De Havilland Canada DHC-8 Series 311, G-BRYP

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Aircraft Type and Registration:	De Havilland Canada DHC-8 Series 311, G-BRYP
No & Type of Engines:	2 Pratt and Whitney Canada PW-123 turboprop engines
Year of Manufacture:	1992
Date & Time (UTC):	10 February 1997 at about 1750 hrs
Location:	South of Aberdeen
Type of Flight:	Public Transport
Persons on Board:	Crew - 4 - Passengers - 26
Injuries:	Crew - None - Passengers - None
Nature of Damage:	Overtorque of both propellers; damage to ball race of one blade of No 2 engine propeller
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	7,140 hours (of which 484 were on type)
	Last 90 days - 138 hours
	Last 28 days - 28 hours
Information Source:	AAIB Field Investigation

History of flight

The crew reported for duty at 1405 hrs to operate a scheduledservice Bristol, Newcastle, Aberdeen, Newcastle, Bristol. Thefirst two sectors were uneventful and the aircraft left the standat Aberdeen for the sector to Newcastle with the commander ashandling pilot. The history of the flight was reconstructed fromthe account provided by the crew and from the FDR.

The anti ice systems were selected 'ON' when the aircraft tookoff from Aberdeen at 1748 hrs; there was a strong gusting crosswindand it was raining. The initial climb was normal and the landinggear and flaps were retracted. The Standard Operating Procedureis then to deselect the autofeather system and select climb power,however the commander decided to retain take off power in orderto expedite the climb through the layer of moderate to severeturbulence they were experiencing; he informed the first officerof his intention and asked for the bleed air to be switched on.The first officer actioned the after take off check from memory,however he did not deselect the autofeather system because climbpower had not yet been requested.

The commander selected climb power at about 2,100 feet amsland asked the first officer to reduce the propellers to theclimb setting. Both propellers were reduced to 900 propeller RPM(Np) and the torques increased momentarily to 100% before beingreselected to 80%. The autofeather system was not deselected.No 1 engine torque increased slowly from 80% until stabilisingat around 90%. However, No 2 engine torque increased rapidly to111% and then returned to 80% over a period of 12 seconds. Thiswas the first of many excursions of No 2 engine torque; most werein the range 10% to 20% and continued for a further 100 secondsuntil the commander retarded No 2 power leverto about 62%. These excursions in Np and torque are shown in Figure 1. ATC was toldof the problem and the climb was continued with No 1 enginetorque at 90%, and No 2 engine torque still at 62%; both propellerswere at 900 Np.

When the aircraft climbed out of icing conditions the commanderselected the No 2 engine intake bypass doors to closed. Shortlyafterwards, as the aircraft climbed through about 7,400 feet amsl,No 1 propeller suddenly feathered, reducingto 400 Np and the torque on No 2 engine roseby about 15%. In this installation it is possible to featherthe propeller blades without stopping the engine. Becausethe engine had not actually failed, fuel was still being scheduledto maintain the level demanded by the power lever and consequentlyNo 1 engine torque increased rapidly to a peak value of 120% beforebeing reduced to below 100%. About 100 secondslater No 1 engine torque was further reduced to 38%, the flightidle value, and No 2 engine torque was increased slightly to 85%.

The UNSCHEDULED PROPELLER FEATHERING drill was consulted; thedrill calls for the shutdown of the engine associated with thefeathered propeller. The flight deck indications were that No1 engine parameters were normal. Because he now thought they hadtwo, apparently unrelated, problems the commander decided notto shut down No 1 engine. An emergency was declared and the aircraftdiverted to RAF Leuchars.

The first officer tried to unfeather No 1 propeller using thealternate system but was unsuccessful. As the aircraft passedabout 7,000 feet amsl during descent to Leuchars, the commanderselected the No 1 engine bypass door to closed and reducedNo 2 engine torque to about 58%. This disarmed the autofeathersystem and No 1 propeller suddenly unfeathered; Np increased rapidlyto 1,200 and the torque fell to zero. There was a yaw to the rightof around 2 to 2.5° as the propeller unfeathered and it appearsthat the commander interpreted this as a failure of the No 2 enginebecause, about 10 seconds later, he retarded No 2 condition leverto the START/FEATHER detent which caused the propeller blade angleto coarsen towards the feather position. The power lever remainedas selected and No 2 engine torque increased rapidly to 100% beforereducing to 55% as the lever was subsequently retarded to FLIGHTIDLE. After 5 seconds No 2 engine torquereduced to zero in response to the condition lever being movedfully back to FUEL OFF. Figure 2 shows the engine torque, Np and fuel flow.

The first officer immediately told the commander that he thoughthe had taken the wrong action and the latter quickly moved thecondition lever fully forward to the MAX GOVERNING position. TheNp immediately increased to 1,200 and, because the igniters werestill selected ON, the engine relit. The propeller was reducedto 900 Np but because the torque gauge pointer was at zero andthe digital readout showed four dashes the crew assumed that theengine had indeed flamed out. The FDR was also sensing a zerotorque output at this stage but other parameters such as fuelflow and gas generator RPM (Ng) showed that the engine was stillrunning with the power lever at a moderate setting. The firstofficer attempted to relight the engine by first retarding thecondition lever to START/FEATHER. The Np reduced to 300 but thestart switch would not engage as the engine was already running.After 17 seconds the power lever was retarded to FLIGHT IDLE,resulting in a Np of 100.

The approach was flown with both engines running normally butwith the No 2 propeller feathered and the power lever at FLIGHTIDLE; No 1 engine condition lever remained at MAX GOVERNING.An uneventful landing was made at Leuchars at about 1814hrs.

Meteorology

An aftercast prepared by the Meteorological Office at Bracknellindicated that there was a deep depression, 971 mb, centred tothe north of the Shetland Isles which was moving slowly north-east.A trough of low pressure embedded in the unstable westerly airstreamgave strong to gale force winds in the vicinity of the incident.There were occasional showers of rain, hail or snow in which thevisibility reduced to 5 km. The main cloud base was 4,000 feet,although there were small amounts with base at 1,000 and 1,500feet. The wind/temperature profile was as follows:

Surface 230°/30 kt gusts to 45 kt veering to +4°C/0°C

250°/25 kt gusts to 35 kt

2,000 feet 300°/70 kt 0°C/-5°C

5,000 feet 270°/60 kt -5°C/-8°C

10,000 feet 270°/52 kt -15°C/-30°C

The 1750 hrs METAR for Aberdeen was:

EGPD 25023G33KT 200V280 9999 SHRA FEW12CB SCT015 04/M00 Q0982TEMPO 5000 BKN012

Crew's flying experience

The commander started flying in 1979 and gained an AFI and thenFI rating which is still current. He gained a CPL in 1985 andflew air taxi, night mail and air ambulance flights in PA31/34type aircraft. In 1988 he became a first officer on DHC-7 aircraftand was later promoted to Captain. From 1990 to 1991, he was afirst officer on the Shorts Belfast, before returning to the DHC-7as a Captain in June 1991. He converted to the DHC-8 in June 1996.His initial technical examination was based on the 100 seriesaircraft which has a different torque sensing system.

The first officer started flying in 1984. He completed the PPLthen BCPL courses, gained an AFI rating and started work parttime as a flying instructor in May 1993. He passed his ATPL examsand Instrument rating and flew as a first officer on Kingair aircraftfrom May 1995. The following May he joined the company as a firstofficer. At the time of the incident he had a total of 1750 hoursof which 386 were on type. His initial technical examination wasalso based on the 100 series aircraft.

The autofeather system

The autofeather system is selected by a single switchlight onthe lower right engine instrument panel; it is used only for takeoff. When the switchlight is pressed a green SELECT caption illuminatesto indicate that the system is selected. The system is armed whenthe power levers are advanced and both engine torques are aboveabout 38%; an amber ARM caption illuminates in the bottom halfof the switchlight.

The Autofeather Controller receives inputs from potentiometerson the power levers which provide Power Lever Angle (PLA) informationand also Outside Air Temperature values from the Digital Air DataComputer. From this a discreet PLA 'HI' or 'LO' signal is outputto a Torque Signal Condition Unit (TSCU) associated with eachengine (PLA 'HI' equivalent to a torque demand of 60% or greaterfor a correctly rigged system). When the crew select Autofeather,each TSCU becomes enabled when it is in receipt of its own (local)PLA 'HI'.

Each TSCU also receives actual local torque information from oneof two sensing coils on its associated engine. Values of torquegreater than 38% result in a local torque 'HI' discreet beinggenerated. This is also fed to the remote TSCU and when a TSCUis in receipt of both local and remote torque 'HI' signals, itsautofeather status changes from 'enabled' to 'armed'.

Transition to 'armed and failed' occurs when local torque dropsbelow 22% on the correct standard of TSCU applicable to G-BRYP(see later paragraph). The affected TSCU will immediately sendan uptrim signal to the remote engine Electronic Engine Control(EEC) to uptrim its torque by about 10% and a green UPTRIM advisorylight will illuminate on the engine control panel. If this conditionlasts uninterrupted for 3 seconds, the TSCU transitions againto 'not armed and feather' and the propeller is feathered. TheTSCU is latched in this condition unless the Autofeather selectoris switched OFF, or both PLA 'HI' discreets are removed, or theremote torque 'HI' is removed.

Whilst one coil in each torque sensor provides information tothe TSCU for Autofeather purposes, the other is effectively aseparate channel supplying torque data to the ARINC 429 data bus,where it is used by the cockpit instrument display and by theDFDR. In addition, it is used by the EEC for closed-loop powercalculations for 60 seconds after uptrim occurs.

Under normal operation, the EEC propeller speed governing logicwould adjust the engine fuel schedule to prevent propeller operationbelow the minimum speed of 785 RPM. When a propeller feathersa cancel signal from the TSCU overrides this governor to preventthe possibility of propeller/engine overtorque as the propellerslows to below the minimum speed. However, should the propellerfeather with the engine operating and the power lever at a high-powersetting, an overtorque situation will still occur.Should the TSCU cancel signal fail,a back up signal from the torque gauge is initiated when the overtorquelimit of 115% is reached.

An auxiliary feathering pump is energised and provides supplementaryoil pressure for 18 seconds before automatically shutting off.Once the autofeather sequence has been initiated on one propeller,an interlock prevents autofeather of the other propeller.

The alternate feathering system provides a back up means of manuallyfeathering/unfeathering a propeller if movement of the conditionlever fails to achieve full propeller feathering/unfeathering.Provided the power lever is at or above flight idle and the conditionlever in START/FEATHER, the alternate system can be used regardlessof whether or not the engine is running. If the autofeather systemis armed the alternate system will also initiate an uptrim.

Pertinent flight crew notices

The Operations Manual Vol 3 - Supplementary, copy supplied tothe AAIB dated 2 March 1995, contained, in part, the following:

"TORQUE SIGNAL CONDITION UNIT

Bombadier have advised ----- of an unusual set of circumstanceswhich have occurred on rare occasions to other operators, namelya false sensing of low torque by the Torque Signal Condition Unit(TSCU) which causes automatic uptrim and autofeather with cockpitindications which are not obvious unless pre-warned:

In series 100 Aircraft TSCU failure results in:

1. Torque Gauge reads ZERO (despite high over-torque)

2. Uptrim light illuminates with simultaneous uptrim of otherengine

3. Np decreases to approximately 600 RPM

4. Autofeather ARM light extinguishes

5. Aircraft yaws away from uptrimmed engine

In series 300 Aircraft TSCU failure results in:

1. Torque gauge reads approximately 140%

2, 3, 4 and 5 as for 100 Series Aircraft above

In both cases, all other engine parameters remain the same asbefore the failure."

and:

"To minimise exposure to this serious situation, and to fitin with the requirement to switch OFF the AUTOFEATHER at onceshould ECU failure occur on take-off, the after take-off SOPsare changed with immediate effect so that the RHS switches OFFthe AUTOFEATHER just prior to reducing power to MCP."

Flight Crew Notice: 37/96 was issued on 25 June 1996 by the Operator;it contained, in part, the following:

"In a recent incident with another Dash 8 operator, a selectionof an engine intake door open resulted in the engine flaming outand feathering. The cause was traced to a chafed wiring loom inthe fuselage, which had resulted in a signal for the emergencyfuel valve to close."

Previous incidents of a similar nature

The operator was in possession of two notifications from Bombardierconcerning uncommanded autofeather and opposite engine uptrimevents. The first of these was dated 19 December 1990 and wasan In-Service Activity Report (ISAR) No 90-12-6120-00 and mentionedthat four cases of uncommanded Autofeather were being investigatedby the manufacturer. In three of the four cases there had beena loss of torque indication similar to that experienced on G-BRYP(but on the Autofeathered engine itself), with the display showingzero analogue and dashed digital display. This was explained asbeing due to an overtorque condition which, when it reached 135%would be interpreted as an out-of-range situation by the indicationsystem.

The second notification, also an ISAR, was dated 15 February 1995and numbered 95-02-6100. This reported a case whereby an apparentlyfaulty torque probe led to intermittent low torque signals tothe TSCU and caused associated uptrims of the opposite engine.The ISAR presented information on the symptoms to assist troubleshootingon both series 100 and 300 aircraft, again pointing out that azero/dashes torque indication could result if the propeller actuallydoes feather on engines programmed with early-standard EEC software.For later standards of software, the indication was said to readMaximum on the analogue and 199% on the digital display. Alsomentioned was the fact that provision of separate torque channelson the series 300 aircraft could result in a normal torque indicationto the crew on an engine which is experiencing a varying torquesignal on the control channel.

The extract from the Operations Manual quoted in the paragraphabove seems to imply that this operator's series 300 aircraftwere fitted with EEC's programmed with the later standard of softwarewhich does not indicate zero/dashes when receiving high overtorquesignals from the torque sensors. However, the figure quoted of140% does not relate to either of the two software standards mentionedin the Bombardier ISAR.

When queried about the precise origin of the information behindthe Operations Manual Supplement, the operator said they recalledthat it had been gathered during a personal visit from a Bombardierdesign specialist.

Engineering investigation and analysis

From the information provided by the crew and analysis of theFDR data, it was clear that the fluctuations in torque of No 2engine which precipitated the subsequent events were caused byuptrim commands due to erroneous low engine No 1 torque signalsbeing received by its EEC. These signals were not reflected eitherin the cockpit instruments or the data recorded on the FDR whichare fed by a separate channel which did not receive the erroneoussignals. It was also clear that the spurious signals were intermittent,since they did not initially result in a feather command to No1 propeller which requires the signal to be present for a minimumof 3 seconds. However, the uptrim command to No 2 engine EEC wasreceived immediately each time the low torque signal was sensed.It is for this reason that the first uptrim command exceeded theintended nominal 10% increase by a factor of about three, sincethe first intermittent signals were received in such quick successionthat the EEC 'ramped' up the command each time until the limitof 107% torque was reached. According to Pratt and Whitney Canada(PWC) the peak figure of 111% recorded was due to overshoot. Thesubsequent excursions in torque were more in line with the nominaluptrim schedule.

The No 1 and No 2 torque sensing probes, and No 1 TSCU were despatchedto PWC for testing and examination. No significant defects werediscovered but the TSCU was found to be of an inappropriate typefor use on the PW123 engines fitted to G-BRYP, having the partnumber 30005-0000-46 and intended for use on PW120 and PW121engines but repeated testing did not reveal any faults or anomalieswith the unit. According to PWC, fitment of this incorrect modelof TSCU to the particular modification standard was probably notsignificant in this incident since the principal difference inperformance of the unit lay in the trigger torque for Autofeatherof a 'failed' engine being increased from 22% to 29%. Since thereason for the erroneous triggering signal probably lay in anintermittent open or degraded circuit (as discussed in the nextparagraph), the TSCU may have been sensing effectively zero orvery low torque and the variation in trigger point therefore wasprobably of minimal significance.

It was suspected at an early stage that the reason for the spuriousautofeather signals probably lay in intermittent poor contactof the connections within the engine nacelle associated with theAutofeather system. Such poor contacts would be difficult to trouble-shooton the ground because they could be influenced by vibration andtransient moisture contamination. Examination of the TSCU didshow signs of light, greasy contamination of connector receptaclesJ6 and J7, although it was not possible to categorically statethat this was responsible for the malfunction. Bombardier have,however, pointed-out that the AFM had been revised to requiredeselection of autofeather *prior* to reducing power aftertake off because the reduced propeller RPM results in a reducedvoltage output from the torque sensor. Hence a torque signal circuitdegraded by, say, contamination of a connector would be more vulnerableto generating a spurious low torque signal at this time. It isfor the same reason that Service Bulletin 21456 was introducedto help overcome such problems (see below).

Arising from previous incidents involving spurious low-torquesignals, PWC had developed two modifications and a maintenancepractice to minimise the problem and has advocated to the operator:-

Service Bulletin (SB) 21456. This modification introduced a revisedtorque sensor shim which optimises the air gap in the sensor,increasing its signal strength and hence reducing its sensitivityto noise caused by vibration. This modification was not embodiedon the operator's fleet.

SB 21463. This modification introduced a new engine wiring harnesshaving improved connector sockets which are less susceptible tofretting damage, have better locking retention and improved sealingagainst moisture ingress. This modification was also not embodiedon the operator's fleet.

In addition, the Dash 8 Maintenance Review Board had requiredperiodic removal and cleaning of connectors and retorquing andre-taping of connectors. Embodiment of SB 21463 obviated the aboverequirements, which the operator was not performing.

Discussion of the incident

The commander's decision to delay the selection of climb powerwas the initiating event in the sequence which started with thefailure of the first officer to disarm the autofeather systemand allowed a train of events to occur which could have had moreserious consequences. It is clear that had the standard practiceof 'autofeather disarm - select climb power' occurred at the normalpoint, this incident would not have happened. However, the subsequentproblem could have occurred at any time after the autofeathersystem had armed during the take off roll and it has served tohighlight both the engineering problem of erroneous signals inthe TCSU system and the difficulty experienced by the crew intheir analysis of the situation, exacerbated by the fact thatthe fault in the operating channel of the torque sensing systemwas not reflected in the indication channel. Indeed, it is difficultto see the logic in having separate channels in this way sincea simplex failure can still result in an uncommanded autofeather.The provision of an independent indication channel in this caseserved only to confuse the crew.

The crew may have identified the problem as an autofeather ifit had initially manifested itself as an increase in No 2 enginetorque followed 3 seconds later by No 1 propeller feathering.Even with the normal No 1 engine torque gauge reading, they mayhave related the higher No 2 engine torque to the feathered No1 propeller and carried out the UNSCHEDULED FEATHERING DRILL andlanded safely without further incident.

The green uptrim light would have been flashing in sympathy withNo 2 engine torque fluctuations, indicating to the crew that theengine was uptrimming in response to a signal from the autofeathersystem. However, it is a small light and is not compelling, beingan indicator of activity rather than a warning; given its positionand colour, it is not surprising that, during the high workloaddeparture phase, they did not notice it among the many other flightdeck lights. The autofeather switchlight would have also beenilluminated with either SELECT or ARM depending on the state ofthe system at the time. The crew did not positively check theselights because they did not at any time suspect that the problemwas in the autofeather system.

The commander had come to terms with a No 2 engine problem, ofunknown source, which could be contained by a power reduction;there was no concern for the No 1 engine which appeared to befunctioning normally. When the No 1 propeller feathered, seeminglyas a consequence of the selection of the bypass door to closed,the commander thought that he now had a further problem this timewith No 1 engine. He recalled having read about an engine flameout and subsequent propeller feathering associated with the selectionof the bypass doors and was convinced that this was the most likelycause. In fact the autofeather system had been triggered by theerroneous low torque signal which had now been present for over3 seconds. The attempt to unfeather No 1 propeller using the alternateunfeather switch failed because the autofeather system uses thesame oil pump and it would have been locked out when the autofeathersystem had operated. The alternate unfeather switches are adjacentto the autofeather switchlight on the lower right side of thecentral instrument panel but neither pilot noticed that it wasilluminated nor that the uptrim light on the left-side of thepanel was also illuminated.

When, during the descent into RAF Leuchars the commander closedthe No 1 bypass door and shortly afterwards No 1 propeller unfeathered,it took him completely by surprise and he misinterpreted the eventas a failure of the No 2 engine. The commander over-reacted tothe situation and failed either to consult the first officer orto get him to confirm his subsequent actions. The first officerreacted quickly and decisively when he told him he had taken thewrong action. However, he then misled himself into thinking thatNo 2 engine had flamed-out, since he attempted to re-light itby moving the condition lever into the START/FEATHER detent andoperating the start switch. Doubtless this misapprehension resultedfrom the zero/dashes display on the torque gauge but there wereother parameters such as fuel flow, and Ng which could have givenclues to the fact that the engine was running normally.

The reason why the No 2 engine torque indication displayed inthis manner are not immediately obvious, since the DFDR indicateda peak torque of somewhat less than 100% immediately prior tothe loss of indication - much less than the gross overtorque which,as has been explained, can be interpreted by the EEC as out-of-range.Bombardier have advised that they believe they can explain thereason, having experienced it during simulated engine failureswhich produced similar conditions during flight-test. In thesecases it was determined that the *rate of change* of torquesignal was beyond the capabilities of the EEC software, whichinterpreted it as an out-of-range signal. Reset of this conditioncan be accomplished via the EEC mode selector or by a power reset.

With the benefit of hindsight, and for the crew a review of theincident in a flight simulator, the sequence of events appearedtotally logical and easily explained. However, itwould be unreasonable to expect the average crew to havedone this type of analysis when confronted with this situationunder the prevailing flight conditions. The main criticism wouldbe of the commander's overreaction when No 1 propeller unfeathereddue to the reduction in torque of No 2 engine and his subsequentlack of consultation with the first officer before shutting downNo 2 engine. As, at this point, he did not realise that No 1 propellerhad unfeathered, he had effectively taken action to shut downthe only source of thrust available to him. Fortunately for theoutcome No 1 engine/propeller combination was now producing thrustand a safe landing was made.

When No 1 propeller unfeathered the commander was totally confused,very apprehensive and probably near his workload saturation level.The first officer reacted quickly and positively when he identifiedthe commander's incorrect action but was otherwise probably ina similar mental state. Despite formal flight deck managementtraining and practice under normal flight conditions, it is understandablethat a pilot with a mainly single crew initial experience backgroundmay revert to trying to do everything himself when under stress.The lesson to be learnt is that it is generally better to taketime to consider and discuss the situation rather than to takeprecipitate action. It is to the credit of the crew that throughoutthe event they retained control of the flightpath of the aircraft.