilot control panel were removed and returned to their manufacturers for testing.

The elevator trim and servo tabs were inspected with the access panels removed. Drops of de-icing fluid residue were found on the left-hand elevator trim jack and on the right-hand elevator gust damper. Small amounts of de-icing fluid gel were observed in the crevices formed between the top and bottom skins of the elevator and its rear face. Samples of this gel were collected for analysis.

Dried out residues of de-icing fluid were also found on the surfaces in the gaps between the servo and trim tabs and the back of the elevator. When a light water mist was sprayed onto these residues, a thin layer of a gel-like substance gradually formed on the surfaces as the deposits slowly rehydrated. There was insufficient of this contaminant to collect for analysis.

Whilst examining the elevators, it was observed that the bearings in the operating rods that connect to the tabs did not show any visible signs of the presence of grease. The bearings were therefore removed for further examination and testing.

Precautionary structural inspections were carried out in accordance with the airframe manufacturers' recommendations, but these did not highlight any airframe damage. After completion of the inspections the aircraft was returned to revenue service, with no further reports of pitch control problems.

Servo tab bearings

The servo tab operating rods are connected to the underside of the tabs. The bearings on the ends of the rods are of the ball-race type and are sealed for life. They are packed with grease during manufacture and have no provision for re-greasing. The grease is retained by teflon seals, which also serve to protect the bearing from the ingress of moisture and dust.

The left-hand servo tab rod-end bearing was examined at the AAIB; the right-hand bearing was sent to the aircraft manufacturer for more detailed examination.

On preliminary examination, it was noted that the servo tab rod end bearings were stiff to rotate and felt 'notchy'. The outer race of the left-hand tab bearing was sectioned to allow the bearing to be disassembled. It was immediately evident that there was no grease present in the bearing. A brown, powdery residue was visible on the surfaces of the inner and outer races and on the ball bearings (Figure 6). The lack of grease was a matter for concern, given that the grease seals were found to be in good condition.

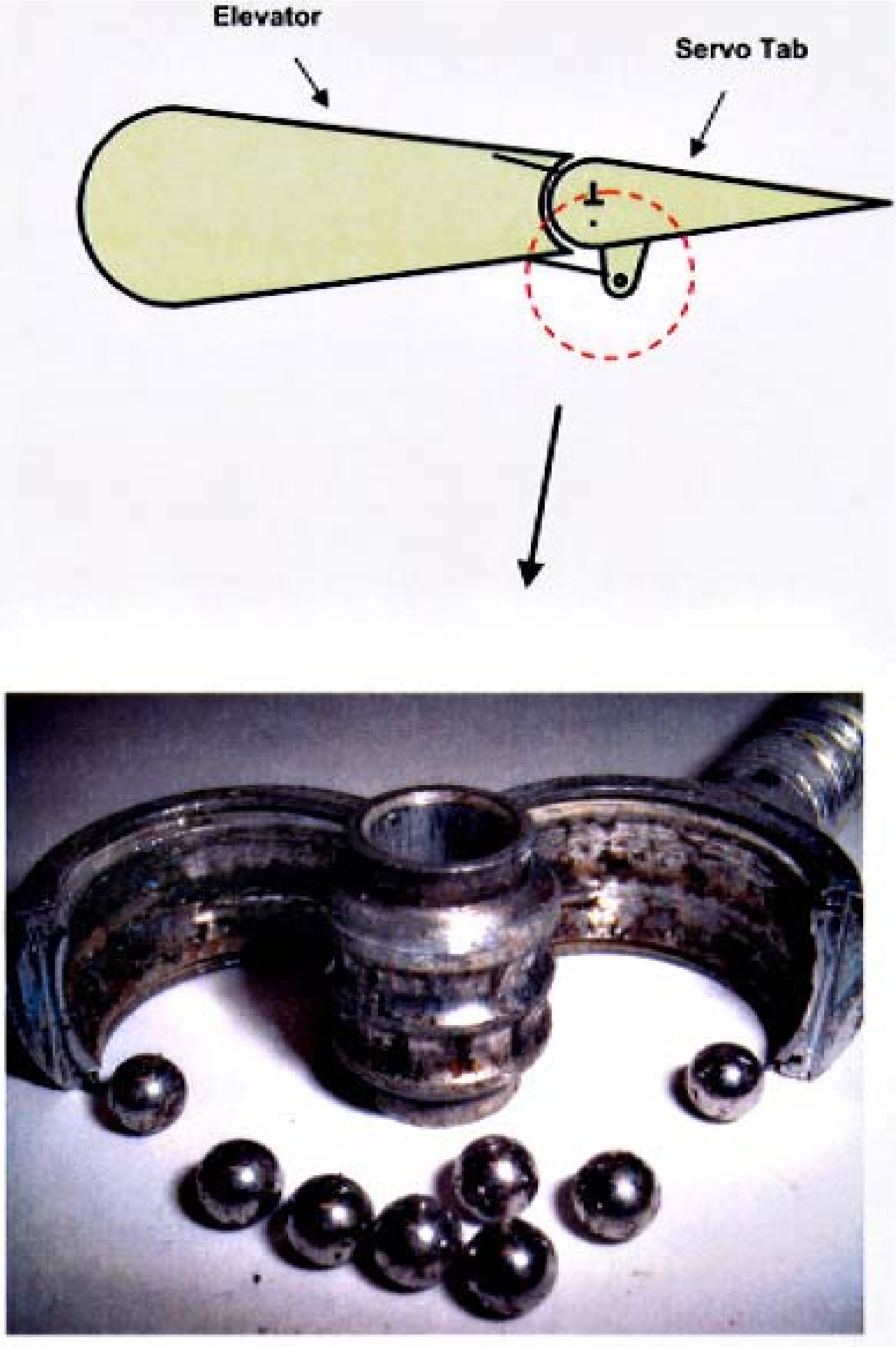


Figure 6: Sectioned Left-Hand Servo Tab Rod End Bearing

The grease seals on the right-hand servo tab bearing were also in good condition, but the bearing was completely lacking in grease, containing the same powdery residue as the left-hand bearing. Chemical analysis of the residue by the aircraft manufacturer showed that its properties were consistent with those of a clay-thickened grease such as Aeroshell 7.

These bearings are 'on-condition' items and there is no requirement in the aircraft maintenance programme for the bearings to be sampled for inspection. The bearings from G-JEAX are believed to be the original bearings that were installed during the aircraft's construction in 1989.

Component testing

The tests on the autopilot and trim system components removed following the incident did not identify any significant defects in any of the components and thus they could be ruled out as contributory factors.

Testing of de-icing fluid residue

The sample of de-icing fluid residue collected from the gap between the elevators and the servo tabs was tested in a laboratory. The refractive index of the gel sample was measured to be 1.377, which corresponds approximately to that of a 75% Type II de-icing fluid mixture, which would be expected to freeze at around minus 21°C. A sample of the gel did not freeze when placed for 30 minutes in a freezer at minus 18°C.

Properties of de-icing fluids

Different types of aircraft de-icing fluids are available that possess specific properties and are used in various applications. One particular property known as 'holdover time' is important to operators in that it represents the elapsed time between fluid application and it losing its effectiveness. All the fluids are expected to flow off the aircraft's treated surfaces during takeoff.

ISO Type 1 fluid (to specification SAE AMS 1424A) is an 'unthickened' fluid that has a high glycol content and low viscosity in its concentrated form. It forms a thin, liquid wetting film which provides limited holdover time especially in conditions of freezing precipitation. It is predominantly used for removing frozen deposits from aircraft surfaces, either as the first step in a two-step de-icing and anti-icing process, or where precipitation has stopped.

ISO Type II and Type IV fluids (to specification SAE AMS 1428A) are known as 'thickened' fluids. These fluids have a lower glycol content and contain a pseudoplastic thickening agent, which enables the fluid to form a thicker layer over the aircraft surfaces, providing longer holdover times. It is designed to shear off during the take-off roll, leaving the critical surfaces free of contamination. In practice however, the fluid may not completely shear off in areas where the local airflow velocity is reduced, such as the trailing edges of the wings and stabilisers and it may also collect in the aerodynamically quiet areas in the control gaps. Type II+ fluid is now becoming more frequently used. It is a new branded fluid of the same standard as Type II, except that it offers improved holdover properties due to its higher viscosity. Type IV fluids provide the best holdover properties, having the greatest viscosity.

Type I Fluids are not commonly used in Europe, due to the limited holdover times that they provide. The limited holdover capability drove the development and introduction of thickened fluids with improved holdover properties and it is these that are most widely used by European operators.

Industry experience showed that following the introduction of the Type II and in particular, the higher viscosity Type IV thickened fluids, problems were experienced by operators of aircraft with non-powered flying controls. The problems were due to the accumulation of residues of thickened de-icing fluid in the aerodynamically quiet areas of the controls. It was found that the glycol in the fluid evaporates, leaving a residue comprised largely of the thickening agent, which then dries out. This residue is not washed away by repeated applications of fluid, but instead tends to accumulate in increasing quantities, due to the high viscosity of the fluid. The residues are hygroscopic and when exposed to precipitation, they re-hydrate and can swell to several times their original volume. With their low glycol content, the residues can freeze with the potential for causing serious control restrictions on aircraft with non-powered flying controls. The problem is particularly prevalent with the Type IV fluids and this led to the JAA (Joint Aviation Authorities) drafting an Operations Directive to discourage the use of such fluids on aircraft with non-powered flight controls. The problem can also occur with the Type II fluids, and the use of Type II+ fluid is becoming more widespread.

AAIB Report EW/C2003/03/01 in Bulletin 12/2003 reports on an incident to a DHC-8 aircraft on 2 March 2003, which experienced heavy elevator controls. The problem was believed to have been caused by an elevator spring tab becoming jammed due to the freezing of re-hydrated residues of Type II de-icing fluid. There are several other documented incidents of pitch control problems on other aircraft types, including the BAe 146/RJ and DC-9/MD80 series, which were attributed to the build up of de-icing fluid residues around control surfaces.

Industry guidelines on de-icing fluid residues

The Association of European Airlines (AEA) document entitled 'Recommendations for De-Icing/Anti-Icing of Aircraft on the Ground' is generally accepted by European airlines to be the definitive guidance document on ground de-icing/anti-icing practices. It includes the following caution regarding de-icing fluid residues:-

'3.8.3.1.2 Application Limits

'CAUTION: The repeated application of Type II or Type IV fluid may cause residues to collect in aerodynamically quiet areas, cavities and gaps. The application of hot water or heated Type I fluid in the first step of the de-icing/anti-icing process may minimise the formation of residues.'

The UK CAA's concerns were transmitted in a Letter to Owners/Operators (LTO) No 2121, dated 13 November 2000. This was superseded by CAA Aeronautical Information Circular AIC 81/2001, dated 15 November 2001, which provided operators with the following information regarding the effects of de-icing fluid residues:-

'11 Pre-flight Inspections

11.2 Repetitive application of thickened fluid (SAE AMS 1428) may lead to a build up of residues in aerodynamically quiet areas such as balance bays, and on wing and stabiliser trailing edges and rear spars. This residue may re-hydrate and increase in volume to many times its original size during flight and freeze under conditions of certain temperature, high humidity and/or rain causing moving parts such as elevators, ailerons, and flap actuating mechanisms to jam in flight. It may also form on exterior surfaces which can reduce lift and increase drag and stall speed, block or impede critical flight control systems, and cause aerials to malfunction.

11.3 Residues may also collect in hidden areas, around flight control hinges, pulleys on cables and in gaps, and inside flight controls affecting water drainage and control balance.

11.4 Additional inspections may therefore be required to ensure that no build-up of residues has occurred in critical areas not visible from the ground. The operator should request guidance/instructions from the aeroplane manufacturer in order to establish satisfactory procedures to prevent, detect and remove residues of dried fluid with the potential to cause any of the problems described above. Appropriate inspection intervals should be established.

11.5 Operators should consider defining a policy on the use of two-step de/anti-icing procedures preferably using hot water or unthickened fluids in the first step. Fluid selection should be based on dry-out and re-hydration data supplied by manufacturers. Appropriate operational and maintenance/handling procedures should be established.

11.6 Information and training should be provided for in-house and contractors staff. This should include appropriate flight safety information.

Note: This paragraph implements the recommendations of JAA Operational Directive OST 01-3 dated 19 July 2001.'

The aircraft manufacturer provided advice on several occasions to BAe 146/RJ aircraft series operators on the dangers of residues from thickened de-icing fluids, together with recommendations that the operators regularly inspect for the build up of such residues and remove them at suitable intervals. This information was included the following documents:-

- Service Information Letter (SIL) 27/74 for the BAe 146 and Avro 146-RJ;
- All Operator Messages (AOMs) 98/018V, 98/009V, 99/023V, 99/004V and 99/002V for the BAe146 and Avro 146-RJ;
- AOM 00/31V issued in December 2000, for operators of all BAE Systems Regional Aircraft types.

De-icing/Anti-icing Practices

Due to the limited availability of Type I fluid, aircraft in Europe are usually de-iced and anti-iced in a single-step process with mixtures of Type II or Type IV fluid. In the United States and Canada, it is understood that the use of a two-step process of de-icing/anti icing is more commonly used. The first step uses either hot water or a mixture of hot water and Type I de-icing fluid, to remove accumulations of snow and ice from the airframe. The second step involves the application of a thin layer of Type II or Type IV fluid for anti-ice protection. This practice is preferable to the single step process, as the application of hot water or Type I fluid helps to wash off any residues of thickened fluid, thus preventing a build-up of residues. The two-step process avoids successive applications of thickened de-icing fluid and the problems that this causes. There have been few reports of problems in the United States and Canada of control restrictions caused by de-icing fluid residues and this may owe much to the common use there of a two-step de/anti-icing process. The two-step process is described in detail in the aforementioned AEA 'Recommendations for De-Icing/Anti-Icing of Aircraft on the Ground' guidance document.

The operator of G-JEAX had adopted the practice of anti-icing aircraft overnight using a 100% concentration of Type II+ fluid. This procedure is referred to in Section 3.8.2.2 of the AEA guidance document and, in conditions of hoar frost formation, has the advantage of removing the need to de-ice the aircraft before an early morning departure. Nevertheless, some operators have abandoned this practice, having discovered that it may encourage the build-up of thickened de-icing fluid residues in the gaps between the flying controls. Shortly after the accident, the aircraft manufacturer issued a notice to the operator of G-JEAX advising them of these concerns, after which the operator immediately stopped anti-icing and reverted to de-icing its fleet.

Whilst CAA AIC 81/2001 recommends that operators consider adopting a two-step de-/anti-icing process, this relies on the availability of Type 1 fluids. (If the OAT is above -3°C, hot water may be used for the first step, but below this temperature the use of a hot mixture of Type 1 fluid and water is recommended in the AEA guidelines.) Unless airport operators and de-icing contractors in Europe stock supplies of Type I fluids, airlines would appear to have little option but to continue with the single-step application of Type II and Type IV fluids for de/anti-icing.

The implications are that the threat of problems caused by the build-up of residues of thickened de-icing fluids is likely to remain, making it imperative that operators rigorously inspect for these residues and remove them as necessary.

Cleaning of De-icing Fluid Residues

The AEA recommendations, the CAA AIC 81/2001 document and the various publications issued by aircraft manufacturers over the years all recommend that airlines adopt procedures for detecting and removing de-icing fluid residues. Enquiries by the AAIB indicate that this advice has not been universally implemented by airlines within the United Kingdom. It was apparent that the airworthiness implications of the presence of the de-icing fluid residues were not always fully understood and the task of inspecting for residues was often loosely controlled. In some cases the operators assumed that cosmetic washing of the aircraft would be sufficient to remove the residues and thus they had no specific inspection or cleaning program for de-icing fluid residues. This situation was also highlighted in the aforementioned AAIB Bulletin Report EW/C2003/03/01 concerning the DHC-8 incident.

Other Operators Experience

The AAIB visited a continental European airline that operates a large fleet of BAe 146/RJ series aircraft to learn of their experiences of winter operation of the aircraft type. The operator pointed out that because unthickened (Type I) de-icing fluids are not widely available at airports within Europe, they have no option but to use the thickened fluids. It transpired that the operator had considerable experience of pitch control problems that had prompted it to take positive action to deal with the issue.

Some of the events experienced were attributed to the accumulation of residues of Type II and Type IV thickened de-icing fluids in the elevator/servo tab gaps. In response to this, the operator introduced a rigorous programme of cleaning the control surfaces after every six applications of Type II fluid and after every four applications of Type IV fluid. This cleaning programme is controlled by the airline's engineering department, through monitoring the number of applications of thickened fluid as recorded in the aircraft technical log and raising a work requirement as necessary for the control surfaces to be cleaned. The task involves removal of the de-icing fluid residues by hand, using brushes, and is carried out by contract maintenance personnel, as opposed to cleaning contractors. Since introducing this procedure, the number of occurrences of elevator control problems experienced by the operator has significantly decreased.

Other cases of pitch control restriction experienced by the operator were determined to have been caused by the accumulation of snow or ice in the gaps between the servo tab and the elevator. This, they believed, could occur when the aircraft was exposed to rain or snow prior to departure in near freezing conditions. On 5 February 2003 aircraft OO-DJG, that had been briefly exposed to rain prior to departure, suffered from extremely heavy elevator controls in flight. Large accumulations of ice were found in the elevator gaps after the aircraft had landed. (See Figure 7.)

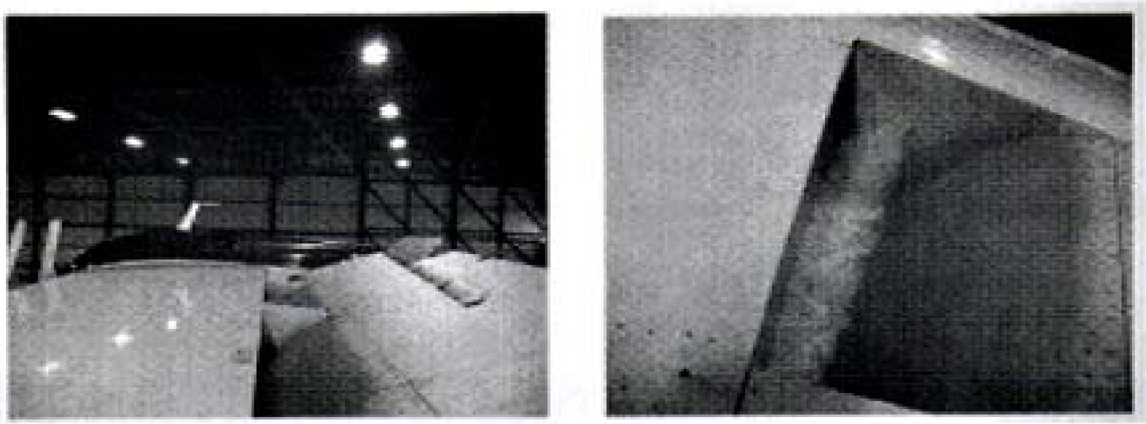


Figure 7: Elevator in parked position and illustration of hail accumulation

The operator commented that the fact that the elevators sit trailing edge up when the aircraft is parked might encourage the accumulation of precipitation in the gaps, which can partially melt, and then re-freeze in flight, leading to pitch control problems. In their experience, the problem could also occur when the aircraft was exposed to hail prior to departure, so that the control freezing problem is not restricted to the winter period. The operator has introduced a specific inspection on the flight crew walk-round inspection. In daylight, crews check for an undisturbed line of sky within the elevator and tab gaps, on the premise that any precipitation in the gaps will refract the light, producing a visible discontinuity in the line. In darkness, one pilot moves the elevator whilst the other looks for precipitation falling through the gaps.

The operators' flight safety department communicated these issues to its flight crews by internal flight safety bulletins and also provided advice to draw their attention to the symptoms of elevator servo tab freezing, with suggestions on the actions to be taken in such an event.

Another European operator of Avro RJ85/100 aircraft has incorporated a specific engineering task in the aircraft maintenance programme during the winter period, to inspect the flying control surfaces every 28 days the for build-up of de-icing fluid residues. Any such residues are removed with Type I fluid or, if this is unavailable, with warm water and a brush.

Previous comparable events

Data provided by the UK CAA, the aircraft manufacturer and other operators dating back many years show that there have been several previous occurrences with symptoms similar to the G-JEAX event, although the outcome in those cases was less dramatic. Table 1 provides a listing of some of these events.

DATE	A/C TAIL NO.	DETAILS OF INCIDENT	CREW ACTION	DE-ICE FLUID RESIDUES FOUND?	PRECIPITATION PRIOR TO TAKEOFF?
02/04/03	HB-IXN	Inability to operate pitch trim.	Emergency declared, flapless landing performed to avoid trim changes.	Yes - on trim jacks	Not known
02/03/03	N/K	When levelling at FL270, a/c overshot by 150' and hunted in pitch at +/-400 ft/min, w/ erratic trim wheel movements. When A/P disconnected both elevators and ailerons were frozen.	A/c slowed was from 265 to 250 kts. Pitch hunting damped out. A/c continued to destination which was warmer and controls unfroze passing freezing level in descent.	Yes - large quantities	Considerable rain prior to departure.
06/02/03	OO-DJG	During alt capture pitch oscillations +/-2000ft/min w/ ELEC TRIM amber light. When A/P disconnected, elevator force was reportedly 'huge'.	A/P disconnected. A/c controlled using manual trim. Flap 24 approach flown using manual trim control.	No, ice found in elevator tab gaps	Rain showers prior to departure.
12/12/02	G-JEAX	Slow pitch oscillations in climb w/ A/P engaged. A/c began to pitch up after levelling at cleared level FL240. When A/P disengaged, elevator control was extremely heavy.	Both crew applied considerable force to control columns, causing trim tab to break out and causing a/c to shudder & large excursions in vertical acceleration. 2 cabin crew seriously injured. Elevator forces subsequently returned to normal.	Yes - v. small amounts, when tested did not freeze at -18C.	Rain, sleet and snow prior to departure. Elevator draining procedure used.
20/4/01	OO-DJN	High amplitude oscillations at FL100 with A/P and A/T engaged. Elevator unfroze @FL80, 15 mins prior to landing.	A/P and A/T disengaged, a/c flown manually to destination where temperature was higher. SEAT BELT light kept on to avoid c.g. changes.	Not known	OAT +4, T/S rain and hail prior to departure. Elevator draining procedure used.
20/4/01	OO-DJS	A/c exceeded cleared altitude of FL120 and continued to climb to FL130 due to frozen elevator. Elevator control regained at 4000ft.	A/P and A/T disengaged, speed was reduced to 250 then 210 kts, airframe anti-ice operated.	Not known	Very heavy rain prior to departure. Elevator draining procedure used.
20/4/01	OO-DWA	Elevator jammed during climb. A/c was being flown manually at climb speed of 250kts. When A/P and A/T engaged, a/c entered uncommanded climb of 4000 ft/min.	A/P disengaged, elevator control v. heavy on both sides. Captain tried to level off very slowly with a very heavy vibration. Speed reduced to 230 kts, controls were OK during the approach.	Not known	Not known
02/03/01	OO-DWJ	Pitch control very stiff. On inspection after landing, maintenance crews found ice on elevators and elevator tabs. A/c was not de-iced prior to departure.	Not known	No, ice found in elevator tab gaps	Light snow in early morning prior to departure.
24/2/01	OO-DWK	A/c oscillated in pitch in climb and cruise. Oscillations stopped after A/P disengaged and then re-engaged, but returned after 20 mins.	Not known	De-iced same day w/ Type IV. Ice found in elevator gaps after landing.	Not known
23/2/01	OO-DJP	During climb with A/P on, LVL CHG selected. ROC between 500 and 3700 ft/min. When A/P disconnected during approach, a/c was difficult to control in pitch. Strong shock felt in controls.	A/c was not de-iced prior to departure.	No. Large amount of snow found trapped in elevator/tab gaps.	Heavy hailstorm during a/c turn-round
27/12/00	OO-MJE	A/c was de-iced w/ Type IV fluid before takeoff in BRU. Flew to MRS without problems. Pitch oscillations experienced with A/P engaged and pitching up in ALT HOLD on return leg to BRU.	When inspected after incident horizontal stab and elevator found coated in de-icing fluid. Fluid was also coming out of elevator drain holes.	Yes	Not known
07/02/00	G-DEFL	A/P failed to capture selected altitude as a/c descended into icing conditions.	P2 attempted to level at FL90 using A/P but a/c continued to descend. P1 attempted to disconnect A/P but unable to do so until 4000 ft. Remainder of descent uneventful.	Not known	Not known
26/1/99	HB-IXF	Periodic pitch disturbance at FL140. Ice detection warning illuminated. Event continued for 10 mins and ceased at FL80/IAS 200 kts, at which time ice detection light also extinguished.	Not known	Yes - elevators heavily coated with a layer of Type IV de-icing fluid (up to 4mm thick in places).	Not known
22/2/98	G-JEAT	A/P did not control a/c in pitch. Pitch trim fluctuated between full up and full down. Excessive force required to control elevators.	A/P disconnected. Elevator breakout operated. P2 control appeared normal, P1 control felt jammed before suddenly becoming free. Controls were reconnected and remainder of flight was uneventful.	Not known	Not known
16/2/96	G-OLHB	A/c failed to level off at selected level with A/P engaged.	A/P disconnected and crew attempted to pitch a/c down, but elevators felt 'solid' - considerable force required. Elevator trim was also stiff. No further problems after a/c descended below freezing level.	Not known	A/c was parked overnight in heavy rain which continued until take off.
22/11/90	G-UKPC	A/P and pitch control problems during climb in heavy hail. ICE warning on MWS. A/P stopped following F/D commands. EL TRIM light illuminated.	A/P disconnected and EL TRIM CB pulled. A/c flown manually with a struggle to control a/c in pitch. Crew suspected elevators jammed in neutral position. Pitch controlled using hand trimmer. Repeated attempts to free elevators during precautionary descent were finally successful at 6000 ft when a/c 'bucked' as the elevators started working again.	Not known	Heavy hail prior to take off

TABLE 1: BAe 146/Avro-RJ Suspected Elevator Icing Events

Some incidents of interest are reproduced as follows:

28 April 2003 EI-CMY

'After being parked overnight at Gothenburg in rain, the aircraft departed early morning for Charles de Gaulle with no de-icing required. Crew did not perform full drain check during full and free. Takeoff was normal and aircraft climbed to cruise at FL260. Crew then became aware that the autopilot was unable to maintain altitude, eventually resulting in a rate of climb of -800 ft/min and +1000 ft/min. Crew disconnected the autopilot to regain FL260 and described manual control through the control column "incredibly tough to move." Electric trim was then used to fly the aircraft, with the response reported as being "sluggish." Card 32B was carried out, although flight controls

were not split. During descent below 8,000 ft and out of icing conditions at less than 200 kt the crew reported improved controllability ...'

03 April 2001 EI-CTM

'In cruise from Dublin to Birmingham at 19,000 ft in icing conditions, aircraft suffered pitch control problems. Altitude deviation of +/-200 ft at up to 1000 ft/min indicated on VSI. Reported to be uncomfortable but not severe. Pitch disturbance lasted 21 minutes. Inspection of aircraft found servo tab hinge bracket areas contaminated with substantial amounts of de-icing fluid residues, samples of which were taken and placed in a freezer and within 10 minutes found to be solid.'

23 February 2001 OO-DJP

'During climb with A/P on, on level change, rate of climb experienced of between 500 and 3700 ft/min. Disconnected A/P during approach, difficult to control pitch with a strong shock felt through the controls, no icing conditions.

Aircraft was on the ground for one hour prior to departure. During this time, there was a heavy hailstorm. Crew departed without de-icing (which was not necessary according to crew). ...When aircraft arrived at Hamburg it was pulled into the hangar ... Mechanics found a lot of snow and ice in between the elevator and servo tab which was responsible for the blockage. No traces of Type IV de-icing fluid were found.'

22 February 1998 G-JEAT CAA Occurrence Report No. 199800889

'Autopilot did not control in pitch, trim fluctuated full up/full down. Excessive force required to control elevators. Icing suspected.'

16 February 1995 G-OHLB CAA Occurrence Report No. 95/00721X

'Aircraft failed to level off at cruise altitude with autopilot engaged. As deviation increased through 200 ft, A/P disconnected and attempt made to pitch down. Elevators felt solid and considerable effort required to break out restriction without injuring pax and cabin crew. Elevator trim also stiff to operate. Manual descent and approach flown with no further symptoms below destination freezing level of 4000 ft. Aircraft had been parked overnight in heavy rain up to take off.'

Many of these incidents share common factors with the G-JEAX accident, for example, similar weather conditions and the aircraft being exposed to precipitation before departure, not de-icing before departure, and the presence of de-icing fluid residues on the elevators and servo tabs. The reported symptoms in many of these events are often similar to those of G-JEAX, for example, the aircraft failing to level off at the selected level, unusual pitch oscillations and very heavy elevator controls on disconnecting the autopilot, usually returning to normal after the aircraft has encountered warmer air. There have also been other comparable events where only roll control has been implicated.

Analysis

Interpretation of FDR Data

The data depicted in Figure 2 show a 12 to 15 second period oscillation in pitch. This phenomenon is discussed in the next paragraph entitled 'Aircraft pitch response'.

The data depicted in Figure 3 show that the autopilot was disengaged twice when the aircraft was above FL200. On the first occasion, lasting 50 seconds, the aircraft appears to have levelled at FL220 before continuing to climb. During this period, operation of the trim tab can be observed which was characteristic of pilot input. The rate of tab movement was greater than that seen under autopilot control due to the higher trim rate available with manual electric trim movement. The autopilot was re-engaged with the aircraft in the climb and was disengaged again 31 seconds later. During this period of engagement, the data show evidence of an autopilot driven pitch oscillation of increasing amplitude. The autopilot was disengaged secondly for a period of 109 seconds. Again, the data show evidence of some pilot initiated trim tab movements but for much of this time, the elevator trim was static, with a corresponding lack of change in the aircraft's pitch attitude and normal acceleration. The aircraft levelled at FL240, still under manual control, whereupon the autopilot was re-engaged. A pitch oscillation of increasing amplitude began once more and after 20 seconds the autopilot was disengaged.

A time history of the pitch upset event is shown in Figure 4. The data show that a nose-down electric trim input was made about two seconds after the autopilot was disconnected, and that the aircraft responded by decreasing its pitch attitude, accompanied by a decrease in the vertical acceleration from a nominal 1g to about 0.4g. This indicates that the elevators responded in the correct sense to the elevator trim, which in turn indicates that the elevators were free to move. It can also be seen that the elevators moved rapidly to about 7° in the aircraft nose-up sense about 10.5 seconds after the autopilot was disengaged. The aircraft appears to have responded to the elevator movement by increasing its pitch attitude, and by the normal acceleration increasing to a maximum value of about +3g. Subsequently the aircraft described an oscillatory motion in pitch, with a period of about 1.5 seconds. Straight and level flight was restored about 22 seconds after the autopilot was disengaged and the aircraft was flown manually for the remainder of the sector.

The elevator trim remained at the position selected at the time the autopilot was deselected for some time after the accident. The graph at Figure 5 shows that during part of the flight prior to the pitch upset event, there is an abnormal relationship between the trim tab angle and the mean elevator angles. However, the circumstances that cause this are temporary and the trim characteristics eventually return to normal some time after the pitch upset event.

Aircraft pitch response

The pitch behaviour of G-JEAX prior to and subsequent to the accident event was similar to that seen in several other previous events.

Following the G-JEAT pitch control incident in February 1998, the aircraft manufacturer carried out a study using the design simulator. (This accurately models the operational features of the mechanical flying control circuits and can be used to evaluate the effects of introducing various fault conditions.) With the simulator configured to represent the conditions of the incident flight, the aircraft response in flight in automatic and manual flight could be reproduced by either freezing the elevator tabs, or grossly adjusting the aerodynamic stiffness of the elevator, the elevator tab or a combination of both. The FDR data from this previous event show that in automatic flight, the pitch trim was cycling up and down with a period of 14 seconds in a similar manner to that seen on G-JEAX during the climb. The manufacturer concluded that the G-JEAT event was most probably caused by a frozen elevator servo tab.

The fact that the period of the pitch oscillations in the two events is similar suggests that both events may have been caused by the same mechanism. In automatic flight, the autopilot controls the aircraft in pitch via the autopilot servomotor. If one or both servo tabs are frozen, the autopilot servomotor will attempt to operate the elevator servo tabs until the autotrim threshold of 1.5 seconds is exceeded. The autotrim system will then attempt to relieve the load on the autopilot servomotor by trimming in the same direction (say, for example, aircraft nose-up). At some stage the autopilot servomotor will then attempt to correct the nose-up pitch attitude by applying opposite elevator. Since the autopilot servomotor is still unable to move the servo tabs, after 1.5 seconds, the autotrim system will again begin to trim (in an aircraft nose-down direction this time) to relieve the load on the servomotor. Continuation of this process results in a periodic cycling of the aircraft in pitch, driven by the autotrim system's dynamic response.

Given that the full and free checks on G-JEAX prior to takeoff were satisfactory and that the elevator response during the takeoff and initial climb was normal, it would seem that the condition that caused the restriction of the servo tabs must have occurred later in the climb, after the autopilot had been engaged. This supposition is supported by the FDR data which shows that the elevator response appeared to be normal up to FL90. It is further reinforced by the fact that the FDR data show that, prior to the accident event, there is an abnormal relationship between the trim tab angle and the mean elevator angle. This abnormality would most likely have been due to one or both servo tabs having frozen in a deflected position so as to provide an effective elevator trim offset.

Given this evidence, it would seem that that icing of the servo tabs was the most likely cause of the event. This would also explain why the pitch response returned to normal some time after the event, by which time the ice would have either broken off or melted.

De-icing fluid residues

When tested, the samples of de-icing fluid collected from the crevices in the elevator servo/trim tab gaps on G-JEAX did not freeze at a temperature of -18 °C. The FDR data show that the servo tabs froze at an OAT of -8 °C, at which point the de-icing fluid would not yet have frozen. Furthermore, there was probably insufficient re-hydrated de-icing fluid residue found on G-JEAX to have directly affected the operation of the elevator controls. It is thus reasonable to conclude that the jamming of the elevator servo tabs was not attributable to the classic problem of freezing of accumulations of rehydrated de-icing fluid residues.

It is, however, possible that the small amount of rehydrated residue that was present, being quite sticky, may have encouraged rain, snow or slush to adhere to the surfaces in the control gaps. If the weather conditions were such that the accumulated rain, snow or slush did not disperse prior to takeoff, these accumulations could freeze in flight, causing the servo tabs to jam.

A further possibility is that accumulations of de-icing fluid or its residues could have reduced the size of the small gap between the elevators and the servo tabs, making it more likely for precipitation, including rain run-back over the elevator, to collect in the gap and subsequently freeze in flight.

Whilst the precise effect that the de-icing fluid and its residues might have had in this accident cannot be ascertained, their presence is unlikely to have been beneficial and the importance of the industry recommendations to inspect for and remove any build-up of such residues must be reinforced. Despite considerable documentation having been issued on the subject, some operators do not appear to have effective programmes for accomplishing this.

Weather conditions

The aircraft had completed three uneventful sectors between Belfast City and Birmingham in broadly similar weather conditions to those of the accident flight. This begs the question as to why the aircraft did not experience any problems on any one of the previous three sectors. The answer may be that, unlike the previous sectors, the aircraft was exposed to snow and rain in near freezing conditions prior to departure.

Although snow was not settling on the visible parts of the aircraft, it is possible that in the near freezing conditions snow or slush could have accumulated in the sheltered areas in the gaps between the elevators and the servo tabs and this would not have been visible to the crew of G -JEAX. If the aircraft was parked into wind, this process might have been aided by the fact that the elevators sit in the trailing-edge up position when the aircraft is parked. This geometry could encourage precipitation to move forwards down the elevator and to accumulate in the gaps as shown in Figure 7.

Evidence from previous events where the aircraft was exposed to precipitation on the ground prior to takeoff in near freezing conditions without being de-iced and where the aircraft subsequently experienced pitch oscillations and/or heavy elevator forces suggests that this scenario may be one which is conducive to the accumulation of ice or slush or even hail in the elevator gaps, which can freeze in flight. Typically the ice melts as the aircraft encounters warmer air, whereupon the controls usually revert to normal, although in some cases the ice has remained and is still visible after landing, as in the OO-DJG event (see Figure 8).

Figure 8: OO-DJ Incient - 5/2/03

Ice Accumulation in Gaps on Top of Elevator
(Photo taken Post Flight)

The crew of G-JEAX decided not to de-ice prior to departure and their decision seems a reasonable one given that no snow or ice was accumulating on the visible parts of the aircraft. Their decision was also in accordance with company procedures. The METARs indicate that there was a slight but perceptible worsening of the weather during the hour immediately following the aircraft's departure, which may explain why a number of aircraft were de-iced during that period. With the benefit of experience from this and previous incidents, it would appear that there is a strong case on the BAe 146/RJ series aircraft for erring on the side of caution and de-icing in weather conditions which might be conducive to the accumulation of snow, slush or hail in the elevator gaps, even though there may be no visible snow or ice accumulations on the fuselage or wings. It would seem sensible to provide advice to pilots to this effect and also to recommend a specific visual check of the elevator gaps in the pre-flight inspection. One European operator has already implemented this practice with apparent success.

Elevator servo tab bearings

Design simulator studies by the aircraft manufacturer have showed that if the servo tabs become so stiff to operate that the autopilot servomotor is unable to move them, a low frequency pitch oscillation, driven by the autotrim system, may occur. The increased torque required to rotate the servo tab bearings due to the lack of grease could increase the overall stiffness of the pitch control system. This, of itself, may not have been sufficient to cause the servo tabs on G-JEAX to jam, but there remains the possibility that with the lack of grease in the bearing, moisture could accumulate in the bearing cage void and freeze in flight. This would further increase the stiffness of the system, possibly to the point where the servo tabs might seize. A previous incident of an aileron jam on a BAe 146 was attributed to moisture ingress into one of the sealed bearings in the aileron control system, which subsequently froze in flight (Report EW/C99/10/1 in AAIB Bulletin 7/2001 refers). Following this incident, the aircraft manufacturer proposed a change to the AMM (Aircraft Maintenance Manual) under All Operator Message Reference 01/001V to introduce a subjective check of the freedom of movement and smoothness of the aileron and elevator servo tabs. Consequently, no safety recommendation was made by the AAIB regarding inspection and maintenance of the bearings.

Since the servo tab operating rods connect to the underside of the tabs and the elevators sit trailing edge up when the control locks are engaged, the exposed servo tab rod-end bearings are particularly vulnerable to the effects of high pressure jets of water and de-icing fluid from aircraft washing and de-icing. This can cause the grease to be washed out of the bearings over a period of time, which would not be apparent during a general visual inspection of the bearings.

Whilst it was not possible to establish whether the absence of grease in the servo tab bearings was a contributory factor to the elevator control problems on G-JEAX, good engineering practice suggests that this condition is undesirable and that the servo tab bearings and other similar bearings need to be sampled for condition at regular intervals and replaced as necessary.

Flight crew actions

On disconnecting the autopilot during the altitude excursion above FL240, the flight crew were presented with a particular situation for which they were neither trained nor provided with an approved emergency procedure. The application of manual electric trim to counter the aircraft's nose up pitch tendency and to supplement the forward pressure on the control column was reasonable, given the fact that the aircraft appeared to be about to exceed its assigned flight level - a factor which may have influenced the crews' actions. Once the aircraft had pitched nose down, its failure to respond to considerable aft force on the column would have been highly alarming to the crew and could rapidly have led to an overspeed condition. Consequently, their response of both pilots pulling on both columns in unison can be understood, although with the benefit of hindsight, it may not have been the most appropriate course of action. Unless they have an approved method of recognising and coping with frozen controls, other flight crews may react similarly when faced with similar circumstances.

One European operator has already issued guidelines to its flight crews about how best to respond to such an incident so as to minimise the risk to the aircraft and its occupants. Given that similar techniques have been previously and successfully used by crews in comparable circumstances, it would seem prudent for the aircraft manufacturer to issue an emergency procedure detailing the actions to take in the event of heavy pitch controls due to suspected frozen servo tabs. The procedure should be based on a safety analysis and the experience gained from previous occurrences of 'frozen controls'. In previous comparable events, other flight crews resorted to reducing the airspeed to reduce the pitch control forces required, switching on the fasten seat belt lights, avoiding the use of excessive control forces and controlling the aircraft in pitch using manual control of the trim tab and, where appropriate, descending below the freezing level.

The crew of G-JEAX elected not to de-ice the aircraft prior to departure. The purpose of de-icing on the ground is to remove any accumulations of snow and ice from critical surfaces, so that the aircraft can take off safely. AIC 81/2001 states that fluids used during ground de-icing/anti-icing are not intended for and do not provide ice protection during flight. Having taken off, the aircraft must rely on its on-board systems for icing protection. In this instance the aircraft became airborne safely and did not experience any problems until established in the climb.

The pre-flight elevator drain check which the crew performed immediately prior to takeoff was in accordance with the company operating procedures which had been implemented in a Notice to Aircrew issued on 15 April 2002 with a validity period of six months. That procedure, which had not been superseded, did not quite reflect the same check as described in the Manufacturer's Operations Manual for this aircraft type which stated:

> *'It is important that, in addition to these full range of movement checks, the elevator is held in the neutral position to ensure that the water is allowed to drain. The position of the control column at this stage is approximately 1.5 ins. aft from its foremost position. This is particularly important, for example, following ground exposure to heavy rain.'*

However, the procedure dated 1 July 2001 in the operator's Operations Manual included a requirement to hold the elevators at their neutral position, as described above. The intent of the Notice to Aircrew was, in part, to convey the company requirement to carry out the elevator drain check on every flight, irrespective of the ambient conditions, but the Notice did not cross-refer the reader to the appropriate section of the Operations Manual. This check is designed to remove collected water from inside the elevators, which is thought to be one of the factors that can induce the high-frequency 146/RJ pitch oscillation but it was not considered to have been a contributory factor in this accident.

Conclusions

The investigation established that there have been a number of incidents over the years of pitch control problems on the 146/RJ series, caused by icing of the elevator servo tabs. Generally, the root cause of these problems has been either:

> a. Freezing of residues of Type II and Type IV thickened de-icing fluids which have accumulated in to elevator gaps,

or, as in the case of G-JEAX,

> b. Exposure of the aircraft to precipitation on the ground in near freezing conditions prior to take off, resulting in accumulations of snow, rain or hail in the elevator/servo tab gaps which then freeze in flight.

The symptoms of frozen elevator servo tab(s) include low frequency pitch oscillations, failure of the autopilot to capture a selected flight level in a stable manner and, on disconnecting the autopilot, very high manual elevator control forces, possibly with an out of trim condition. The aircraft in-flight anti-icing and de-icing systems seem, from time to time, unable to prevent these situations from occurring. Consequently, other precautions may need to be taken prior to departure, such as specifically inspecting the elevator gaps, and/or precautionary de-icing of the aircraft when the aircraft is exposed to rain or snow in near freezing conditions, or hail regardless of the temperature, prior to departure.

Although UK operators have been advised of the dangers of re-hydrated Type II and Type IV residues in various publications, operators of aircraft with non-powered flying controls have not universally adopted the recommendations to inspect regularly for the build up of residues and remove these where found. This may be due to a lack of awareness of the risks posed by such residues. In some cases where efforts were made to check for and clean away the residues, the task appeared to be loosely controlled and not necessarily effective.

The response of G-JEAX's flight crew to the situation that they faced caused rapid variations in the normal acceleration felt within the aircraft and this resulted in serious injury to two of the cabin crew and minor injury to two other occupants in the cabin. The pilots had no recourse to an emergency procedure appropriate to the abnormal control characteristics they were experiencing and the rapidity of their subsequent actions may have been the result of a desire not to 'bust' the flight level to which they had been cleared. In view of the lack of any other aircraft in their immediate vicinity, they had ample airspace in which to regain control of the aircraft. An early PAN call and a knowledge of the nature of the problem would have relieved the perceived pressure on the crew to take such hasty action.

Safety Recommendations

The dangers posed by de-icing fluid residues to aircraft with non-powered flying controls are well documented. Despite this, some UK operators of BAe 146/RJ series aircraft and other affected types do not appear to be fully aware of the airworthiness implications of failing to remove these residues and do not have an effectively controlled programme for accomplishing this. This situation was recently identified in AAIB Bulletin Report EW/C2003/03/01, which led to the issue of Safety Recommendation 2003-81 dated 30 October 2003, which is repeated as follows:-

Safety Recommendation 2003-81

It is recommended that the Civil Aviation Authority satisfy itself that operators have in place the necessary measures to ensure that they have adopted the advice given in AIC 81/2001.

This safety recommendation was under consideration by the Civil Aviation Authority in December 2003.

In order to ensure that the task of inspecting for and removing de-icing fluid residues is controlled in a manner appropriate to an airworthiness critical task, the following additional Safety Recommendation is made:-

Safety Recommendation 2003-119

It is recommended that the Civil Aviation Authority require operators of aircraft with non-powered flying controls that are vulnerable to the effects of freezing of re-hydrated de-icing fluid residues, to establish engineering procedures for the inspection and removal of such residues from critical flying control surfaces.

Regarding the long-term solution to the problem of residues of thickened de-icing fluids, Safety Recommendation 2003-82 dated 30 October 2003 that was raised in AAIB Bulletin Report EW/C2003/03/01 is also re-stated here:-

Safety Recommendation 2003-82

The Civil Aviation Authority should consult with anti-icing fluid manufacturers with a view to encouraging them to develop fluids, with suitable 'holdover' times, that incorporate gelling agents that are not rehydratable.

This safety recommendation was also under consideration by the Civil Aviation Authority in December 2003.

AAIB Special Bulletin S1/2003 was issued soon after the G-JEAX accident and in responding to this bulletin, the aircraft manufacturer committed to providing a flight crew procedure for recognising and responding to frozen flight controls. This procedure should differentiate between jammed controls and frozen controls and will, in the case of the elevators, need to encompass the possibility of separating the elevator control circuit. Therefore, it is recommended that:-

Safety Recommendation 2003-120

On behalf of EASA the CAA should take an oversight on the manufacturer's proposed flight crew abnormal and emergency checklist procedure for recognising and responding to frozen flight controls on the 146/RJ series aircraft to ensure the timely introduction of a suitable procedure.

Evidence from this investigation and other similar incidents shows that the BAe 146/RJ aircraft series is vulnerable to the accumulation of precipitation in the form of snow or hail in the elevator gaps, which may partly melt on the ground and then re-freeze in flight, causing pitch control problems. The greatest risk appears to be in near freezing conditions and contamination may be present in the elevator gaps even though no ice or snow is visible on other parts of the airframe. For this reason the following Safety Recommendations are made:-

Safety Recommendation 2003-121

The aircraft manufacturer, BAE Systems, should alert operators of 146/RJ series aircraft to the possibility of precipitation accumulating in the elevator gaps whilst the aircraft is parked in near freezing conditions, or following a hailstorm, and that if untreated, this precipitation can lead to pitch control problems in flight.

Safety Recommendation 2003-122

The CAA should require UK AOC holders operating BAe 146/RJ series aircraft to issue instructions to their staff for inspecting the gaps between the elevator and the tailplane and between the elevator and the trim and servo tabs for any precipitation contamination prior to departure, with a recommendation to de-ice the aircraft, when any doubt exists.

Given the findings of the elevator servo tab bearing examination, the following Safety Recommendation is made:-

Safety Recommendation 2003-123

The aircraft manufacturer, BAE Systems, should consider the introduction of a sampling programme for the elevator servo tab bearings and other flight control system bearings that are vulnerable to the effects of aircraft washing and de-icing, with a view to establishing a regular maintenance or replacement requirement for those bearings as necessary.

Figure 3: FDR Data showing pitch characteristics abov