DHC-8-311, G-BRYR

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Aircraft Type and Registration:	DHC-8-311, G-BRYR
No & Type of Engines:	2 Pratt & Whitney PW-123 turboprop engines
Year of Manufacture:	1992
Date & Time (UTC):	8 May 1997 at 1230 hrs
Location:	Paris Charles de Gaulle Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 4 - Passengers - 17
Injuries:	Crew - None - Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	28 years
Commander's Flying Experience:	3,123 hours (of which 1,440 hours were on type)
	Last 90 days - 179 hours
	Last 28 days - 55 hours
Information Source:	AAIB Field Investigation

History of Flight

On the day of the incident the crew were scheduled to operatefive sectors; from Edinburgh to Bristol and then via Plymouth,Jersey, and Paris back to Bristol. The flight departed Edinburghat 0600 hrs. On lining-up for take-off from Bristol at the beginningof the second sector, the commander noticed that the rudder pedalsseemed stiff to operate, however this did not cause him undueconcern and he continued with the take off. The stiffness disappearedduring that sector and was not felt again until the aircraft departedfrom Paris on the final sector of the day.

After a short delay for air traffic clearance, the flight departedfrom Charles de Gaulle airport at 1220 hrs for Bristol. The windon departure was 240_/32 kt and Runway 27R was in use, consequentlythere was a crosswind from the left of approximately 16 kt. Aftertake off the commander, who was the handling pilot for the sector,found that he was unable to move the rudder

pedals. During thesubsequent climb to Flight Level (FL) 100, the landing gear andflaps were retracted with no noticeable effect on the rudder pedals,which remained immovable. Control of the aircraft was passedto the first officer who confirmed the condition. Rudder trimwas applied and movement was confirmed on the trim indicator. The flight deck switchlights for the two rudder hydraulic actuatorswere then checked to ensure that they were not illuminated andto confirm filament integrity. Had either switchlight been lit,this would have indicated a failure of the respective rudder powercontrol unit actuator linkage; however neither was illuminated. The autopilot was then selected successfully. In addition torelieving the pilots of the physical control of the aircraft,this also served to confirm that the yaw damper was operatingbecause yaw damper failure would have prevented autopilot coupling.

After confirming that there was no appropriate emergency drillin the aircraft Quick Reference Handbook (QRH), the crew advisedParis ATC that they had an emergency situation and requested diversionto an airfield which had a suitable into-wind runway. ATC suggesteda diversion to Beauvais which is approximately 30 nm north-westof Paris Charles de Gaulle airport, for a landing on Runway 23. The surface wind was given as 240_/12 kt. On approaching Beauvais,the crew decided to delay their landing until the arrival of thefull fire service cover. As that day was a public holiday inFrance, the fire service from the nearby town had to be calledout to provide full cover, and this resulted in a 35 minute delaybefore a landing could be made.

During this delay, the crew were able to check their landing distancerequirements. As Runway 23 was wet, they calculated that thelanding distance required would be 992 metres. Although ParisATC had advised that Runway 23 was 1,500 metres long, the flightdocuments for the runway showed that there was only 1,105 metresavailable for landing, the remainder being declared unusable. In addition, there was no runway instrument approach aid norapproach lighting available for this runway. As the runway wasalso slightly narrower than usual at 40 metres, the commanderdecided to carry out an approach to Runway 31 which was 2,430metres long, 45 metres wide, with high intensity approach lightingand an instrument landing system (ILS). By this time the surfacewind was 240_/12 kt with gusts up to 16 kt.

The crew then found that they were unable to tune the ILS usingthe frequency promulgated on their approach chart and on checkingthis with ATC they were informed that the frequency had been changed. It was later ascertained that the company which produced thechart had not promulgated the change in time for the amendmentto have been incorporated in the manual prior to this flight. Having set the correct ILS frequency, the crew then carried outan uneventful approach and landing.

Flight Data Recorder Information

The Flight Data Recorder (FDR), a Loral Fairchild F800 serialnumber 4494, was removed at Beauvais and returned to the AAIB. From the 25 hours of recorded data, which was divided into 6 tracks,there was valid data on track No 5 and part of No 6. This covered7 complete flights, but did not include the incident flight. Part of a flight was recorded on track No 3, ending mid-cruise,and the most recent data was on track 4. The replay showed nosignal on track 1: this was investigated by the overhaul agency,and it was found that a small build up of magnetic oxide had accumulatedon the recording head, causing loss of signal. For the remainderof the transcription the data was in synchronisation, but it wasnot possible to convert the data into meaningful values. Thissuggested that there may have been an intermittent acquisitionproblem, since the FDR was working at intervals during the 25hour period.

A new FDR was fitted to -YR at Beauvais; a replay of this followingthe aircraft's flight to Plymouth showed no problems with thedata. Subsequently, a number of additional readouts from thisaircraft have been analysed without difficulty.

Description of the rudder system

The commander and co-pilot's rudder pedals are connected, viarods and bellcranks, to a duplicated cable system under the floor. The two sets of rudder pedals are linked by an interconnect strut. The cables come together at a mixing quadrant approximately halfwayalong the fuselage, from which a single cable system runs to therudder input quadrant in the fin. A rod from this quadrant formsthe input to a summing lever assembly, which also takes inputsfrom the (electric) trim actuator and autopilot rudder servo. The latter component also serves as the yaw damper actuator andthe arrangement of the linkage is such that yaw damper/autopilotinputs to the rudder are not fed back to the rudder pedals. However,trim operation does result in rudder pedal movement. The summinglever assembly also incorporates a feel spring assembly, consistingof two springs, which provides artificial feel to the rudder pedals. Two spring strut assemblies connect the summing assembly outputlevers to each of two hydraulic actuators, which in turn are attachedto the rudder. The spring struts each have an associated camand microswitch assembly such that, in the event of a jam in anactuator or its linkage, the resultant cam motion causes illuminationof the corresponding RUD 1 or RUD 2 powered flight control shut-offswitch light on the glareshield. When the switch is pushed tothe Off position, the jammed system is depressurised and the pressurein the serviceable system is doubled to 3000 psi.

Finally, the rudder is equipped with a gust damper. This consistsof a hydraulic cylinder and piston assembly, and has an internalspring loaded valve which opens when aircraft hydraulic systempressure is applied, thus allowing fluid to transfer from oneside of the damper piston to the other during normal rudder movement. When system pressure is removed, the valve closes and the unitreverts to damper mode.

Examination of the aircraft

The airline's engineering personnel examined the aircraft at Beauvaisand after finding no fault with the rudder system, cleared theaircraft for a non-revenue flight to Plymouth, which was the mainengineering base. The rudder control system was then subjectedto a detailed examination, with the AAIB in attendance.

Consideration of various aspects of the system design in relationto the symptoms, ie the restricted/jammed pedals, ought to haveprovided an indication as to the likely location of the problem. For example, in the event of a complete mechanical jam involvingthe hydraulic actuators, the gust damper, or even the rudder itself,the rudder pedals would still be capable of being moved, althoughthis would simply deflect the feel springs. Furthermore, an actuatorjam would cause a RUD 1 or RUD 2 caution light to illuminate. The absence of any such indications suggested that there wasno problem with either the actuators or the hydraulics system. Additional confirmation of hydraulic system integrity and freedomfrom mechanical jams in this area was provided by the fact thatthe autopilot remained engaged, with the aircraft responding toinputs. It was therefore concluded that the restriction or jamhad probably occurred upstream of the summing lever/feel springassembly.

The trim system was apparently effective, as the aircraft respondedto small trim inputs, with confirmation provided by the trim indicator. However, the latter is signalled by a potentiometer

within thetrim actuator, as opposed to movement of the rudder. In the eventof a 'rigid' mechanical jam, the trim actuator output rod simplydeflects the feel springs, with no output from the summing leverassembly to the hydraulic actuators. (This was confirmed by pinningthe cable quadrant immediately ahead of the summing lever assemblyand operating the trim system). Subsequent to the incident, thecommander could not be certain as to whether any rudder pedalmovement occurred as a result of trim operation. The fact thatthe aircraft responded to trim inputs indicated that the trimsystem was operational. However, actual rudder movement was likelyto have been small and it was possible that the trim actuatorachieved this movement by a combination of limited system movementagainst the jam and localised cable stretch.

The examination at Plymouth consisted of a complete visual inspectionof the system, which was achieved by removing all external accesspanels, together with the seats and floor panels. The only noteworthyfeature found was a contact mark made by the end of one of thefeel springs on the summing lever mounting bracket. It was foundthat the spring end would almost contact the bracket if the rudderpedals were held in the neutral position with full left trim applied:such a condition is unlikely to have occurred in flight. Howeverany actual contact, although undesirable, would have exerted aninsignificant force on the rest of the rudder system.

The cable tensions were checked and found to be satisfactory. Finally, one of the hydraulic actuators was changed, as a smallamount of free play was found on one of the valve input links,and the gust damper was also changed as a precaution. The aircraftwas then released back into service.

On 2 June another rudder restriction occurred, which was describedas "rudder operation very stiff at high speed, [togetherwith] more than usual rudder force required during landing phase". After an otherwise uneventful landing at Newcastle, an inspectionagain failed to find any defect in the rudder system. By thistime, the airline had acquired a spare summing lever/feel unitand this was fitted to the aircraft before it was returned toservice. However, two days later "more force than usual"was reported to have been required on the rudder pedals at lowspeed whilst on approach to Bristol. As in the previous incidents,no fault was found on the ground and so the aircraft was onceagain cleared for a flight to the maintenance facility at Plymouthfor further investigation. On this occasion, the cables wereloosened so that they could be slipped off the pulleys and quadrants. This enabled an assessment to be made as to whether the latterwere able to move freely on their bearings. No problems werefound, apart from some minor binding of a 'paxolin' guide pulleyagainst a sheet metal diaphragm.

Consideration was given to the possibility of environmental factors,such as ice, being responsible for the restrictions, despite thefact that the aircraft was not known to have flown through significantprecipitation prior to any of the incidents. The summing lever/feelunit that had been removed from the aircraft at Newcastle wasplaced in a freezer for two hours in order to establish whetherthe component was affected by frozen moisture within the bearinggrease. It was found that the unit operated normally on removalfrom the freezer. However, during the examination of the feelunit it was noted that the springs differed in appearance in thatthe coils of one of them were 'opened out' at one end. Referenceto the aircraft manufacturer indicated that this was a dual-ratespring, the other being single-rate. This condition was likelyto have existed since the unit had been manufactured, and probablyresulted from a spring vendor supply problem. The result of thedissimilarity would have been slightly different pedal forceseither side of the neutral position, although these had clearlynot been detectable to the extent that pilots had made any comment.

The cables aft of the mixer quadrant were replaced as a precaution,although in fact no fault was found with the existing cables. The hydraulic actuator that had not been changed following theinitial incident was also replaced at this time, and the aircraftwas once again returned to service.

The aircraft operated normally until 19 June, when a further incidentof stiff rudder pedals occurred, once again during an approachto Bristol. Yet again, the problem could not be reproduced onthe ground. Having already replaced so much of the system, itwas decided to disassemble the rudder pedal linkages beneath theflight deck floor, ahead of the cable run. It was during thisoperation that the bearing bushes at the base of the commander'sleft rudder pedal were found to be badly worn. A diagram of thearea is presented at Figure 1 where it can be seen that the verticallyorientated tubes that carry the pedals are welded to short, horizontalsections of tube. The bushes are inserted into the ends of thelatter, with the assembly rotating on a steel pivot shaft attachedto the aircraft structure. The shaft also carries two brake controllevers. It was noted that, under hand pressure, the bearingsfelt "tight" in comparison with the equivalent componentson the co-pilot's side, which were found to be in good condition.

The worn bushings were removed and new components inserted intothe ends of the tube. However, it was then found that the pivotshaft could not be inserted through both sets of bushings in therudder pedal tube, although it fitted easily into either end. Suspecting the tube was distorted in some way, the operator decidedto scrap the rudder pedal assembly and pivot shaft, which wasthen sent to AAIB for a detailed metallurgical examination.

The bearing bushes were found to be commercially available itemsmade from mild steel strip. The inner (bearing) faces were coatedwith sintered bronze, and this in turn was coated with a filmof lead-impregnated PTFE. It was found that the surface coatingon the bearings had worn non-uniformly into the bronze at intervalsaround the circumference, such that in the worst affected position,a total of 0.010 inch of PTFE and bronze had been worn away. In places the coating had been wiped into 'ridges'. The bearingsin the commander's right rudder pedal tube, and in the brake controllevers, were found to be in good condition. A photograph of oneof the worn bushes is shown at Figure 2.

The bushes had been an interference fit in the rudder pedal tube,the ends of which had been counterbored to a depth equal to thewidth of each bushing. Thus the inner edge of each bushing abutteda machined edge within the bore of the tube. When the counterboredsurfaces were measured at several locations, it was apparent thatthe counterbore axes were not aligned with each other. The degreeof misalignment could not be quantified due to the difficultyof establishing a datum, as the tube itself was neither roundnor straight. This accounted for the difficulty encountered whenthe pivot shaft was inserted into the rudder pedal tube followingthe bush replacement. There must have been a similar degree ofdifficulty in inserting the shaft into the tube with the originalbearings when the rudder pedal assembly was built by the aircraftmanufacturer. Forcing the shaft through the tube would have hadthe effect of pre-loading the assembly in a manner which tendedto straighten out the misalignment in the tube, and to bend thepivot shaft. This in turn would have led to high contact stressesbetween the bearing mating surfaces over part of the circumference,leading to excessive and uneven wear.

The pivot shaft outer surface was scored and worn to varying degreesin the locations occupied by the bearings, including the brakecontrol levers (see the photograph at Figure 3). The shaft wasplated with cadmium, a soft metal, and it was apparent that thishad been worn away, exposing the steel substrate in places. Inother areas it had 'balled up' and appeared to contain quantitiesof PTFE from the bearings. It is probable that material generatedas a result of the wear in the bearings

was responsible for theintermittent restrictions experienced in the rudder system. The'balling up' or 'galling' process would have caused lumps of materialto have become wedged between the moving surfaces, thus hinderingrelative motion until such time as they migrated out of the endsof the bearings. Although it seems unlikely that such a processcould have resulted in a complete jam, it is possible that pilotscould perceive a restriction as a jam, bearing in mind there wouldhave been an understandable reluctance to apply excessive pressureon the pedals in case the restriction was suddenly overcome, therebycausing a large and sudden rudder deflection.

The use of two soft materials, in this case the bronze/PTFE andthe cadmium plating in a bearing, was considered to be dubiousengineering practice due to the possibility of galling. The ruddercontrols of the Dash 8's predecessor, the Dash 7, utilised a similardesign concept although the components are not interchangeable. It was noted that the pivot shaft on this aircraft was chromiumplated, which provides a smoother and harder bearing surface.

It was concluded that the series of incidents that occurred toG-BRYR probably resulted from a combination of the misalignedbearing recesses in the commander's left rudder pedal tube andthe soft cadmium plating on the pivot shaft. This would haveled to locally high contact stresses within the bearing, resultingin excessive wear and galling.

Previous occurrences

The aircraft technical records contained one other case of rudderpedal stiffness, which occurred on 30 September 1996. Noassociated fault was found and there was no reported recurrenceuntil the Paris incident on 8 May. The aircraft manufacturerstated that they were not aware of any similar incidents associatedwith the Dash 8 series of aircraft, of which there are currentlyin excess of 450 in service, which have accumulated more than7.8 million flight cycles. The lead aircraft has flown 44,500flight cycles, compared to approximately 11,200 achieved by G-BRYRat the beginning of May 1997.

Future action

Notwithstanding the absence of similar incidents on other aircraft,the manufacturer is proposing to change the surface finish onthe pivot shaft from cadmium to chromium. The modified componentswill be incorporated on new production units and will be interchangeablewith the existing part. In addition, the manufacturer has issuedan In-Service Activity Report (ISAR) which advises operators ofthe problems that occurred on G-BRYR, and requests that any similarexperiences be reported to them. The ISAR also suggests appropriatetroubleshooting action.

Postscript

On 21 September 1997 another Dash 8 aircraft, G-BRYI, belongingto the same operator, suffered an event in which the rudder pedalsjammed in the neutral position during a take-off roll at Bristol. The take off was aborted and as the aircraft decelerated through50 to 60 kt, the rudder pedals abruptly freed and operated normallythereafter. Subsequent investigation revealed that the commander'srudder pedal pivot shaft was worn in places, although the associatedbearing bushes appeared to be in better condition than those fromG-BRYR. In addition, some corrosion was found on some of thefeel unit components.

On 8 October 1997, another incident occurred to G-BRYR when rudderpedal stiffness was experienced whilst attempting to keep theaircraft straight during take off. This led to the take off

beingabandoned at 60 kt. The recently replaced pivot shaft on thecommander's side, which had achieved only 1082 hours since installation,showed evidence of rubbing, together with a 'dusty' deposit. The component was reinstalled after being polished to a smoothcondition.