AIRCRAFT ACCIDENT REPORT

AIRCRAFT RUNWAY EXCURSION WHILE LANDING ROLL
JEJU AIR
DHC-8-402
HL5256
GIMHAE INTERNATIONAL AIRPORT
12 AUGUST 2007

04 November 2011

AVIATION AND RAILWAY ACCIDENT INVESTIGATION BOARD
MINISTRY OF LAND, TRANSPORT AND MARITIME AFFAIRS
REPUBLIC OF KOREA
According to the provisions of the Article 30 of the Aviation and Railway Accident Investigation Act of the Republic of Korea, it is stipulated;

*The accident investigation shall be conducted separately from any judicial, administrative disposition or administrative lawsuit proceedings associated with civil or criminal liability.*

And in the Annex 13 to the Convention on International Civil Aviation, Paragraphs 3.1 and 5.4.1, it is stipulated as follows;

*The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability. Any investigation conducted in accordance with the provision of this Annex shall be separate from any judicial or administrative proceedings to apportion blame or liability.*

Thus, this investigation report issued as the result of the investigation on the basis of the Aviation and Railway Accident Investigation Act of the Republic of Korea and the Annex 13 to the Convention on International Civil Aviation, shall not be used for any other purpose than to improve aviation safety.

In case of divergent interpretation of this report between the Korean and English languages, the Korean text shall prevail.
Korea Aviation and Railway Accident Investigation Board (ARAIB) is a government organization for independent investigation of aviation and railway accident, and the accident investigation shall be carried out based on the Aviation and Railway Accident Investigation Law of the Republic of Korea and the Annex 13 to the Convention on International Civil Aviation.

The objective of accident or incident investigation of the Korea Aviation and Railway Accident Investigation Board is not to apportion blame or liability but to prevent accidents and incidents.

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Appendix
Appendix 1 The comments of TSB Canada to the Draft Final Report of Flight 502
Appendix 2 The comments of the NTSB to the Draft Final Report of Flight 502
Aircraft runway excursion while landing roll

Jeju Air, Republic of Korea
Bombardier Aerospace
DHC8-402
HL.5256
The Gimhae International Airport, Runway 18R,
Latitude: N35° 11′ 38.72″, Longitude: E128° 56′ 14.68″
12 August 2007, at about 09:38 (Korea Standard Time1))

Synopsis

On 12 August 2007, about 09:38, Jeju Air Flight 502 (DHC-8-402, HL.5256 hereinafter referred to as "Flight 502") was on a scheduled flight from the Jeju International Airport (hereinafter referred to as "Jeju Airport") to the Gimhae International Airport (hereinafter referred to as "Gimhae Airport").

As Flight 502 touched down on runway 18R, directional control was lost and the aircraft departed the left side of the runway and collided with a concrete drainage ditch. Four (4) passengers were injured and the aircraft sustained substantial damage as a result of this occurrence.

The ARAIB determines that the cause of the runway excursion of the Flight 502 was that 「The rudder failure was not recognized by the pilots during flight and as well as during landing roll.」.

Contributing to this accident was that 「① the rudder was failing to respond to the pilots' rudder pedal input and ② After departing from the runway, no appropriate alternative measure was taken to control the aircraft direction.」

1) Unless otherwise noted, all time stated in this report represents the Korea Standard Time.
1. Factual Information

1.1 History of Flight

On 12 August 2007, at about 09:38, Jeju Air Flight 502, which departed from the Jeju Airport to the Gimhae Airport with 2 pilots, 3 flight attendants and 74 passengers on board. After touched down on the runway 18R, directional control was lost and the aircraft departed the left side of the runway and collided with a concrete drainage ditch.

As a result of the accident, the aircraft sustained substantial damage and 4 passengers were injured. Flight 502 was a scheduled domestic passenger aircraft operating from the Jeju Airport to the Gimhae Airport. At the time of accident, the aircraft was operating on the instrument flight rules under the visual meteorological condition.

On 12 August 2007, about 05:20, the flight crew showed up and prepared for the flight of Gimpo/Jeju/Gimhae/Gimpo at the crew lounge of the Gimpo Airport. For a flight duty of the flight 103 (Gimpo to Jeju section), the flight crew departed from the Gimpo Airport at about 06:50 and arrived at the Jeju Airport at about 08:15.

For the flight 502 (Jeju to Gimhae section), they departed the Jeju Airport at 08:49. While the aircraft passing through an altitude of 9,500 feet, RUD CTRL caution lights and #2 RUD HYD caution lights illuminated. Accordingly, the pilots followed and carried out the procedures of QRH (Quick Reference Handbook).

Referring to the pilots’ statements, #2 RUD HYD caution lights illuminated constantly during the flight; however, RUD CTRL caution lights illuminated intermittently. As it reached a cruising altitude of 15,000 feet, the pilots notified the condition of malfunctions and actions taken according to the QRH to a mechanic stationed at the Gimhae Airport.

The pilots received a clearance from the Gimhae Approach Control for ILS RWY 36L then circling approach to RWY 18R. At the final approach course of ILSDME RWY 36L, after visually identifying the runway, the captain received a clearance for conducting a circling approach on initial contact with the Gimhae Control Tower.

2) According to the pilots, the lights illuminated when the aircraft reached an altitude between 6,500 feet to 7,000 feet.
3) Refer to the factual information 1.18.2 QRH
Referring to the pilots’ statements and the data of Flight Data Recorder (hereinafter referred to as "FDR"), from 09:33:57 until 09:34:03 (for the time of turning from the final approach course of ILS to enter a downwind for circling approach), the caution lights of Elevator Feel, RUD CTRL, Pitch Trim and other warning lights illuminated on the caution and warning lights panel. However, the pilots stated that they couldn’t recall all the caution lights illuminated at the time, and did not take any measures considering the illuminating lights as "nuisance." 4)

The first officer who was a pilot flying continued the circling approach, and aligned his aircraft with the runway 18R on the final approach course. After aligned with runway 18R, the aircraft heading was at 178 degrees magnetic. At that time, according to the ATIS information, the wind direction/speed was 130 degrees at 13 knots gusting to 18 knots, ceiling 4,000 feet, and it was mostly cloudy.

According to FDR record, at 09:38:08, about 2 feet above the runway, the rudder started to be applied to the right side. Concurrently, the pilot moved the control wheel to the right. At that time, the aircraft heading changed from 174 degrees to 175 degrees.

At 09:38:09, the main landing gear of the aircraft touched down on the runway, and the aircraft heading was at 174 degrees. From the point where the main landing gear touched down, the aircraft continued to drift left into the wind. Initially the pilots applied right rudder in an attempt to maintain runway center-line. Rather then apply left wing down, the control wheel input was toward the right.

According to the Cockpit Voice Recorder (hereinafter referred to as "CVR"), at 09:38:11, as the captain kicked onto the rudder pedal and said, "Why, why, Ah?" and the first officer replied, "it doesn’t respond." 5)

At 09:38:13, the nose landing gear touched down, and the pilots started to apply brakes. At 09:38:15, all of sudden, the deceleration rate dropped. According to the tire marks, the aircraft departed the left edge of the runway at 3,500 feet from the end of runway. At 09:38:19, the groaning sound of one of the pilots, "Uh. Uh" was recorded on CVR.

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4) It was not actual discrepancies in the aircraft; it was rather false defects which appeared momentarily due to computer errors or data that was stored in the computer memory
5) The rudder
After 09:38:15, the heading direction of the aircraft was increasing to the left. According to CVR, at 09:38:25, there was a recorded voice of the captain, "Oh, no, Gosh," and then at 09:38:27, with a sound of crash, the captain’s screaming sound, "Ah!" was recorded. The aircraft collided into a concrete drainage ditch, which is located 340 feet away from the centerline of the runway 18R and 4,600 feet away from the end of runway, and then it came to rest.

When the aircraft stopped in the concrete drainage ditch, the pilots shut off the right engine, declared emergency to the air traffic control tower, and instructed the passengers to perform emergency evacuation.

### 1.1.1 Reconstruction of Landing and Landing Roll According to FDR

At 09:38:06, about 2 feet above the runway 18R, while the first officer was flying the aircraft, the captain started to apply the rudder pedal to the right to align the aircraft heading with the runway. At the same time, the pilots’ control input was to the right, and the aircraft heading changed to 175 degrees from 174 degrees.

At 09:38:09, the main landing gear touched down in the vicinity of the runway centerline. At that time, the air speed was 118–120 knots, the bank attitude of the aircraft was at about 1 degree to the right, the aircraft heading was at 174 degrees, that is to say, it was turning left into the wind. When the main landing gear touched down, the heading direction of the aircraft kept facing to the windward direction, that is to say it was turning counterclockwise. On the contrary, the pilots’ rudder pedal inputs were on the right, the control inputs were increasing clockwise. According to FDR record, there was no record of a hard landing or extraordinary attitude of the aircraft.

Approximately 4 seconds after the main landing gear touched the ground, at 09:38:13, the nose landing gear touched down on the runway, and the pilots’ rudder pedal pressure was maintained at its maximum to the right all the way till 09:38:14. At 09:38:14, both main wheel brakes were applied. At that time the aircraft heading was at 171 degrees. When the brakes were applied, the propeller pitch changed to reverse pitch and its RPM began to increase simultaneously.

At 09:38:15, the aircraft departed the runway. At that time, the aircraft heading was at 172 degrees, and the brake pedal pressure was symmetric. After the aircraft departed the runway, from 9:38:16 until 09:38:18, there was a sharp decrease in the control input
and rudder input however, it recovered at 09:38:21.

At 09:38:27, the movement of the aircraft stopped completely. From the time it departed the runway and till it stopped completely, the aircraft heading changed from 172 degrees to 158 degrees.

1.1.2 The pilot's Statements

On 12 August 2007, at about 08:37, Flight 502 started both engines after boarding the passengers. After completing the takeoff procedures normally, the aircraft took off from runway 24R. At that time, the first officer was flying the aircraft, and the captain monitored it.

The aircraft took off normally and was cleared to fly directly to the airway by the Jeju Departure Control. While climbing to an altitude of 15,000 feet as following the ATC instruction, #2 RUD HYD and RUD CTRL caution lights illuminated, and the pilot carried out QRH procedures accordingly.

QRH procedure was relatively simple that there was no need for the pilots to take any actions for #2 RUD HYD, and just maintain the aircraft speed of 200 knots or less for RUD CTR. The captain notified this information to the company Jeju station office, and then he asked them to forward the information to the maintenance person of the Gimhae Airport. Thereafter, Flight 502 continued to fly to the Gimhae Airport.

While listening to Gimhae ATIS information, the captain realized that the wind was 130 degrees at 13 knots gusting to 18 knots. He informed the Gimhae Approach Control that he had the runway in sight about 10 miles out as conducting ILS final approach, and then he was transferred to the Gimhae Tower.

The air traffic controller of the Gimhae Tower cleared him for a circling approach and requested to report at the downwind leg. At Eight (8) miles to the runway, after setting the Landing gear down, flaps at 15 and the condition lever at Max, while turning to make a downwind for circling approach, several caution lights illuminated on the upper left side of the caution and warning light panel illuminated. However, considering them as nuisance, the captain allowed the first officer to continue flying for approach and the landing.
After receiving landing permission from the local traffic controller, the aircraft touched down on the center of the runway. While touching down on the runway, the captain noticed that the aircraft was drifting toward the left side of the runway. Thinking that it wasn’t manipulated by the first officer, the captain kicked onto the right side rudder in an attempt to bring the aircraft back to center-line, however the aircraft did not respond to the command. Although the brakes were applied, likewise, there was no movement or reaction.

As the aircraft kept on drifting to the left side of the runway, there was a drainage ahead all of sudden. To stop the aircraft, brakes were applied but the aircraft impacted the drainage located in the in-field area between runways 18R and 18L.

### 1.2 Injuries to Persons

<table>
<thead>
<tr>
<th>Injuries</th>
<th>Crew</th>
<th>Passengers</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Serious</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minor / None</td>
<td>0 / 5</td>
<td>4 / 70</td>
<td>0</td>
</tr>
</tbody>
</table>

### 1.3 Damage to Aircraft

As a result of the accident, the aircraft sustained serious damage. As shown in [Photo 1], the left wing of the aircraft mostly sustained major damage (near wing station 436). Although the wing was bent upward where the aileron and flap meet, the leading edge did not receive any noticeable impact damage.
Since the left wing was tilted, fuel was leaking out of the side of the aircraft; however, no exterior damage was found to its fuel tank. The horizontal and vertical stabilizers which include the elevators and rudder, auxiliary engine inlet port, and the APU exhaust did not appear to be damaged, however, the surface of the aft cargo compartment was damaged.

As shown in [Photo 2], the right strake did not sustain damage, however, the lower left aft fuselage strake broke off. Ground impact damage started at the nose cone and continued along the lower left side of the fuselage until aft of the cargo compartment, the impact damage penetrated the pressurized fuselage in multiple areas.
As shown in [Photo 3], the landing gear was all remained down, and the right main landing gear did not appear to be damaged.

[Photo 3] Right Main Landing Gear

As shown in [Photo 4] and [Photo 5], due to the impact of the drainage collision, the left main landing gear and the nose landing gear were pushed backward and sustained serious damage. The nose landing gear and its structure box sustained severe impact damage. Also, the nose landing gear door actuation hydraulic lines were damaged resulting in system 2 hydraulic fluid loss. The left main landing gear had pushed backward, and both left side main landing gear doors were torn off.

[Photo 4] The Nose Landing Gear
The related landing gear actuation hydraulic lines were ruptured resulting in hydraulic fluid loss from the number 2 system. All of the tires of nose landing gear and the main landing gear were inspected and their pressures appeared to be normal. There were no ruptures or scuff marks on all of the main landing gear tires.

The number one hydraulic system reservoir contained 5 quarts of fluid; however, the number 2 hydraulic system reservoir did not contain any fluid since it all leaked due to the damaged nose landing gear and left main landing gear hydraulic lines. The left and right main landing gear brake units were inspected, and their wear indicators were within the limits.
As shown in [Photo 6] and [Photo 7], the left hand propeller sustained severe damage due to ground impact; however, the right hand propeller did not sustain any damage.

[Photo 7] The Right Hand Propeller

1.4 Other Damage

There was no other damage due to the accident.

1.5 Personnel Information

Flight crew consists of one captain and one first officer, before this accident, on 19 June 2007, they had an experience of flying together for Jeju-Gimhae flight.

Three days prior to the accident, on 9 August, the captain flew to Jeju Airport and spent a night there. And then he flew back to Gimhae Airport and had a two-day break. As from 9 August, when was three days prior to the accident, the first officer had performed 10 legs of flight duty.

1.5.1 The Captain

The captain (age 50) joined the Jeju Air as an experienced pilot on 30 March 2006. Before joining the Jeju Air, he had worked for the Asiana Airlines as a captain of B737 and B747 aircraft.
He held a valid Airline Transport Pilot License, a type rating for DHC-8-402 issued on 7 June 2006, and a first class Airman Medical Certificate issued with no particular limitation on 11 June 2007.

The captain had accumulated a total of 8,655 hours of flight time, 799 hours 37 minutes for the latest one year, 202 hours 55 minutes for the last 90 days, and 71 hours 36 minutes for the last 30 days.

The results of the captain’s blood test and breathalyzer test were negative, there were no sign of drugs and no alcohol was detected. According to the captain, while taking a two-day break prior to the flight, he had done some light exercise nearby his residence and had a plenty of rest.

1.5.2 The First Officer

After graduating from college, the first officer (age 30) joined the Jeju Air as a first officer trainee through open recruitment. Prior to the employment at the Jeju Air, he had accumulated a total of 834 flight hours.

He held a valid Commercial Pilot License, a type rating of DHC-8-402, and a first class Airman Medical Certificate issued with no particular limitation on 30 November 2006.

Including military flying hours, the first officer had accumulated a total of 1,213 hours 35 minutes of flight time, 379 hours 35 minutes for the latest one year, 211 hours for the latest 90 days, and 67 hours 36 minutes for the latest 30 days.

For three days prior to the accident, the first officer made a total of 10 flight legs- 4 flight legs on 9 August, 4 flight legs on 10 August, and 2 flight legs on 11 August. The flight legs on 9 August and 10 August were all midnight flights, which were scheduled to land at the Gimpo Airport at 22:40.

The results of the first officer’s blood test and breathalyzer test were negative, there were no sign of drugs and no alcohol was detected.
1.6 Aircraft Information

1.6.1 History of the Aircraft

Flight 502 aircraft was a twin-engine turboprop aircraft built on 12 December 2006 by the Bombardier Aerospace in Canada. It was registered on 29 December 2006 and on the same day, the airworthiness certificate and the air operator certificate were issued by the Busan Regional Aviation Administration.

Flight 502 aircraft was equipped with two PW150A turboprop engines, which were manufactured by the Pratt & Whitney. On the day of accident, Flight 502 was on the second flight leg of Gimpo-Jeju. When referring to the flight maintenance log, there was no indication of any fault. The following [Table 1] and [Table 2] are general information concerning Flight 502 aircraft.

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>· State of Registry</td>
<td>Republic of Korea</td>
<td></td>
</tr>
<tr>
<td>· Registration Number</td>
<td>HL5256</td>
<td></td>
</tr>
<tr>
<td>· Operator</td>
<td>Jeju Air Corp., Ltd.</td>
<td></td>
</tr>
<tr>
<td>· Registration Number / Issue Date</td>
<td>2006-069 / 29 December 2006</td>
<td></td>
</tr>
<tr>
<td>· Airworthiness Certificate / Issue Date</td>
<td>IB06007 / 29 December 2006</td>
<td></td>
</tr>
<tr>
<td>· Total Flight Hours</td>
<td>1,645 hours</td>
<td></td>
</tr>
<tr>
<td>· Total Number of Cycles</td>
<td>1,876 times</td>
<td></td>
</tr>
<tr>
<td>· Last Inspection / Completion Date</td>
<td>A check / 26 July 2007</td>
<td></td>
</tr>
<tr>
<td>· Total Flight Hours since last inspection</td>
<td>143 hours</td>
<td></td>
</tr>
<tr>
<td>· Total Number of Cycles since last inspection</td>
<td>146 times</td>
<td></td>
</tr>
</tbody>
</table>

[Table 1] General Information of the aircraft

6) Manufacturer: Bombardier Aerospace, with manufacture serial number of 4141
### Airframe

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>The Bombardier Aerospace, Inc</td>
</tr>
<tr>
<td>Aircraft Type</td>
<td>DHC8-402</td>
</tr>
<tr>
<td>Serial Number</td>
<td>4141</td>
</tr>
<tr>
<td>Date of Manufacture</td>
<td>21 December, 2006</td>
</tr>
</tbody>
</table>

### Engine

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Pratt &amp; Whitney.</td>
</tr>
<tr>
<td>Model</td>
<td>PW 150A</td>
</tr>
<tr>
<td>Serial Number</td>
<td>PCE-FAO326/PCE-0327</td>
</tr>
<tr>
<td>Total Engine Hours</td>
<td>1,645/1,645</td>
</tr>
</tbody>
</table>

[Table 2] General Information of the Fuselage and the Engine

### 1.6.2 Aircraft Maintenance Information

The maintenance records of Flight 502 were reviewed. When referring to Flight Control Electronic Control System (hereinafter referred to as "FCECU"), there has been no record of failure ever since the aircraft was introduced and commenced its operation.

#### 1.6.2.1 Maintenance Records

Faults occurred in the control system and hydraulic system since the aircraft introduction and the maintenance works conducted to repair the damage caused by two events of lightning strike were as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Types of Faults</th>
<th>Details of Maintenance Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>08 Feb</td>
<td>Both Wing Aileron Tip Area Lightning Struck</td>
<td>Based on AMM05-50-21 P601, A/C INSP, Result NML CJU 08-FEB-07</td>
</tr>
</tbody>
</table>
## Details of the Major Maintenance Faults

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Mar</td>
<td>TC127 Ramp return, #3 HYD PUMP Caution LT still ON, When Pump C/B Trip is Off, then Pump is off status</td>
<td>STBY Contactor Box Contactor K24 Exchange P/N : 1096224-2 S/N : on-5031, off-4811</td>
</tr>
<tr>
<td>14 Apr</td>
<td>#2 HYD Case Drain Filter popped out</td>
<td>Replaced with new Filter</td>
</tr>
<tr>
<td>01 Jul</td>
<td>Lightning Strike during flight</td>
<td>Based on AMM 05-00-00, No defects on its surface and no functional flaws were found.</td>
</tr>
<tr>
<td>06 Jul</td>
<td>Lightning Strike Burn Damage Repair Assist</td>
<td>From 4 July, 20:00 to 7 July, 06:00 On the ground. Repair was done on the damaged part (EO 5300-00055/54)</td>
</tr>
<tr>
<td>13 Jul</td>
<td>#2 HYD PUMP Caution Light on both #2 SYSTEM ELEV ACTUATOR was changed</td>
<td>#2 HYD System Flushing all 3 filters were changed / Replaced with New EDP bleeding C/W</td>
</tr>
</tbody>
</table>

### 1.6.2.2 Fault Trend of Jeju Air DHC-8-402 aircraft

The related personnel of the Jeju Air had mentioned that while operating DHC-8-402 aircraft, they often found the faults, on and off, in the cockpit instruments. They also mentioned that they had often noticed the caution lights illuminated on for a while and then off.

Regarding these kinds of faults as nuisance, the Jeju Air only took simple measures against the faults. For instance, they just reset the system to remove its fault record, then they carried on their flight duties.

### 1.6.3 Flight Control System

According to the Flight Control System of DHC-8-402, the bank is controlled by ailerons, the pitch is controlled by elevator; and yaw direction is controlled by rudder.

The flight controls are operated in the cockpit providing control signals through cables to activate each of the hydraulic actuators to shift relevant control surfaces. As shown in [Figure 1], the rudder control system of DHC-8-402 activates the
rudder surfaces - this is when the rudder pedal is applied by the captain or first officer.

As shown in [Figure 2], the rudder pedal movements are transmitted to two power control units through the attached quadrant, cable, lever, push rod, and etc.,

The hydraulic actuator controls the rudder surfaces in proportion to the rudder pedal movements. Also the rudder control system can be operated by Automatic Flight Control System (AFCS) and the signals of the rudder trim actuator.

The hydraulic actuators, which is to control the rudder surfaces [Figure 3], are
installed in the vertical stabilizer rear spar\(^7\) and are connected to the midpoint of the fore rudder.

![Figure 3] Rudder Actuator

Number 2 hydraulic system provides hydraulic pressure to the upper hydraulic actuator, and number 1 hydraulic system provides lower hydraulic pressure to the lower hydraulic actuator.

In normal circumstances, two hydraulic actuators operate the rudder simultaneously, but if either hydraulic actuator loses hydraulic pressure or jams, then the remaining actuator controls the rudder.

There are caution and warning light panels in the cockpit to inform the pilot in case of a hydraulic system failure or bungee spring jam.\(^8\) When caution lights illuminate, the pilot is able to disengage the system failure by pressing push-off switch of rudder-1 or rudder-2.

The range of the rudder travel is determined by rudder pedal movement but is limited in travel depending on airspeed, wing flap position and flap selector lever. Airspeed information about limiting hydraulic pressure can be obtained from Air Data Unit (hereinafter referred to as "ADU"), and it can be achieved by the rudder Hinge

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7) The airfoil of the aircraft wing structure is referred to as spar structure.

8) It is a type of air suspension to alleviate from high pressure or shock.
Moment Limiter (hereinafter referred to as "HML") which is controlled by the FCECU.

HML is an internal part of the two rudder hydraulic actuators. It has a pressure unloading valve, a pressure control valve, and two pressure sensors connected mutually and regulated by FCECU.

1.6.4 Flight Control Electronic Control System

1.6.4.1 Flight Control Electronic Control Unit (FCECU)

As shown in [Figure 4], there are two independent cards installed in a box, which are in charge of the rudder control, elevator and spoiler control surface of the aircraft.

![Figure 4] FCECU Composition

The weight of the FCECU is 6.75 lbs, and each channel gets its power from the left and right side 28V DC bus. And its average power consumption is less than 75 watts, and it cools down by a convectional cooling method.

The normal operating temperature range of the FCECU is from -15 degrees Celsius to 55 degrees Celsius, and at 71 degrees Celsius, it is able to operate for a short period of time.

FCECU is connected to the airframe structure in such a way that it is to protect from static electricity which may be caused by lightning, electromagnetic interference or
FCECU performs following functions: pitch trim for the aircraft control, pitch feel, limit pressure entering rudder actuator, lift dumping spoiler control, outboard spoiler inhibition at high speed, flight control surface indication, and built-in test.

As shown in [Figure 5] and [Figure 6], FCECU is composed of left channel (or channel 1) and right channel (or channel 2). Each channel receives signals independently and operates the rudder hydraulic actuator, and each of them is internally cross linked to exchange information about defects.

FCECU limits the movement of the rudder with the airspeed, and depending on the flap position, pressure control valve is controlled. It makes a comparison between two channels, checks overpressure and underpressure, and monitors conflicting information from each channel.

If one of the two channels experiences malfunction, the remaining channel performs a redundancy function and has the caution and warning lights illuminate.

[Figure 5] FCECU Left Channel
1.6.4.2 Rudder Hinge Movement Limiter

Each hydraulic rudder actuator is allocated with each HML and is linked to the corresponding FCECU. With the corresponding pressure sensors, which is to monitor deficient pressure, it regulates hydraulic pressure by using a dual shut-off valve and dual pressure control valve. Hydraulic pressure is needed for the rudder control and it is determined by the state of the air speed and the rudder actuator.

If one of the FCECU channels fails, that particular channel will deenergize the shut-off valve, and sets the pressure control valve input to zero. In this case the rudder is able to operate normally, as the pressure increases in the opposite FCECU channel.

At this time, the respective RUD HYD caution light will illuminate in the channel that has a power failure, while RUD CTRL caution light will not illuminate. If this failure is concurrent with gradual loss of the rudder hydraulic system, HML function will be recovered to normal, and then RUD HYD caution light will extinguish when the system pressure is recovered to normal.

If a malfunction is not concurrent with a loss of system pressure, HML function of the channel will be disabled. Furthermore, the relevant RUD HYD caution light will remain illuminated throughout the rest of the flight, and the HML function will be
disabled. In order for HML to monitor its malfunction, both HML channels should be operating with hydraulic pressures in a normal condition. Following conditions are the indications of HML malfunction;

○ Overpressure Condition: If combined with an excessive rudder input, the structure of aircraft would be in a catastrophic condition. Therefore, if overpressure condition is detected, even in a short period of time, it has to be maintained in latch condition\(^9\)), and it can be recovered by turning off the power and then turning it on again.

○ Underpressure Condition: If the temperature goes below -15 degrees Celsius to prevent errors in false failure detections or if hydraulic pressure changes from unpressurized situation to pressurized situation, the operation will be stopped for 10 seconds. This particular situation is not considered hazardous unless it occurs with an engine failure.

In situation where only one hydraulic system or HML channel is in operation, to prevent further function failure in the remaining channel, the monitor function for the checking underpressure on the operating channels is made to be banned.

Also HML channel will readjust actuator pressure when all the pressure difference feedbacks of the opposite channels indicate underpressure; when applying power to the rudder push off switch of one of the opposite channels; or when power turns off in the HML shut-off valve of the opposite channel.

On the other hand, RUD CTRL caution light will illuminate when the pressure difference of the opposite channel is at low pressure, and when other conditions are not meet that the channel does not readjusted to constant pressure. At this point, RUD CTRL caution light will indicate insufficient pressure, which means ½ of the expected hydraulic operation shows insufficiency. This course of action is to prevent errors in pressure readjustment.

If #1 and #2 hydraulic pressure systems fail to function, RUD CTRL caution light will illuminate. If either of the hydraulic pressure systems is recovered, the monitoring and operating function of the FCECU channel will be reset and RUD CTRL caution light will illuminate.

If two airspeeds do not coincide, RUD CTRL caution light will illuminate, and an

\(^9\) Latch Condition: Represents the continued presence of the defective conditions
order will be issued to HML to change the appropriate alternate value based on the flap position. When airspeeds recover, HML function will be restored.

1.6.5 Caution and Warning Light

1.6.5.1. RUD CTRL Caution Light

RUD CTRL caution light will be illuminated ① when FCECU is aware of the loss of ability to pressure control in both channels of electrical hydraulic valves; ② when #1 and #2 rudder hydraulic systems fail to function; and ③ when the airspeed becomes invalid. ⑩

- If airspeed becomes invalid, rudder actuator pressure will be regulated at about 700 psi in each channel.
- If flaps position indicator shows normal condition and exceed 15 degrees, rudder actuator pressure for each channel will be adjusted at about 1,225 psi.
- If airspeed and flap position are regarded as invalid, rudder pressure will be adjusted at 1,225 psi.

Such caution lights will be turned off immediately after the faults are adjusted. When the caution light illuminates, the pilot has to reduce aircraft speed to below 200 knots.

When one of the channels of FCECU shows difference in contradictory pressure, it is necessary to turn on RUD CTRL caution light. In this case, it indicates a potential underpressure condition.

1.6.5.2 #1 RUD HYD Caution Light

#1 RUD HYD caution light illuminates when the hydraulic pressure of #1 hydraulic system is less than 350 ± 50psi; when FCECU shut down the hydraulic pressure of the actuator due to the pressure control valve failure of the left channel; and when the pilot pressed #1 RUD push off switch. At this time, the right FCECU sends a compensation signal to electro-hydraulic valve to let rudder operate properly.

---

10) ELEVATOR FEEL, SPLR OUTBD and PITCH TRIM caution lights illuminate simultaneously.
11) Airspeed #1 and 2 do not coincide, and data transmission is failed for monitoring ADU1 and ADU2
1.6.6 Takeoff Warning

Each of the FCECU channels sends a take-off warning signal to Integrated Flight Cabinet (hereinafter referred to as "IFC"). When inboard or outboard spoiler is all above 3.95 degrees deployment (referred to as "symmetrical deployment"), take-off warning will be generated.

Also for the take-off procedure, another take-off warning signal is generated when pitch trim range is outside the range of elevator actuator location, from $0 \pm 0.5$ degrees to $-6 \pm 0.5$ degrees (forward). These two signals are logically operated as "OR" gate and transmitted to each IFC channel.

1.6.7 Surface Position Indication

FCECU is connected with eight (8) surface position sensors, transfers location information to IFC and signals to the pilot, and then records in FDR.

Each channel of FCECU is connected with four (4) surface position sensors, and its information is sent to each of the IFC. From each of the ECECU channels, left and right pitch trim actuator locations and HML pressure information are transmitted to IFC.

FCECU, which is connected with four (4) surface position sensors of LVDT form, makes LVDT excitation, process LVDT output and calculate its position, and transmit the position information to IFC.

1.6.8 Weight and Balance

As a result of comparison between the actual weight and the maximum allowable weight of Flight 502 in [Table 4], there was the excess weight available. The take-off fuel (TOF) was suitable for the flying from Jeju Airport to Gimhae Airport, and Take-off C.C % MAC was within the restrictions (19.0 ~ 34.0 C.G % MAC).

12) If any of these conditions apply, then it should logically go by its circuit operation.
13) Linear Variable Differential Transducer - depending on the operation of control surfaces, at the position sensor, it is a part that converts into a voltage from the transformed range.
### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight and Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger/Cargo</td>
<td>74 passengers/23,966 kg</td>
</tr>
<tr>
<td>Maximum Zero Fuel Weight (ZFW)</td>
<td>25,855 kg</td>
</tr>
<tr>
<td>Maximum Take-Off Fuel (TOF)</td>
<td>5,310 kg</td>
</tr>
<tr>
<td>Maximum Take-off Weight (TOW)</td>
<td>28,998 kg</td>
</tr>
<tr>
<td>Trip Fuel (TIF)</td>
<td>737 kg</td>
</tr>
<tr>
<td>Maximum Landing Weight (LDW)</td>
<td>28,009 kg</td>
</tr>
<tr>
<td>Take-off Weight (TOW C.G% MAC; Center of Gravity in Percent Mean Aerodynamic Chord)</td>
<td>25%</td>
</tr>
</tbody>
</table>

[Table 4] Weight and Balance Chart

### 1.7 Meteorological Information

#### 1.7.1 METAR

Following is METAR of Gimhae Airport at 09:00;

"METAR RKPK 2007/08/12 00:00UTC, 13016, 9999, FEW020 BKN040 OVC100 28/23 Q1003" [Wind direction: 130 degrees, wind velocity: 16 knots, visibility: more than 10Km, sky coverage and height of cloud: 1〜2 octas at 2,000 feet 5〜7 octas at 4000 feet, overcast at 10,000 feet, temperature: 28 degrees, dew point 23 degrees: and altimeter: 1003 Hpa].

#### 1.7.2 The Contents of Automated Terminal Information Service (ATIS)

Gimhae Int'l Airport Information GOLF, Time 0100 UTC, Active Runway 18 Right, Expect Radar Vector to ILS/DME Runway 36 Left Approach, then Circle to Runway 18 Right, Weather Wind 130 at 13 Knots Gust 18 Knots, Visibility 7 Miles, Sky Condition 2 Octas 2 Thousand, 6 Octas 4 Thousand, Temperature 30, Dew point 24, Altimeter 2964 inches, Advice You Have Information GOLF.
The above is the content of Automated Terminal Information Service that the pilots listened before landing at Gimhae Airport: At that time, the circling approach procedure which Flight 502 conducted was runway 18R, the wind was 130 degrees at 13 knots gusting to 18 knots, visibility was 7 miles, the sky condition 2 octas at 2,000 feet, 6 octas at 4,000 feet.

1.7.3 Visual Observation Weather from the Control Tower

After the accident, an interview was conducted with the local controller of Gimhae Tower and the ground controller. As a result of the interview, at the time of accident, while Flight 502 was conducting the circling approach to runway 18R, there were no obstacles standing in a way for making visual observation of the weather condition.

1.8 Aids to Navigation

Flight 502 performed a circling approach to the runway 18R after an instrument approach to the runway 36L. At that time, the instrument landing system was operating normally.

1.9 Communications

Upon verification of the recordings, there were no communication problems between the flight 502 and the approach controller and aerodrome controller of the Gimhae Airport.

1.10 Aerodrome Information

Gimhae Airport, which is operated and managed by the Republic of Korea Air Force, has been used by commercial aircraft in accordance with the agreements between the Ministry of Land, Transport and Maritime Affairs and the Air Force.

As shown in [Photo 8], Gimhae Airport has two parallel runways, north-south direction (180 degrees / 360 degrees), and its dimension is 3,200 m × 60 m, 2,743 m × 45 m.
1.10.1 Information on the landing strips

Runway 18R, which Flight 502 performed the circling approach\textsuperscript{14}) and touched down, is a non-instrument runway. From the centerline of runway 18R, 100m to the left, there is an installation of a concrete drainage ditch. This drainage ditch is located outside of the landing strips for the runway 18R, however, it is located inside the landing strips\textsuperscript{15}) for the runway 36L.\textsuperscript{3}

Referring to the Airport Security Operational Standards, Article 34, if the maintenance management range of the non-instrument landing strip falls under classification number 3 or 4\textsuperscript{16}), the width of the landing strip should extend 75 m from the runway centerline. The landing strip in this range is prepared for aircraft departing the runway, and it has been arranged so that an appropriate maintenance is needed to be cleared from any projecting parts, surface subsidence, and surface changes.

On the other hand, runway 36L is an instrument approach runway, which is the opposite direction of runway 18R. As set forth in Article 34 of the Airport Security Operational Standards, "the maintenance range of the landing strip of the instrument approach runway", as shown in [Figure 7], the width of the landing strip extends up to 105 m from the runway centerline.

\textsuperscript{14}) While executing the visual flight rules, the pilot watched the related objects on the runway with their naked eyes.
\textsuperscript{15}) Its runway classification number is 3 or 4, and it is located 150 m from the centerline of the runway.
\textsuperscript{16}) Public Law Enforcement Regulation, Appendix 1, classification number of land aerodrome, based on the installation runway strip.
At the time of the accident, when referring to the Gimhae Airport information in the Aeronautical information Publication of Republic of Korea, there is no indication of a concrete drainage ditch.

### 1.11 Flight Recorders

#### 1.11.1 Flight Data Recorder (FDR)

The aircraft was equipped with a Solid-State Data Recorder, capable of 25 hours of recordings, manufactured by Allied Signal. 17)

The Board detached it, extracted all the data of 25 hours before and after the accident. The final approach and landing data were analyzed among the data, and results are as follows:

#### 1.11.1.1 Before the flight 502

At 07:43:49, during performing the flight 103 from Gimpo to Jeju, without the pilot's rudder pedal application and without any change in lateral acceleration, the rudder position indicated about 6 degrees to the left. At the same time, it was recorded that the left outboard spoiler was open at 10 degrees. The left rudder deviation and the left outboard spoiler's open position remained until 07:54:49. The caution light did not illuminated during this time period.

#### 1.11.1.2 The Concerning Flight

17) Semiconductor used electronics
<table>
<thead>
<tr>
<th>Time</th>
<th>FDR data</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:43:42</td>
<td>Left Outboard Spoil opened at 12.5 degrees.</td>
<td></td>
</tr>
<tr>
<td>08:44:20</td>
<td>Rudder position moved to the right, 23.8 degrees from the left side position, 6 degrees. Each rudder pedal position was at 9 degrees - right and left direction.</td>
<td>PFCS (Powered Flight Control Surface) checked at Jeju Airport</td>
</tr>
<tr>
<td>08:48:55</td>
<td>Left outboard spoiler opened at 12 degrees. Output level was proceeding more than 53 degrees.</td>
<td>It had remained open at 12 degrees most of the time from the start of take-off until just before landing.(FDR)</td>
</tr>
<tr>
<td>08:53:20</td>
<td>The caution light illuminated for 7 seconds.</td>
<td>Passed through 9,538 feet. (FDR)</td>
</tr>
<tr>
<td>09:11:24</td>
<td>The caution light illuminated for 5 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:12:00</td>
<td>The caution light illuminated for 3 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:15:14</td>
<td>&quot;RUD CTRL went away, it is okay to accelerate the speed &quot;(CVR)</td>
<td></td>
</tr>
<tr>
<td>09:17:39</td>
<td>The caution light illuminated for 7 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:17:52</td>
<td>&quot;The reader control came in.&quot;(CVR)</td>
<td></td>
</tr>
<tr>
<td>09:18:45</td>
<td>&quot;It came it again&quot;(CVR)</td>
<td></td>
</tr>
<tr>
<td>09:26:28</td>
<td>The caution light illuminated for 3 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:31:09</td>
<td>The caution light illuminated for 2 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:33:10</td>
<td>The landing gears were down.</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Notes</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>09:32:57</td>
<td>The caution light illuminated for 2 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:33:32</td>
<td>Landing flap setting at 15 degrees</td>
<td></td>
</tr>
<tr>
<td>09:34:00</td>
<td>The caution light illuminated for 7 seconds.</td>
<td></td>
</tr>
<tr>
<td>09:36:12</td>
<td>Gimhae Control Tower gave clearance to Flight 502 for landing (CVR)</td>
<td></td>
</tr>
<tr>
<td>09:37:58</td>
<td>Radio Altitude at 18 feet, aircraft heading at 176 degrees, airspeed passed through 123 knots</td>
<td></td>
</tr>
<tr>
<td>09:38:06</td>
<td>When the position of rudder pedal and aileron was indicating to the right side, rudder position was at 7 degrees to the left. Aircraft heading is at 176 degrees.</td>
<td>3 seconds prior to the main landing gear touch down. (FDR)</td>
</tr>
<tr>
<td>09:38:09</td>
<td>Main landing gears touched down, airspeed at 119 knots, aircraft heading at 175 degrees, rudder position at 7 degrees to the left, rudder pedal input was increasing to the right.</td>
<td></td>
</tr>
<tr>
<td>09:38:13</td>
<td>Nose landing gear touched down, airspeed at 103 knots, aircraft speed at 103 knots, aircraft heading at 172 degrees.</td>
<td></td>
</tr>
<tr>
<td>09:38:15</td>
<td>Aircraft axis acceleration value - it was recorded -0.62g, then changed to -0.28g</td>
<td>This was when the flight departed the runway. (FDR)</td>
</tr>
<tr>
<td>09:38:26</td>
<td>Aircraft slope position changed rapidly at 15.6 degrees, aircraft heading reversed to the right (clockwise) Aircraft axis acceleration value recorded at -.88g, and then at 09:38:30, its value changed approximately to 0g.</td>
<td>The aircraft collided into the drainage ditch.</td>
</tr>
</tbody>
</table>

[Table 5] FDR parameter of the concerned flight
1.11.2 Cockpit Voice Recorder

The cockpit voice recorder was installed\(^1\) with a Solid-State Cockpit Voice Recorder (SSCVR), with capacity of 120 hours of recordings, manufactured by Honeywell International, Inc.

The Board detached the SSCVR and downloaded the data from it. Thereafter, the Board prepared about 49 minutes of transcript of Flight 502, from the time when the engine started until the time when the aircraft departed runway after landing.

1.12 Wreckage Information

The aircraft came to rest at the drainage ditch, and there was no particular wreckage.

1.13 Medical and Pathological Information

Two pilots held the valid Airman medical Certificate, and there was no medical and pathological information that could have a negative impact on their flight mission.

1.14 Fire

Not applicable

1.15 Survival Aspects

When the aircraft came to rest after a collision with the drainage ditch, the first officer declared emergency to the control tower, and the pilot made an announcement to the passengers to evacuate from the aircraft. The flight attendants helped the passengers to exit the aircraft through the left fuselage front entrance.

\(^1\) Part No: 980-6022-01, Serial No: 120-08507
1.16 Tests and Examination

In regard to the runway excursion, tests and examinations for the rudder and steering system were conducted in the parts manufacturer.

For the component test of the aircraft, as shown in [Table 6], following are the disassembled components, the component serial numbers, and the names of parts manufacturers. The results of the tests showed that all other components were normal other than FCECU.

<table>
<thead>
<tr>
<th>Name of Component</th>
<th>Serial Number</th>
<th>Manufacturer</th>
<th>Supervision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudder Actuator</td>
<td>3900500-1011</td>
<td>Parker Hannifin</td>
<td>ARAIB</td>
</tr>
<tr>
<td>FCECU</td>
<td>398500-1007</td>
<td>BAE System</td>
<td>ARAIB</td>
</tr>
<tr>
<td>LVDT</td>
<td>399900-1001</td>
<td>Parker Hannifin</td>
<td>ARAIB</td>
</tr>
<tr>
<td>Potentiometer</td>
<td>90834</td>
<td>Honeywell</td>
<td>NTSB</td>
</tr>
<tr>
<td>Pedal Force Sensor</td>
<td>900441-2</td>
<td>Honeywell</td>
<td>NTSB</td>
</tr>
<tr>
<td>IOP</td>
<td>C12432AAO6</td>
<td>Thales</td>
<td>BEA France</td>
</tr>
<tr>
<td>Gage-Potentiometer</td>
<td>90834</td>
<td>Goodrich</td>
<td>TSB Canada</td>
</tr>
<tr>
<td>PSEU</td>
<td>30145-0301</td>
<td>Goodrich</td>
<td>TSB Canada</td>
</tr>
</tbody>
</table>

[Table 6] Component Test and Manufacturer

1.16.1 FCECU Examination

The manufacturer’s test of the FCECU was performed four (4) different times. The first test for the FCECU was, from 17 September 2007 to 19 September 2007 at BAE systems Inc. in New York, performed with tests for the Steering Control Unit (SCU) and LVDT; the second test was, from 3 December 2007 to 6 December 2007 in Fort Wayne, Indiana, conducted in order to find the nature of the defect in the FCECU; for the humidity test for the FCECU, the third test was carried out for two straight days from 1 April 2008; and the fourth test was carried out for 8 straight days from 4 May 2009.
An investigator of Aviation & Railway Accident Investigation Board was in charge of the manufacture’s test of the FCECU, and the test was collaborated with some of the investigators and engineers of NTSB, TSB Canada, Bombardier Aerospace, Parker Aero Space Corp, and BAE Systems, Inc.

Upon completion of the third manufacturer’s test of the FCECU, on 27 May 2008, a flight simulator of the FSI in Toronto, Canada was used to identify the characteristics of the directional control of Q400 aircraft in a cross wind condition. And then it was followed by a technical meeting, which was held by the Bombardier Aerospace.

1.16.1.1 The First Examination on the Components

From 17 September 2007 to 18 September 2007, SCU\(^{19}\) was tested at BAE System in New York; from 18 September to 19 September 2007, FCECU ATP\(^{20}\) (Acceptance Test Program) was performed at BAE Systems, Inc in Fort Wayne, Indiana; and then from 19 September 2007 to 26 September 2007, the test was relocated to Parker Aero Space Co. located in Irvine, CA. to perform a component test on upper rudder actuator(Power Control Unit)\(^{21}\), lower rudder actuator,\(^{22}\) and LVDT\(^{23}\).

During the FCECU test, which was performed on 18 September 2007 to 19 September 2007, at BAE Systems, Inc. in Fort Wayne, Indiana, while performing the receipt inspection of ECECU\(^{24}\), a little physical damage in J1 connector\(^{25}\) was found; however, there was no other damage.

A continuity check\(^{26}\) was done on J1 and J2 plug pins, and no defects were found.

For the FCECU fault code reader and conversion, the FCECU was put into a test bed in FCECU ATP of BAE Systems, Inc. and power was supplied to the device.

---

19) BAE System - component number: 406300-05-01, Serial Number: 00274
20) Regulation programs and testing procedures for equipment operation testing
21) Component Number: 390500-1011, Serial Number: 329
22) Component Number: 390500-1011, Serial Number: 330
23) Component Number: 390500-1001, Serial Number: 1158
24) BAE Systems, Inc, component number: 406475-05-01, Parker Aero Space Corp, component number: 398500-1007, serial number: 00376
25) A part that links FCECU computer to the external system.
26) It is a continuity check on the conductor to see whether electric current flow is normal or not.
The fault data record of the FCECU was downloaded from Non Volatile Memory (hereinafter referred to as "NVM") and it was converted into 512 bytes of Hexadecimal. Thereafter, it was converted to engineering error code.

As the FCECU was still attached to the FCECU test bed, for the flight control system of electronic control unit of DH8FCS\textsuperscript{27}), an ATP test of BAE systems, Inc. was performed.

While performing an ATP test, faults were found in monitoring watchdog\textsuperscript{28}), HML function, the integrity checking of the analog and discontinuity value through RTM\textsuperscript{29)}, and the survival portion of retaining circuit for 50 millisecond of loss power. Therefore, in conclusion, ATP test did not pass.

1.16.1.2 Second Examination on the Components

To find a comprehensive cause of ATP test failure of the FCECU, which was performed in the first examination, a joint survey was conducted by the officials and engineers of ARAIB, NTSB, Bombardier Aerospace, BAE Systems, Parker Aero Space Corp, and Jeju Air at BAE systems in Fort Wayne, Indiana on 3~6 December 2007.

An ATP test of the FCECU was performed at room temperature, however, the FCECU did not pass ATP test. To determine the worst of the condition that affects FCECU, it was placed in the environmental chamber of BAE Systems. The temperature in the chamber was set at -15 degrees Celsius to let the device absorb the cold air for one hour in that temperature. And then an ATP test was performed on the device but it did not pass.

Thereafter, the room temperature was increased to +55 degrees Celsius and placed the FCECU in that temperature for an hour, and followed by an ATP test; however, it did not pass. Since the FCECU did not pass the ATP test, the FCECU was disassembled and scrutinized to find out the cause of failing to pass the ATP test.

\textsuperscript{27) Parker Aero Space Corp, component number: 398500, Reference number: TR406475-05}
\textsuperscript{28) In the process of checking the computer work, it is to ensure the checking is being normally processed.}
\textsuperscript{29) For a moisture protection of the electronic components and processing methods.}
As shown in [Photo 9], a tiny crack was found in FCECU channel 1 card capacitor C464. Register Packet Z95 did not have black epoxy coating, however, it was transparent.

As shown in [Photo 10] and [Photo 11], cracks were discovered on the FCECU channel 2 cards — C211, C305, C306 and C457 on Z5, a substance was found, which was more like a red ballpoint pen ink.

---

30) Serial Number: 717
31) Serial Number: 726
The resistance of the tested component, Z5 \(^{32}\) and channel 2 card – R44/C210/C21 \(^{33}\) group resistance were measured; the result of the data was similar to the data of the normal card.

Since the FCECU did not pass the ATP, the engineers of BAE Systems verified which components might have caused the problems based on the fault. To find out, they opened the resistance bundle Z5 Pin-5 of the component Channel 2 card and made the space short between channel 2 card Z5 Pin-6 and Pin-7. And then ATP was carried out and it was compared to the original fault data.

Thereafter, the FCECU was reassembled into its original configuration; as the FCECU was placed at room temperature, an ATP was performed once again on the FCECU. Soon after, all the faults were gone and the FCECU passed the ATP.

As the FCECU was placed in a temperature chamber, the temperature was gradually lowered to -15 degrees Celsius, and then a relevant ATP test was performed. As a result, the FCECU passed the ATP test.

---

32) A component name in an electronic circuit board is expressed in number.
33) A component name in an electronic circuit board is expressed in number.
1.16.1.2.1 Review of Fault code of FCECU

BAE Systems, Inc. announced about the fault code analysis recorded in NVM. During one power cycle\(^{34}\), up to 10 records of fault code can be composed of a combination of two letters or numbers. As shown in [Table 7], the fault code that is displayed in blue represents the fault history.

![Entire NVM buffer](image)

[Table 7] Fault History

\(^{34}\) One cycle – from the point where the power turns on / off to the point where power turns off/on.

![Fault History Buffer](image)

[Table 8] Below is an analysis of the fault history.

![Fault History Buffer (Fault Record 6) - Decoded](image)

[Table 8] Fault History Analysis
A monitoring data for fault detection of underpressure and overpressure of upper and lower rudder hinge moment limiter (HML) seemed to be false during takeoff and landing phases.

Such monitoring data of the fault history indicates an evidence of flying with continual power supply. This is when there are one or more flight sections, the fault monitoring starts from the former aircraft with an engine failure and continued to fly without the power supply shut off. The monitoring failure of the upper and lower HML was recorded in a different landing stage. If one of them fails, the underpressure monitoring will stop its function.

The 10th fault, as shown in the fault history, is about the fault record of the lower HML underpressure monitoring. The record of the event may have taken place after the first 10 faults were documented. Because the data might have been lost at the time of the event, the interrelation between the actual circumstances of the accident and the fault record on NVR did not correspond.

1.16.1.3 Third Examination on the Components

Based on the second examination result, to find the cause of the faults, electric excitation was applied to a component that was likely to show fault. And then an ATP was performed on the component. To verify its result, a technical meeting was held under the auspices of the U.S. National Transportation Safety Board. The engineers of Parker Aero Space Corp, BAE Systems, Inc., and Bombardier Aerospace got together and carried out the test at BAE Systems, Inc. in Fort Wayne, from 1 April 2008 until 2 April 2008.

An ATP test of FCECU was performed in two different chambers: The first ATP test was performed at room temperature and the other test was performed at low temperature. As a result, it passed both tests. The FCECU channel 2 card was installed on the engineering bench35) and then electric excitation was applied to it. While applying electric excitation, the electric circuit was monitored but did not show any changes or unusual phenomenon.

35) It is installed equipment to test computer components.
The FCECU was placed in a modified ESS (Environment Stress Screening), the temperature was changed two times from -50 Celsius to 25 degrees Celsius, and the electric circuit was monitored, but no particular information was found.

After the FCECU was disassembled, channel 2 was connected to the extender card. As cold air was applied locally to it, changes in the electro stimulator circuit were monitored, but there were no unusual changes.

Lastly, from the channel 2 card, 6 of the resistances\(^{36}\) were removed, and 6 of the Transzorbs\(^{37}\) were monitored to see if there was any voltage leakage. However, no particular information was found.

After a new kind of resistance was mounted on the original mounting position, an ATP test was performed on it. It was to confirm the resistance had been mounted properly.

### 1.16.1.4 Simulator Test Flight

From 27 to 30 May 2008, a technical meeting to evaluate the results of examination conducted so far was held and a flight test by the simulator of the FSI to determine the characteristics of the directional control of Q400 aircraft without rudder control in cross wind conditions were conducted in Toronto Canada.

The weight and balance data of the simulated flight was set at 55,720 pounds, 20% MAC, flap was set at 15 degrees. And wind was at 130 degrees with applying the speed changes from 13 knots, 18 knots, 20 knots, and then lastly to 25 knots.

As a result of the simulated flight test, it was observed that the directional controllability of the Q400 aircraft was reasonably available by asymmetrically applying the brake up to the speed of 20 knots cross wind under the premise that pilots had recognized the rudder would be inoperative.

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36) R480, R481, R482, R492, R493, R494
37) Transient Protection Device - VR43, VR44, VR45, VR46, VR47, VR48
1.16.1.5 Results of Technical Meeting

At the technical meeting, the results of the simulation flight test were discussed, and then followed by the FCECU results from the first test to the third test. The results were as follows:

- It was presumed that for the rudder system to have completely lost its function, a fault occurs and its function stops in the right channel FCECU, the operating left channel HML function should fail independently.

- Since the failure is independent of the initial failure at the right HML channel function, the failure has not been identified on the FCECU box.

- No single failure mode which has been identified that explains the loss of both channels of HML, and there was no systemic design flaw or common failure resulting in the loss of both channels of HML.

- It was confirmed that the result of the first ATP of FCECU was different from the second ATP examination result. After hot and cold teats the unit failures cleared and has not recurred since. The FCECU was tested for the protection from lightning and instant excessive current flows, and it was indicating that there was no lighting effect to the FCECU.

- The NVM data from the FCECU matched the problems and the caution lights illuminated at the flight of occurrence.

- The relevant personnel of BAE Systems explained that during every landing and takeoff phase results in hydraulic underpressure faults being recorded in the NVM.

- There were 10 faults recorded, but with no time stamp. Only the first 10 faults are recorded and repeating faults are not recorded but are overwritten in the pre recorded places.
• The NVM faults show that the upper and lower PCU’s were unpowered, but without a time stamp, it cannot be clearly determined when it occurred.

• FCECU design logic is such that when one channel fails the other channel shall not fail or allow the remaining PCU to be unpowered.

• The aircraft manufacturer's design philosophy is that loss of rudder is a major issue, not hazardous or catastrophic one and as such is designed to a certain way.

• BAE tried to cause a second channel failure by introducing ADU input problems and were not successful in 1.6 million flight hours on Dash 8 - 400 fleet. BAE is saying that finding the actual root cause may be fruitless as it is a finite failure with no other issues in the total system and by addressing a specific circuit problem would not prevent another one time circuit failure from happening again. The design of the system and flight crew actions and training would absorb these rare one time failures.

• Discussion about take off warning with respect to single and double spoiler deployed. Bottom line, even though a single spoiler deployment will not activate the take off warning horn, the AFM line up check requires a visual check of the PFCS (Powered Flight Control Surface) display to ensure that all spoilers are down.

• ARAIB commented that the FCECU could be individually separated into two boxes for the purpose of preventing similar events. Bombardier could be open to such an idea.

1.16.1.6 Fourth Examination on the Components

After the third examination of the FCECU, followed a humidity test which was carried out at BAE Systems on 4 to 8 May 2009.

At the second examination which was conducted at the room temperature and the cold temperature environments, the FCECU failed to pass ATP. However, after the FCECU was placed into a hot chamber, all the fault codes disappeared. Therefore,
based on the fact that the FCECU finally passed the ATP after a hot soaking, a humidity test was carried out to see if humidity affects the FCECU.

A fourth examination was conducted on the FCECU which was taken out of custody. The humidity effect on the FCECU was examined through the three consecutive ATPs in which fault codes were verified after putting the FCECU into the humidity chamber for a certain period of time.

The preliminary test of ATP of the fourth examination conducted at room temperature was passed with the same result as the second examination.

In the first humidity test, environmental conditions starting with initial temperature at 20º C, humidity of 50%, then they were gradually stabilized for 2 hours from 50º C until the desired humidity of 80%. While in that stage, humidity of 85% was maintained for six hours, and then maintained for another 14 hours with the temperature at 38 ºC, and humidity of 75%. Thereafter, the FCECU was taken outside after cooling down at room temperature, and an ATP was performed. As a result, the FCECU passed the ATP.

In the second humidity test, the FCECU was put into the chamber which was saturated with humidity of 90%. After it was stabilized for 8 hours, once again at humidity of 90% stage, a change in temperature was applied for 10 hours. Then the FCECU was taken out of the chamber, and an ATP was performed. As a result, it passed the ATP.

The first and second humidity test results were identical. To create the worst humidity condition, all the FCECU covers were wide open and two interior channel cards were exposed to humidity for 18 hours. Thereafter, an ATP was performed; as a result, the FCECU passed the ATP.

1.16.2 Input Output Processor (IOP) Examination

The Integrated Flight Computer (IFC), which is located left side of the cockpit entrance, is equipped with essential components (FGM\textsuperscript{38}, SPM\textsuperscript{39}, IOM\textsuperscript{40}, IOP, PPSM\textsuperscript{41})

\textsuperscript{38} Flight Guidance Module: A component that is related to flight guidance.
for flying. Flight Guidance Module (FGM) receives ARINC 429 data through two of the flight data processing system data concentrators. The test result of IOP are as follows:

1.16.2.1. General Description

- An Automatic Test Equipment Computer (ATEC), Series 6 bench was used to download the data.

- To verify following items, the first two data were read out from the test device (IOP #2):
  - Verified the performance of the test bench.
  - Verified if the data had been altered during the process of data download.
  - Memory data of Central Diagnostic System (hereinafter referred to as "CDS") was read out from IOP #1

- The data was read out and a cross check was done in two different locations - Thales Group and BEA.

1.16.2.2 Data Analysis

- Only the faults related to the electronic system are recorded in CDS, and it is used solely for maintenance purposes.

- There were 13 messages recorded in the CDS.
  - Four (4) messages that are related to the weather radar and remote controlled passenger address system were recorded in all flight segments; therefore, they were regarded as repetitive minor faults.
  - One of the fault messages recorded at 09:31 was the fault related to the FCECU. This particular fault was detected by FGM2, which monitors pitch

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39) Stall Protection Module: A component that is for a stall protection.
40) Input Output Module: A component that is related to input and output of the signal.
41) Primary Power Supply Module: A component that is related to the primary power supply.
trim rate. If an invalid signal of pitch trim rate is monitored, FGM2 will send a message of fault to IOP. This message has been recorded in most of all other flights, including the prior flight.

- The other seven faults recorded at 09:38 (time of occurrence) were related to several other faults (AHRS2, VHF-NAV2, FGM2, and ADU2) monitored by FGM2, including TCAS fault. These faults are likely to be subsequent to the accident, and they might have been resulted from the damages of the accident. All these were consistent with one of the faults from FMG1 or the first officer’s computer related faults.

1.17 Organizational and Management Information

1.17.1 Pilot Training

Jeju Air's pilot training is classified into the two following types, the pilot training is categorized into the ground school, simulator flight training, aircraft flight training, and flight operating experience training.

A. Initial Training (No other Type Rating in Possession)

<table>
<thead>
<tr>
<th>Training Requirement</th>
<th>Screening Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground school (G/S)</td>
<td>Cockpit Procedure (CPT)</td>
</tr>
<tr>
<td>80.5 hrs</td>
<td>12 hrs</td>
</tr>
<tr>
<td>Flight Simulator (SIM)</td>
<td>Flight Operating Experience (OE)</td>
</tr>
<tr>
<td>20 hrs</td>
<td>40 leg</td>
</tr>
<tr>
<td>Aircraft (A/C)</td>
<td>Flight Simulator (SIM)</td>
</tr>
<tr>
<td>2 hrs</td>
<td>1 time</td>
</tr>
<tr>
<td>Flight Check of MLTM</td>
<td>Aircraft (A/C)</td>
</tr>
<tr>
<td></td>
<td>2 leg</td>
</tr>
</tbody>
</table>

B. Transition Training (Other Type Rating in Possession)

<table>
<thead>
<tr>
<th>Training Requirement</th>
<th>Screening Requirement</th>
</tr>
</thead>
</table>


According to the result of reviewing the ground school and other details of flight training, it was found that the information and flight procedure regarding the case of rudder not responding to the pilot input is listed in the section of Rudder Control Jam of the QRH.

However, it was confirmed during the interview with Jeju Air pilots that they had not received any type of training or Ground school for the cases where the rudder does not respond to the pilot's rudder pedal input without a warning or caution in advance.

1.18 Additional Information

1.18.1 Pilot Operating Manual

The Pilot Operating Manual of Jeju Air accepted all the normal and non-normal operating procedures of DHC-8 manufacturer. It is a company policy that pilots should follow all the procedures in the pilot operating manual and they must comply with the procedures in flight or in ground operation.

According to chapter 4 of the Pilot Operating Manual, General42) of the normal operation, it is clearly described that any of the items included in the Normal Checklist are those which, if omitted, would have a direct and adverse effect on normal flight operations.

According to Chapter 5 of the Pilot Operating Manual, General of Non-normal operations, it is described that if a non-normal situation occurs other than the procedures

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42) Pilot Operating Manual, General Page 4.1.2
covered by the Pilot Operating Manual, the PIC should use best judgement in dealing with the situation.

1.18.1.1 Control Surface Check in Flight Preparation

◦ PFCS\(^{43}\) Indicator…………………Check

Make sure all the spoiler needle on the MFD (Multi Function Display) indicate spoilers retracted (horizontal). If a cross wind exists, the rudder may indicate a deflection left or right of center.

1.18.1.2 After Start Rudder Check

◦ Rudder Travel ………………. Full Travel

1.18.1.3 Line Up Control Surface Check

◦ Flight Controls………………..Check / Free

According to the description for this item in the Pilot Operating Manual, it is defined that check the operation and freedom of movement of flight controls and spoilers as follows:

• Hold the control wheel and release the flight control lock.
• Push the control column forward and rotate the control wheel full right.
• Monitor the PFCS indicator on the MFD and make sure Right Inboard and Right Outboard spoilers extend fully, and the L and R ELEV needles point DOWN.
• Pull the control column fully aft then roll the control wheel fully left.
• Monitor the PFCS indicator on the MFD and make sure Left Inboard and Left Outboard spoilers extend fully, and the L and R ELEV needles point UP.
• Release the control column and return roll control wheel right to level position.
• Make sure Left Inboard and Left Outboard spoilers retract, and L and R ELEV needle return to neutral.

\(^{43}\) Powered Flight Control Surface; flight control surface
1.18.2 Quick Reference Handbook (QRH)

1.18.2.1 Control Surface Check in Normal Procedure Checklist

○ Cockpit Preparation - Captain
  - PFCS Indicator……………………Check

○ After Start
  - Rudder Travel………………… Full Travel

○ Line Up
  - Flight Controls………………… Check / Free

○ After Line up
  - In the flight phase after line up, there were no checklist items of normal operating procedures for checking the flight control.

1.18.2.2 Non-Normal procedure Checklist for Flight Control System

○ #1 RUD HYD or #2 RUD HYD Light
  • No crew action is required.
    Note: maintenance action required prior to next flight

The descriptions for this caution light in the Flight Crew Operations Manual⁴⁴) are as follows:

  • #1 or #2 hydraulic pressure of hydraulic system is low, or  
  • The FCECU has shut down a PCU because of a malfunction, or  
  • The RUD 1 or RUD 2 Push off switchlight has been pushed.

○ RUD CTRL light

  • Airspeed…………………….. 200KIAS (max)

The description for this caution light in the flight crew operations manual\(^{45}\) is as follows:

- \#1 and \#2 hydraulic systems have failed, or
- The FCECU is unable to control rudder control pressure, or
- Airspeed \#1 is not equal to airspeed \#2, showing a difference of 17 knots, or ELEVATOR FEEL, SPLR OUTBD, and PITCH TRIM caution lights will also come on.

○ ELEVATOR FEEL, PITCH TRIM, SPLR OUTBD and RUD CTRL

- Autopilot ...................... disengage
- Airspeed ...................... 200KIAS(max)

○ RUDDER CONTROL JAM (Directional Control malfunction)

- Use roll control as required for directional control
- Considerations for Landing:
  - Nosewheel Steering ........................................ Off
  - Land at an airport with minimum cross wind and turbulence using Flap 10, 15 or 35.
    ※ Note: If rudder jam occurs on takeoff and conditions permit, return for landing on the takeoff runway.
  - Small amount of asymmetric power may be used to maintain directional control on approach and after landing.
- After Landing:
  - Nosewheel Steering ........................................ On

\(^{45}\) Flight Crew Operations Manual: Refer to page 9-31
2. Analysis

2.1 General

It was verified that the pilots of Flight 502 held valid certificates. Their schedule had complied with the Aviation Act concerning flight duties and rest rules. Any medical factors or pathological factors which might have affected their performance of duties were not found.

Flight 502 was properly certificated, equipped, and maintained in accordance with the Aviation Act of the Republic of Korea and International Civil Aviation Organization standard and recommended practices.

Flight 502 was loaded properly within the regulatory limitations of weight and balance. There were no flight restrictions imposed by the application of the minimum equipment list. At the time of the accident, the weather condition was above the minimum condition for Flight 502 to initiate a circling approach.

With regard to the accident, the Board analyzed the pilot's duty, the FCECU design and its function, the suitability of the non-normal procedures, the take-off warning system, and the warnings related to the rudder malfunction.

2.2 Pilot's Performance

2.2.1. Flight Control Surface Check in Flight

According to the Jeju Air's procedures, the captain is to make sure all the spoiler indication of PFCS indicator are retracted horizontally. The captain and first officer stated that, at the time of the aircraft inspection according to the normal operating procedure, the control surface indicators of the aircraft were all normal, including the spoilers. However, according to FDR data, the left outboard spoiler was extended at 12 degrees at that time.
According to FDR data, during a line-up check before the takeoff at Jeju Airport, the left outboard spoiler was extended at 12 degrees. The pilots were supposed to verify the spoiler indications (extend or retract) during a line-up check, but they took off without verifying the spoiler indication on the PFCS.

According to the Jeju Air's procedures, after the engine starting, the pilot is to check the rudder travel to see if it moves full travel. However the captain stated that he simply checked that the rudder pedal was moving freely, but did not verified if the rudder indication returned to a neutral position on the PFCS indicator. But, the first officer stated that he confirmed the rudder had returned to a neutral position on PFCS. But according to FDR, when the captain checked the rudder travel, the rudder indicated at 26.8 degrees which is exceeding the limits. Even after checking the rudder travel, there was no indication of the rudder returned to a neutral position.

During the flight, the rudder position indicated deflecting more than 7 degrees to the right regardless of the pilots’ rudder pedal inputs. However, this abnormal indication during the flight was not dealt by the pilots, and even it was never mentioned appropriately.

It would not be impossible for pilots to see with naked eye when the outboard spoiler is extended at 12 degrees or the rudder position indicates deflecting at 7 degrees on the PFCS. Therefore, if abnormal indications of the spoiler and the rudder had not been verified by the pilots during flight, it would mean that their monitoring was not cautiously carried out, or perhaps the pilots might have ignored the abnormal indications even after verifying them.

It could not be said that the rudder sticking during landing at the Gimhae Airport is the consequence of the proceeding flight while the abnormal indications of the spoiler were not verified. However, the Board determines that the pilots' not adhering to the suggested standard practices, in other words, all the abnormal indications should be confirmed and dealt accordingly, was such performance that should be corrected.

2.2.2 Performing QRH Procedure in Flight

When #2 RUD HYD and RUD CTRL caution lights illuminated, the pilots performed appropriate QRH procedures. There was no particular actions required in the QRH procedures by the pilots to respond to the situation, except for maintaining the speed below 200 knots.

While performing the related QRH procedures, the pilots were not concerned about the possibility that the rudder could be not responding to the pilot input, since there was no information provided in the QRH suggesting the pilots of the possible rudder not responding to the pilot input.

2.2.3 Pilot's Directional Control

2.2.3.1 Concurrent Use of Rudder Pedal between Pilots

According to FDR, immediately after the aircraft touched down, the rudder pedals of the captain and the first officer were applied in the opposite direction each other. According to the airline procedures, when delegating the aircraft control, the pilots need to call out to verify and confirm each other’s intentions. But this procedure was not observed by the pilots in this occurrence.

Yet, because of causes unknown, the rudder was already in a state where it did not respond to the pilots’ rudder pedal input, the pilots' concurrent use of the pedal could not be considered as the cause of the runway excursion.

2.2.3.2 Controls Performed before Runway Excursion

Before touching down, the pilots applied on the right rudder pedal to align the aircraft with the runway direction. However, contrary to the pilots’ input, the aircraft was not aligned with the runway direction.

After the aircraft touched down, even though the pilots applied on the right rudder pedal, the direction of the aircraft continued turning to the left, and 4 seconds later,
when the nose landing gear touched down on the runway, the aircraft was shortly before it departed the runway. Shortly before the aircraft departed the runway edge, the pilots began to apply the brakes symmetrically in an attempt to make the aircraft remain on the runway.

If the pilots had recognized in advance that the rudder was inoperative, they would have employed the asymmetric use of power or brakes\(^{47}\) instead of applying the rudder. However, since the pilots had not had any prior information on the rudder abnormality, they had to make use of ineffective rudder pedals. After the nose landing gear touched down, just before the runway excursion, the pilots made an effort to stop the aircraft on the runway by applying the brakes.

It is known that one’s cognition and information processing capacity are significantly reduced or neutralized when one encounters an unexpected situation. When considering totally unexpected rudder unresponsiveness and the brief time of about 4 seconds - from the time when the nose landing gears touched down to the time when the aircraft departed the runway, the pilots might not have been able to come up to an alternative measure such as applying the brakes or thrust asymmetrically in timely manner.

**2.2.3.3 Controls Performed after Runway Excursion**

After the aircraft departed the runway, until it hit the concrete drainage ditch, other than applying the brakes symmetrically for about 10 seconds, no other attempts were made to avoid the collision with the concrete drainage ditch.

If the pilots had applied the brakes or thrust asymmetrically, the aircraft might have been prevented the collision with the concrete drainage ditch. However, the captain did not know there was an uncovered concrete drainage ditch at the side of the runway. He testified that he could not think of anything except just to stop the aircraft at that time of the accident.

\(^{47}\) Without using the pedal pressure evenly; it is to manipulate either side of the brake pressure to have a much greater effect.
Since there was no information regarding the location of the drainage ditch in the Aeronautical Information Publication (AIP), the captain could not have any idea about the obstacles in the vicinity of landing strip. However, when considering the captain’s statements that he could not think of anything but to stop the aircraft, even if the drainage had been aware in advance, it is still unclear that the he might have taken an alternative measure to change the direction of the aircraft.

Based on the facts and assumptions above, the Board considered that the reason why the captain was unable to perform alternative measure was that he did not know the presence of the obstacles in the grass beside the runway, and he was so preoccupied with the situation of the runway excursion that he could not come up with an alternative measure.

The ability to employ an appropriate alternative in timely manner depends on the pilot’s personal experience or skill. Therefore, providing the training for the pilot on the alternative measure such as using aileron when rudder is not available in the air and applying asymmetric brake on the ground, might greatly enhance the ability of the pilot's applying alternative measures in the future.

2.3 Maintenance Performance

2.3.1. Lightning Strike Repair

There were total of two lighting encounters for Flight 502 aircraft - in February 2007 and July 2007. According to the maintenance manual, when lightning strikes to the aircraft occurs, it has to be reported to the manufacturer and maintenance tasks should conducted in accordance with the manual, however, there was no record of such maintenance task has been conducted.

Through the technical meeting, it was determined that FCECU channel malfunctions were not caused by the lightning strikes. Even if flimsy maintenance tasks after the lightning strikes were not relevant to the occurrence of the FCECU faults, the fact that correct maintenance operations or maintenance procedures had not been observed was
considered as overall lack of experience and competence of DHC-8 aircraft on the part of the Jeju Air maintenance organization.

2.3.2 NVM Reset

When the FCECU faults were discovered, the maintenance personnel of Jeju Air determined that faults could be resolved once NVM was reset. However, if NVM were reset without carrying out a proper maintenance task, only the recorded fault codes would be erased from the NVM memory.

There is no evidence that the FCECU fault is related to these maintenance practices in this accident. However, the improper reset procedure could lead fault code history record to disorder, and consequently it had caused confusion in identifying the exact cause of the accident.

Currently, in the process of the accident investigation, Jeju Air has modified NVM fault code reset procedure and has been applied it ever since.

2.4 Aircraft System

2.4.1 Cause of Rudder not responding to the pilot input

To determine why rudder did not correspond normally to the pilots’ rudder pedal inputs, an examination was conducted on the related components of the rudder control, including the FCECU. As a result of the examination, one of the two channels of the FCECU was found to be faulty. However, according to the aircraft manufacturer’s design concept, it is not that the rudder would not work because of the failure of one of the two channels of the FCECU.

In order to have a total loss of rudder function of the aircraft, in addition to faulty channel, the normal channel needs to be failed by an independent cause. However, the normal channel did not reveal the cause of the malfunction, at the same time, no single
mode of failure was introduced to explain the failure of the two channels of the FCECU at the same time.

### 2.4.2 Cause of FCECU Malfunction

To find the cause of the malfunction in one of the FCECU channels, the examinations were carried out three times at the component manufacturer. However, the cause of one channel failure was not isolated, as well as the cause of the normal channel failed to perform its functions.

When referring to the result of NVM fault code interpretation, overpressure and underpressure were recorded in the last power cycle.

Though there is no way to determine the time of the faults occurrence since there is no time stamp on the NVM fault code history record, it was hard to exclude the possibility that the rudder not responding to the pilot's rudder input was consequential to the NVM fault codes of underpressure and overpressure recorded in the same power cycle.

Therefore, the Board has determined that there should be a need for consistent research and analysis for the problem that the rudder failed to function when one channel of the FCECU is in operating condition.

### 2.4.3 Rudder not responding to the pilot input Warning System

There is no particular warning light was designed to warn a rudder not responding to the pilot input in DHC-8. As per design concept, the failure of rudder system is not considered as catastrophic event.

However, the risk of the rudder failure may vary depending on the circumstances and the timing of occurrence as well as whether the pilot's recognition of failure beforehand. In other words, if the pilot did not recognize the state of the rudder not
responding to the pilot input during take-off or landing procedure in a cross wind condition, the consequence could be catastrophic.

With current caution light system, the pilot could recognize that the rudder system will fail when there appears three caution lights at the same time, RUD CTRL, #1 RUD HYD, and #2 RUD HYD respectively, yet the pilot is capable to make a comprehensive interpretation for the situation.

To be prepared for this type of circumstance such as the rudder not responding to the pilot input occurs for an unknown cause, like in the case of this accident, it is advisable for the pilots to operate the aircraft tentatively until the exact cause of the accident is identified, under the premise that the rudder could be not responding to the pilot input when RUD CTRL and #1 RUD HYD or #2 RUD HYD caution lights concurrently illuminate.

2.4.4 Takeoff Warning System

According to the Flight Crew Operating Manual\(^{48}\), if Inboard or Outboard Spoilers are extended during takeoff, the takeoff warning tone sounds. However, the takeoff warning is designed to activate either Inboard or Outboard Spoilers are extended symmetrically at 3.95 degrees. For that reason, the takeoff warning did not activate in respect of the extended spoilers in this flight.

Even though the lateral control is possible for the aircraft with the spoilers are extended asymmetrically, if the spoilers are asymmetrically extended during take off, it may affect the take off performance; therefore, it is desirable to give warning and caution to the pilots of any kinds of the spoilers extended in an appropriate manner.

If it is the design concept of the aircraft manufacturer to halt a take-off when the spoilers are extended exceeding the specified range, it cannot be seen as a prudent

\(^{48}\) Flight Crew Operations Manual: Refer to Chapter 6, page 37
manner to design the warning system to activate only when the spoilers are extended symmetrically. The Board determined that the flight would not have continued if the take-off warning system had been activated and the pilots had been cautioned on the asymmetrical spoilers deployment.

2.5 Aircraft Manual

2.5.1 Warning for Rudder not responding to the pilot input

In the Flight Crew Operating Manual for the aircraft systems knowledge and the Pilot Operating Manual for the flight procedures, there is no explicit information, explaining that the rudder system will not responding to the pilot input in some cases where the FCECU fails or the hydraulic system fails. Also there is no information found in the QRH, which pilots always carry and refer to during flight, describing the possibility of the rudder system malfunction when RUD CTRL caution light illuminates.

The manufacturer mentioned that since not all of the both channels of the FCECU failed and malfunction of the both channels was not due to a single cause, there is no need to consider a changing the FCECU system design and modifying some of the manuals or QRH. The manufacturer also mentioned that the rudder failure was not regarded as a catastrophic event, and the directional control of the aircraft can be available even without the rudder.

The Board believes that only if pilots are aware of the rudder malfunction beforehand, it cannot be a catastrophic event. On the contrary, if pilots are not aware of the rudder malfunction beforehand, it would turn out to be a catastrophic event. The severity of risk may be much more serious if the malfunction occurs at the time of takeoff or landing.

If the pilots had received the warning about the rudder not responding to the pilot input during flight, they could have prevented the aircraft departing the runway by applying brakes or thrust asymmetrically.
Based on the factual information and presumptions, until the root causes are identified, although the manual said when one of the FCECU channels fails, the remaining channel stays normal, the Board believes that it is desirable the aircraft manufacturer to state the potential malfunctions of the rudder by unknown causes.

Furthermore, the Board considers that it would be effective in preventing further similar accidents if the steps requiring evaluation for the operability of the rudder system are introduced to the item of RUD CNTL in the QRH when the caution light illuminates, and an appropriate non-normal procedures are added to the QRH.

2.6 Grading of the landing strips

The drainage ditch into which Flight 502 collided was outside of the prescribed range of the landing strip to be based on the maintenance and repair standards for the aircraft runway excursion.

But in terms of the aircraft using runway 36L which is physically identical but only the direction is in opposite to runway 18R, this drainage is located within the prescribed range to be based on the maintenance and repair standards of the landing strip.

It is not directly related to the cause of the accident, however in this case, it can be concluded that the drainage should be relocated or covered to meet the maintenance and repair standards of the landing strip. The drainage covering construction was included in the safety facility expansion construction of the Gimhae Airport commencing on 1 October 2007, and completed on 31 October 2009.
3. Conclusions

3.1 Findings

1. The rudder failed to respond to the pilots’ rudder pedal inputs.

2. The rudder not responding to the pilot's input was not recognized by the pilots during flight and as well as during landing roll.

3. After departing from the runway, no appropriate alternative measure was taken to control the aircraft direction.

4. Although there were abnormal indications for the rudders and spoilers, they were not confirmed and no particular measures were taken through the normal procedures.

5. There were no clear statements in the QRH suggesting caution light conditions and possibilities of no rudder response to pilots' rudder pedal input in the abnormal procedures of RUD HYD and RUD CTRL caution lights.

6. The content of the recorded maintenance tasks of the lightning strike was different from the maintenance procedures of the manual.

7. NVM fault code was reset in an inappropriate way.

8. Before takeoff, the left outboard spoiler was open at 12.5 degrees; however, there was no warning system for it.

9. According to the article 34 of the Airport Safety Operational Standard, the drainage which the aircraft collided into was located outside the range of the runway 18R (non-instrument runway) to be based on the maintenance and repair standards of the landing strip.
3.2 Causes

The Aviation and Railway Accident Investigation Board determines that the cause of the runway excursion of the Flight 502 was that 「the rudder failure was not recognized by the pilots during flight and as well as during landing roll.」.

Contributing to this accident was that 「① the rudder was failing to respond to the pilots' rudder pedal input and ② After departing from the runway, no appropriate alternative measure was taken to control the aircraft direction.」
4. Safety Recommendations

As a result of an investigation into the accident of Jeju Air's Q400, HL5236 occurred on 12 August 2007 at Gimhae Airport, the Aviation and Railway Accident Investigation Board makes the following safety recommendations;

**To Bombardier Aerospace, Inc**

1. To help the pilots carrying out the procedures, improve the QRH layout by describing the conditions to perform the procedures or the conditions of illumination of the caution lights. (AAR0701-1)

2. Include the facts that the rudder may not respond to the pilot's rudder pedal input when FECEU is not able to control the hydraulic pressure of the rudder actuator into the conditions of RUD CNTL caution light illumination in the Flight Operation Manual, and establish the measures into the associate normal procedure in the QRH. (AAR0701-2)

3. Consider modifying the manner of takeoff warning associated with the spoiler so that pilots can be able to have the take-off warning at takeoff, when spoiler is open at 3.95 degrees or more, regardless of whether malfunction of FCECU channel or symmetrical opening of the FCECU channel. (AAR0701-3)

**To Jeju Air**

1. When the pilots perform the procedures for a control surface investigation, the instrument indications of PFCS must be verified. Therefore, specific measures need to be taken to check the instrument indications. (AAR0701-4)

2. Notice the pilot that without relevant caution, the rudder can be inoperative, and establish an appropriate procedure the pilots should follow. (AAR0701-5)

※ After the accident, because disposal by Sale of DHC-8-402 was done by Jeju Air, it is considered that safety recommendations had been completely implemented.
3. Reinforce education and training for the pilots to improve their ability to take an alternative measure in the event of a situation not specified in the manuals or QRH. (AAR0701-6)

4. Establish an NVM reset procedure. (AAR0701-7)

   ※ After the accident, because disposal by Sale of DHC-8-402 was done by Jeju Air, it is considered that safety recommendations had been completely implemented.

5. Reinforce education and training for the pilots to apply the aircraft control transfer procedure in an appropriate manner under every possible circumstance. (AAR0701-8)

To Korea Airports Corporation

1. Cover the drainage between the runway 18L and the runway 18R of Gimhae Airport. (AAR0701-9)

   ※ On 31 October 2009, a drainage covering construction was completed, and it is considered that the safety recommendations had been completely implemented. (AAR0701-9)
Appendix 1: The comments of Transportation Safety Board of Canada to the Draft Final Report of Flight 502

※ All the comments of Transportation Safety Board of Canada except the Findings No 3 are accepted. Comment on the Finding No 3, Page 57 is appended in this appendix.

※ Transportation Canada's comment on the Recommendation AAR0701 is accepted. The comment on the Recommendation AAR0701-4 is partially accepted and appended in this appendix.

※ Among the comments of the Manufacturer, those which not accepted are appended in this appendix.
06 September 2011

Mr. Tae-hwan Cho
Chairman
Korea Aviation and Railway Accident Investigation Board (ARAB)
281 Gonghang-dong, Gangseo-gu
Seoul, 157-815
Republic of Korea

RE:  Canada State Comments – ARAB/AAR0701
     Bombardier DHC-8-402, HL5256, Jeju Air Flight 502
     Gimhae International Airport, Busan, Republic of Korea, 12 August 2007

Dear Mr. Cho,

Thank you for providing Canada, as the State of Manufacturer of the occurrence aircraft, with the opportunity to comment on the subject draft Final Report.

Attached you will find the comments from the Transportation Safety Board of Canada, Transport Canada and Bombardier Aerospace for whatever action you may deem appropriate.

We look forward to receiving your Final Report on this investigation.

Sincerely,

Mark Clitsome
Director, Air Investigations Branch

Attachments: 3

cc:  Nicole Girard, Director, Policy and Regulatory Services, Transport Canada
     David Fisher, Manager, Air Safety Investigation, Bombardier Aerospace
Appendix

Transportation Safety Board of Canada comments of the Draft Final Report
ARAIB/AAR0701.

Page 57, Findings, No. 3. The TSB suggests, "From touchdown to contact with the ditch, no appropriate alternative measures were taken to maintain directional control of the aircraft." It is clear from the FDR data that the flight crew were trying to maintain directional control with right rudder shortly after touchdown. Referring to Transportation Safety Board of Canada Engineering Report LP075/2007 - FDR Analysis, shortly after touchdown, there is an attempt to align the aircraft with the runway heading. This response is the application of right rudder. This is maintained for 10 seconds until the aircraft departs the runway. It is evident that the flight crew were well aware of the need to maintain directional control but only used right rudder and right aileron to do so. From touchdown to contact with the drainage ditch was almost 20 seconds (10 seconds on the runway and 10 seconds in the grass).
Transport Canada’s comments to Draft Republic of Korea Aviation and Railway Accident Investigation Board (ARAIB), Aviation Investigation Report A07F0126, Runway Excursion while Landing Roll, JEJU Air, DHC-8-402, HL5256, Gimhae International Airport, 12 August 2007

Draft Safety Recommendation AAR0701-4
Consider changing the manner of takeoff warning associated with the spoiler so that pilots can be able to have the take-off warning at takeoff, when spoiler is open at 3.95 degrees or more, regardless of whether malfunction of FCECU channel or symmetrical opening of the FCECU channel.

Transport Canada’s comments
The flight control position is indicated in the cockpit and the pilots are required to verify visually per Quick Response Handbook (QRH), that the spoilers and other flight controls are operating as expected. Provisions of a “takeoff warning” system for flight control position was not designed into the Dash-8 aircraft. Safe flight with uncommanded spoiler deployment (both symmetric and asymmetric) has been demonstrated using aileron trim as required.

Transport Canada suggests that the ARAIB take into consideration pilots are required to verify visually per Quick Response Handbook (QRH), that the spoilers and other flight controls are operating as expected, and remove this recommendation from their Final Report.
BOMBARDIER

August 15, 2011

Jon Lee
Transportation Safety Board of Canada
Western Regional Manager – Air,
Transportation Safety Board of Canada
T: (780) 495-3866
F: (780) 495-2079
C: (780) 983-3619

Dear Jon:

RE: Aviation and Railway Accident Investigation Board, Seoul, Republic of Korea AAIB
Bulletin ARAIB/AAR0701: “Aircraft runway excursion while landing roll, Jeju Air flight
502, DHC-8-402, HL5256, Gimhae International Airport, Runway 18R, 12 August,
2007”.

Bombardier appreciates the opportunity to offer comment on the draft accident report of the investigation into this occurrence.

suggests, adds, changes, removes, changes/corrects, replaces and comments are accepted except the followings:

1.16.1.4 Simulator Test Flight Section.

Page 37, Last Paragraph: “Under the premise that pilots had recognized the rudder would be inoperative.”

General Comment: this statement should be removed; a pilot responds to required directional control regardless of prior knowledge of a control inadequacy. As written it suggests a pilot would do nothing to react to an aircraft condition unless he has prior knowledge of an impending event.
2.2.1 Flight Control Surface Check in Flight Section.

Page 48, 4th Paragraph, Last Line, "...would mean that their monitoring was not cautiously carried out, or perhaps the pilots might have ignored the abnormal indications even after verifying them."

Note: The rudder position indication was at 7 degrees with no rudder trim present would confirm their monitoring was not cautiously carried out.

Page 48, 5th Paragraph, "could not be said that the rudder sticking during landing at the Gimhae Airport is the consequence of the proceeding flight while the abnormal indications of the spoiler were not verified. However, the Board determines that the pilots' not adhering to the suggested standard practices48), in other words, all the abnormal indications should be confirmed and dealt accordingly, was such performance that should be corrected."

General Note on this paragraph: If the FCECU was removed after realizing the failures in the preceding flight, the incident would most likely have been averted.

2.2.3.2 Controls Performed before Runway Excursion Section,

Page 50, 3rd Paragraph, "When considering totally unexpected rudder unresponsiveness and the brief time of about 4 seconds – from the time when the nose landing gears touched down to the time when the..."

Comment: Timing 4 seconds seems incorrect. The TSB Engineering Report LP075/2007, has the aircraft on the runway for a longer period of time.

2.4.3 "Rudder Stuck Warning System", Suggest: Rudder Jam

Page 53, 5th Paragraph, "There is no particular warning light was designed to warn a rudder stuck in DHC-8. As per design concept, the failure of rudder system is not considered as catastrophic event."

Comment: Not correct, the illumination of either RUD 1 PUSH-OFF or RUD 2 PUSH-OFF advised the flight crew that one of the two rudder power control units (PCU) has jammed and maintenance action is required before next flight.

However, there were a number of associated Rudder caution warning lights provided to the flight crew that suggest the system was not performing normally.
Page 55, 4th Paragraph, "If the pilots had received the warning about the rudder stuck during flight, they could have prevented the aircraft departing the runway by applying brakes or thrust asymmetrically."

Comment: The paragraph as written is speculation. The flight crew were presented numerous rudder system warning lights; however, did not appear to have any heightened awareness to a possible issue with directional control. The landing at Gimhae was performed without crew caution regardless of a possible rudder control anomaly.

3.1 Findings Section,

Page 57, Item 8, "Before takeoff, the left outboard spoiler was open at 12.5 degrees; however, there was no warning system for it."

Note: There is no caution warning system for a single spoiler panel and there is none required. However, the Aircraft Flight Manual requires that the flight crew perform a preflight flight control system freedom of travel check and cross-check flight control movements on the Powered Flight Control System (PFCS) to ensure there are no flight controls deployed or out of position before flight.

4. Safety Recommendations Section,

Page 59, Item 2, "To help the pilots carrying out the procedures, improve the QRH layout by describing the conditions to perform the procedures or the conditions of illumination of the caution lights. (AAR0701-2)."

Comment: The Aircraft Flight Manual (AFM) contains a RUDDER JAM procedure addressing a Restricted Rudder Pedal Movement procedure. AFM, PSM 1-84-1A, Section 3, 3.8.5 Directional Control Malfunction (Rudder Jam).

Page 59, Item 4, "Consider changing the manner of takeoff warning associated with the spoiler so that pilots can be able to have the take-off warning at takeoff, when spoiler is open at 3.95 degrees or more, regardless of whether malfunction of FCECU channel or symmetrical opening of the FCECU channel. (AAR0701-4)."

Comment: The aircraft's take-off warning system will be activated when two or more spoiler panels are > 3.95 degrees up. The aircraft is certified to fly with one spoiler panel fully extended. Therefore a take-off warning system is not required when one spoiler panel is deployed. However, the PFCS must be checked prior to take-off. In this event the flight crew would have been presented with the indication that one spoiler panel was deployed.
Appendix 2: The comments of the NTSB to the Draft Final Report of Flight 502

※ Among the comments of the NTSB and the Component Manufacturer, those which not accepted are appended in this appendix.
3) Discussion of the captain’s input (rudder) while the First Officer was performing the flight. There looks to be section in the analysis (2.2.3.1) but needs to be discussed in the factual section as well.

15) Page 35, Section 1.16.1.2.1 – Regarding Table 7, the complete table is unnecessary for the final report. It is appropriate to have the decoded fault messages for the accident flight, but entire NVM buffer is unnecessary. In addition, Table 8 appears to be a conversion of the fault codes into English, technical terms, and not analysis.

17) Page 38, Section 1.16.1.5 – Some of the results cited here may be considered proprietary by Bombardier, Parker, or BAE Systems.
3. On page 33, a summary of the factual findings of the FCECU cards is shown and various capacitors were found cracked. These findings are not discussed in the Analysis or Conclusion section. Throughout the examinations of the FCECU, it was not determined how or when these components were cracked, and if this was a normal or abnormal condition. A statement could be added to the Analysis section to address these findings.

6. Page 39, last bullet: "ARAIB commented that the FCECU could be individually separated into two boxes for the purpose of preventing similar events."

There already is a separation within the box, effectively creating 2 boxes within one enclosure. The two channels are on separate cards and are independent of each other. In this event, a single failure did not affect both channels of the FCECU, so separate enclosures for each card would not have prevented the flight control anomalies experienced in this event. The design of the FCECU is standard practice in the industry and has proven itself in this and other aircraft.