INCIDENT

Aircraft Type and Registration:	Embraer EMB-145EU, G-EMBT
No & Type of Engines:	2 Rolls-Royce AE 3007/A1/1 turbofan engines
Year of Manufacture:	2001
Date & Time (UTC):	29 December 2006 at 2001 hrs
Location:	Bristol Airport
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 15
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	8,000 hours (of which 3,300 were on type) Last 90 days - 150 hours Last 28 days - 50 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

During the landing roll, in a strong crosswind, the aircraft's rudder hardover protection system (RHPS) tripped, which resulted in the loss of both rudder hydraulic systems and reversion to the rudder's mechanical mode. Despite the loss of hydraulic power to the rudder, the commander was able to maintain directional control using a combination of asymmetric braking and rudder. There was no fault found in the aircraft and no evidence of a rudder 'runaway'; high rudder pedal or brake pedal force application by the commander, or incorrectly adjusted pedal force microswitches, may have triggered the RHPS.

This report includes one Safety Recommendation to Embraer SA.

History of the flight

The aircraft was on approach to Bristol Airport after a flight from Edinburgh. During the first coupled ILS approach the commander became visual with Runway 27 at approximately 500 ft agl and took manual control. The last reported wind was a direct crosswind of between 23 and 27 kt; the aircraft's crosswind landing limit was 30 kt. During the final stages of the approach the commander estimated from his drift angle of approximately 15º that the crosswind was now beyond the limit, so he initiated a go-around.

During the second approach the commander became visual with the runway between 700 ft and 500 ft agl. After decision altitude ATC reported a crosswind of 31 kt. The commander decided to initiate another go-around but the next wind report was '30 kt across' so he continued the approach. The aircraft touched down on the runway centreline near the touchdown markers. He then applied heavy manual braking. At some point during the ground roll he started to lose directional control and had to apply a large rudder pedal input to correct it. At about the same time he felt that he had lost hydraulic assistance to the rudder. This was followed by a Master Caution warning and a 'RUDDER SYS 1-2 INOP' EICAS message. The commander reported that he was able to maintain directional control using asymmetric braking and he could not tell if the rudder pedals were having an effect. Once the aircraft had decelerated below 40 KIAS he was able to use the tiller to steer the aircraft and make a normal exit from the runway.

Post-flight engineering rectification consisted of cycling both rudder systems on and off. This resulted in the reactivation of both hydraulic systems and a return to normal hydraulic-assisted rudder operation.

Weather and runway surface conditions

The reported weather conditions at 1950 hrs (11 minutes before the incident) were: broken cloud at 400 ft, wind from 180º at 26 kt with gusts to 43 kt, light rain, visibility of 4,000 m and a temperature of 11ºC. The last runway surface condition report at 1923 hrs was 'Damp-Wet-Damp' indicating that the centre section of the runway was soaked but to a depth of less than 3 mm. A section of the runway, 300 m long, had recently been resurfaced and had not yet been grooved.

The subject of the runway resurfacing programme, and of two runway excursion incidents, involving an ATR and another EMB-145 on 29 December 2006, is covered by a separate AAIB investigation and the results will be published in a future AAIB Formal Report.

Rudder control system description

The rudder on the EMB-145 is split into two sections in tandem, forward and aft. The forward rudder is driven by the control system while the aft rudder is mechanically linked to the forward rudder and is thus deflected as a function of forward rudder deflection. The forward rudder is driven by two rudder actuators connected to a Power Control Unit (PCU). The PCU is commanded by the rudder pedals via control cables that run from the pedals in the flight deck to the PCU in the rear fuselage (see Figure 1). The rudder PCU is a dual hydraulic unit which is powered by two hydraulic systems at the same time. Each PCU hydraulic circuit controls the hydraulic power to one rudder actuator. Therefore, the rudder system is divided into Rudder System 1 and 2. Either system can be automatically or manually shut off. When both hydraulic systems are shut off the rudder can be operated directly through the mechanical controls. In mechanical mode the control forces are greater because the aerodynamic loads on the rudder are directly transmitted to the rudder pedals. If either Rudder System becomes inoperative a caution message is presented on EICAS. If both become inoperative the message 'RUDDER SYS 1-2 INOP' is displayed.

During normal operation both systems are powered at speeds below 135 KIAS. Above 135 KIAS, Rudder System 1 is automatically shut off. If Rudder System 2 hydraulic power supply fails above 135 KIAS, then Rudder System 1 automatically takes over.

The maximum rudder deflection on the ground is ±15º and in the air is ±10º. The corresponding rudder pedal deflection on the ground is ±9º and in the air is ±6º.

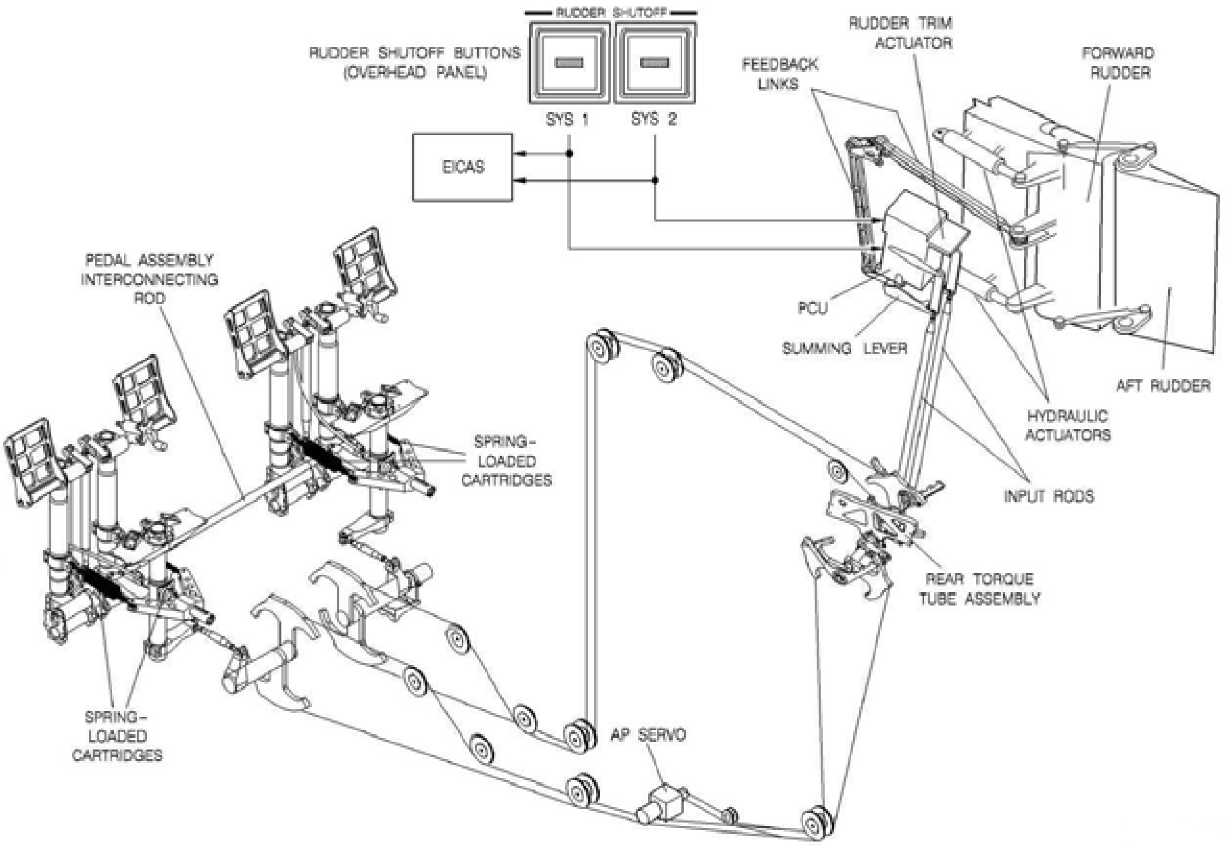

Figure 1

Embraer 145 Rudder System Schematic

Rudder hardover protection system (RHPS)

The rudder hardover protection system is designed to remove hydraulic power to the rudder PCU in the event of a rudder runaway (ie uncommanded rudder deflection). RHPS will automatically shut off both Rudder System 1 and 2 if the following three conditions are met simultaneously:

1. Rudder pedal force greater than 130 lbf (59 kgf)
2. Rudder deflected greater than 5º (±1º) in the direction opposite to the applied pedal force
3. Both engines operating (based on engine N_2 greater than 56%)

Condition 3 ensures that RHPS is disabled in the event of an engine failure. RHPS will indirectly trigger the 'RUDDER SYS 1-2 INOP' message on the EICAS once the pressure switches sense the loss of pressure.

The 130 lbf pedal force is measured by a spring-loaded cartridge. There are four cartridges – one attached to each rudder pedal. The cartridge contains a spring and microswitch. When a pedal force in excess of 130 lbf is applied, the spring compresses sufficiently to release the microswitch, which sends a signal to the RHPS.

A rudder deflection in excess of ±5º is detected indirectly by a pair of microswitches mounted on the pilot's pedal assembly stop. One microswitch is triggered when the rudder deflects more than 5º to the left and the other microswitch is triggered when the rudder deflects more than 5º to the right. These microswitches send their respective signals to the RHPS.

Brake system description

The EMB-145 has two main landing gears, with two wheels on each gear. Each wheel has a disk brake and an associated brake control valve which controls the hydraulic pressure to the brake. Normal braking is controlled by toe brakes on the rudder pedals. The anti-skid system controls the amount of hydraulic pressure applied by the pilots to the brakes. The anti-skid is designed to provide the maximum allowable braking effort for the runway surface in use, while preventing skidding. This is accomplished by measuring each wheel speed. If one wheel speed drops significantly below the aircraft's average wheel speed, a skid is probably occurring, so brake pressure is relieved to the appropriate wheel brake until its speed recovers.

The anti-skid system does not apply pressure on the brakes, but only relieves the pilot-commanded pressure to avoid a skid. Therefore, in order to steer the aircraft using asymmetric braking, during a heavily braked landing, the pilot needs to reduce brake pressure on the side opposite to the direction of turn, instead of applying pressure to the desired side. The pedal force required to command maximum braking is 61.9 lbf, and is achieved when the brake pedal reaches its maximum deflection of 15º.

Flight Data Recorder

The FDR was removed from the aircraft and downloaded by the operator. A copy of this data was sent to the AAIB for analysis. The download contained just over 25 hours of operation, recording parameters at a rate of 128 words per second (wps).

The FDR identified the aircraft on both approaches to Bristol Airport, the second approach showing the aircraft heading slightly to the left of Runway 27. No drift angle or aircraft position was recorded but this heading suggests that the aircraft was positioned with respect to the crosswind conditions. The heading increased as the aircraft neared the runway, coincident with right rudder pedal input and a left roll input on the control column. The aircraft touched down at 19:59:47 (Figure 2) with an airspeed of 124 kt, heading of 266º, the rudder pedals deflected 4.6º to the right and control wheel 37º to the left (maximum achievable is 40º).

The FDR shows that, once on the ground, the ground spoilers deployed, braking was applied and further rudder pedal deflections were applied, predominantly to the right. Longitudinal deceleration reached its greatest value around five seconds after touchdown. Throughout the following five seconds, this deceleration decayed from -0.37 g to -0.16 g, indicating that the level of aircraft retardation was reducing. The engine N_2 speed remained between 62% and 67% on both engines, consistent with IDLE power selection (the aircraft was not equipped with thrust reversers).

At 20:00:01, a master caution was triggered with the aircraft at a groundspeed of 79 kt. Based on the pilot's report, this master caution was probably triggered by the RHPS. According to the manufacturer, the 'RUDDER SYS 1-2 INOP' message requires a 3 second confirmation time. The message should appear at the same time as the master caution. The master caution is recorded by the FDR every second so, in this case, the event which triggered it would be between three and four seconds before 20:00:01.

Figure 2 confirms that, during this 4 second period, the minimum rudder pedal deflection was 4º, corresponding to 6.7º of right rudder deflection.

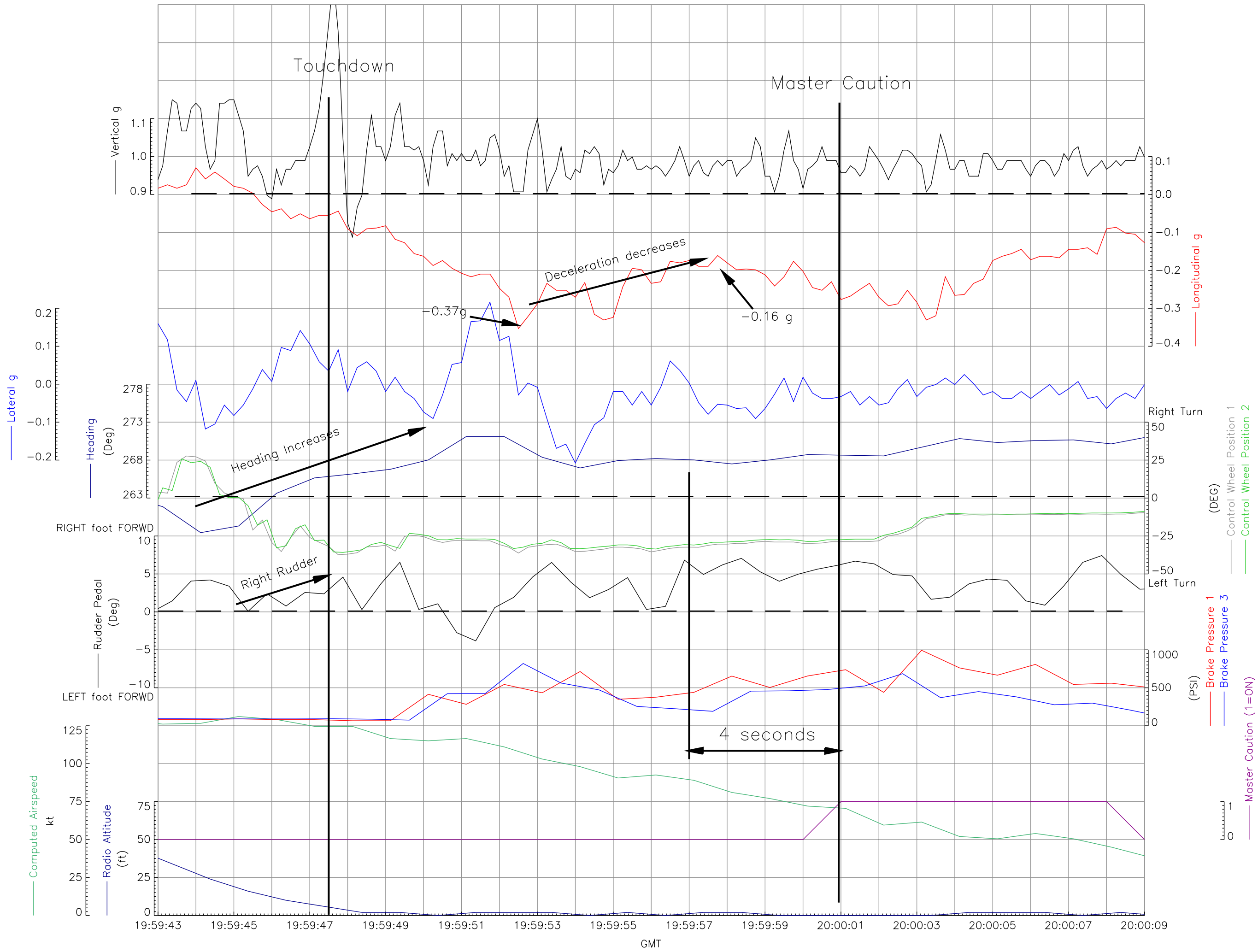

Figure 2

G-EMBT FDR Parameters

Previous incidents of dual rudder system shutoff

The aircraft manufacturer reported that they were aware of previous occurrences of the 'RUDDER SYS 1-2 INOP' message during landing. They believe that these were most likely caused by the pilot applying 'excessive' force on the rudder pedals (that is, force greater than that required for maximum braking) while attempting to brake – particularly in strong crosswinds – although these events were difficult to confirm with the limited parameter set of the Flight Data Recorder (FDR). They have also had reports of dual system shutoff in the air, usually during approach in strong turbulence, where they believe the pilot most likely applied rapid opposite pedal control inputs.

The operator of G-EMBT experienced a similar incident on another EMB-145 (G-EMBI) on 9 January 2007 while it was landing at Birmingham airport. According to the operator the aircraft experienced a 'RUDDER SYS 1-2 INOP' EICAS message during landing and directional control was maintained using differential braking. Engineers were unable to find a fault with the aircraft, but it was noted that there was a strong crosswind at the time of the landing. The FDR data from this event showed similar characteristics to that from G-EMBT.

Analysis

The 'RUDDER SYS 1-2 INOP' message was triggered below 135 KIAS and was accompanied by the pilot's sensation of a loss of rudder assistance. These factors indicate a genuine shutoff of both rudder hydraulic systems rather than a sensor or indication problem. Both systems were easily reset by engineers on the ground, which indicates that it was a transitory event triggered by specific conditions rather than a permanent failure of both systems. Therefore, RHPS was the likely cause of the dual rudder system shutoff.

Of the three conditions required to trigger RHPS, two conditions were apparent most of the time. First, the N_2 on both engines was above 56% during the entire ground roll. Second, the rudder pedal deflection was 3º or greater for a large portion of the ground roll which corresponds to 5º, or greater, of rudder deflection. The third condition, pedal force, is not known because it was not recorded by the FDR.

The Master Caution associated with the RHPS trip occurred at 20:00:01 hrs. According to the aircraft manufacturer there is a 3 to 4 second delay time between RHPS trip and Master Caution trigger. Therefore, the probable time of RHPS activation was between 19:59:57 and 19:59:58. During this period the pedal was deflected by more than 3º to the right, which means that the rudder was deflected by more than 5º to the right. So, during this period the left pedal spring cartridge microswitch probably tripped in order to trigger RHPS. This would normally only occur as a result of a 130 lbf force being applied to the left pedal. It is possible that the pilot was applying a heavy force to both pedals as a result of his attempts to brake and slow the aircraft. A component of brake pedal force application is detected by the rudder pedal force microswitch; for example, a 163 lbf force applied to the brake pedal will be sensed as 130 lbf by the pedal force microswitch. During this same period (19:59:57 to 20:00:01) the aircraft's deceleration rate reduced to a minimum of -0.16 g, after a maximum deceleration of -0.37 g. However, the 'Brake pressure 1' FDR parameter had not reduced significantly so this loss of deceleration was probably caused by reduced friction on the wet and ungrooved centre section of the runway. This loss of deceleration might make a pilot increase the force applied to the brake pedals. Unfortunately the brake pedal pressure parameters on the FDR do not indicate brake pedal force or show whether asymmetric braking was being used, because the brake pressures were probably reduced by the anti-skid system.

It is possible that one of the pedal spring-loaded cartridges was incorrectly adjusted and thus triggered at a force lower than 130 lbf of pedal force. The only accurate method for testing the spring cartridge is to remove it from the aircraft and bench test it in accordance with the component maintenance manual instructions (CMM 27-25-01). The aircraft operator plans to carry out this test during G-EMBT's next base maintenance check.

The low sample rate of the recorded pedal position and brake pressures, combined with the lack of recorded rudder position, rudder pedal force and brake pedal force, make it impossible to determine exactly what caused the RHPS to trigger. However, dual system shutoff had not recurred on G-EMBT (as of 14 September 2007) and therefore it is most probable that this event was caused by heavy pedal forces in the unusually strong crosswind and slippery runway surface conditions.

A landing in a strong crosswind, with slippery runway conditions, is a time when maximum rudder authority and control is desired in order to maintain directional control. It is highly undesirable to have a system in which the rudder's hydraulic assistance may drop out as a result of a pilot's energetic attempts to control and slow the aircraft. Therefore, the following AAIB Safety Recommendation is made:

Safety Recommendation 2007-112

It is recommended that Embraer SA should review and modify the design of the RHPS (rudder hardover protection system) in the EMB-145, to prevent unnecessary RHPS triggering.

Safety actions

Subsequent to this incident, and the AAIB draft report, the National Civil Aviation Agency (ANAC) in Brazil and the manufacturer, Embraer, have been actively reviewing this incident, with a view to issuing an Operational Bulletin to operators and potential design improvements.

Embraer has stated that they will be issuing a revised Component Maintenance Manual (CMM) procedure for testing the spring-loaded cartridges, to ensure that activation of the microswitches occurs within a specified range of loading.