AA2024-1

AIRCRAFT ACCIDENT

INVESTIGATION REPORT

Fukushima Prefectural Police Aviation Unit
J A 1 3 9 F

January 25, 2024

Japan Transport Safety Board

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Japan Transport Safety Board and with Annex 13 to the Convention on International Civil Aviation is to determine the causes of an accident and damage incidental to such an accident, thereby preventing future accidents and reducing damage. It is not the purpose of the investigation to apportion blame or liability.

TAKEDA Nobuo
Chairperson
Japan Transport Safety Board

Note:

This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.

《Reference》

The terms used to describe the results of the analysis in "3. ANALYSIS" of this report are as follows.

i) In case of being able to determine, the term "certain" or "certainly" is used.
ii) In case of being unable to determine but being almost certain, the term "highly probable" or "most likely" is used.
iii) In case of higher possibility, the term "probable" or "more likely" is used.
iv) In a case that there is a possibility, the term "likely" or "possible" is used.

AIRCRAFT ACCIDENT INVESTIGATION REPORT

INJURIES TO PERSONS ON BOARD AND ROTORCRAFT DAMAGE CAUSED BY HARD LANDING FUKUSHIMA PREFECTURAL POLICE AVIATION UNIT AGUSTA AW139 (ROTORCRAFT), JA139F AT MIHOTA TOWN, KORIYAMA CITY FUKUSHIMA PREFECTURE, JAPAN AT ABOUT 08:08 JST, February 1, 2020

December 22, 2023

Adopted by the Japan Transport Safety Board

Chairperson	TAKEDA Nobuo
Member	SHIMAMURA Atsushi
Member	MARUI Yuichi
Member	SODA Hisako
Member	NAKANISHI Miwa
Member	TSUDA Hiroka

SYNOPSIS

<Summary of the Accident>

On Saturday February 1, 2020, when an Agusta AW139, JA139F, operated by the Fukushima Prefectural Police Aviation Unit, was flying from the Aizu Chuo Hospital Temporary Operation Site in Aizuwakamatsu City, Fukushima Prefecture toward Fukushima Airport in order to transport organs for transplantation, at 08:08 JST, the main rotor blades severed the tail drive shaft and controlling the helicopter became difficult over Mihota Town in Koriyama City, Fukushima Prefecture. Therefore, the helicopter tried to make a forced landing in a paddy field in the town but made a hard landing and rolled over.

On board the helicopter were seven persons in total, consisting of a captain, a co-pilot, two mechanics, and three passengers. Four of them were seriously injured, and the other three sustained minor injuries.

The helicopter was destroyed, but there was no outbreak of fire.

＜Probable Causes＞

The JTSB concludes that the probable cause of this accident was that as the main rotor blades severed the tail drive shaft and controlling the helicopter became difficult while flying, the helicopter tried a forced landing, but made a hard landing, which resulted in injuries to persons on board and damage to the helicopter.

The reason why the main rotor blades severed the tail drive shaft is most likely because when the helicopter encountered a strong downdraft while flying at a high speed over mountain regions in strong winds, it started a right rolling motion exceeding 360° after the rapid increase airspeed, and the main rotor blades were largely flapping toward the fuselage. In addition, regarding the fact that the helicopter became a right rolling motion, it was probably affected by the captain’s large stick movement when encountering a downdraft.

This report uses the following abbreviations:

ADC:	Air Data Computer
ADS:	Air Data System
AFCS:	Automatic Flight Control System
AFT:	After
AHRS:	Attitude Heading Reference System
ANSV:	Agenzia Nazionale per la Sicurezza del Volo (Italian civil aviation safety investigation authority)
AP:	Autopilot
ATT:	Attitude retention mode
AW:	Agusta Westland
CG:	Center of Gravity
CRM:	Crew Resource Management
DCU:	Data Collection Unit
DN:	Down
ECL:	Engine Control Lever
EEC:	Electronic Engine Control
EECU:	Electronic Engine Control Unit
ELT:	Emergency Locator Transmitter
FD:	Flight Director
F.E.:	First Event
FFS:	Full Flight Simulator
FMS:	Flight Management System
FTR:	Force Trim Release
FWD:	Forward
GPS:	Global Positioning System
GS:	Ground Speed
IAS:	Indicated Air Speed
ITT:	Inter Turbine Temperature
JTSB:	Japan Transport Safety Board
KIAS:	Indicated Air Speed (Knots)
LAT:	Lateral
LONG:	Longitudinal
LT:	Left

MPFR:	Multi-Purpose Flight Recorder
NF:	Number of engine Free power turbine speed
Ng/NG:	Number of engine Gas Generator speed
NPT:	Number of engine free Power Turbine speed
NR:	Number of Rotor speed
NTSB:	National Transportation Safety Board
PFD:	Primary Flight Display
PI:	Power Index
PT:	Potential temperature
RT:	Right
SW:	Switch
TAS:	True Air Speed
TQ:	Engine Torque
VFR:	Visual Flight Rules

Conversion table

1ft:	0.3048 M
1kt:	1.852 km/h (0.5144 m/s)
1in:	25.40 mm

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1. PROCESS AND PROGRESS OF THE AIRCRAFT ACCIDENT INVESTIGATION

1.1 Summary of the Accident

On Saturday February 1, 2020, when an Agusta AW139, JA139F, operated by the Fukushima Prefectural Police Aviation Unit, was flying from the Aizu Chuo Hospital Temporary Operation Site in Aizuwakamatsu City, Fukushima Prefecture toward Fukushima Airport in order to transport organs for transplantation, at 08:08 JST (JST: UTC+9 hours; unless otherwise noted, all times are indicated in JST in this report on a 24-hour clock), the main rotor blades severed the tail drive shaft and controlling the helicopter became difficult over Mihota Town in Koriyama City, Fukushima Prefecture. Therefore, the helicopter tried to make a forced landing in a paddy field in the town but made a hard landing and rolled over.

On board the helicopter were seven persons in total, consisting of the captain, the co-pilot, two mechanics, and three passengers. Four of them were seriously injured, and the other three sustained minor injuries.

The helicopter was destroyed but there was no outbreak of fire.

1.2 Outline of the Accident Investigation

1.2.1 Investigation Organization

On February 1, 2020, the Japan Transport Safety Board (JTSB) designated an investigator-in-charge and two other investigators to investigate this accident.

Regarding this accident, the numerical analyses utilizing the weather simulation model was commissioned to the Atmosphere and Ocean Research Institute, The University of Tokyo.

1.2.2 Representatives of the Relevant State

An accredited representative and an adviser of the Italian Republic, as the State of Design of the helicopter involved in the accident, an accredited representative and an adviser of Canada, as the State of Design and Manufacture of the engine of the helicopter involved in this accident, and an accredited representative and an adviser of the United States of America, as the State of Manufacture of the helicopter involved in this accident, and Design of the helicopter's equipment, participated in the investigation.

1.2.3 Implementation of the Investigation

February 1 to 4, 2020	On-site investigation
February 13, 2020	Interviews and document investigation
February 15 to 17, 2020	Wreckage investigation and interviews
March 18 to December, 2020	Detailed investigation of Flight Management System (FMS[*1]) (Conducted by the FMS manufacturer under the witness of the accident investigation authority National Transportation Safety Board (NTSB))
April 18 to May 5, 2020	Detailed investigation of Electronic Engine Control Unit (EECU) and Data Collection Unit (DCU[*2]) (Conducted by the engine manufacturer under the witness of the accident investigation authority, Transportation Safety Board (TSB) of Canada)
June to October, 2020	Wreckage analysis of the main rotor blade tips and the tail drive shaft (conducted at the helicopter manufacturer with the participation of the accident investigation authority, Agenzia Nazionale per la Sicurezza del Volo (ANSV))
May 1 to June 30, 2021	Numerical analyses utilizing the weather simulation model (commissioned to the Atmosphere and Ocean Research Institute, The University of Tokyo)
March 8, 2022	Investigation on the flight control with a full flight simulator

1.2.4 Interim Report

On January 21, 2021, the JTSB submitted an interim report to the Minister of Land, Infrastructure, Transport and Tourism based on the facts found up to that date, and the report was made available to the public.

1.2.5 Comments from Parties Relevant to the Cause

Comments on the draft Final Report were invited from the parties relevant to the cause of the accident.

[*1] The "FMS" is an integrated on-board navigation system that comprises following equipment such as aircraft navigation sensors, a system that receives radio signals from aeronautical radio navigation facilities, and a computer with navigation database, and the optimal performance guidance are provided to the displays and autopilot system.
[*2] The "DCU" is a device that records Engine Identification, Blade Creep Life, Exceedances, Running Time, Fault Codes, Cycles, and Engine Trim Data (Torque Shaft manufacture and ITT Harness).

1.2.6 Comments from the Relevant State

Comments on the draft Final Report were invited from the Relevant States.

2. FACTUAL INFORMATION

2.1 History of the Flight

On February 1, 2020, an Agusta AW139, JA139F (hereinafter referred to as "the helicopter"), operated by the Fukushima Prefectural Police Aviation Unit (hereinafter referred to as "Aviation Unit"), departed from the Fukushima Prefectural Police Heliport (hereinafter referred to as "Prefectural Police Heliport") at 07:09. In order to transport organs for transplantation, the helicopter landed at the Aizu Chuo Hospital Temporary Operation Site in Aizuwakamatsu city, Fukushima Prefecture (hereinafter referred to as "Aizu Operation Site") at 07:40. After boarding the two passengers with organs for transplantation, the helicopter took off from Aizu Operation Site at 08:00 and was flying toward Fukushima Airport.

The helicopter's flight plan was outlined as follows:

Flight rules:	Visual Flight Rules
Departure aerodrome:	Prefectural Police Heliport
Estimated off-block time:	07:10, Cruising speed: 120 kt,
	Cruising altitude: VFR[*3]
Transit point	Aizu Operation Site
Destination aerodrome:	Fukushima Airport
Total estimated elapsed time:	1 hour 20 minutes
Fuel load expressed in endurance:	2 hours 40 minutes
Persons on board:	7 persons

In the helicopter, the captain sat in the right pilot seat, the co-pilot in the left pilot seat, and two mechanics in the forward left and right seats of the cabin respectively. In the after cabin, one passenger boarded from the departure aerodrome sat in the left seat, and the two passengers boarded from Aizu Operation Site sat in the central and right seats respectively.

The outline of the transport plan for organs for transplantation was as follows:

*3 "VFR" refers to visual flight rules, which is described as VFR in the flight plan when flying without setting the cruising altitude.

(1) Transport plan for organs for transplantation instructed before the take-off

07:40	Departure from Takeda General Hospital (transportation by vehicle)
07:55	Arrival at Aizu Operation Site
08:00	Departure from Aizu Operation Site (Transportation by the helicopter)
08:20	Arrival at Fukushima Airport

In accordance with this transport plan, the helicopter was instructed to be at Aizu Operation Site at 07:40 for standby.

(2) Transport plan for organs for transplantation instructed during the flight

At 07:28, while the helicopter was flying toward Aizu Operation Site, due to the delay in extirpative surgery, the Fukushima Prefectural Police Headquarters instructed the helicopter by radio to change the transport plan as follows:

07:55	Departure from Takeda General Hospital (transportation by vehicle)
08:15	Arrival at Aizu Operation Site
08:20	Departure from Aizu Operation Site (Transportation by the helicopter)
08:40	Arrival at Fukushima Airport

According to records of the Multi-Purpose Flight Recorder[*4] (hereinafter referred to as "MPFR"), and the statements of the captain, the co-pilot, two mechanics, a passenger, and an eyewitness, the history of the flight of the helicopter up to the time of the accident was summarized as below.

2.1.1 Outline of History of the Flight (See Figure 1 and Figure 2)

07:09	The helicopter took off from Prefectural Police Heliport in order to transport the organs for transplantation and the passengers, flew over Koriyama City for the pre-check weather conditions, and headed for Aizu Operation Site.
07:24	The helicopter passed over the vicinity of the accident site at an altitude of about 3,000 ft and an indicated airspeed (IAS[*5]) of about 120 kt.
07:28	The captain obtained the information on the change of transport plan by police radio.

*4 "Multi-Purpose Flight Recorder (MPFR)" refers to a recording device in which a flight data recorder and a cockpit voice recorder are integrated.

*5 "IAS" means the airspeed which is displayed on the airspeed indicator including the Pitot static system.

07:29	After confirming that winds were blowing at about 50 kt from the northwest over the southeast side of Lake Inawashiro, the captain consulted with the co-pilot about flying at a higher altitude on the homeward journey than on the outward journey.
07:34	The co-pilot reported to the Prefectural Police Headquarters by police radio that there would be no problem for the flight route to Fukushima Airport.
07:40	The helicopter landed at Aizu Operation Site.
07:55	The captain informed all in the cabin that the helicopter would fly above the clouds on the homeward journey.
08:00	After the two passengers sat in the seats of aft cabin while holding the boxes containing organs for transplantation, the helicopter took off from Aizu Operation Site.
08:04	The captain informed the Fukushima Airport Mobile Communication Station (Fukushima Radio) of the take-off time and obtained the information about the landing at Fukushima Airport.
08:05	After climbing up to an altitude of about 5,700 ft over Lake Inawashiro, the helicopter started descending gradually.
08:06:10	The captain recognized with a tailwind that Ground Speed (GS[*6]) increased from 193 to 200 kt.
08:06:55	The co-pilot informed the captain that they were ahead of schedule.
08:07:31	While flying at IAS 152 kt and GS 198 kt with its heading 150° at an altitude of about 4,300 ft, the helicopter started rolling to the right at a rotational speed of 100 deg/s or more after the IAS increased rapidly to 188 kt, and made right rolling motion exceeding 360 °.
08:07:38	In the MPFR voice information, the contact noise was recorded, and then the record of wind noise started.
08:07:49	The captain operated the gear lever to extend the landing gears.
08:08:06	The co-pilot reported by police radio that the helicopter would make a forced landing in a paddy field.
08:08:20	The co-pilot set the AP switch[*7] to OFF in an attempt to reset the Autopilot (AP).
08:08:55	The helicopter made a forced landing in a paddy field in Mihota Town in Koriyama City, Fukushima Prefecture and rolled over. The airframe was scattered around with the rear section of the tail rotor separated and the main rotor blades damaged. (See 2.9 for details.)

[*6] "GS" refers to the relative speed of an aircraft to the ground surface.
[*7] "AP switch" refers to a switch to turn Automatic Flight Control System (AFCS) ON or OFF.

2.1.2 Statements of Crewmembers, Passengers and Eyewitness

(1) Captain

After taking off from Prefectural Police Heliport, the helicopter was flying southward on the east side of the Ou Mountain Range, and the captain confirmed the weather conditions in route beforehand. The wind from Koriyama to the Aizu Operation Site had somewhat strong turbulence, but the captain judged it would be able to control the helicopter attitude.

In order to make a major change in the aircraft attitude and the speed change, the captain had never used the Cyclic Stick's[*8] Beep Trim[*9] , instead used to depress the Force Trim Release Switch (FTR[*10]) and operated by adjusting the pitch attitude while using the distance between the airframe equipment located on the central window frame and the horizon as a guide. Besides, when encountering turbulence, the captain used to prioritize manual control by pushing the FTR of cyclic stick by SAS mode[*11] while looking at the horizon as thinking that it would be able to stabilize the helicopter's attitude earlier than reducing speed or operating in the ATT mode[*12].

After taking off from Aizu Operation Site, the captain was going to avoid low-level clouds and climb to about 5,500 ft and fly via the direct route to Fukushima Airport. After the climb, the helicopter was flying while lowering the altitude around when passing Lake Inawashiro. During the descent, there was no jolt with stable air current, the captain maintained approximately IAS 140 kt that the captain usually uses when cruising, and the never exceed speed[*13] (V_{NE}) shown on the airspeed indicator was 154 kt. As the GS was 190 to 200 kt, the captain was conscious that they were flying with a strong tailwind.

Around 08:07:30, when flying at an altitude of about 4,000 ft while avoiding upper clouds, first, air currents are disrupted, and the captain felt the movements from aft section of the helicopter that would influence the heading direction. After pulling the nose up by about 2 ° in order to decelerate, the captain felt "trembling" vibrations, therefore pulled down the collective

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*8 "Cyclic Stick" is one of the control devices of a helicopter, and in order to control the aircraft, and refers to a device that operates mainly in the direction of tilting the aircraft attitude.

*9 "Beep Trim" refers to a switch that can make a minor adjustment for pitch attitude or roll attitudes.

*10 "FTR" refers to a function to release the steering reaction force that is given according to the control inputs. While FTR button is pressed, the ATT mode is changed to the SAS mode.

*11 "SAS mode "refers to a mode in which the autopilot stability augmentation system improves the handling capabilities during hands-on flying.

*12 "ATT mode" refers to a mode that gives a function enabling a helicopter to control the pitch, roll, yaw and collective pitch and maintain the attitudes, in addition to a Stability Augmentation function provided by the SAS.

*13 "Never Exceed Speed" indicates the air speed which, if exceeded, may result in structural damage to the aircraft.

pitch lever[*14] by 10 to 15 % to make pitch attitude to 5 ° nose up, almost same attitude of 100 kt. At that time, the helicopter received gusts as if to feel both lateral G (lateral acceleration) and vertical G (vertical acceleration), therefore the captain held the cyclic stick as if to look for it, trying to maintain the attitude, then the helicopter looped like being drawn into the forward.

When the helicopter pitched nose down well enough for me to be able to see the ground, the wind that had entered the cockpit hit my face and the headset came off my ears before the captain knew it. Afterwards, as the captain was unable to use the intercommunication system and listen to the audio alert. After the attitude returned to a horizontal position, the captain operated the collective pitch lever upward, trying to reduce the descent rate, but could not do it. The captain pulled down the collective pitch lever and operated the rudder pedals[*15] in order to maintain the number of rotor speed (NR), but the helicopter did not respond to this rudder pedals' operation. In doing so, as noticing "x" marks displayed on instruments such as the airspeed indicator and vertical speed indicator on the PFD[*16], the captain felt the flight instruments was unable to be relied on, decided to make a forced landing, and then manually extended the landing gears in person.

As the captain concentrated on controlling the attitude of the helicopter while avoiding landing in a village, the captain was not able to correctly grasp the situation caused by the occurrence, however, the captain intended to make a forced landing by an autorotation[*17], and operated the collective pitch lever to maintain the NR. During the descent when the captain intended to perform an autorotation landing, it was manual backup mode[*18] in engine before the captain knew it. As the captain knew that the engines were operating, the captain operated the engine trim switch[*19], and felt as if the NR rose. However, the captain did not have the confidence to land at while maintaining NR, therefore, the captain stopped the autorotation and descended while moving the collective pitch lever up and down.

During the descent, the helicopter continued to rotate to the right, but the captain made

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[*14] "Collective pitch lever" refers to a control device that varies the pitch angle of the main rotor blades at the same time, and controls the engine power.

[*15] "Rudder pedals" are operated by foot pedals in the cockpit and provides a means to control the direction of the aircraft. For a single rotor helicopter, the rudder pedals are served as a device to change the pitch angle of tail rotor blades and steer the aircraft.

[*16] "PFD" refers to a multicolor integrated display in front of the pilot, which is integrated with a speed indicator, a pressure altimeter, a vertical speed indicator, heading and other functions, and displays information on the aircraft navigation and airspeed.

[*17] "Autorotation" is the state of rotorcraft flight where the main rotor system, which produces a lifting force, is being driven solely by the upward flow of air through the rotor.

[*18] "Engine manual backup mode" refers to in the state where a failure is detected in the automatically controlled engine and the fuel flow is manually controlled.

[*19] "Engine trim switches" refers to the switches, which are located at the tip of the collective pitch lever, remotely operate the engine control lever.

the nose up trying to restore the helicopter to the horizontal position as much as possible before the forced landing. And while receiving a strong shock, the helicopter touched down and rolled over. After the helicopter rolled over, the captain confirmed there was no smoke rising from the helicopter, and make all persons on board evacuate the helicopter from the window on the right side of the pilot seat.

(2) Co-pilot

Before the landing at Aizu Operation Site, the co-pilot checked the weather conditions en route and confirmed low clouds at an altitude of from about 3,000 to about 6,000 ft. And the co-pilot talked with the captain that the helicopter would be able to fly via straight flight path from Aizu Operation Site to Fukushima Airport, and fly with a tailwind above the clouds if it climbed up to about 6,000 ft.

After taking off from Aizu Operation Site, the helicopter climbed to achieve about 6,000 ft over Lake Inawashiro, and then gradually started reducing the altitude from around the time when crossing over the Ou Mountain Range. Even when crossing the pass, with smooth air, the helicopter did not jolt. The co-pilot remembered indicating the around IAS 149 kt and the captain was saying the GS indicated about 200 kt, but did not see it in detail. When the town was seen through rifts of cloud and the helicopter was descending under the clouds, the helicopter was suddenly blown up by the wind with a booming shock and its attitude changed abruptly. The window on the left side came off and the co-pilot thought the helicopter entered the cloud. Afterwards, although the co-pilot tried to operate the cyclic stick, but it did not move, therefore the co-pilot thought the autopilot (AP) had gone out of control, and reset the switch of the AP. The captain was struggling to control the helicopter, but was not able to maintain its nose heading, and the helicopter continued to turn right. Immediately after broadcasting that the helicopter was going to make a forced landing via police radio, the helicopter made a forced landing in a paddy field. After the forced landing, the co-pilot shut down the fuel systems and escaped.

(3) Crewmember A (Mechanic A) seated in the left seat in forward cabin

During the flight, the wind was strong, but the visibility was good and the horizon was in sight, therefore, the crewmember A thought that the helicopter did not enter the cloud. During the flight, without any noise and vibration, there was no feeling that the air current conditions were bad. After crewmember A heard the in-flight conversation of the pilots saying that the GS was about 200 kt with a tailwind, the helicopter suddenly descended and the forward window in the sliding door on the right side of the cabin came off and rolled around my feet. At first, the helicopter was in an abnormal attitude with its nose down, however, the captain controlled to restore the helicopter to the horizontal position, and the helicopter made a forced landing while rotating.

(4) Crewmember B (Mechanic B) seated in the right seat in forward cabin

The air current during the flight was the same as usual. After hearing that it was fast with a tailwind, the crewmember B looked ahead to find there were clouds and an open space below. Within a minute of seeing the cloud ahead, there occurred a vertical vibration with a big sound called "da-da-da". When the helicopter attitude changed significantly, the crewmember B saw something flying to the aft right of the helicopter from the window. After that, the crewmember B felt the helicopter descending as if to be rotating centering in its main rotor mast. The crewmember B did not know about the detailed change in the attitude, as having looked downward afterwards.

(5) Passenger A seated in the left seat in aft cabin

As flying with a headwind up to Aizu Operation Site, the helicopter was considerably shaking. After the helicopter took off from Aizu Operation Site and passed over Lake Inawashiro, the blue sky was showing, the weather conditions were improving and better than those on the outward journey flight, and the helicopter's attitude was in a stable condition with a tailwind almost without shaking. After passing over the Ou Mountain Range, there was a sudden impact that caused the helicopter to be shaken, turn over on its back and made one revolution. When the helicopter returned to its original attitude, the window on the right side came off and entered the cabin. After making some two rotations while the captain was controlling its attitude, the helicopter went into spin, but somehow held horizontal and made a forced landing while rotating to the right. When making the forced landing, its nose was up, therefore the helicopter landed from the backward. The helicopter rolled over to the left at the same time as making the forced landing. As the passenger A was trapped in the bottommost of the cabin and unable to move, the co-pilot assisted me to evacuate.

(6) Eyewitness A

The eyewitness A visually recognized the helicopter at a point 560 m north-east of the forced landing site. And the eyewitness A saw the helicopter making some two turns in the sky and heard unusual sound, taking a picture with a tablet quickly. The helicopter rapidly descended, flew southward while rotating, became invisible, and afterwards, the engine sound disappeared. (See Figure 3)

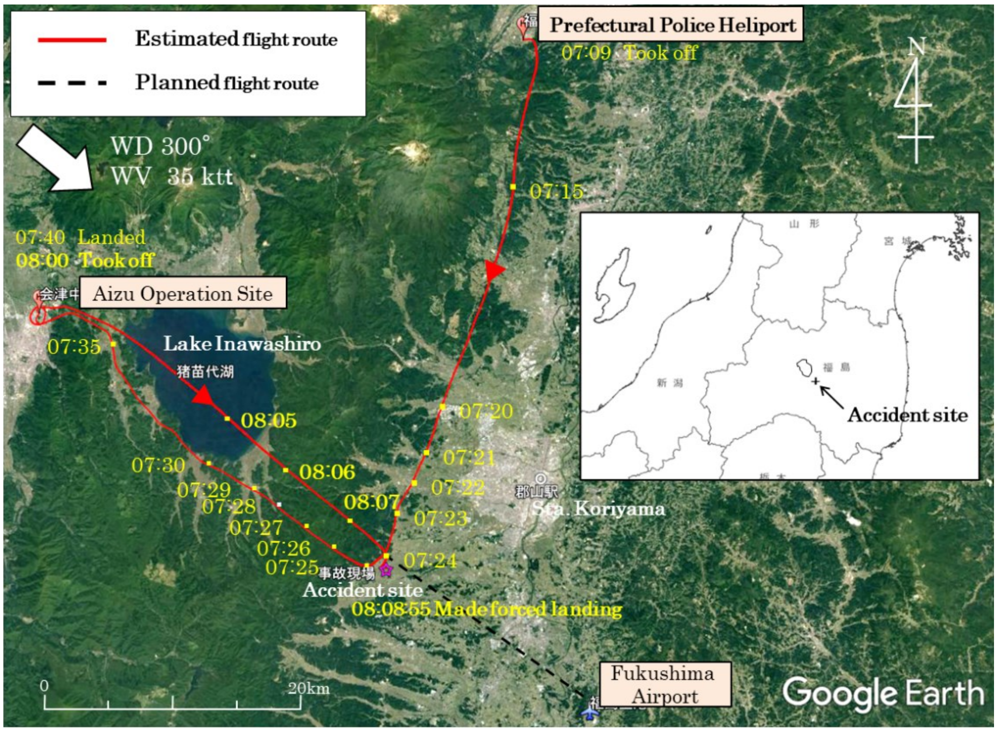

Figure 1: Estimated flight route of the helicopter

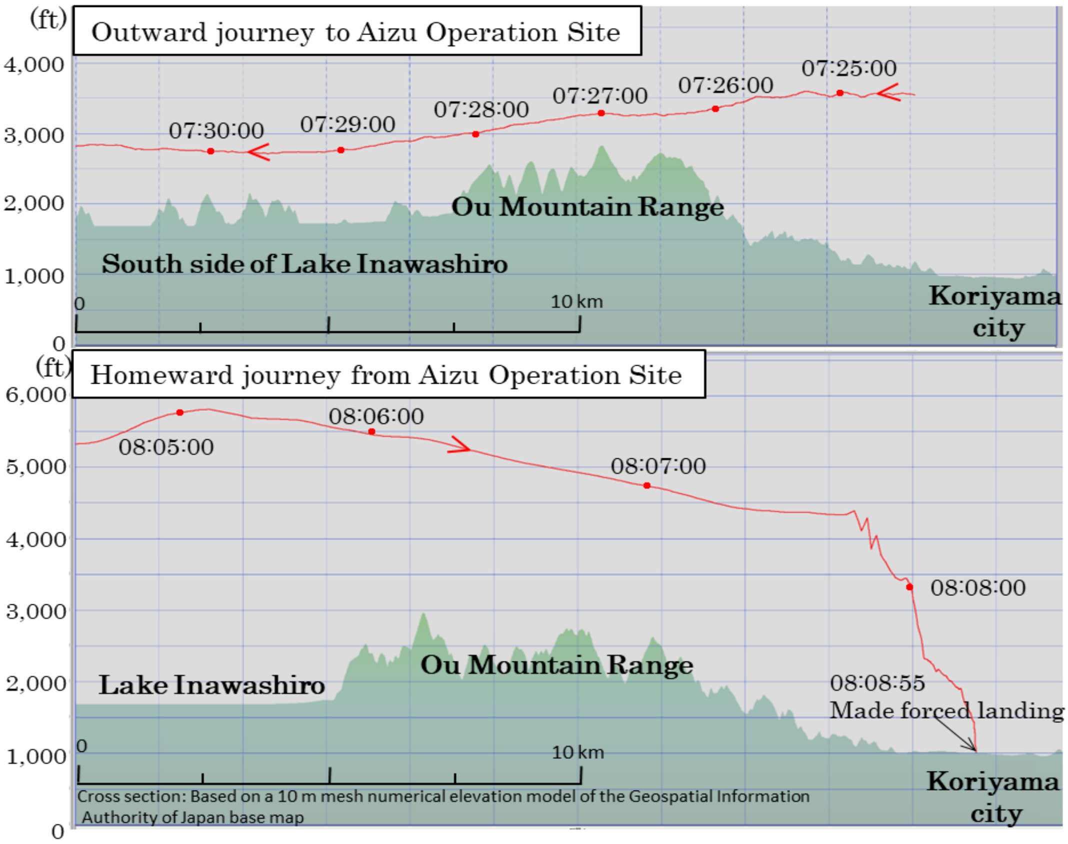

Figure 2: Cross-sectional view during the helicopter's flight over the Ou Mountain Range

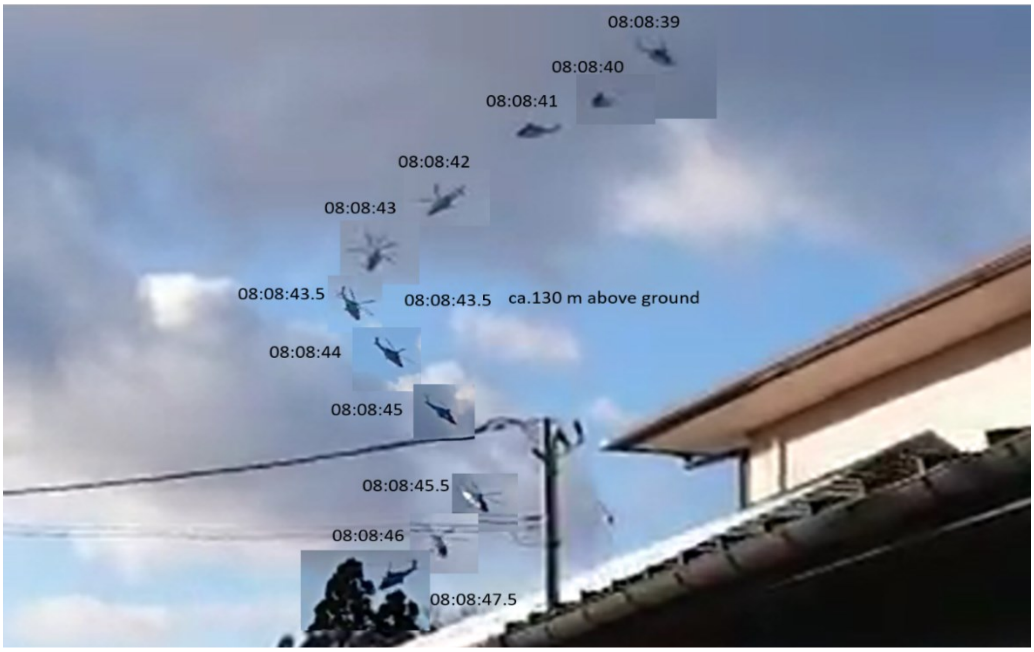

Figure 3: Composite view of images taken by the Eyewitness

The accident occurred in a paddy field in Shimomoriya in Mihota Town in Koriyama City, Fukushima Prefecture (N37°20'10", E140°14'59") at 08:08:55 on February 1, 2020.

2.2 Injuries to Persons

Three crewmembers such as the captain, the co-pilot and the Mechanic B sustained minor injuries, while four people in total, including the Mechanic A and three passengers, were seriously injured. (See 2.10 for details)

2.3 Damage to the Aircraft

2.3.1 Extent of Damage

Destroyed

2.3.2 Damage to the Aircraft Components

- Fuselage : Deformed from the nose to the bottom surface of the main landing gears
- Tail section : Separated, damaged
- Engines : Damaged (Partially deformed)
- Rotor system : Main rotor system: Damaged, blades scattered
  Tail drive shaft: Damaged, scattered
- Landing gears : Damaged

Figure 4: Rollover of the Accident Helicopter

2.4 Personnel Information

(1) Captain Age 38

Commercial pilot certificate (Rotorcraft)	March 27, 2009
Specific pilot competence	
Expiry of practicable period for flight	January 13, 2021
Type rating for single-engine turbine Land	March 27, 2009
For Multi-Engine Turbine Land	April 14, 2010
For Agusta AB139	January 6, 2015
Class 1 aviation medical certificate	
Validity	August 7, 2020
Total flight time	1,399 hours 30 minutes
Total flight time in the last 30 days	10 hours 40 minutes
Flight time on the same type of Rotorcraft	449 hours 40 minutes
Total flight time in the last 30 days	10 hours 40 minutes

(2) Co-pilot Age 50

Commercial pilot certificate (Rotorcraft)	November 12, 1993
Specific pilot competence	
Expiry of practicable period for flight	January 8, 2021

Type rating for single-engine turbine Land	April 14, 1993
For Multi-Engine Turbine Land	November 15, 2002
For Agusta AB139	January 6, 2015
Class 1 aviation medical certificate	
Validity	September 19, 2020
Total flight time	3,801 hours 30 minutes
Total flight time in the last 30 days	9 hours 40 minutes
Flight time on the same type of Rotorcraft	350 hours 00 minute
Total flight time in the last 30 days	9 hours 40 minutes

2.5 Aircraft Information

2.5.1 Aircraft

Type	Agusta AW139
Serial number	41373
Date of manufacture	May 8, 2014
Certificate of airworthiness	No. Toh-2019-276
Validity	October 3, 2020
Category of airworthiness	Rotorcraft, Transport TA, TB or Special X
Total flight time	1,027 hours 45 minutes

(See Appended Figure 1: Three Angle View of Agusta AW 139 and Direction of Force Acting on the Tail)

2.5.2 Weight and Balance

Immediately before the accident occurred, the weight of the helicopter is estimated to have been 5,707 kg and the position of the center of gravity is estimated to have been 5.27 m, both of which are estimated to have been within the allowable range (the maximum takeoff weight of 6,400 kg, and the center of gravity was within the range of 5.08 to 5.53m for the weight at the time of the accident)

2.6 Meteorological Information

(1) General weather forecasts and cloud conditions near the accident site

According to the observation of the Japan Meteorological Agency, the general weather forecast and cloud conditions near the accident site on the day of the accident were as follows:

As shown in the Surface Analysis Chart at 09:00 on February 1, 2020, in the left in Figure

5, a low-pressure system developed in the west of Kyushu on January 26, was moving eastward along with the southern coast of Japan while developing, and reached the southern part of Hokkaido on January 30, and then on February 1, it had gone away far to the east of Hokkaido. On the other hand, there was a high-pressure system near Shanghai, resulting in the weak winter-type pressure pattern over eastern Japan including Koriyama and its vicinity. The right in Figure 5 is the Meteorological Satellite Imagery (Visible) at the same time (09:00 on February 1, 2020), which shows wavelike clouds with the shear lines running through the north-northeast to the south-southwest, from Niigata Prefecture to the southern part of Fukushima Prefecture. Especially the clouds with the same shear lines were locally observed on the east side of the mountain range near Koriyama of the accident site located in the east-southeast of Lake Inawashiro.

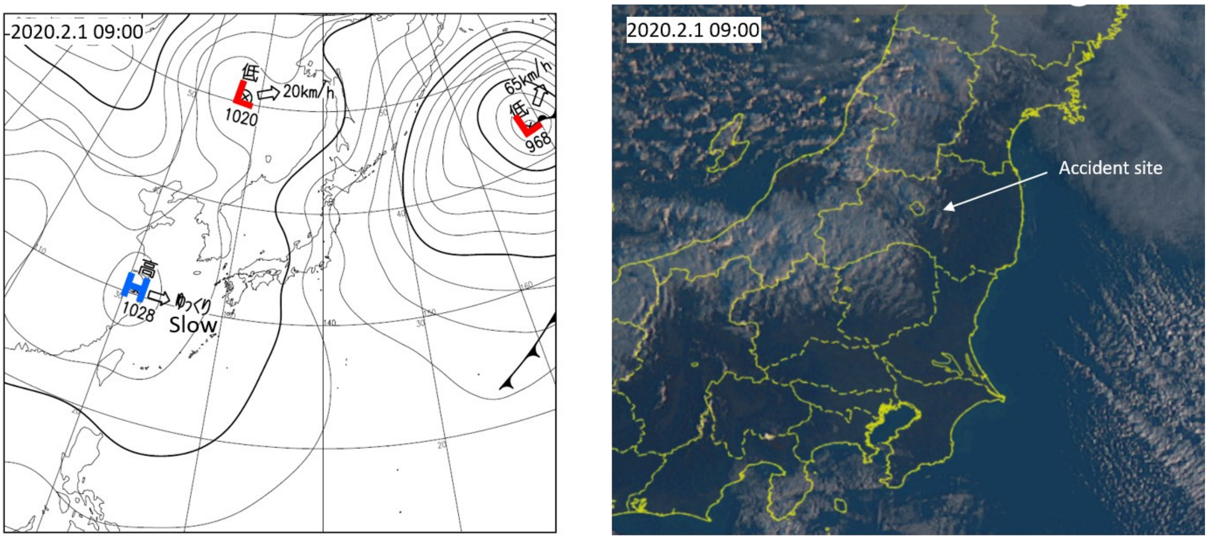

Figure 5: Surface Analysis Chart and Meteorological Satellite Imagery (Visible)at 09:00 on February 1, 2020

(2) Aeronautical weather observed at Fukushima Airport

Aeronautical weather observations for Fukushima Airport, located about 20 km southeast of the accident site, around the time of the accident were as follows:

08:00 Wind direction: 300°, Wind velocity: 09 kt, Prevailing visibility: 10 km or more

Cloud: Amount 1/8, Type Cumulus, Cloud base 2,000 ft

Temperature: 3℃, Dew point: -4℃, Altimeter setting (QNH): 29.88 inHg

(3) Figures observed at Koriyama Regional Weather Station

The observation values during the time period relevant to the accident at Koriyama Regional Weather Station located about 9 km northeast of the accident site were as follows:

08:10 Wind direction: west-northwest, Average wind velocity: 5.0 m/s,

Wind direction at the maximum instantaneous wind velocity: west-northwest,

Maximum instantaneous wind velocity: 8.8 m/s , Temperature: 2.4℃

(4) Wind profiler*20 in Wakamatsu

The wind profiles observed from 07:00 to 09:00 at the wind profiler in Wakamatsu located about 35 km northwest of the accident site were shown in Figure 6. At an altitude of about 4,300 ft (1,310 m), the winds around 08:00 were blowing from the northwest (300°) at about 35 kt when the helicopter started the right rolling motion.

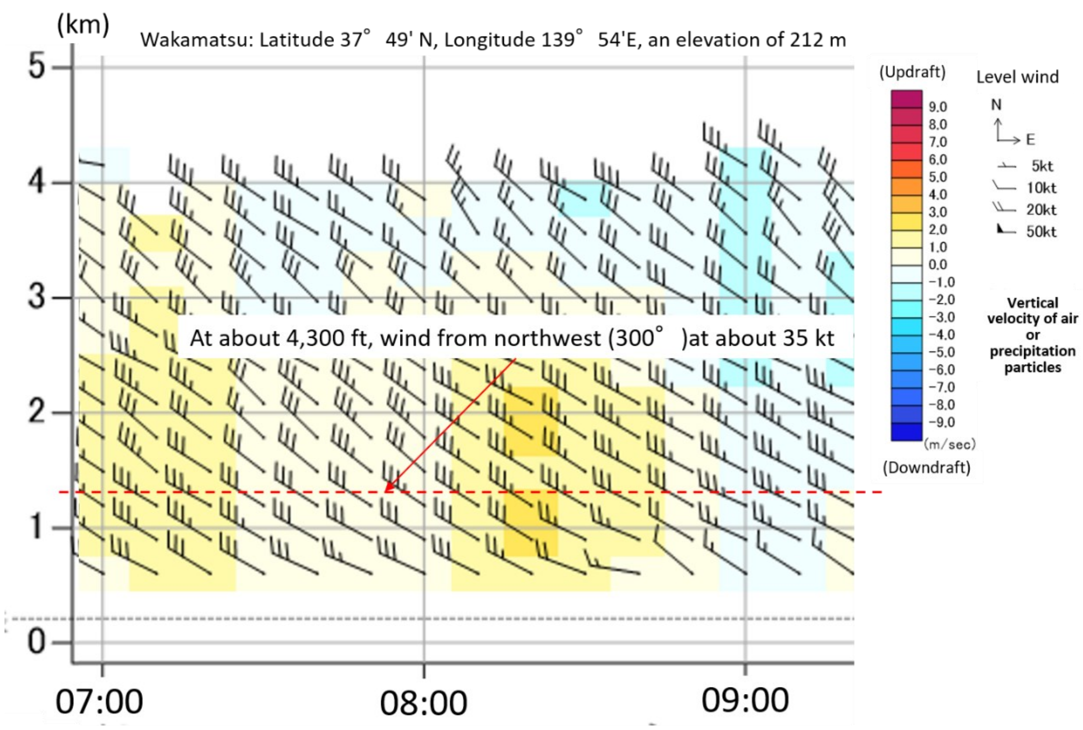

Figure 6: Upper wind profiles observed from 07:00 to 09:00 on February 1, 2020, at the wind profiler in Wakamatsu

2.7 Communication Information

After taking off from Aizu Operation Site under VFR, the helicopter established communication with Fukushima Airport at about 08:05, and obtained the landing information. About two minutes after that, controlling the helicopter became difficult, and while descending, the helicopter reported by police radio that it was going to make a forced landing. In addition, at the time of the forced landing, as the Emergency Locator Transmitter (ELT) was not

*20 "Wind profiler" is a type of instrument used to observe upper-air wind direction/speed. From the ground to the sky, these units emit radio waves, which are scattered as a result of turbulent atmospheric density. The returning waves are used for analysis to determine wind direction/speed.

automatically activated to transmit, the captain turned it ON manually and escaped.

2.8 Information on Flight Recorder

In the tail section of the fuselage, the helicopter was equipped with a Multi-Purpose Flight Recorder (MPFR), which functions both as a flight data recorder and a cockpit voice recorder, manufactured by Curtiss-Wright in the U.K.

The MPFR recorded about 25 hours of flight data and about 2 hours of cockpit voice, both of which were recorded at the time of the accident.

2.9 Information on the Accident Site and Wreckage

2.9.1 The Accident Site

As shown in Figure 7, the accident site is located in a rural area extending toward the west side in Koriyama City, and there is a village about 100 m to the north of the accident site.

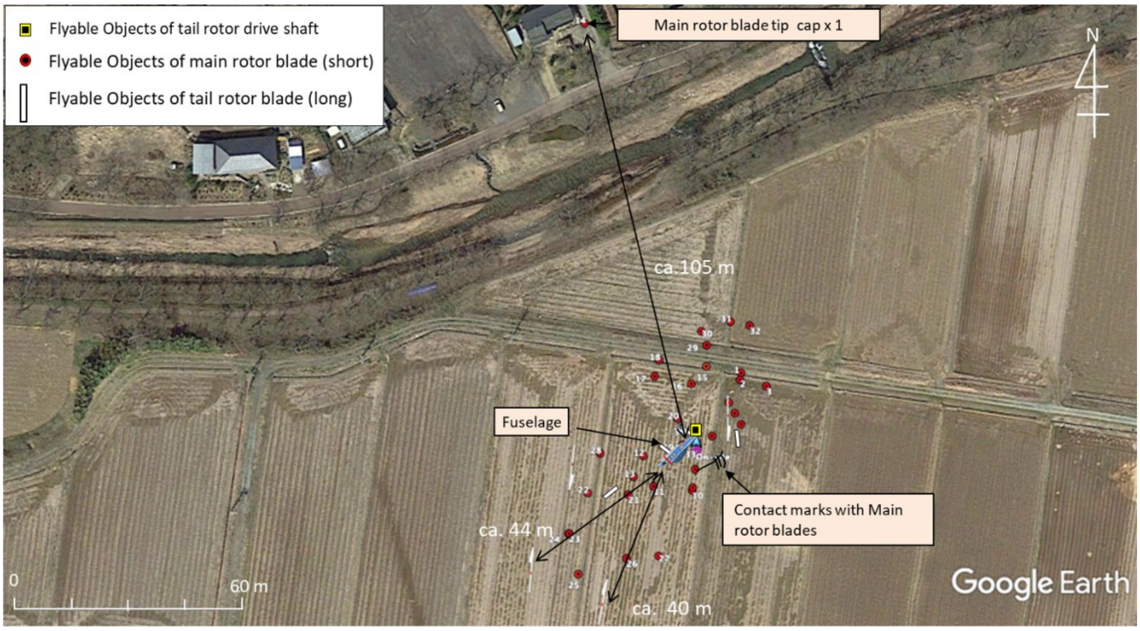

Figure 7: Wreckage scattered near the accident site

2.9.2 Details of the Damage

(1) Fuselage (See Figure 8)

- Almost all over the lower part structure of the fuselage from the nose section to the main landing gear attachment position was deformed by buckling upward.

Figure 8: Damage to fuselage and landing gears

(2) Tail section (See Figure 4, 8, 9 and 10)

- The tail section separated in front of the vertical stabilizer, and there was no significant damage to the tail rotor blades.
- The red colored part of tail drive shaft No.2 at the front upper portions of the tail section was found together with other upper tail drive shaft cover including the No.2 GPS antenna in the mountains about 1,300 m north of the accident site. (See Figure 9 and 10.)
- The fracture surface seen from the side of the tail drive shaft cover at the aft fuselage coincided with the position and shape when the main rotor blade lowered, and the left cover had more damage than the right cover. In addition, the lower fuselage where the tail drive shaft was damaged had scratch marks.
- A part of the tail drive shaft (corresponding part in Figure 15) had contact marks with jagged shaped dents.

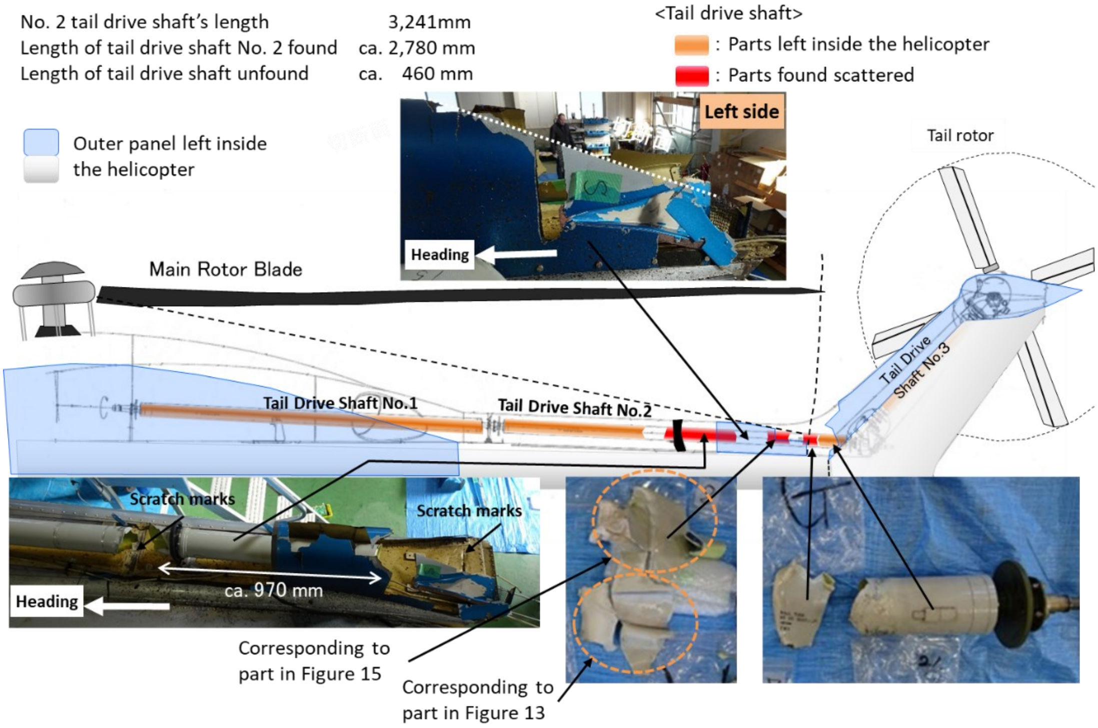

Figure 9: Damage to Tail Drive Shaft

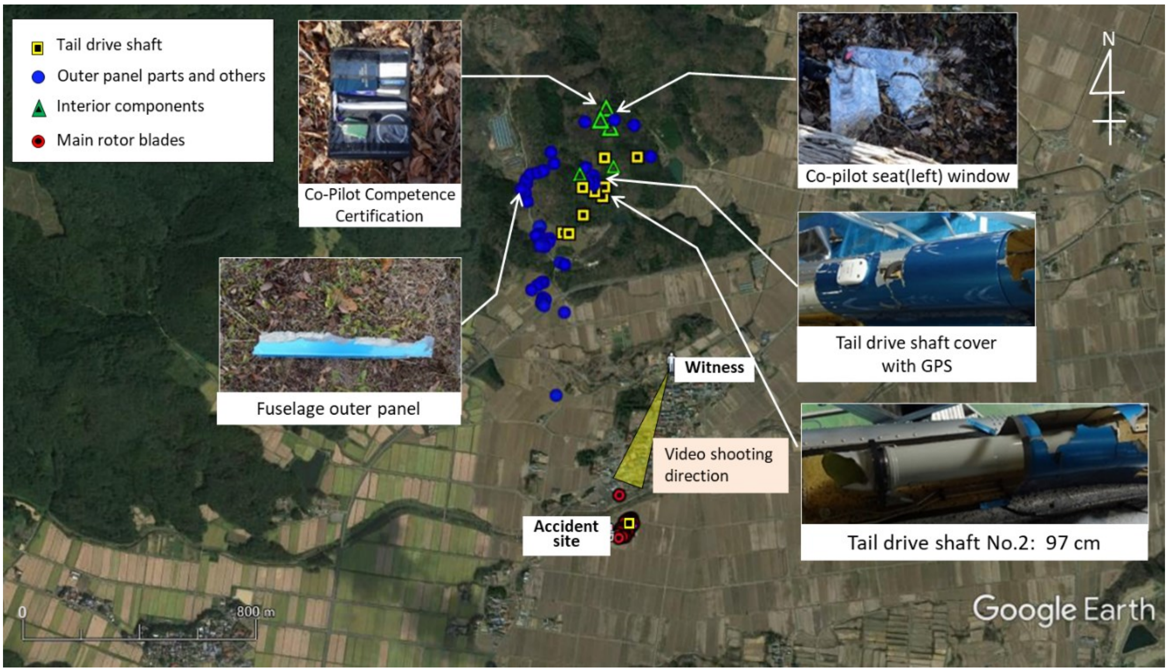

Figure 10: Flyable objects located on the north side of the accident site and the eyewitness's video shooting direction

(3) Engines

- There was no major apparent damage other than the deformation of the bulkhead of the left engine.

(4) Main rotor system (See Figure 11)

- All five main rotor blades identified in 5 colors (red, blue, orange, white, black) were broken from the attachment part and were scattered around the accident site. The tip erosion shields (Made of Ni-Co alloy) of three main rotor blades (blue, orange and white) had dent marks, and on the tip erosion shield of the black there were scratch marks not seen in the other main rotor blades.

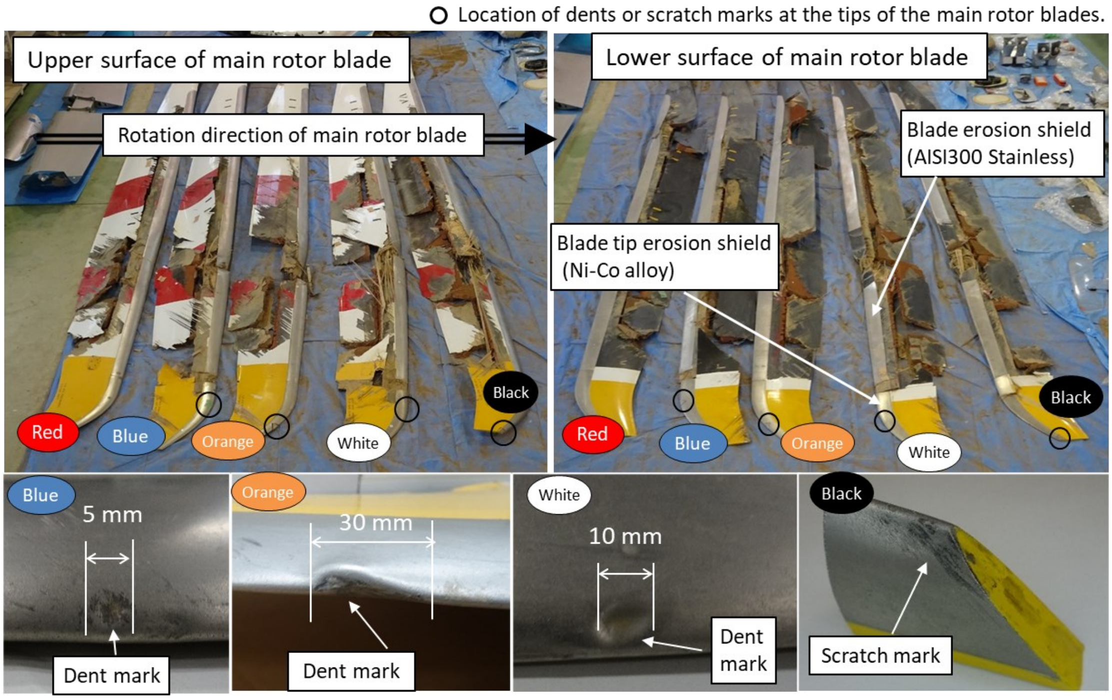

Figure 11: Wreckage of main rotor blades and the locations of the dent or scratch marks on the main rotor blades

(5) Landing gear system

- The three wheels of retractable landing gears were broken (See Figure 4 and 8) near their mounting portion. Particularly the left main landing gear was broken from the mounting portion and was separated.

(6) Others

- The upper window in the co-pilot seat (left side) dropped off during the flight and was found in the mountains about 1,300 m north of the accident site.
- The forward window in the sliding door on the right side of the cabin was found deformed inward inside the helicopter.

2.10 Information on Injuries to Persons

The degrees of injuries and the occupant positions of seven persons on board were shown in Figure 12, two persons in the cockpit sustained minor injuries, while in the cabin, four persons were seriously injured, and one sustained a minor injury. There was no abnormality in the operation of the seatbelts for all the seats on board, and the seating surface was moved to the lowermost position as the load limiter*21 operated. In addition, the bases of the seating surface for the right seat in forward cabin (c) and the middle seat in after cabin (g) were broken.

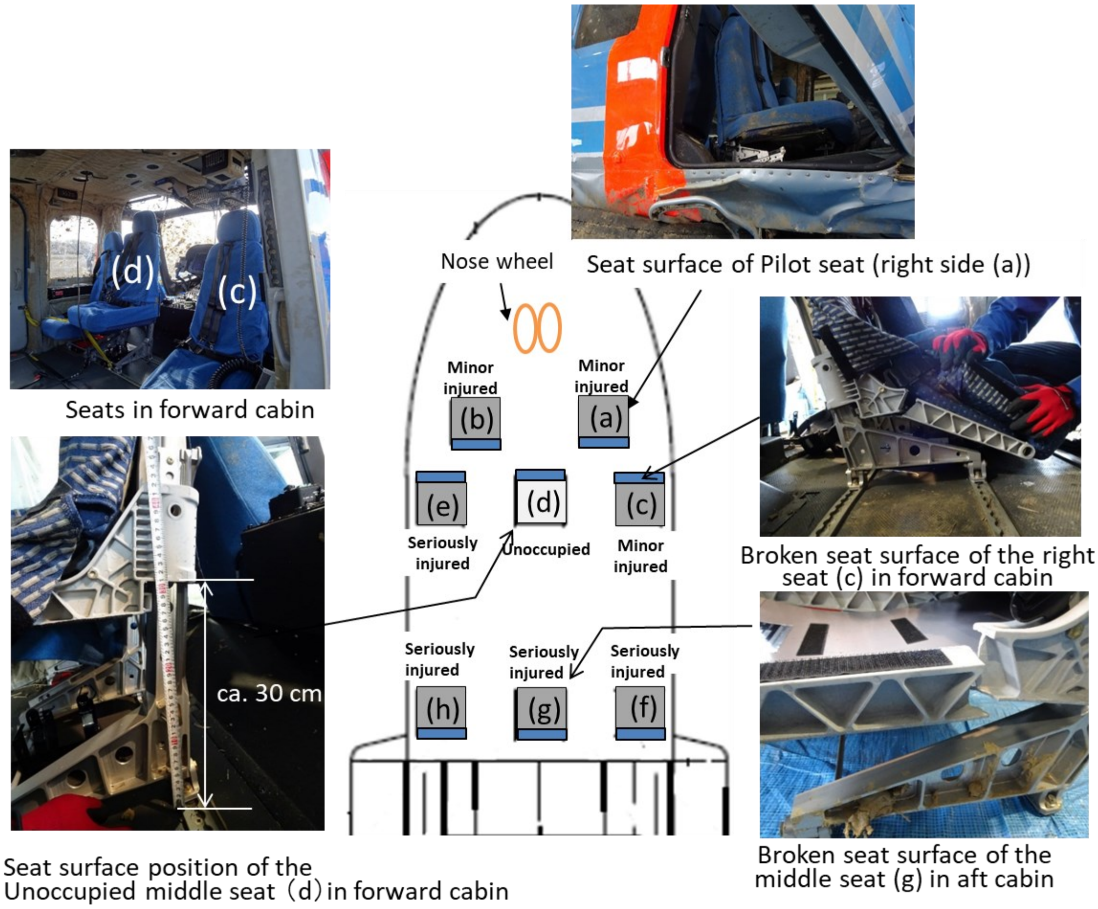

Figure 12: Occupant positions of all persons on board, and damage to the seats

2.11 Information on Test and Research

2.11.1 Investigation regarding Contact Marks between main rotor blades and tail drive shaft

As the main rotor blades of the helicopter were speculated to contact the tail drive shaft from the status of damage to the helicopter, the contact marks between the main rotor blade tips and the tail drive shaft were investigated in the Helicopter Design Company with the participation of the by accident investigation authority in the relevant state (ANSV). And furthermore, the JTSB conducted an additional investigation for the main rotor blade tips and

*21 "Load limiter" refers to a device which is designed to reduce the load that are imparted to the body of the occupants by deforming under a certain load.

a part of the tail drive shaft. The details of the investigation were as follows:

2.11.1.1 Investigation in the Helicopter Design Company (Leonardo S.p.A.)

(1) Reconfiguration investigation of wreckage parts

a. Tail drive shaft 10 fragments

b. Main rotor blade tips (blue, orange, white) 3 fragments

(2) Detailed investigation items of the contact marks on the parts

a. Visual inspection and the identification of the parts

b. Identification of foreign substances / fragments by optical microscope

c. Identification of different elemental component materials (Ni-Co alloys, AISI 300 stainless steel and aluminum) by scanning electron microscope (taking into consideration other contamination that was adhered at the time of the forced landing)

d. Component Material matching at the specific points by energy dispersive X-ray spectroscopy

(3) Results of investigation

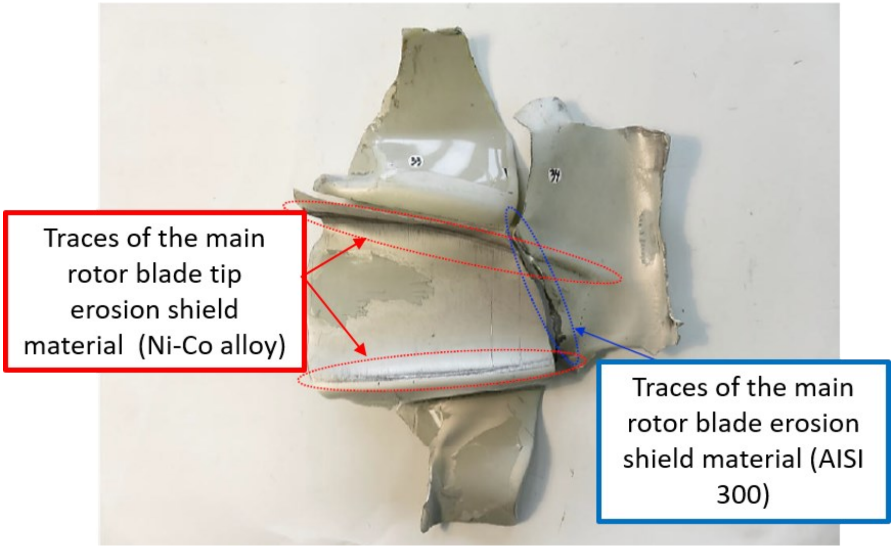

Figure 13: Investigation results of the contact marks between main rotor blades and tail drive shaft

a. Contact marks on tail drive shaft

On the two tail drive shaft fragments with matching cut surface shapes as shown in Figure 13, there were contact marks in the shape indicating the main rotor blade tip erosion shield, and the trace (part within red dotted line) of friction with the component material compatible with the erosion shield (Ni-Co alloy) on its outer side. Furthermore, on the cross-section surface where those fragments were separated, it was confirmed that there was a trace (part within blue dotted line) of friction with the material (AISI 300 stainless) that was compatible with the main rotor blade erosion shield. From a point of view of each shape of those two contact marks, it was indicated that the tail drive shaft initially had contacted the main rotor blade tip, and next had been separated into two by the main rotor blade.

b. Contact marks on main rotor blades

A component material inspection was conducted on the locations of the blue, orange and white dents on the main rotor blades (see Figure 11), but the characteristic component material of tail drive shaft was not detected sufficiently.

2.11.1.2 Investigation by the JTSB

As contact marks were confirmed on the tip of the main rotor blade (Black) which had not been sent to the Helicopter Design Company after the completion of the investigation by the Helicopter Design Company, the JTSB conducted the investigation by optical microscope and scanning electron microscope in reference to the results of the Design Company's investigation.

(1) Reconfiguration investigation of wreckage parts

a. Tail drive shaft 1 fragment

b. Main rotor blade tip (Black) 1 fragment

(2) Detailed investigation items of the contact marks on the parts

a. Visual inspection and the identification of the parts

b. Identification of foreign substances / fragments by optical microscope

c. Identification of different elemental component materials (Ni-Co alloy and aluminum alloy) by scanning electron microscope (taking into consideration other contamination that was adhered at the time of the forced landing)

(3) Results of investigation

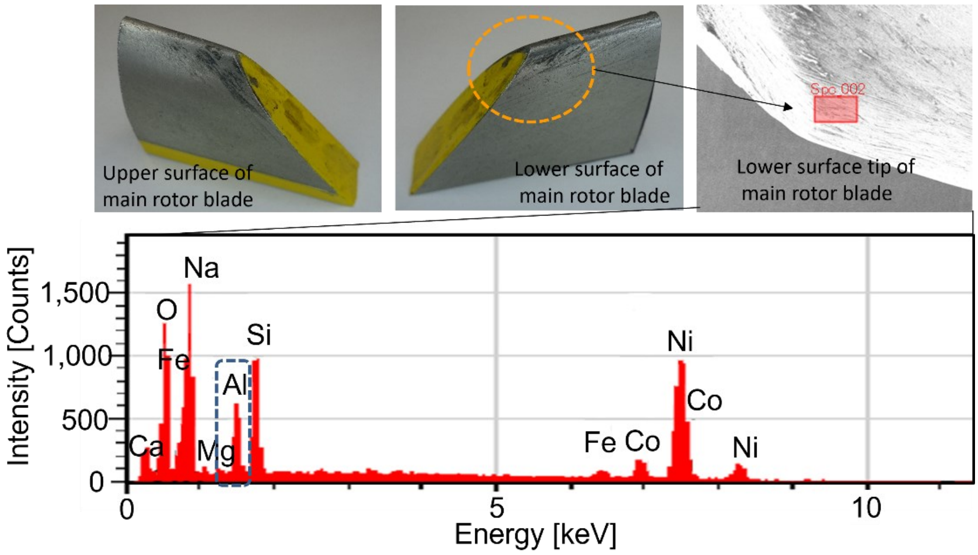

Figure 14: Contact marks on the black main rotor blade tip (above) and component material analysis (below)

On both sides of the tip of the black main rotor blade shown in Figure 14, there were contact marks. Besides, there were many of adhered component materials indicating that the helicopter made contact with the ground when rolling over at the time of the forced landing. And among the component materials, there was the one that was compatible with that of the tail drive shaft (aluminum alloy). Furthermore, it was confirmed that the four contact marks on the fragment (see Figure 15) of tail drive shaft found in the mountains matched well with the shape of the main rotor blade tip.

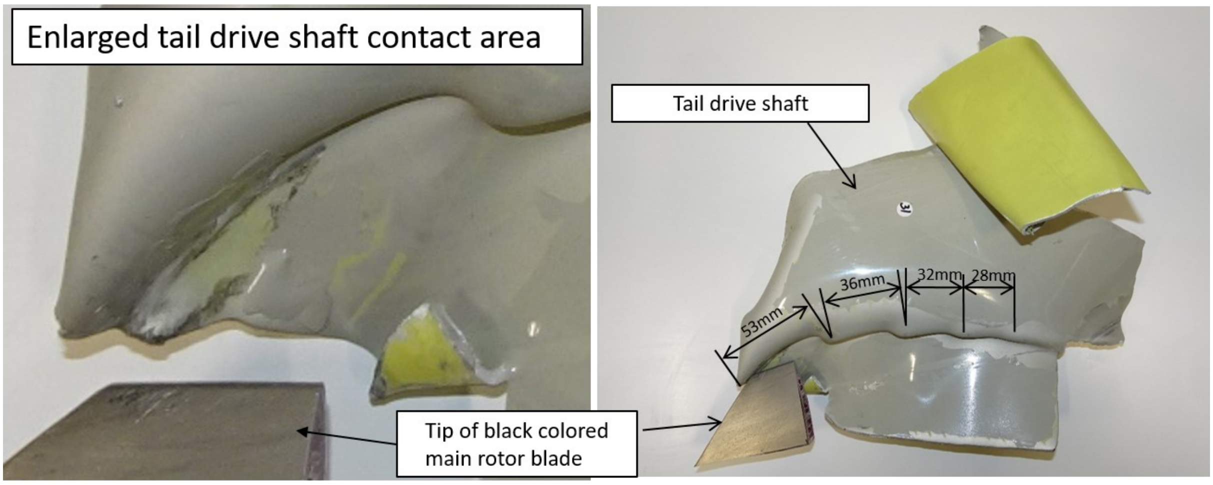

Figure 15: Contact marks between black main rotor blade tip and tail drive shaft

2.11.2 Results of Detailed Investigation regarding Engine Data

The Design Company of the engines installed on the helicopter conducted the investigation regarding the recorded data on the DCU with the witness of the accident investigation authority in the relevant State (TSB of Canada). The investigation results were shown in Figure 16 and Table 1.

As the DCU recorded only the occurrence of failures or events but not the complete flight data, therefore the analysis was performed against MPFR records.

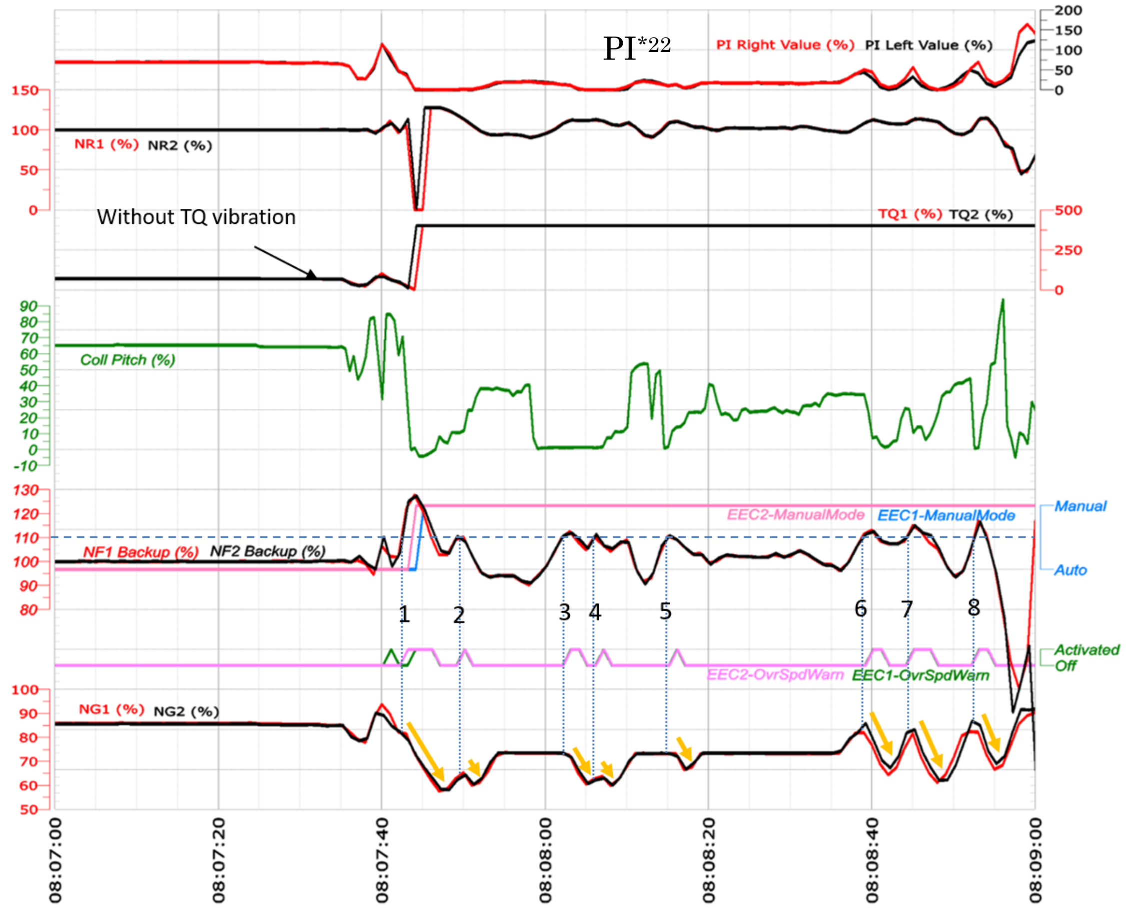

Figure 16: Engine operating conditions from just before right rolling motion to emergency landing

[22] "PI" provides the pilot with an overall indication of engine power by displaying a composite of three key parameters at the same scale: torque shaft twist quantity (TQ), engine internal temperature (ITT) and compressor speed (Ng), with the parameter values closest to operational limits displayed on the instruments.

Table 1: DCU recording due to event occurrence

	delta time	No1 Engine							No2 Engine				
		NGIND	QIND	NFFLT	ITTIND	LOOP	CLP	NGREQ	NGIND	QIND	NFFLT	ITTIND	LOOP
	sec	%NG	%Q	%NF	DEG.C	DEC	%CLP	%NG	%NG	%Q	%NF	DEG.C	DEC
a	F.E.	74.965	0.8281	125.527	489.5625	11	-0.8359	69.3984	75.5664	3.1953	123.496	491.188	11
b	0	74.965	0.8281	125.527	489.5625	11	-0.8359	69.3984	75.5664	3.1953	123.496	491.188	11
c	0.432	72.734	0.125	0	466.4375	11	1.2188	67.1289	73.4766	1.3125	0	468.875	11
d	0	72.734	0.125	0	466.4375	11	1.2188	67.1289	73.4766	1.3125	0	468.875	11
e	0	72.734	0.125	0	466.4375	11	1.2188	67.1289	73.4766	1.3125	0	468.875	11
f	0	72.734	0.125	0	466.4375	11	1.2188	67.1289	73.4766	1.3125	0	468.875	11
g	76.46	91.863	-111	0	542.125	30	32.6367	86.5781	93.9336	-111	-111	567.313	30

In Table 1, the event data is shown in blue for No. 1 engine, and those in orange for No.2 engine. According to the MPFR record in Figure 16, the category a and b show the first event data at 08:07:44. The NF[*23] value for No. 1 engine was recorded at "125.527 %", and at "123.496 %" for No. 2 engine. Subsequently, from Category c to f, the NF value exceeded the measuring range 0.432 seconds after the occurrence of the first event, thus, 0 for the NF value was recorded. Almost at the same time, the engines were switched to the manual back-up mode. In Category g, it was recorded at "-111" indicating that the signals of both No.1 and No.2 engines were lost at 08:09:01 of 76.46 seconds after the occurrence of the first event. This was when an abnormal value of rotor speed was recorded after the helicopter rolled over.

The manual backup mode is a function that limits the fuel flow to a minimum to prevent the engine from over-speeding. When the NF value exceeds 111%, the overspeed governor is activated. Following a sudden change in the helicopter's flight attitude, the overspeed governor cycled between active and inactive eight times from 08:07:44 until touchdown.

2.11.3 Investigation on Wind Direction and Velocity calculation by FMS

Generally, the values of wind direction and wind speed that are digitally displayed on a PFD are calculated after considering the reduced visibility of the digital numbers due to fluctuations in wind direction and wind speed, and such as turning of the aircraft. Therefore, it is likely that the value is different from the instantaneous value of wind direction and wind speed.

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*23 "NF" refers to the number of engine Free power turbine speed.

There was a large difference in the tailwind equipment between the wind direction of 262° and the wind speed of 35 kt recorded in the MPFR when the helicopter's IAS suddenly increased and the wind profiler's northwest (300 °) wind of approximately 35 kt. Since there is a possibility that the instantaneous wind direction and wind speed may be different, the display system designer investigated the instantaneous values of the wind direction and wind speed before calculating the wind direction and wind speed using MPFR records.

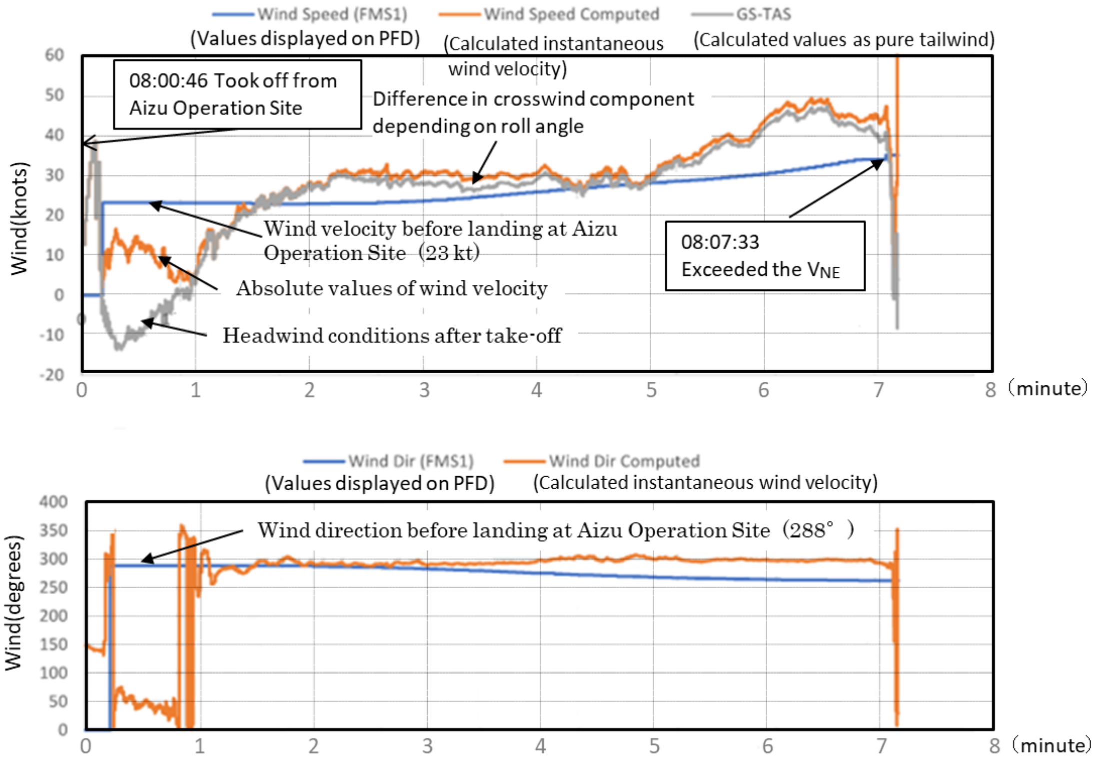

Figure 17: Comparison between the winds computed by FMS and the instantaneous wind

Regarding the wind direction and velocity during the flight, the wind direction and velocity vector can be computed by the wind force triangle, given the true airspeed vector measured along the aircraft's longitudinal axis (heading) and the ground speed vector along the aircraft's orbital angle. The wind direction and velocity were recalculated using the airspeed, pressure altitude, temperature, AHRS[*24] magnetic direction, and FMS magnetic deviation recorded on the helicopter's MPFR, as well as a crosswind equipment calculated by the inertial velocity of AHRS.

Figure 17 is a graph comparing the wind displayed on the PFD via the FMS from the take-

[*24] "AHRS", which stands for Attitude and Heading Reference System, is a high-precision inertial sensor system that integrates angle acceleration sensor (gyro) for rotation, acceleration sensor for movement, and direction.

off from Aizu Operation Site up to the start of a right rolling motion and the instantaneous wind calculated from the MPFR records. The instantaneous wind velocity shown in an orange line reached approximately 50 kt about 40 seconds before the start of a right rolling motion and then decreased rapidly at 08:07:33 when the IAS exceeded Never exceed speed (V_{NE}) 158 kt. As for immediately after take-off from Aizu Operation Site, the wind velocity in a blue line on the PFD shows the wind velocity before landing at Aizu Operation Site, and the wind velocity gradually increases from about three minutes after take-off from the Aizu Operation Site, reaching 35 kt immediately before the start of a right rolling motion. In addition, regarding immediately after take-off from Aizu Operation Site, the wind direction on the PFD shows the wind direction before landing just same as for the wind velocity, and the difference with the instantaneous wind direction becomes gradually larger from about three minutes after take-off, indicating 262° from one minute before the start of a right rolling motion up to immediately before the start of a right rolling motion, but the recomputed instantaneous wind direction was 300°.

2.12 Education and Training for Pilots in Aviation Unit

2.12.1 Education and Training in the State of Design and Manufacture

For the type rating change, the captain took flight trainings including the emergency procedures training on AW 139 FFS[*25] and an actual AW 139 helicopter in the company Leonardo in Italy from November to December in 2014.

Regarding the training for emergency procedures training related to the tail rotor drive failure, the captain had experienced the training assuming the occurrence of the failure during the forward flight immediately after the take-off, but never experienced the training in the same flight conditions as in this accident.

2.12.2 Implementation Status of Emergency Procedures Training

Aviation Unit had conducted flight trainings and emergency procedures trainings performed by one pilot using AS350B3 FTD[*26] for two to four hours about once a year. According to the statement of the captain, in the training using the relevant FTD, about 30 minutes were required every time to familiarize with flight operations of the FTD whose main rotor rotates

[*25] "FFS (Full Flight Simulator)" refers to a flight simulator system with visual and motion simulations, which is suitable for flight crew trainings, tests, examinations, and others, simulating the specific type of aircraft's cockpit environment.

[*26] "FTD (Flight Training Device)" refers to a flight training device other than the Full Flight Simulator (FFS) and is suitable for flight crew trainings, tests, examinations, and others, simulating the specific type of aircraft's cockpit environment or part of it.

in the opposite direction to the AW139. The emergency procedures trainings included helicopter's major emergency procedures items such as engine failure and hydraulic system failure including tail rotor system failure. The emergency procedures trainings were conducted by two pilots using the training system during flight trainings for the type rating change in the company Leonardo, but after that, those trainings had never been conducted.

In addition, recurrent trainings for emergency procedures were conducted in line with the specific pilot competence training for each pilot, and changes in procedures were confirmed.

2.13 Other Necessary Matters

2.13.1 Characteristics of the Retreating Main Rotor Blade Stall[*27]

According to the company Leonardo, the first sign of the retreating main rotor blade stall is usually roughness, including torque oscillations, and a low-frequency vibration in the main rotor. When the stall progresses, the stall range of the retreating main rotor blade widens, and the nose pitches up, resulting in rolling left. The stall range of the retreating main rotor blade of the AW 139 was identified by monitoring its control angle, power and control load in the flight test at the design stage. In case of the weight of the helicopter at the time of the accident, the retreating main rotor blade stall is expected to occur in the range of TAS[*28] 190 to 200 kt.

2.13.2 Flight in Severe Turbulence

The AW 139 flight procedures in severe turbulence is stipulated in normal procedures in the flight manual as follows:

1. All occupants must be seated with seat belts fastened.

2. Slow the aircraft to a comfortable speed.

3. Fly a constant attitude. Do not attempt to correct rapidly changing airspeed indications.

4. Do not make large, rapid collective pitch adjustments.

2.13.3 The AW 139 Emergency and Malfunction Procedures

2.13.3.1 Excess of Aircraft Never Exceed Speed

The excess of aircraft never exceed speed of the AW 139 is stipulated Malfunction Procedures in the flight manual as follows:

[*27] "Retreating main rotor blade stall" refers to a phenomenon that occurs when the relative airspeed through the rotating surface of the main rotor is different between the forward and retreating sides during forward flight of the helicopter, and the greater the forward speed the lower the relative airspeed of the blade on the retreating blade side, resulting in widening and developing the stall range of the retreating main rotor blade.

[*28] "TAS" is "true airspeed", which is the speed of an aircraft relative to the undisturbed atmosphere.

AIRCRAFT NEVER EXCEED SPEED

Voice warning 'AIRSPEED AIRSPEED' and airspeed indication RED

/

－Confirm airspeed

/

－Reduce/maintain speed below Vne

2.13.3.2 Tail Rotor Drive Failure

The AW 139 tail rotor drive failure is stipulated Emergency Procedures in the flight manual as follows:

A tail rotor drive failure will result in a rapid yaw to the right and a loss of yaw control, possibly accompanied by noise or vibration in the tail section. The severity of the initial yaw rate will be determined by the airspeed, altitude, gross weight, center of gravity and torque settings at the time that the failure occurs.

The effectiveness of the vertical fin in limiting the yaw rate and yaw angle will depend on the airspeed at the time of the failure, fin effectiveness increasing at higher airspeeds.

The following cues will be present:

－Aircraft yaws rapidly to the right

－Loss of yaw control, pedals free but ineffective

－Possible noise and vibration from the aft fuselage area.

Severe yaw rates will result in large yaw angles within a very short period of time and, depending on the flight conditions at the time of failure, it is possible that yaw angles in excess of 30° will be experienced.

Additionally, very high yaw rates will produce aircraft pitching and rolling making retention of control difficult without the use of large cyclic inputs, which are structurally undesirable. Finally, very high yaw rates will produce disorienting effects on the pilots. Therefore, it is vital that corrective action, as outlined in the following procedures, be taken quickly to prevent post-failure yaw rates from reaching unacceptably high levels.

In Hover

－Lower collective to LAND IMMEDIATELY while maintaining attitude and minimizing lateral translation with the cyclic control.

－Retard ENG MODE switch (or ECL's) to OFF if time available.

In Forward Flight

– Lower collective immediately to minimize yaw right

– Establish an airspeed/power/roll angle sufficient to reach a suitable landing site.

– At landing site assess running landing capability.

– If a running landing cannot be carried out with a suitable power and speed, shutdown engines.

– Carry Out Engine Off Landing.

Note

- Land into wind

- Raising or lowering the collective while maintaining NR within limits may be effective in helping control sideslip. (Increasing collective, nose left)

2.13.4 Emergency Procedures for AS350B3 Tail Rotor Drive Failure

The emergency procedures for the tail rotor drive failure of AS350B3 FTD used by Aviation Unit for the recurrent trainings are stipulated in the flight manual as follows:

Symptom: The helicopter will yaw to the left with a rotational speed depending on the amount of power and the forward speed set at the time of the failure.

IN CRUISE FLIGHT

1. *Airspeed............ MAINTAIN Vy*[*29] *or higher.*
2. *Collective .... ADJUST to obtain minimum sideslip angle.*

LAND AS SOON AS POSSIBLE

APPROACH AND LANDING

On a suitable area for autorotative landing:

1. *Twist Grip*[*30] *... IDLE position.*
2. *Carry out an autorotative landing according to the autorotation procedure.*

3. ANALYSIS

3.1 Flight Crew Qualifications

*29 "Vy" is the best rate-of-climb speed.

*30 "Twist Grip" is a device installed on the collective pitch lever to control the engine power.

The JTSB concludes that the captain and Co-pilot held both a valid airman competence certificate and a valid aviation medical certificate.

3.2 Airworthiness Certificate

The JTSB concludes that the helicopter had a valid airworthiness certificate and had been maintained and inspected as prescribed.

3.3 Weather Analysis

The JTSB concludes that as follows regarding the weather analysis of this accident.

As described in 2.6(4), according to the wind profiler, the wind over near the Ou Mountains from Aizu Wakamatsu to Fukushima Airport at the time of the accident was analyzed to be blowing at about 35 kt from the northwest, but as described in 2.11.3, it had a great discrepancy in the relationship the wind direction and velocity processed by FMS filtering. In addition, as the rapid increase in IAS might be caused by mountain waves locally generated over the mountain range on the southeast side of Lake Inawashiro, in the Atmosphere and Ocean Research Institute, the University of Tokyo conducted numerical analyses of the weather conditions in the vicinity where the helicopter started rolling to the right with the two weather simulation models in 3.3.1.1 and 3.3.1.2. In numerical analysis A with a resolution of 1 km in 3.3.1.1, analysis was conducted on the distribution of horizontal and vertical flows over a wide range. Combining the result of the numerical analysis A with the flight route on the MPFR revealed the possibility that the helicopter flew in the vertical flow area existing from the southeast side of Lake Inawashiro, above and to its south side of the mountain range. Besides, regarding the vicinity where the IAS of the helicopter increased rapidly and started rolling to the right, the numerical analysis B with a resolution of 100 m in 3.3.1.2 was conducted. In this analysis, the four-dimensional variational method of mesoscale analysis used by the Japan Meteorological Agency used for the initial values was calculated by regarding non-on-the-hour observations as hourly observations on the hour. A time lag of up to an hour may occur.

3.3.1 Weather Analysis with numerical analyses

3.3.1.1 Numerical Analysis A

(1) Calculation condition

Default values: JMA mesoscale analysis at 03:00 on February 1, 2020

Boundary value: JMA mesoscale analysis

Use model: The JMA non-hydrostatic model (Saito et al. 2006)

Computational region: 300 km square centered around the point where a right rolling motion occurred (Left, Figure 18), 21.1 km in vertical direction.

Resolution: As horizontally 1 km, 80 vertical layers are placed (the lower part of the computational region is based on a coordinate system along the terrain).

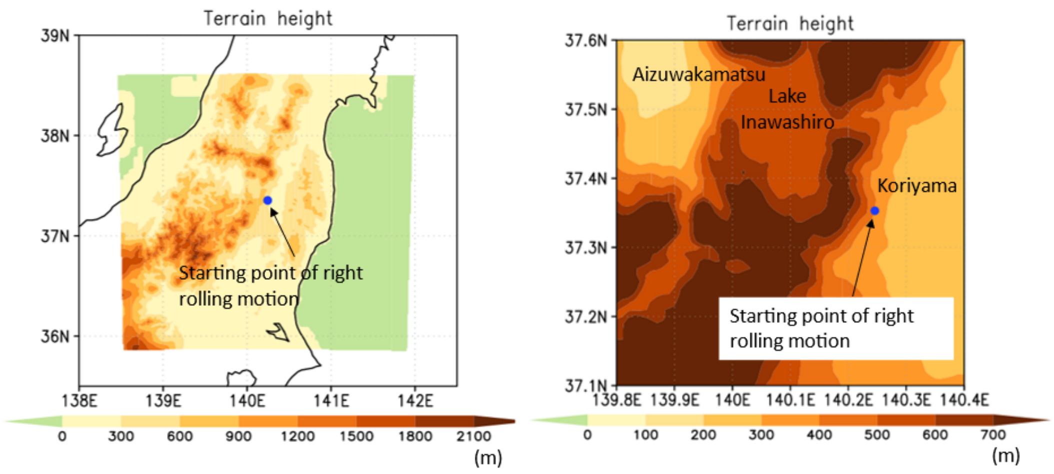

Figure 18: Computational region of numerical analysis A and model terrain (Left) Enlarged view of model terrain around Lake Inawashiro (Right)

(2) Results of Numerical Analysis A

The left in Figure 19 shows the result of analyzing the distribution of vertical and horizontal flows at an altitude of about 1.3 km at 09:00 on the day of the accident, using the 1 km horizontal resolution model. A wind of about 20 to 30 m/s was almost uniformly blowing from the northwest, and as described in 2.6 (1), there was the vertical flow pattern extending through the north-northeast to the south-southwest that seemed to correspond to the wavelike clouds shown in the Meteorological Satellite Visible Imagery in the right in Figure 5. This is more likely an internal gravity wave (mountain waves) generated when stably stratified air currents hit in a direction almost perpendicular to the mountain range.

The right in Figure 19 shows the cross section of potential temperature[*31] and vertical flow around the point where a right rolling motion occurred, and it is known that the wind in the sky blows along the isothermal lines during steady state. At both (a) 07:30 and (b) 08:00, downdrafts and updrafts occurred in the southeast side of Lake Inawashiro. Compared to (a), the downdraft occurrence region in (b) was wider. And further Appended Figure 8 shows the cross section of potential temperature over the time from 07:30 to 09:00 on the flight path when

[*31] "Potential temperature" is the temperature that is realized when an air parcel at a certain pressure is adiabatically moved up to 1,000 hPa,and is the conserved quantity as the air parcel moves.

the helicopter flew to and from Aizu Operation Site. On the round-trip flight routes, there were downdrafts and the updrafts corresponding to a hydraulic jump[*32] above and on the southeast side of the mountainous terrain located on the southeast side of Lake Inawashiro. The helicopter likely encountered these vertical flows on the round-trip flight routes.

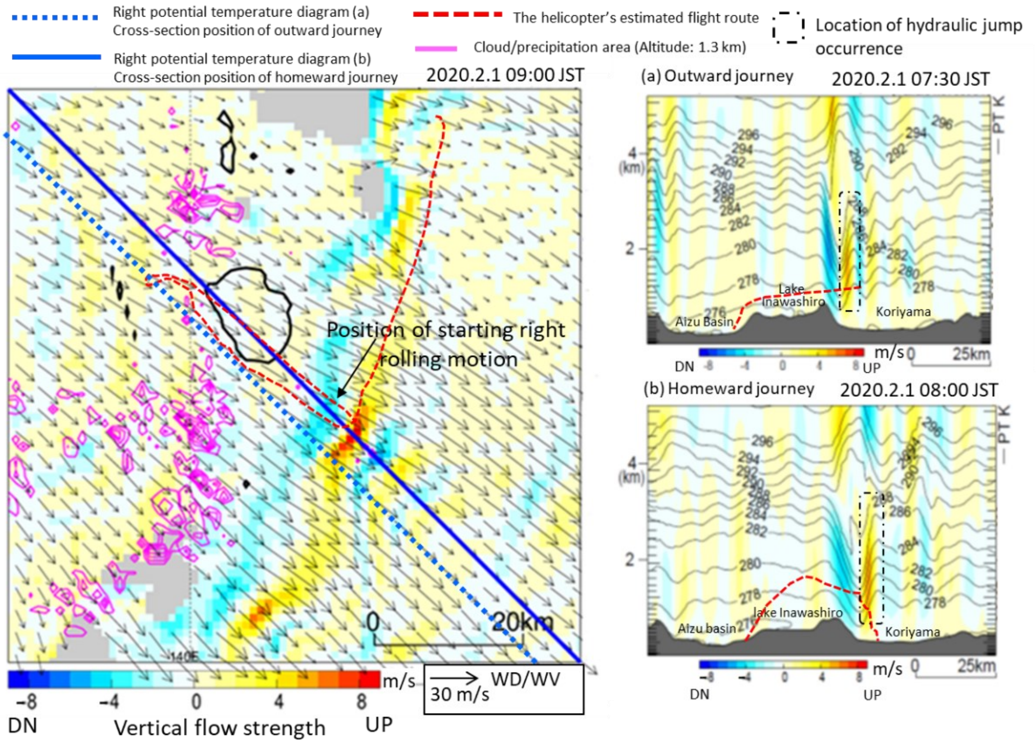

Figure 19: Numerical Analysis A Horizontal distribution of vertical and horizontal flows at an altitude of 1.3 km (Left) and Cross section of potential temperature and vertical flow according to the blue dotted line / the blue solid line in the left (Right (a) / (b))

3.3.1.2 Numerical Analysis B

(1) Calculation condition

Default values: Results of numerical analysis A at 06:00 on February 1, 2020

Boundary value: Results of numerical analysis A

Use model: The JMA non-hydrostatic model (Saito et al. 2006)

Computational region: 150-km square centered around the point where a right rolling motion occurred (Left, Figure 20), 21.1 km in vertical direction.

*32 A "hydraulic jump" is a phenomenon which is observed in a fluid where airflow passing over obstacles including mountains increases the speed rapidly, and a sudden updraft (jump) occurs on the leeward side of the obstacle.

Resolution: As horizontally 100 m, 80 vertical layers are placed (the lower part of the computational region is based on a coordinate system along the terrain).

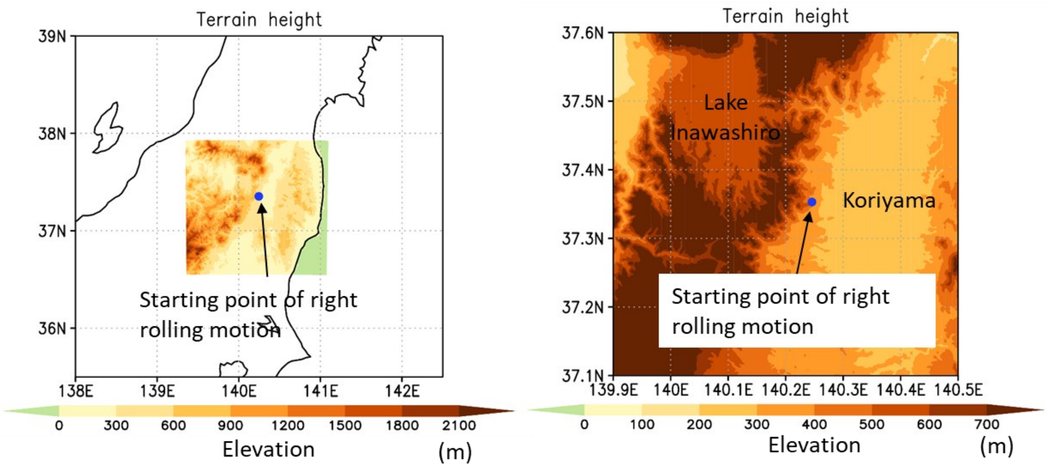

Figure 20: Computational region and model terrain of numerical analysis B (Left)
Enlarged view of model terrain around Lake Inawashiro (Right)

(2) Results of Numerical Analysis B

The Appended Figure 9 and Figure 10 shows the result of analyzing the atmospheric phenomenon around the site a right rolling motion occurred, using the numeric model of a resolution of 100 m during the time from 08:00:00 to 08:14:45. In this numerical analysis, in a narrow updraft region appeared from around 08:08 to around 08:14 at the altitude on the windward side where the helicopter started right rolling motion over the mountainous terrain on the southeast side of Lake Inawashiro. Furthermore, a strong downdraft region appeared on the leeward side. In the vicinity of the transition from updraft to downdraft, the horizontal wind speed changed noticeable, and the atmospheric pressure decreased. Besides, on the leeward side, there were updrafts corresponding to the hydraulic jump seen in Figure 19 (b), and on the further leeward, another strong downdraft was observed. As described above, due to the nature of this numerical analysis, in the reproduced result, the time deviations of up to 1 hour may occur, and a positional deviation may also be included.

As a result of matching the position at 08:07:36 when the helicopter started right rolling motion and the area where the horizontal wind velocity decreased rapidly and a strong downdraft was generated from the numerical analysis results in Appended Figure 9 and Figure 10, there was a gap of about 5 minutes from the numerical analysis time, however, the helicopter possibly flew in the area where updrafts and downdrafts change over a short period of time, as shown in these figures. Figures 21 and 22 are enlarged views of Appended Figures

9 and 10 at 08:13:00. There is an area on the east side of the mountain range where the atmospheric pressure is about 2 hPa (200 Pa) low, and near this area there are parts where the horizontal component of the wind is decreasing. It is possible that the helicopter flew in an area where the atmospheric pressure was low.

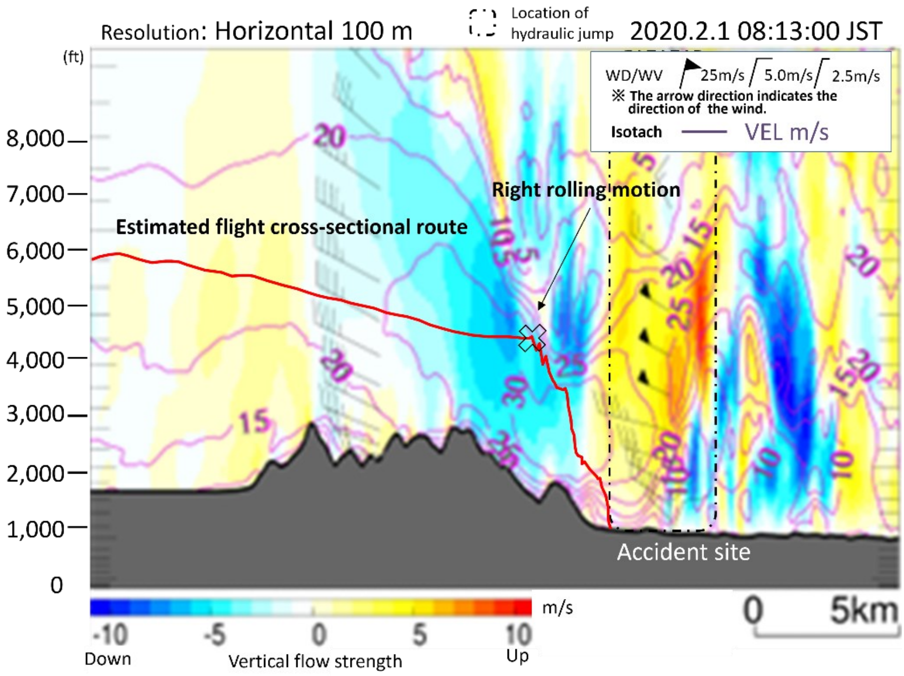

Figure 21: Vertical cross section of horizontal wind velocity and vertical flow

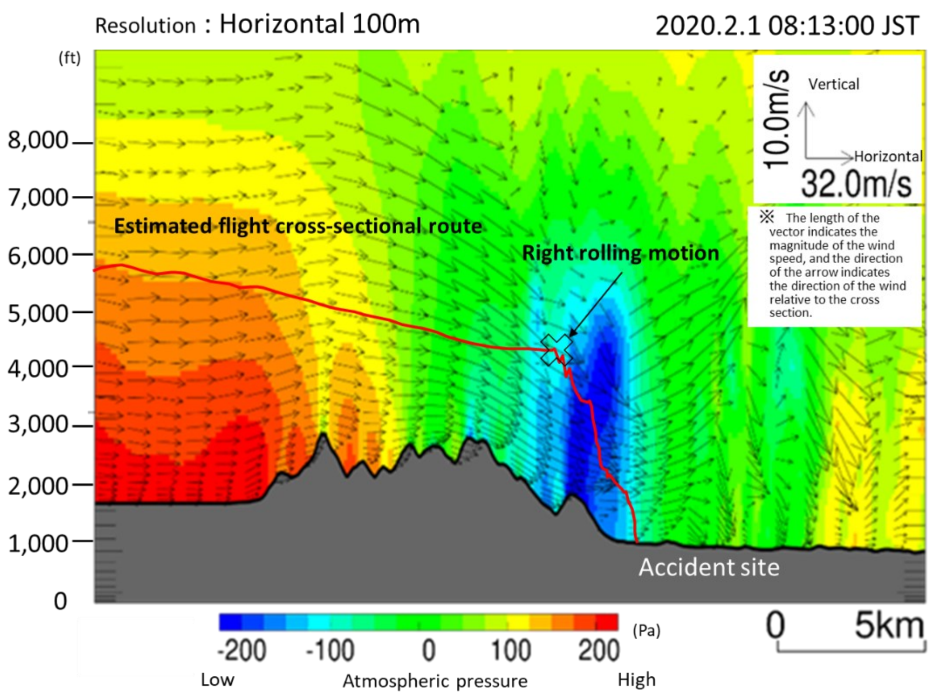

Figure 22: Distribution map of wind and Atmospheric pressure deviation along the cross section

3.3.2 Weather Analysis Considerations

From the numerical analysis results described in 3.3.1, the over the area from Aizuwakamatsu to Koriyama, it is likely that a general wind*33 blew 20 m/s (40 kt) to 30 m/s (60 kt) from northwest, in addition it is likely that a vertical air flow with strike direction from southwest to northeast was occurring above the leeward side of the Ou Mountains. Especially, over the mountainous terrain on the southeast side of Lake Inawashiro, where the helicopter passed over, it is more likely that occurred generating a strong vertical air flow causing as the hydraulic jump phenomenon. On the windward side before the strong updraft, there is a weak updraft region and a strong downdraft region, and it is probable that the horizontal wind speed suddenly decreased near the exchange of airflows. According to the MPFR records, it is probable that the helicopter encountered an area where the vertical air flow changed locally in a short period of time, as shown in Figures 21, 22, and Appended Figures 9 and 10. At the altitude where the helicopter was flying, the horizontal wind velocity rapidly decreased from more than 25 m/s (50 kt) to less than 15 m/s (30 kt) with a decrease in atmospheric pressure, therefore, it is probable that the flight control of the helicopter was strongly affected over the area.

3.4 Flight status of the helicopter until the forced landing

The JTSB concludes that as follows regarding the flight status of the helicopter until the forced landing.

In order to compare the changes in the weather effect, the aircraft status, flight control systems and others in details, the flight status and the final approach profiles were analyzed for the five time phases as follows: "The outward journey flight from Prefectural Police Heliport to Aizu Operation Site", "From the take-off from Aizu Operation Site up to the rapid increase in IAS", "Rapid increase in IAS and the right rolling motion", "The right rolling motion caused the main rotor blades and the tail drive shaft to contact ", and "After the contact between the main rotor blade and the tail drive shaft up to the forced landing".

3.4.1 Flight on the Outward Journey from Prefectural Police Heliport to Aizu Operation Site

As for the flight status on the outward journey, a described in 2.1.1, after the helicopter flew from Prefectural Police Heliport southward to the east side of the Ou Mountain Range to head for Koriyama City in order to confirm the weather conditions of homeward previously, at

*33 "General wind" means a wind that represents a wide area and is not affected by local factors such as topography.

about 07:24, it passed over the vicinity of the accident site at an altitude of about 3,000 ft and IAS about 120 kt, decreasing gradually the altitude in order to fly below the cloud base and heading for Aizu Operation Site. As described in 2.1.1 and 2.1.2, the wind above the mountain regions on the southeast side of Lake Inawashiro was strong, and the helicopter was significantly shaken, but the captain judged that there would be no problem on the homeward journey flight from Aizu Operation Site to Fukushima Airport if they made an on-topflight at about 5,500 ft or more.

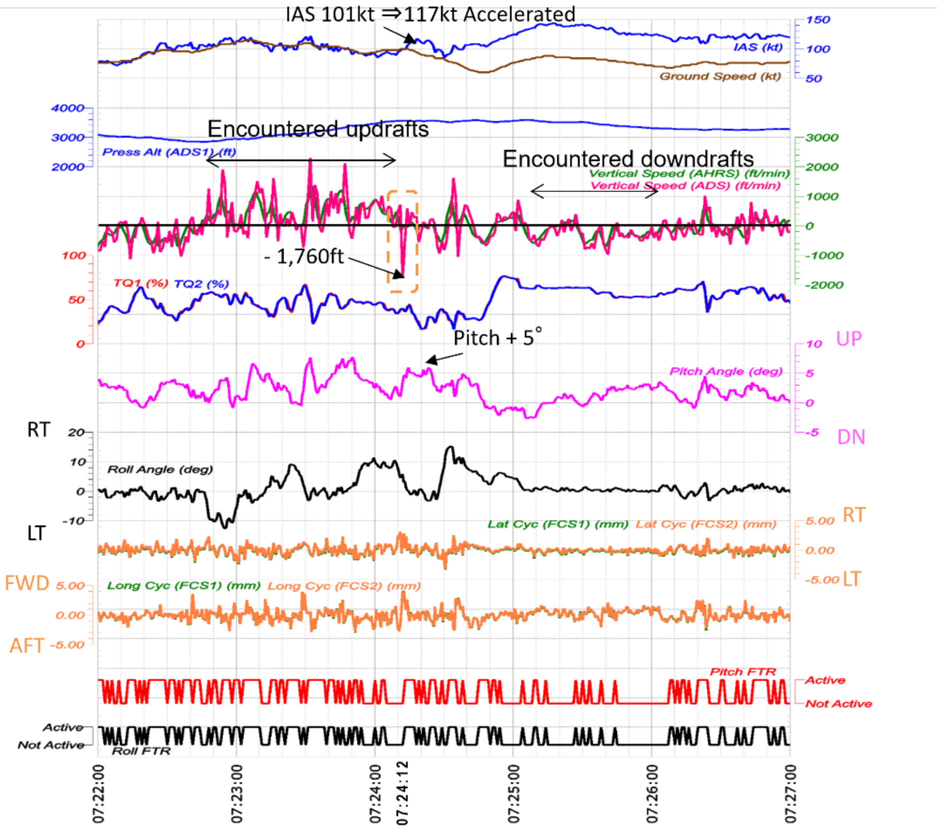

Figure 23: Flight status in the vicinity of the mountains on the southeast side of Lake Inawashiro on the outward journey up to Aizu Operation Site

As described in 3.3.2, it is probable that strong vertical currents occurred on the southeast side of the mountain range area in the southeast side of Lake Inawashiro that the helicopter passed through, it is possible that the helicopter encountered this on its outward flight, therefore, as shown in Figure 23, the effects of vertical air flow was analyzed by the MPFR records. From about 07:22:50 to about 07:24:30, when flying southward at IAS about 120 kt from an altitude of 3,000 to 3,300 ft, the helicopter encountered the updrafts while receiving a wind from the right. And there was evidence that the helicopter encountered a downdraft from about 07:25:05 to about 07:26:00 when flying at IAS about 120 to 140 kt while receiving a wind from the front. Especially, at 07:24:12, although the Vertical Speed (AHRS) by the inertial vertical velocity[*34] was at 0 ft/min, the Vertical Speed (ADS[*35]) by the atmospheric pressure change was recorded at (-) 1,760 ft/min. As for the pitch attitude, the helicopter kept the nose-up attitude at an angle of about 5°, and the power output decreased, but the IAS rapidly increased from 101 kt to 117 kt for six seconds. When comparing the point where the Vertical Speed (ADS) significantly changed at 07:24:12 was aligned with the point in the numerical analysis A in Figure 1: Estimated flight route and in Figure 19 (left), it was in front of the point where the helicopter started turning to Aizu Operation Site on the east side of the Ou Mountain Range, and it was generally consistent with respect to points where strong updrafts were considered to have existed, a result of Numerical Analysis A.

A comparison of the captain's operations with the change in helicopter's attitude during the section where the helicopter encountered a vertical air flow revealed the pitch and roll attitudes were unstable and were in a state tending to climb during the section when encountering an updraft, therefore the captain performed the attitude control by pressing the FTR frequently. During the section where the helicopter encountered a downdraft, the captain pressed the FTR less frequently and the helicopter's attitude was stable. Particularly, when flying in the ATT mode without pressing the FTR, the flight control system (FCS) was moved less, and the helicopter was stable with no major attitude changes or climbs and descents. While long pressing the FTR, the FCS was moved actively. This is more likely because the ATT mode was switched to SAS mode by pressing FTR, and the attitude retention function stopped, the SAS responded to mitigate the motion caused by the pilot's maneuvers to maintain the desired attitude, in addition to the short period disturbance, and the change in aircraft attitude continued.

3.4.2 Flight from the Take-off at Aizu Operation Site up to the Rapid Increase in IAS

As described in 2.1.1, after taking off from Aizu Operation Site at 08:00, in order to avoid clouds, the helicopter climbed up to an altitude of about 5,700 ft over the area on the east side of Lake Inawashiro, from which it started descending gradually and was flying over the mountainous terrain on the southeast side of Lake Inawashiro. As described in 2.6(4), the wind near at an altitude of about 4,300 ft that was observed blowing from the northwest at about 35 kt by the wind profiler, and the numerical analysis described in 3.3.2, about 40 to 50 kt

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[*34] "Inertial vertical velocity" refers to velocity in the vertical direction in inertial space (true altitude).
[*35] "ADS" stands for Air Data System, which refers to a device to output pressure altitude, airspeed, and vertical speed of pressure altitude as digital data based on the measured values of pitot static pressure system (static pressure, dynamic pressure) and outside air temperature.

northwest. During the climb to above Lake Inawashiro, the helicopter was flying at approximately IAS 130 to 140 kt, but after starting the descend from the sky above Lake Inawashiro, the IAS increased gradually, thus the helicopter was descending at approximately IAS 150 kt. At 08:05:50, the captain confirmed the increase in GS together with the co-pilot and thought that they would be able to fly with a tailwind to arrive at Fukushima Airport without delay.

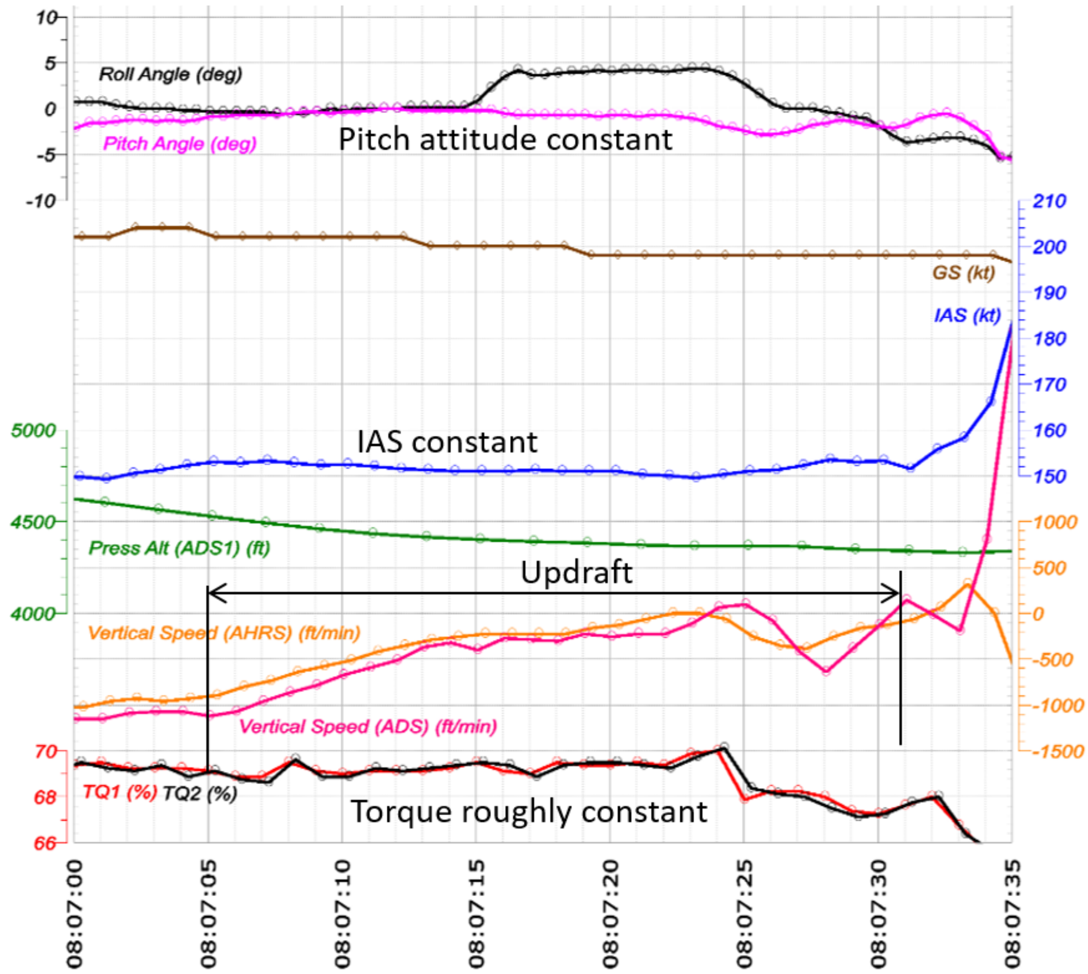


Figure 24 Presence of updraft before rapid IAS increase

At around 08:07:10, the aircraft became level flight at an altitude of around 4,500 ft, with the engine output remaining roughly constant during the descent. Although the IAS pitch attitude was generally constant, the rate of descent decreased from around 08:07:05 and rose temporarily until around 08:07:30, therefore it is possible that there was an updraft of approximately 1,000 ft/min. As shown in the analysis results before and after 08:13:00 in Appended Figures 9 and 10, an updraft region of 3 to 5 m/s can be seen before the right roll movement start position on the route by the estimated flight cross section. It is probable that the helicopter passed through an updraft region on its flight path before the IAS suddenly increased, as the atmospheric conditions above the mountain range were constantly changing.

3.4.3 Encounter with Downdrafts and Rapid Increase in IAS

As described 2.1.2 (1), the captain stated that while flying at IAS 150 kt while avoiding clouds, before the helicopter looped like being drawn into the forward, the captain felt the movements affecting the heading control from aft section of the helicopter. According to the MPFR records in Figure 25, during the time between 08:07:15 and 08:07:25, the cyclic stick was moved slightly to the right to change the course, after that, at 08:07:31, the helicopter started to veer to the left in order to correct the course, therefore, these operations were more likely course correction to avoid clouds. At 08:07:31, the FTR on the cyclic stick was depressed once, the roll angle was maintained at about 3° left and started to veer to the left. From 08:07:31 to 08:07:35 when the IAS rapidly increased from 152 kt to 188 kt, and from 08:07:33 to 08:07:34, the pitch attitude changed from (-)0.5° to (-)5°, the left roll attitude changed from 3° to 5°, and it continued. It is probable that this is because the flight control system (FCS) instantaneously moved to near the neutral position by pressing FTR, which continued the nose-down and left-roll attitudes. After that, until 08:07:38, the cyclic stick was pulled backward by about 15% while FTR was pressed, and then moved to the 100% position on the right side in about 2 seconds. It was operated in about 2.5 seconds to the 7% position. During this time, the FTR of the cyclic stick was continuously pressed, so it is probable that the manual operation was prioritized while the attitude retention function was stopped, and the rapid right rolling motion started. In addition, the collective pitch lever was lowered by about 20% while moving up and down for about two seconds after the FTR was pressed at 08:07:35. It is probable that the right roll and IAS deceleration started rapidly because the cyclic stick was moved to the right rear while pressing FTR from the 5° left roll and 5° nose down state.

When the IAS increased rapidly to 188 kt, as shown in Figure 25, the Vertical Speed (ADS) by the atmospheric pressure change was recorded as plus (+) 3,072 ft/min and the Vertical Speed (AHRS) by the inertial vertical velocity was recorded as minus (-) 800 ft/min, thus there was a large difference in each Vertical Speed. If an aircraft flying at GS 200 kt encounters an atmospheric pressure change of about 2 hPa (200 Pa) during one second of travel (approx. 100 m), it will become 50 ft when converted to altitude, and the Vertical Speed will be 3,000 ft/min. Therefore, the difference in records of the two types of Vertical Speed was likely the phenomenon created due to the sudden drop in atmospheric pressure, and at this time, the helicopter probably encountered the downdraft area as described in 3.3.1.2 (2). (Factor analysis is described later in 3.5.1 and 3.5.2.) In addition, the pitot tube of the same type of aircraft is attached to the nose, and the static pressure hole is open vertically at the tip of the pitot tube, so it is possible that this difference in elevation rate was affected by changing pitch attitude. Especially after the right roll movement started, it is more likely that the ADS elevation rate was recorded excessively.

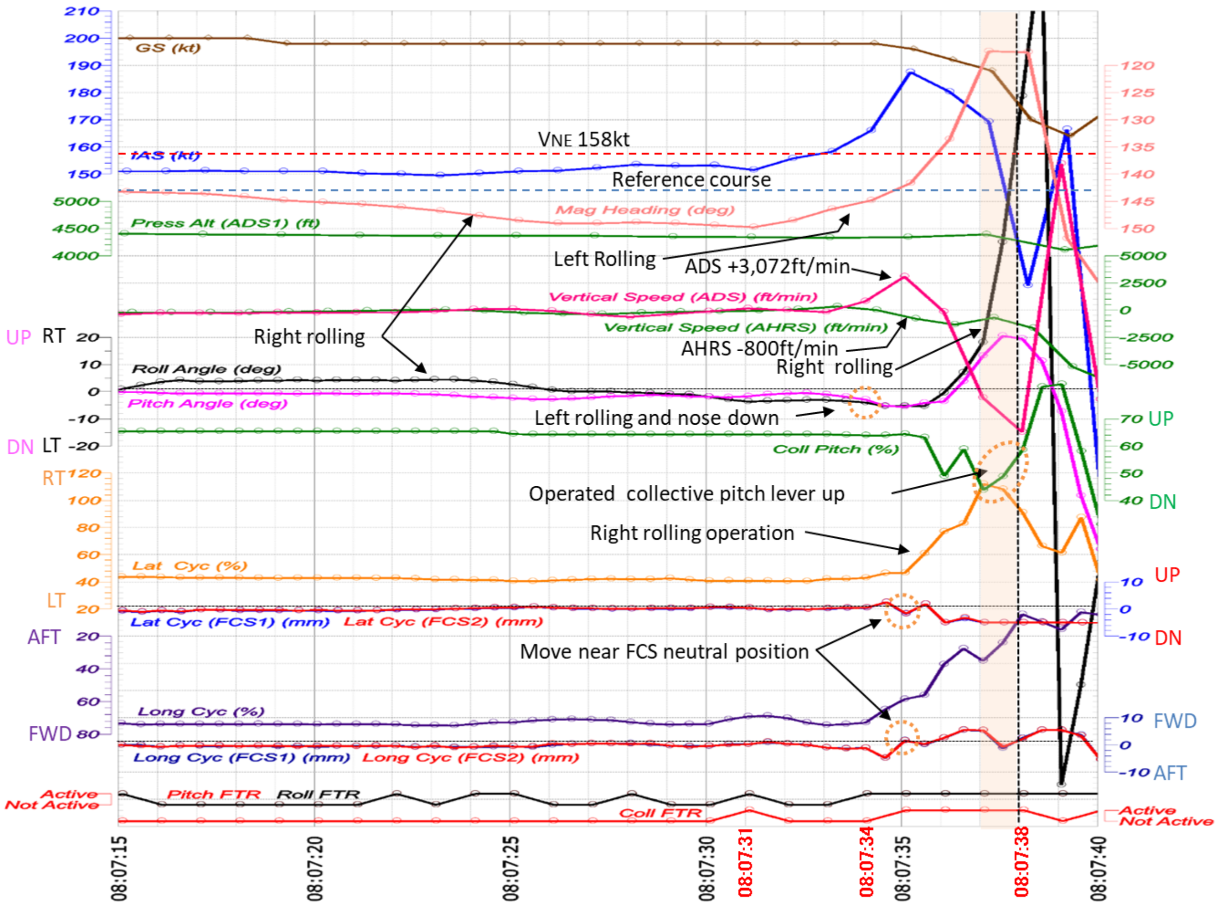
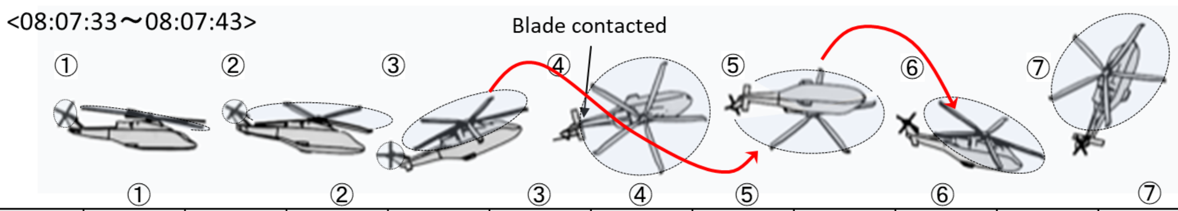


Figure 25: The record of MPFR when the IAS increased rapidly.

3.4.4 Flight during Contact between Main Rotor Blades and Tail Drive Shaft Caused by Right Rolling Motion

According to the MPFR records at the time of starting a right rolling motion in Figure 25, 26 and Appended Figure 4 to 7, immediately after the IAS increased up to IAS 188 kt at 08:07:35, as described in 3.4.3, the cyclic stick was largely controlled for approximately 2 to 3 seconds, therefore the helicopter started a rapid right rolling motion exceeding 360° with a roll rate of 100 °/second or more. During right rolling motion, the collective pitch lever was operated up and down like exceeding 20% of the control range for about two second. During the right rolling motion leading to the inversion between 08:07:37 and 08:07:39, and the collective pitch lever with depressing the FTR of the collective pitch lever pulled up from 45 % to 82 %, and as shown in Appended Figure 6, at 08:07:38, (-) 1.4 G was recorded. As shown in Figure 26, after 08:07:38, the contact noise and wind noise in the cabin were recorded as the voice information, and almost at the same time, sudden changes in engine instruments and yaw rate occurred. Therefore, it is probable that at this time, the main rotor blades contacted with the upper part of the tail section.



	① 08:07:33	08:07:34	② 08:07:35	08:07:36	③ 08:07:37	④ 08:07:38	⑤ 08:07:39	08:07:40	⑥ 08:07:41	08:07:42	⑦ 08:07:43
IAS (kt)	158	166	188	180	170	120	166	10	125	71	0
TAS (kt)	165	173	195	187	177	127	173	10	131	74	0
ALT (ft)	4,238	4,270	4,303	4,212	4,121	4,203	4,285	4,125	3,965	4,278	4,592
Pitch (deg)	-1	-3	-6	-4	13	19	-7	-58	-33	38	70
Roll (deg)	L3	L4	L5	L1	R18	R108	L144	L63	R39	R58	R45
CVR	・“Be careful, be careful” (Co-Pilot) ・”Oh! Ah!”(Captain) ・Pu, Air Speed（Voice warning） ・Bank Angle（Voice warning） ・Ga-cha, Ga-cha, Ga-cha （contact noise for about 0.07 seconds) ・Wind noise（continued）→ ・Rotor High （Voice warning）										

Figure 26 Flight data at the time of contacting with the main rotor blades.

Regarding the wind noise inside the cabin, it is probable that the forward window in the right sliding door on the right side of the cabin came off and entered the cabin. In addition, it is likely that part of the window of the co-pilot seat (left side) fell outside the aircraft, flowing air into enter the cabin. During rapid right rolling motion, the heading continued to veer to the left, and as shown in Appended Figure 6, the lateral acceleration was about 0.9 G to the right where it should be 0 G under normal conditions. Therefore, it is probable that the forward window in the sliding door on the right side of the cabin was deformed inward by the wind pressure from the right and came off.

At 08:07:43, the cyclic stick was operated to the left, which stopped a right rolling motion, however, as the cyclic stick remained pulled backward, the helicopter's attitude temporarily changed to 70° nose-up. As described in 2.11.2, at 08:07:44, the engines were switched to the manual back-up mode because an abnormal value was detected. Therefore, it is highly probable that the tail drive shaft was completely severed and the tail rotor stopped, resulting in a tail rotor drive failure condition. (Factor analysis is described later in 3.5.3.)

3.4.5 Estimated Flight after the Contact between the Main Rotor Blades and the Tail Drive Shaft until the Forced Landing

As described in 3.4.4, when the helicopter started a rapid right rolling motion, at about 08:07:38, the main rotor blades contacted with the tail drive shaft. From the location (Figure 10 in 2.9.2 (2)) where scattered objects of the tail drive shaft and the outer panel were found, it is probable that the tail drive shaft was completely severed while the helicopter was moving southwestward, the outer panel parts to which the GPS antenna was attached and some parts of in-flight equipment were scattered.

After the main rotor blades contacted with the tail drive shaft, judging from the fact that the positional information error increased as GPS antenna had fallen off, therefore as shown in Figure 27, the helicopter's flight route was estimated from the MPFR records, the location of fallen objects and the information provided by the eyewitness.

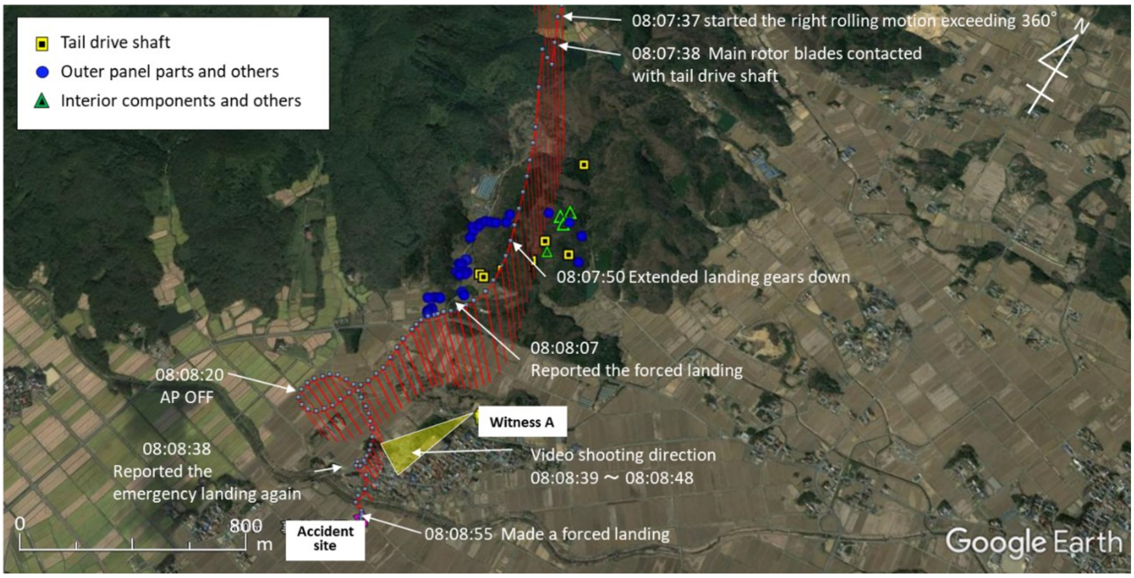


Figure 27: Estimated flight route from the occurrence of the right rolling motion up to the forced landing

The helicopter fell into a tail rotor drive failure condition as its tail drive shaft was completely severed, and as described in 2.11.2, at 08:07:44, its engines were switched to the manual back-up mode. During the period between the tail rotor drive failure and the forced landing, while the engine overspeed prevention function activated eight times, the engines were operating. The descent rate during this time changed between 570 ft/min and 6,700 ft/min, the helicopter was descending while largerly changing the its attitude in pitch, roll, and yaw. At 08:07:49, the collective pitch lever was held in the lowest position for about five seconds, therefore, the captain seemed to attempt by descending an autorotation, however, after that, the NR changed as the collective pitch lever was operated largely up and down, the autorotation status was not continued. (Factor analysis is described later in 3.5.4.)

It is probable that after falling into tail rotor drive failure condition, the helicopter flew somewhat straight when the IAS increased, and repeated turning to the right due to the deceleration. From the video information from the Eyewitness (Figure 3) described in 2.1.2 (6) and the MPFR records, it is highly probable that just before the touchdown, its attitude was raised up while the helicopter continued to turn to the right, and landed in a state of tilting to the right.

3.4.6 Estimation of Final Approach Profile during Forced Landing

(1) Vertical acceleration

According to the MPFR records, the maximum value of the vertical acceleration at the center of the helicopter at the time of touchdown was plus (+) 1.86 G, and the maximum value of vertical acceleration at the nose position was plus (+) 6.8G, which was 0.2 seconds later than the maximum vertical acceleration at the center of the helicopter.

(2) Descend rate, velocity and others

According to the MPFR records, at the time of touchdown, the descend rate was minus (-) 2,720 ft/min (AHRS inertial vertical velocity), the right yaw rate was 87 deg/s, and the ground speed was less than 20 kt.

(3) The helicopter's attitude at the time of touchdown

According to the MPFR records, at the time of touchdown, the pitch attitude was minus (-) 2.6° and the right roll attitude was 14.7°.

(4) Evaluation of impact resistance

As described in 2.9.2 and 2.10, and according to the MPFR records, at the time of the forced landing in the paddy field, as described in (1), (2) and (3), the helicopter touched down with slightly nose-down, right roll attitude, and the landing gears down, and then rolled over to the left, which resulted in damage to the helicopter. Because the helicopter stopped with the left side down, and the lower forward fuselage and the left main landing gear were damaged and detached, it is highly probable that the nose went down after the right main landing gear touched down, and the helicopter rolled over to the left with the lower surface of the fuselage subjected to a large load, resulting in the damage to the helicopter.

Although the helicopter touched down with the vertical acceleration of plus (+) 1.86 G at the center of the fuselage and plus (+) 6.8G at the nose position, yet the damage to personnel was limited to injuries. It is probable that this was because the helicopter was able to touch down from the landing gear as the attitude was almost horizontal and the following three elements most likely functioned as impact-resistant airframe design.

a. As described in 2.9.2 (5), during a forced landing, a large amount of energy was absorbed while the landing gears were damaged until the fuselage touched the ground.
b. As shown in Figure 8, the underfloor structure of the lower fuselage was compressed, buckled and deformed to absorb energy, and the cockpit and cabin were protected by the structural members of the fuselage.
c. As shown in Figure 12, the seating surface was moved to the lower position and absorbed energy as the load limiter of the seating surface of each seat, on which they were seated, had operated.

3.5 Abnormal Events that Occurred after Rapid IAS Increase

The JTSB concludes that among the flight conditions described in 3.4, "Rapid increase in IAS", "Attitude change when IAS increased", "Contact between main rotor blades and tail drive shaft", "Engine manual backup mode" considered as specific events. And they were analyzed as follows:

3.5.1 Rapid IAS Increase when the Horizontal Wind Velocity Rapidly Decreased

At around the altitude at which the aircraft flew over the Ou Mountains, as described in 2.11.3 and 3.3.2, the wind was most likely blowing at the wind direction of 300 °and at the wind velocity from 40 kt (20 m/s) to 50 kt (25 m/s) on the east side of the mountainous terrain on the southeast side of Lake Inawashiro. Furthermore, judging from the computed values of the instantaneous wind based on the MPFR records and the results of the numerical analyses, it is probable that the horizontal wind velocity almost disappeared at the point where the IAS rapidly increased.

When the wind conditions suddenly from a tailwind of 50 kt to a horizontal wind of 0 kt while flying, the aircraft will try to continue uniform motion due to the law of inertia, but the

GS will be slowly reduced as much as it receives air resistance (drag). The IAS will be more likely increase temporarily as if to be replaced by the wind velocity deceleration.

As described in 3.4.1, when the IAS of the helicopter increased at 07:24:12 on the outward journey to Aizu Operation Site, the drag increased due to the attitude with the nose-up pitch angle of 5°, resulting in the earlier GS deceleration, but the IAS increased by 16 kt in six seconds. In addition, as shown in Figure 25, during four seconds between 08:07:31 and 08:07:35 on the homeward journey from Aizu Operation Site, the GS decelerated by 2 kt from 198 kt to 196 kt, but the IAS increased by 36 kt from 152 kt to 188 kt.

The rapid increase in IAS on both the outward and homeward journeys was a phenomenon caused by a rapid decrease in horizontal wind velocity. Especially, as in the case of the homeward journey, when a strong tailwind that causes a large difference between IAS and GS suddenly decreases, IAS will more likely increase rapidly.

3.5.2 Relationship between attitude change during IAS increase and attitude control by autopilot

As shown in Appended Figure 1, the AW139 tail rotor disc is tilted to the left by about 15°, which can provide the nose-down pitching attitude by giving the lift upward, in addition to movement in a horizontal direction. Besides, the vertical stabilizer holds a right camber and the horizontal stabilizer holds a camber on its upside, which makes it possible to keep the aircraft attitude horizontal during cruise flight and make up for the necessary thrust as an antitorque tail rotor so that the camber of the airfoil can help to produce lift by an increase in airspeed. The tail rotor is mounted on the position higher than the center of gravity, and a right rolling motion can occur due to the change in the tail rotor thrust. Therefore, in order to maintain the desired attitude, corrections in a lateral direction should be made according to the change in the tail rotor thrust.

When IAS 45 kt or more, if the ATT mode are maintained, the autopilot controls the flight control system to maintain the attitude, so it is considered which the pilot can fly without being conscious of the cyclic stick.

As shown in Figure 23, when the helicopter encountered an updraft on the outward journey, nose-up moment was generated, and as shown in Figure 25, when the helicopter encountered a downdraft on the homeward journey, nose-down moment was generated. It is probable that when the updraft component entered the tail rotor section due to the tail rotor tilt and the influence of the horizontal stabilizer, the lift decreased and nose-up moment was generated, and when the downdraft component entered the tail rotor section, the lift increased and the nose-down moment was generated. Besides, when the airspeed increases, the required tail rotor thrust decreases due to the effect of vertical stabilizer, in addition, the right roll moment decreases, therefore, the cyclic stick should be operated slightly to the right of the position when held in low speed.

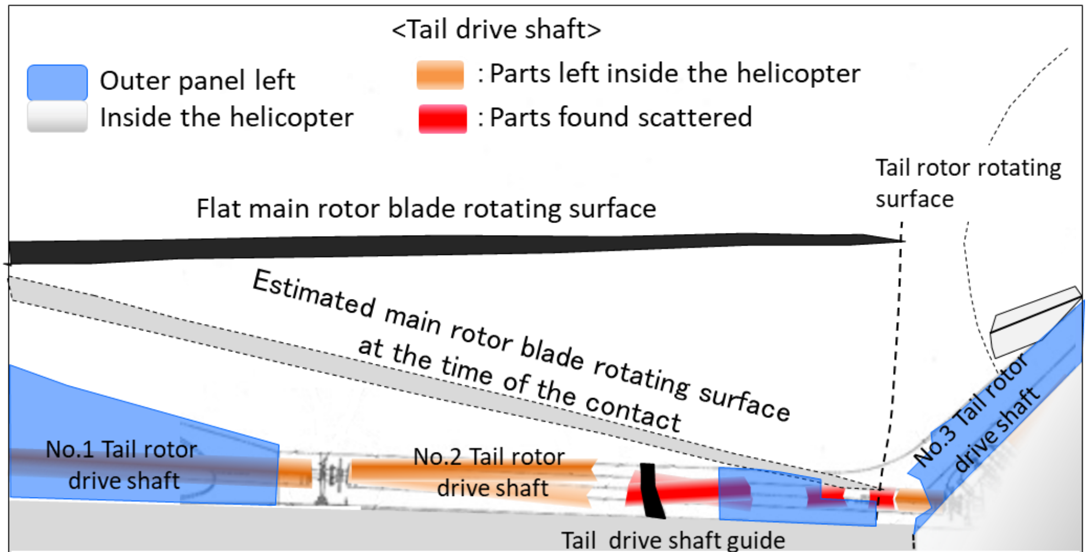
As shown in Figure 25, as for the position of the flight control actuators, when the IAS rapidly increased from 08:07:31 to 08:07:34, the longitudinal cyclic (Long Cyc) was moved gradually backward by attitude retention function, and the lateral cyclic (Lat Cyc) was moved gradually to the right.

However, at 08:07:34, the FTR of the cyclic stick was pressed and held for a long time, which stopped the attitude retention function, and the longitudinal and lateral cyclic flight control actuators shifted from the controlled position to the center position. For this reason, it is probably that the pitch was kept at (-) 5° and the roll was kept at 5° left for about 1 second, and the movement of the cyclic stick was slightly delayed.

3.5.3 Contact between Main Rotor Blades and Tail Drive Shaft during Right Rolling Motion

Figure 28: Attitude of the helicopter and location of the flight control system at the time of contacting between the main rotor blades and the tail drive shaft

The main rotor blades of the AW139 are structured to limit the vertical flapping*36 movements by upper and lower limiters that make it difficult to contact with the fuselage. As described in 2.13.1, in case of the weight of the helicopter at the time of the accident, the first sign of the stall of the retreating main rotor blade is expected to be shown in the range of TAS 190 to 200 kt. Because while the helicopter was in level flight, the airspeed rapidly increased to IAS 188 kt (TAS 195 kt), in which the sign of the stall should be shown, but low-frequency vibrations of the main rotor blades, including torque oscillations (see Figure 16), did not occur, and because a right rolling motion started in response to the control by auto-pilot and the operation of cyclic stick during acceleration, it is unlikely that the retreating main rotor blades stall caused the main rotor blades to contact with the tail drive shaft.



1 The main rotor blades were flapped largely, and the rotation surface contacted with the outer panel, and part of the tail drive shaft.
2 Part of the tail drive shaft that touched contacted with the lower surface of the fuselage.
3 The No. 2 tail drive shaft lost its rotational balance, the aft part of the No. 2 tail drive shaft scattered while contacting with the outer.

Figure 29: Estimated movement plane of rotation of main rotor blades at contact, and scattering of No. 2 tail drive shaft rear part

As described in 3.4.4, at around 08:07:38, there was a contact sound in the audio data. At that time, as shown in Figure 28, the flight condition of the helicopter was nose up 19°, right bank 108°. The right roll rate exceeded 100 deg/s, and it was close to the inverted flight. At the time of the contact, the cyclic stick was positioned right backward while the FTR was depressed, and when the collective pitch lever was made large adjustment from 45 % to 82 % for two seconds, as shown in Atttached Figure 6, the vertical acceleration at the center of the helicopter

*36 "Flapping" refers to the vertical movement of the rotor blades around the flapping hinge, which raises and lowers the rotor blades to balance the different lift forces on the forward and reverse sides of the blades.

was recorded as (-) 1.4 G. Therefore, as shown in Figure 29, it is probable that the main rotor blades were flapped largely toward the fuselge, and contacted with the outer panel and the aft part of the tail drive shaft No.2. As described in 2.9.2 (2), judging from the shape of the damaged tail drive shaft, the state of contact with the fuselage and No. 2 tail drive shaft was rotating at a high speed, therefore, it is highly probable that as the main rotor blades contacted, the tail drive shaft No. 2 was instantly deformed and lost its rotational balance, which caused the aft part of the tail drive shaft No. 2 to scatter while contacting with the outer panel, resulting in cutting off the tail drive shaft.

3.5.4 Effect of engine manual back-up mode

As described in 2.11.2, following a rapid right rolling motion, at 08:07:44, the engines were switched to the manual back-up mode, therefore its effect was analyzed.

When an engine signal failure is detected, there is a possibility of compressor surge (aerodynamic instability) or flameout (engine shutdown) due to engine overspeed, therefore, in order to prevent the engines from over-speeding, it is changed to a manual back-up mode. It is probable that due to the tail rotor drive shaft cutoff, the load on the tail drive shaft was lost, the NF value became abnormal, and the engine changed to the manual back-up mode. When the engines are switched to the manual back-up mode, the fuel flow will be constant and, and when the NF value exceeds 111 %, the fuel flow will be limited by engine overspeed prevention function, and when the NF value is 109 % or less, the fuel flow will be constant. As described in 2.1.2 (1), after deciding to make a forced landing, during the descend, the captain intended to execute an autorotation, confirmed it was in the manual back-up mode, and "felt as if the NR rose", as in his statement, when operating the engine trim switch on the collective pitch lever. However, according to the MPFR records, the engine trim switch operation was not recorded. After that, the captain stopped to execute an autorotation and tried to descend while moving the collective pitch lever up and down, but due to his large movement of the collective pitch lever, the flight attitude was not stable. As the engine load changed and the NF value exceeds 111 %, during the period until the forced landing was made, the engine overspeed prevention function activated eight times. As shown in Figure 16, the engine continued to operate while increasing and decreasing the output by adjusting the fuel flow, and the descent rate was changing in line with the collective pitch lever operation.

When both engines are switched to the manual back-up mode, by regarding it as both engine failure, the procedure is also possible to immediately switch to the autorotation status, however, if the IAS is below the V_Y, the forced landing is difficult to make by proper autorotation. According to the MPFR records, when the helicopter's attitude and the NR are not maintained, the helicopter flew in the state where the variable state of the descent rate was between 2,000 ft/min and 6,700 ft/min, however, when the IAS was at about 60 kt and about 95% of the NR and in a horizontal attitude, there were some sectors where the helicopter flew in the decreasing descent rate between 570 ft/min and 800 ft/min. During the descent, as the right rolling motion continued, and there was almost no stable flight, but it is probable that the engine overspeed prevention function prevented the engines from shutting down. And in the sector where the engine output was recovered, the descent rate was reduced, leading to guiding to the forced landing site and alleviating the impact at touchdown.

3.6 Pilots' Responses

The JTSB concludes that as follows regarding the pilots' responses.

3.6.1 Pitch Attitude and Velocity during IAS increase

As described in 2.1.2 (1), the captain stated that he had maintained around IAS 140 kt (TAS 147 kt) by checking the pitch attitude relations between the airframe equipment located on the central window frame and the horizon as a guide. In order to analyze the validity of the flight operations, as shown in Figure 30, the change in pitch attitude due to differences in airspeeds are graphically illustrated based on the calculation model of the design company. The red circle is the pitch attitude based on the relationship between the position of the equipment on the window frame and the horizon as stated by the captain, while other graphs show the calculated pitch attitude under different flight conditions (weight, center of gravity position, horizontal or in descent). Regarding the calculated values, the closer to the high-speed area, the smaller the difference in pitch attitude under different flight conditions, and the pitch attitude will be approximately at 0 degree around at TAS 140 kt to TAS 150 kt.

From the weight and center of gravity at the time of the accident, which was described in 2.5.2, the pitch attitude of level flight at IAS 140 kt (TAS 147 kt) was about 0°, however, according to the MPFR records about the IAS, at 08:07:31, immediately before the IAS increased rapidly, the pitch attitude was (-) 1.75 °at IAS 152 kt that has a difference of 6 kt from V_{NE}. It is probable that the attitude was not maintained according to the reference used by the captain, which caused a speed difference of (+) 10 kt or more, and the attitude easier to exceed the V_{NE} was continued.

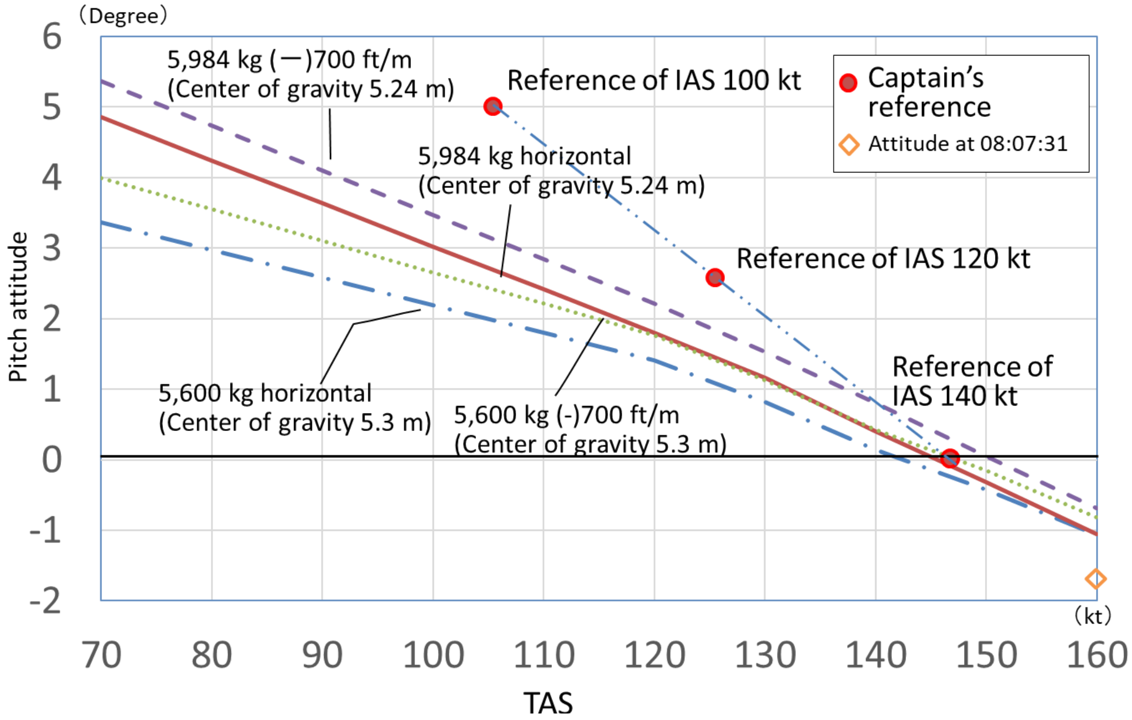


Figure 30: Change in pitch attitude depending on different airspeeds

In addition, as described in 2.1.2 (1) and (2), neither the captain nor the co-pilot was able to recognize the rapid increase in IAS, but as shown in Figure 26, at 08:07:35, when the IAS increased rapidly, the CVR recorded the co-pilot's saying "be careful, be careful". From this, it is likely that the co-pilot uttered it, probably because it visually recognized the background color of the airspeed indicator changed from black to the red that means the excess of V_{NE}, or he felt a rapid attitude change starting. The captain stated that he had lowered the collective pitch lever by 10 to 15% and set the pitch attitude to 5°, which is the attitude of IAS 100 kt, however, as described in 3.4.3, after the collective pitch lever was lowered by 20%, the pitch attitude did not stop at 5°, but continued to change. From this, it is probable that the pitch attitude could not be properly controlled when the IAS suddenly increased.

3.6.2 Flight Control Operations at the time of Right Rolling Motion

As described in 3.4.3, immediately after the IAS increased rapidly, when the helicopter started a right rolling motion exceeding 360°, the cyclic stick was largely moved to the right backward. As described in 2.1.2 (1), as the captain used the FTR in order to make a correction for the aircraft attitude, the FTR usage conditions was confirmed with the MPFR records (see Appended Figure 3: MPFR Analysis after Take-off from Aizu Operation Site–2), which revealed that the captain frequently used the FTR in order to correct the attitude and did not use the Beep Trim Switch. The normal procedures in the AW 139 flight manual includes the description as follows: "*The force trim release button (FTR) on the cyclic stick should be kept depressed during all large stick movements*", on the other hand, "*For small attitude adjustments in forward flight (± 2 to 3 kt) the system beep trim mode (TRIM) can be used* ", and while "*The trim method most commonly used is a combination of trim release and beep trim*". Especially during high-speed flight, the reaction to flight control operations becomes more sensitive. For this reason, the AW 139 is designed so as to make the pitch angle change rate of the beep trim small. Therefore, it is more likely necessary for high-speed flight to limit cyclic inputs or use the beep trim.

As described in 2.1.2, the captain stated, "The helicopter was subjected to gusts as if to combine both lateral G (lateral acceleration) and longitudinal G (longitudinal acceleration), therefore I held the cyclic stick like looking for, trying to maintain the attitude, then the helicopter looped like being drawn into the forward." At 08:07:35 when the IAS increased to IAS 188 kt, the pitch angle was from (-) 0.5° to (-) 5°, while the left roll angle was from 3° left to 5° left and for the vertical acceleration, 0.36 G (reference value 1.0 G) at the center of the helicopter and (-) 0.92 G (reference value 0.0 G) at the nose position were recorded. It is probably that the captain experienced such a rapid nose-down and acceleration on the negative side, thought that he would somersault forward, and at 08:07:34, moved the cyclic stick largely to the right backward by pressing FTR, which was the direction opposite to the helicopter's attitude. It is most likely that this encouraged the right rolling motion.

In addition, the reason why the captain moved the cyclic stick largely is likely because if the Beep Trim was not used but the FTR was used to operate, artificial steering reaction force according to control inputs was turned OFF, and it is possible that the steering reaction force that tries to return the cyclic stick to the position where it was held by the actuator disappeared due to this state, and the amount of correction became excessive.

In the ATT mode uncoupled with FD[*37] mode, the Automatic Flight Control System (AFCS) of the AW 139 will keep the rolling attitude with the attitude retention function when the IAS exceeds 45 kt and the roll angle exceed 3°, and it will force the roll angle is forced to 0° and maintain the heading when the roll angle is less than 3°. SAS mode can be selected when pushing the FTR, therefore, the attitude retention function stops its operation and the pilot's operations can override it. It is possible that the ATT mode allows the helicopter to maintain its pitch and roll attitudes against a long-term disturbance, thus, the ATT mode cannot prevent the IAS from increasing. However, making corrections while feeling steering reaction force

[*37] "FD" refers to the function to perform automatic flight (guidance control) such as speed control, climb/descent, flight route, by controlling the four axes (roll, pitch, yaw and collective) in the ATT mode.

could have constrained large control inputs by using the beep trim, it is possible that the attitude change did not lead up to the rapid right rolling motion seen as in this accident.

3.6.3 Understanding the failure of Tail Rotor Drive

As described in 3.5.2, the tail drive shaft was severed at the time of right rolling motion and the tail rotor stopped, which resulted in difficult pilotage of the helicopter. However, as described in 2.1.2, the captain and the co-pilot were not able to grasp the tail rotor drive failure condition. After the helicopter started a right rolling motion, the captain was more likely too concentrated on controlling the helicopter attitude to have time to think. In addition, probably the co-pilot tried to reset the AP as thinking that the autopilot went out of control.

As described in 2.13.3.2, the AW 139 tail rotor drive failure can be detected by a rapid yaw to the right and a loss of yaw control. The emergency procedures in forward flight are described as follows: After lowering collective pitch lever to minimize yaw right, establish sufficient airspeed and power according to the aircraft weight, raising or lowering the collective pitch lever while maintaining NR within limits may be effective in helping control sideslip, and reach a suitable landing site and shut down engines.

According to the MPFR records, after starting a right rolling motion, when the helicopter started to turn right, the captain depressed the left rudder pedal but the right turn continued, therefore, the captain might have a chance to know the occurrence of the tail drive failure, but he was unable to grasp it. At around 08:08:00, when the attitude was temporarily stable at IAS about 80 kt to 100 kt with the pitch/roll angles at about 0 degree, the helicopter was flying straight for about 10 seconds, but was unable to continue it.

As described in 2.12, for the type rating change to the AW 139, both pilots took flight trainings in Leonardo S.p.A. in Italy from November to December in 2014, which conducted the emergency procedures' training of tail rotor drive failure in the FFS training. After that, trainings with the AW 139 type FFS and others were not conducted. The flight control trainings were conducted with AS350B3 FTD about once a year in Japan. As a procedure during cruise flight, the intent of the procedure to maintain airspeed / power and adjust to minimize the sideslip angle is not significantly different from the AW139 and AS350B3, but as described in in 2.13.4, when comparing the symptoms of tail rotor drive failure and emergency and malfunction procedures of the AW 139 and AS350B3, the direction of rotation of the main rotor of AS350B3 is opposite to that of the AW 139, therefore, there is a difference in that its symptom of failure is the yawing to the left, which may more likely cause delays in the determination of failure symptoms. In addition, for the approach and landing procedures, AS350B3 is stipulated to execute autorotative landing procedures over a proper landing site, while the AW139 does not execute an autorotation, but shut down the engines immediately before the touchdown and make landing roll, therefore, it is possible that the procedures may not be properly performed.

The reason why neither the captain nor the co-pilot was able to fully grasp the tail rotor drive failure, they had not conducted any training using the AW 139 type FFS after the training for the type rating change, but as described in 2.12.2, they conducted only training with AS350B3 type FTD that was not normally operated, it is likely that they could not grasp rapid yawing to the right as the symptom of tail rotor drive failure.

At the time of the accident, in Japan, there was no AW 139 type FFS and others in operation, but it has been in operation since 2021.

3.6.4 Responses at the time of the forced landing

As described in 2.1.2 (1), during the descent, the captain visually recognized “x" marks displayed on instruments such as the airspeed indicator and others on the PFD, decided early to make a forced landing, and lowered the landing gears. According to the MPFR records, at 08:07:40, the data of “ADC1 FAIL” was recorded for about one second, and in respond to this signal, “x" marks were more likely displayed on the co-pilot PFD.

As described in 3.4.6 (4), making a forced landing with the landing gears down was extremely effective from the impact-resistance point of view, which most likely contributed to the limited injuries to persons. In addition, it was probable that the captain made a forced landing was appropriate avoiding landing in a village even while a difficult controlling condition of the helicopter.

3.6.5 Coordination between Pilots during Emergency Operations

The AW 139 is designed to enable one pilot operation, therefore even in the event of an emergency operation, it is feasible for the captain alone to respond to the situation. However, in the difficult pilotage situation that the helicopter encountered, emergency procedures, such as external communication, accurately grasping the situation, and shutting down the engines at the time of forced landing, can be likely responded by two pilots quickly.

When the helicopter started a right rolling motion, as described in 2.9.2, sideslipped to the right due to the abnormal change in the helicopter’s attitude, the forward window in the sliding door of the cabin was compressed and fell in the helicopter while the window on the co-pilot’s seat side was sucked out of the helicopter and dropped off. As a result, it is probable that the captain's headset came off by the wind incoming into the cabin, and in-flight intercommunication became impossible, resulting in insufficient communication between the pilots.

As described in 2.1.2 (2), the co-pilot thought that the flight control system had gone out of control and tried to reset the AP switch. According to the MPFR records in Appended Figure 6, at 08:08:20, the AP was OFF, thus the FO probably left the AP OFF and did not turning it ON again. Therefore, it is possible that the actuator signal of the flight control system (FCS) became zero, and the cyclic stick inputs gradually increased, which caused a large attitude change, resulting in the difficult corrective operation at the time of the forced landing.

The two-pilot system enables safer operations by effectively utilizing the resources of both parties. However, in the event of an emergency, in-flight communications may be disrupted, and it is possible that verbal communication between pilots may be incapable. Therefore, by taking into these situations, it is likely necessary to conduct extensive emergency procedures trainings so that both pilots can communicate and work together even in such a situation.

3.7 Verification using Full Flight Simulator (FFS)

The JTSB concludes that as follows regarding verification using full flight simulator.

As described in 3.5.1, the rapid increase in IAS probably occurred due to a sudden decrease in the tailwind of the horizontal component when the helicopter encountered a strong downdraft. Therefore, the following items were confirmed using the AW 139 type FFS. However, as it was impossible to reproduce the rapid change in atmospheric pressure that might have occurred around the helicopter by using an actual AW 139 helicopter, it was confirmed by using a constant atmospheric pressure and the deceleration rate of wind velocity on system.

3.7.1 Verification of IAS Increase/Decrease due to Differences in Flight Control Modes

The AW 139 is equipped with ATT, SAS, and FD as flight control systems. By using these functions, the following flight conditions were set and confirmed regarding the effect of the flight control mode on the rapid increase in IAS.

(1) Characteristics of dynamic stability of flight control by hands-off

The AW 139 is equipped with FD and the specific setting for the flight (attitude, airspeed, and pressure altitude) to be maintained can be selected according to the difference in flight modes, thus the characteristics of flight control dynamic stability were confirmed by inputting a wind velocity change to 0 kt from a 50 kt tailwind condition in the following three flight control modes.

Case-1 : Only ATT mode (Cyclic stick and collective pitch lever fixed)

Case-2 : IAS HOLD mode

Case-3 : IAS HOLD mode and ALT HOLD mode

Default values: IAS 150 kt, Heading 120°, Altitude 4,500 ft

Weight: 5,707 kg, CG 5.27 m (same as at the time of the accident)

Wind direction and velocity: 300° 50 kt (Tailwind)

Wind velocity reduction rate from 50 kt to 0 kt: About 2.3 kt/sec

Outside air temperature on ground: 1°C

Terrain information: Over the Ou Mountain Range on the southeast side of Lake Inawashiro

Turbulence level: None (Because randomly generated turbulence affects the results of dynamic stability)

Flight control system: Hands-off

Verification result

a. In all three cases, for about 20 seconds when the wind velocity of the system was 0 kt, the IAS increased and exceeded the V_{NE}.

b. The maximum IAS value was Case-1 > Case-2 > Case-3, and the VNE exceeding time was shortest in Case-3.

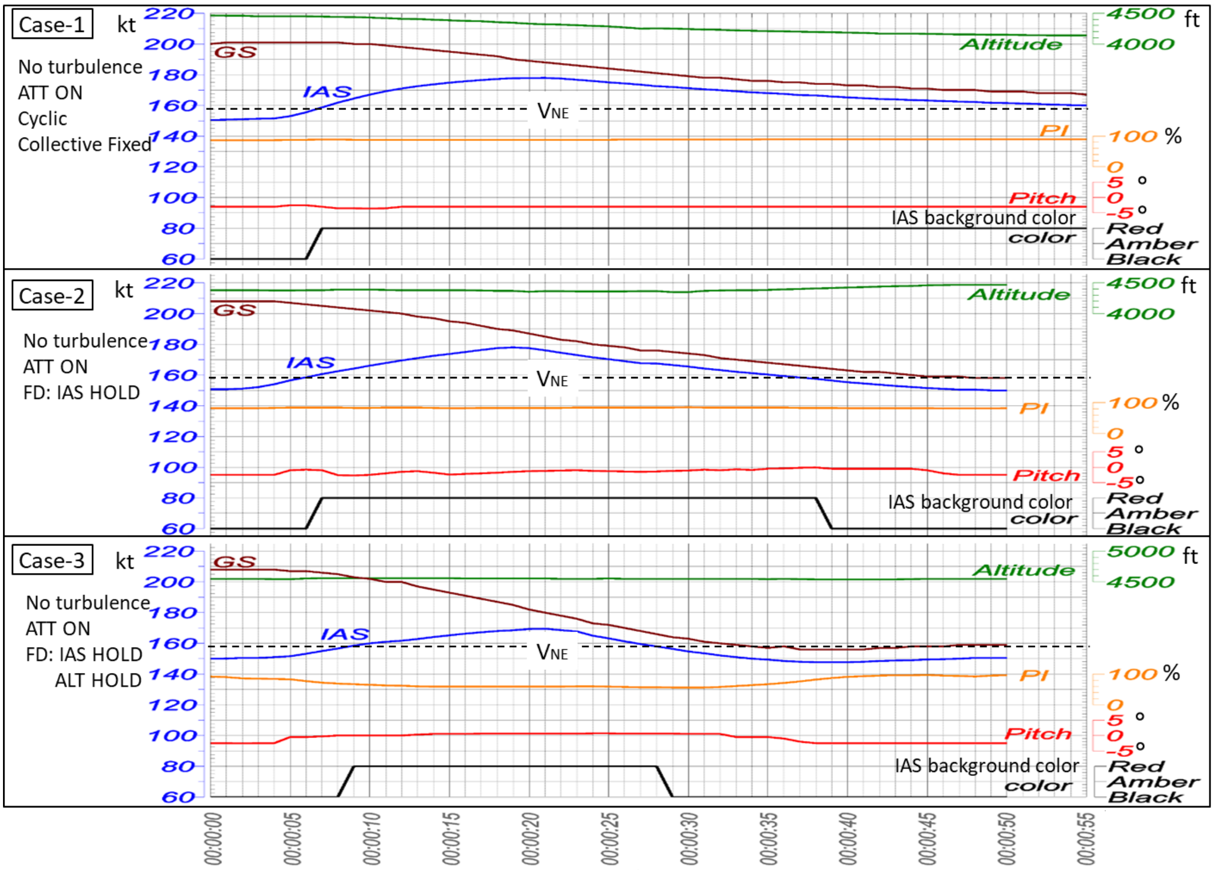


Figure 31: Characteristics of dynamic stability of flight control by hands-off

(2) Deceleration operation by Beep Trim in the ATT mode

In the flight status of the ATT mode, the wind velocity change from a 50 kt tailwind condition to a wind velocity of 0 kt was input, and when the IAS increased rapidly, the deceleration operation by the Beep Trim and collective pitch lever was performed in the ATT mode, and it was confirmed about the characteristics of flight control dynamic stability in the following three cases.

Case-4 : Fix the collective pitch lever, and operate the Beep Trim backward for five seconds after checking the amber caution of background color that appears before the red warning indicated when exceeding the VNE at the time of the IAS increase.

Case-5 : Fix the collective pitch lever, and after checking the amber background color indicated at the time of the IAS increase, operate the Beep Trim backward until the IAS decelerates. (For about seven seconds)

Case-6 : after checking the amber background color indicated at the time of the IAS increase, operate the Beep Trim backward for three seconds, and then lower the collective pitch lever so as to maintain the altitude.

Default values: Same as the (1) above, ATT ON, FD OFF

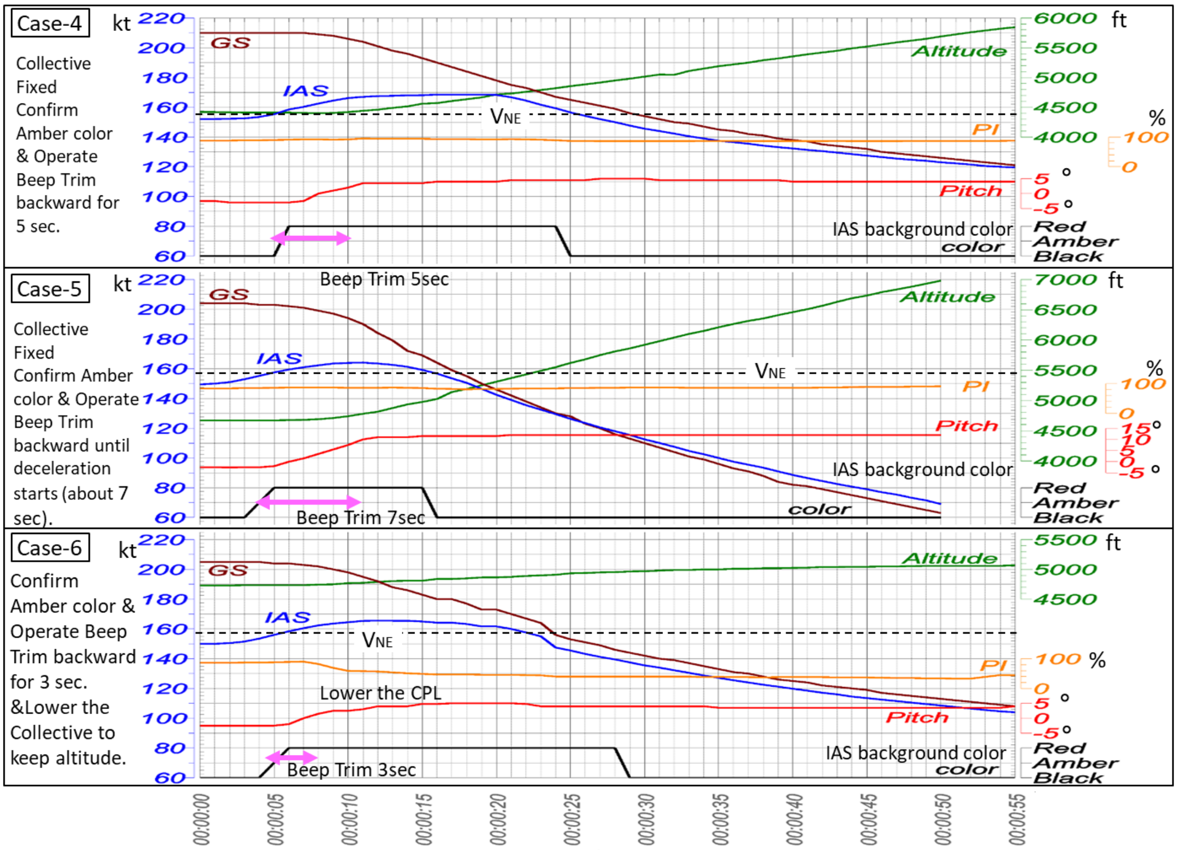


Figure 32: Deceleration operation by Beep Trim in the ATT mode

Verification result

a. In all three cases, the VNE was exceeded, but the duration of time when the IAS increased, and the background color became amber was less than one second.

b. The maximum IAS value was Case-4 > Case-6 > Case-5, and the longer the beep trim operation was, the shorter the VNE exceeding time became.

c. In Case-4 and Case-5, the helicopter failed to hold altitude and climbed more than 500 ft until the velocity was below the VNE.

d. In Case-6, the VNE exceeding time was about the same as Case-3, and a stable attitude was able to be maintained.

(3) Comprehensive consideration based on verification result

In none of the six confirmed cases was it possible to prevent the IAS from rapidly increasing beyond the V_{NE}. Due to FFS systematical limitations, the confirmation was made at the wind velocity reduction rate of (-) 2.3 kt/sec. Considering that the helicopter's IAS increased by 36 kt in 4 seconds, it is probable that the reduction rate of horizontal wind velocity at the time of the accident would have been much greater, and it is possible that the IAS increased equally or more the result by FFS. In all cases, the attitude was stable by the ATT mode, therefore, when flying in cruising, it is desirable to fly by using the FD or make corrective operation by using the Beep Trim.

As described in 2.13.2, the flight manual of the AW 139 stipulates about the flight method such that at the time of flight in severe turbulence, the helicopter shall slow to a comfortable speed, fly a constant attitude, and the rapid change of speed shall not be performed, and furthermore, large, rapid collective pitch adjustments shall not be made. In addition, as it stipulates that the flight control mode to use shall be decided by the pilot according to the flying method, the pilot must select an appropriate mode.

3.7.2 Procedures at the Time of Tail Rotor Drive Failure and Verification of Speed at Which Straight Line Flight is Possible

As described in 2.13.3.2, at the time of tail rotor drive failure, as sideslip can be controlled by establishing sufficient IAS / Power / Roll and raising or lowering the collective pitch lever while maintaining NR within limits, thus it was confirmed about the airspeed at which a straight-line flight is possible by the following procedures.

Default values: IAS 120 kt, Heading 120°, Altitude 4,500 ft

Weight 5,707 kg, CG 5.27 m (Same as at the time of the accident)

Wind direction and velocity: No wind

Outside air temperature on ground: 1°C

Turbulence level: None

During flight according to the default values, the emergency operation procedures were performed assuming that tail rotor drive failure occurred.

Verification result

Airspeed at which a straight-line flight is possible: IAS 110 kt

1 Effects of collective pitch lever

As raising or lowering the collective pitch lever have a great effect on NR change, it was required to make small and slow movements.

2 Confirmation of the airspeed at which a straight line flight is possible

The weight and balance of the helicopter at the time of the accident required the airspeed at IAS 110 kt or more while maintaining the left roll angle of 3° in the event of tail rotor drive failure. At IAS 105 kt or less, it started to yaw right, and it went yawing gradually larger in proportion to the deceleration. Once the IAS decreased and the helicopter started rotating right largely, it was quite difficult to bring the helicopter back to its condition for straight line flight.

Comprehensive consideration

As described in 2.13.3.2, the AW 139 tail rotor drive failure will result in a rapid yaw the right and a loss of yaw control, accompanied by noise or vibration in the tail section. The severity of the initial yaw rate will be determined by the airspeed, altitude, gross weight, center of gravity and torque settings at the time that the failure occurs. And the effectiveness of the vertical fin increases at higher airspeeds because the higher the airspeed is, the easier the lift can be generated on the right side.

As a result of the verifications above, the weight and balance at the time of the accident required the airspeed at IAS 110 kt or more and the left roll angle of 3° in order to make forward flight. When the airspeed decreases once, large nose-down inputs will be required for the airspeed to increase as seen at the time the accident during which the descent rate will be larger. Accordingly, the sufficient altitude above the ground level (AGL) will be required until the airspeed is recovered. Therefore, it is more likely necessary for pilots to quickly judge the altitude and airspeed at the time of the tail rotor drive failure and take corrective action following procedures in forward flight or in hover, or to judge whether the landing by auto-rotation is possible or not.

4. CONCLUSIONS

4.1 Findings

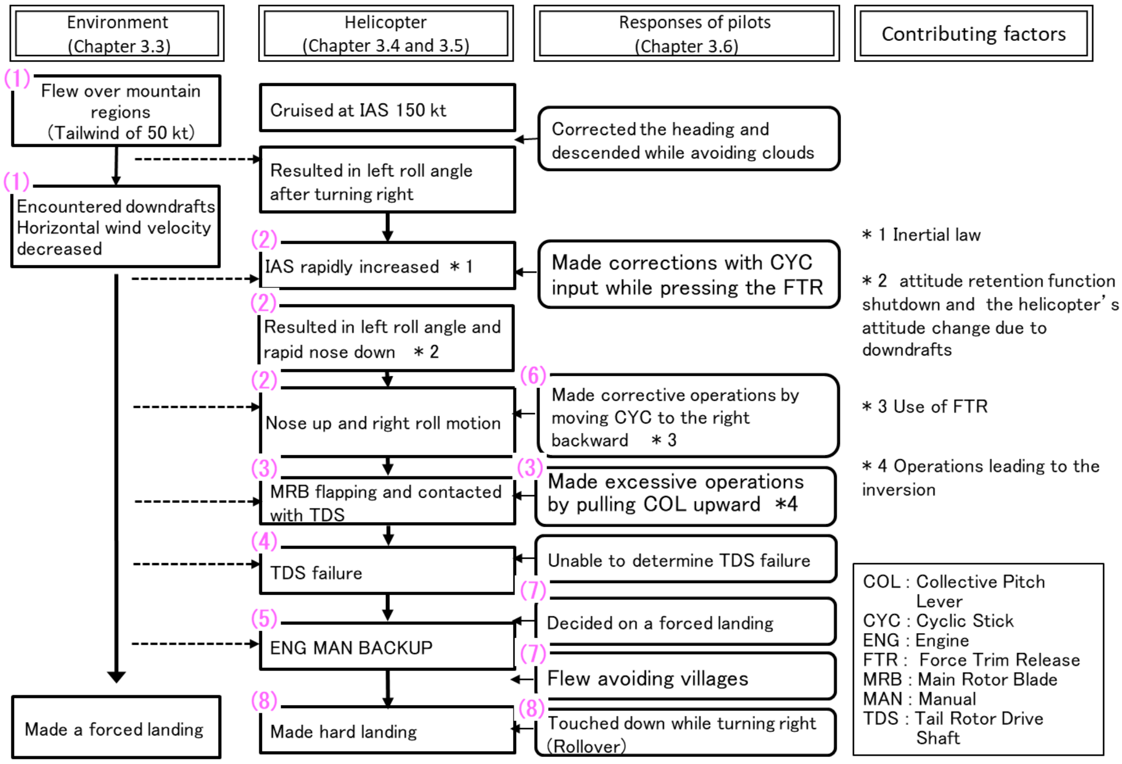


Figure 33 Summary of analysis

(1) A strong vertical flow was generated over the mountainous terrain on the southeast side of Lake Inawashiro due to strong northwester, and the helicopter flying at high speed with a tailwind probably encountered an area where the air currents drastically changed in a short period of time. It is probably that the flight control of the helicopter was strongly affected by the sudden decrease in horizontal wind speed. (3.3.2)

(2) Regarding the sudden increase in IAS and the start of the right rolling motion, on the east side of the Ou Mountains, while flying in a northwest wind with a tailwind of about 50 kt, the helicopter encountered a strong downdraft. And when the horizontal wind speed of the tailwind suddenly decreased, the ground speed did not change significantly due to the inertial force, resulting in an increase in the IAS. When the IAS suddenly increased, pressing FTR stopped the attitude retention function, causing a left roll attitude and a nose-down attitude. It is probable that the right rolling motion exceeding 360° started when the cyclic stick was largely manipulated rearward to the right to counteract this attitude change. (3.4.3, 3.4.4, 3.5.1 and 3.5.2)

(3) During the right rolling motion, the main rotor blades contacted and the tail drive shaft was severed, which resulted in the failure of the tail rotor drive. At the time when the contact noise was recorded, the helicopter had an abnormal attitude with a nose-up pitch angle of 19°, the right bank angle of 108° and the roll rate of the right rolling motion at 100 deg/sec. And at a vertical acceleration of (-) 1.4G, when the collective pitch lever was operated up, the main rotor blades were flapping largely toward the fuselage, contacted with the tail drive shaft, and cut it off. (3.4.4 and 3.5.3)

(4) It is probable that after falling into tail rotor drive failure condition, during the descent, the helicopter flew straight due to the IAS increase, repeatedly rotated to the right due to the deceleration. It is highly probable that at the time of the forced landing, while the helicopter continued to turn to the right, its attitude was being pulled up just before the touchdown and landed in a state of tilting to the right. (3.4.5)

(5) During the descent, the engines were switched to the manual back-up mode and the engine overspeed prevention function activated eight times, but the engines did not shut down until the forced landing. In the sector where the engine output was recovered, it is probable that the descent rate was reduced, leading to guiding to the forced landing site and alleviating the impact at touchdown. (3.5.4)

(6) When the IAS suddenly increased, the captain operated the collective pitch lever and cyclic stick to control the pitch attitude but operated the cyclic stick farther to the right rear, which is the opposite direction of the aircraft attitude. Since this operation was performed while pressing FTR, it is possible that the amount of correction has become excessive. (3.6.1 and 3.6.2)

(7) It was more likely extremely effective from the impact-resistance point of view for the captain to have made a forced landing with the landing gears extended. In addition, it was probably appropriate for the captain to make a forced landing while avoiding landing in a village under a difficult condition of controlling the helicopter after the right rolling motion started and the tail rotor shut down. (3.6.4)

(8) It is probable that the reason that the casualties were limited to injuries was that when the helicopter attempted a forced landing, it made a hard landing while turning to the right, but its attitude was almost horizontal when it touched down, and each part of the aircraft absorbed a large amount of energy, it is most likely that the impact-resistant airframe design worked well. (3.4.6 and 3.6.4)

4.2 Probable Causes

The JTSB concludes that the probable cause of this accident was that as the main rotor blades severed the tail drive shaft and controlling the helicopter became difficult while flying, the helicopter tried a forced landing, but made a hard landing, which resulted in injuries to persons on board and damage to the helicopter.

The reason why the main rotor blades severed the tail drive shaft is most likely because when the helicopter encountered a strong downdraft while flying at a high speed over mountain regions in strong winds, it started a right rolling motion exceeding 360° after the rapid increase airspeed, and the main rotor blades were largely flapping toward the fuselage. In addition, regarding the fact that the helicopter became a right rolling motion, it was probably affected by the captain’s large stick movement when encountering a downdraft.

5. SAFETY ACTIONS

5. 1 Safety Actions Considered Necessary

The following can be considered in order to prevent the recurrence of similar accidents in the same situation as this accident.

(1) Important notes when flying over mountainous regions in strong winds

Although it is difficult to accurately predict the location of strong vertical winds as in this accident, especially when general wind orthogonal to mountainous areas blows, large-amplitude mountain waves are generated and rapid change in horizontal wind velocity is expected to occur. Therefore, it is necessary to constantly monitor the weather conditions outside the aircraft and changes in flight specifications, and to fully consider the flight control capability of the aircraft so as to be able to respond to sudden weather changes, and to select appropriate flight control mode during flight.

When flying with a tailwind, if there is a large difference between airspeed and ground speed, it is necessary for pilots to decelerate in advance above the areas where mountain waves would occur and fly selecting the appropriate altitude and flight route.

(2) Implementation of recurrent trainings using the FFS and others

Pilots need to judge flight objectives and environmental conditions in order to select a proper flight control mode during the flight. In order to fully understand and properly use the flight control modes, it is necessary for them to read carefully the flight manuals and other related documents and learn the differences of flight control by using the FFS and others.

With normal flight training and ground training only, it is difficult to respond quickly and calmly between two pilots in the event of an emergency operation. Therefore, as much as possible, it is desirable to conduct trainings using the FFS and others that are corresponding to each boarding aircraft type and including the coordination of two pilots.

5. 2 Safety Actions Taken after the Accident

5.2.1 Safety Actions Taken by the National Police Agency

(1) Issuance of administrative notice on ensuring aviation safety of police aircraft (February 2020)

a. Ensuring the importance of safe flights

Ensuring that relevant personnel are thoroughly informed about the safe flight of aircraft.

b. Response to turbulence

(a) When flying in airspace where turbulence is expected, check the latest weather information and plan the flight route, altitude and cruising speed appropriately.

(b) When encountering turbulence, try to minimize the effects of turbulence by maintaining appropriate engine power and flight attitude, and such as attempting to leave the airspace as soon as possible.

c. Ensuring the implementation of emergency operation procedures

(a) Endeavour to improve emergency operating capabilities by conducting recurrent trainings on a regular basis, and share awareness among crew members of the risk estimation and response procedures according to the situation.

(b) Carry out operation procedures in accordance with the flight manual without missing the opportunity in the event of an emergency situation, and if the emergency is complex, conduct CRM*38 so that all crew members shall be aware of the situation and the most appropriate response measures shall be taken.

(2) Issuance of a notice regarding the operation of police aircraft (April 2022)

a. Pilot training

Make efforts to understand proficiency of pilots and improve their skills systematically based on the step-by-step training according to the experience and skill of each pilot.

Furthermore, necessary budgetary measures shall be taken for emergency operation simulator training and instrument flight simulator training, and the training shall be

*38 "CRM" stands for Crew Resource Management and refers to the effective use of all available resources: human resources (such as Flight crew members, Cabin attendants, Dispatcher, Maintenance personnel, Air traffic controllers), hardware and information, in order to accomplish safe and high-quality operations.

carried out without fail. (From fiscal 2022, the National Police Agency will start subsidizing the expenses necessary for emergency operation and instrument flight simulator annual trainings conducted by prefectural police)

b. Ensuring the aircraft safety system

Ensure Pilots and mechanics required to operate the aircraft. Police use aircraft shall be operated by two pilots.

c. Ensure that education and training is provided to improve skills so as to properly conduct CRM during flight.

(3) Issuance of Guidelines for Air Service Planning (April 2022)

Based on the Regulations Concerning such as the Operation of Police-Use Aircraft, guidelines for the formulation of the 2022 Air Service Plan have been established, and the promotion of services and operations is required in accordance with the plan. The following instructions are given for the training of pilots using training equipment.

Trainings in foreign countries or such as simulators, shall be actively utilized in order to learn the operation that maximizes the performance of the aircraft, and efforts shall be made to improve the pilots' ability to carry out their duties.

a. Emergency operations procedures (especially training for responding to such as engine failures)

b. Instrument Flight Training

c. Various pilot's operating procedures for specific weather and terrain conditions, such as whiteouts, brownouts and low visibility and low ceiling.

d. Mission rehearsal

5.2.2 Safety Actions Taken by the Fukushima Prefectural Police Headquarters

(1) Safety Measures at the time of flight planning

a. Appropriate operation control

(a) Make use of the meteorological analysis services provided by weather forecasting companies when unusual weather is expected.

(b) Newly create a check sheet for flight planning and report it the supervisor after mutual confirmation among relevant operation personnel.

b. Response to emergency situations

(a) Properly recognize the emergency situation at the time of its occurrence and consider conducting CRM training so that all crewmembers would be able to respond it.

(b) Trainings relating to ordinary emergency responses

(2) Responses after deciding to perform a flight

a. Have a briefing among all crewmembers to share the information by thoroughly understanding necessary matters such as major risk factors and countermeasures.

b. Establish means of communication with ground staff at the time of sudden change of weather conditions and confirm with a weather forecasting company as needed.

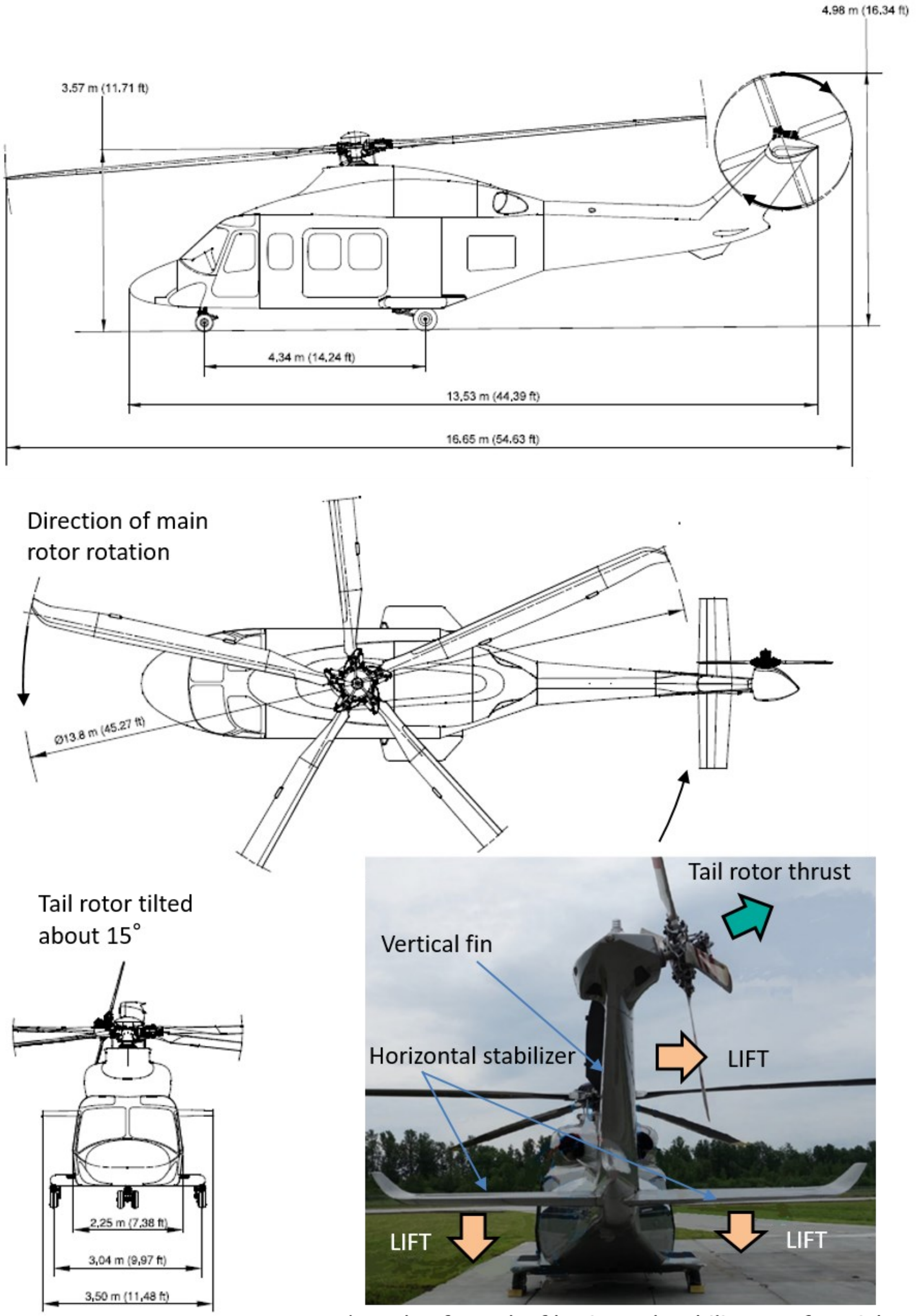
c. Try to unify common awareness among crewmembers by having an in-flight briefing according to the change of duties and weather conditions.

(3) Actions to be taken upon recognition of risk

a. When encountering turbulence, promptly leave the said airspace or try to execute a preventive landing.

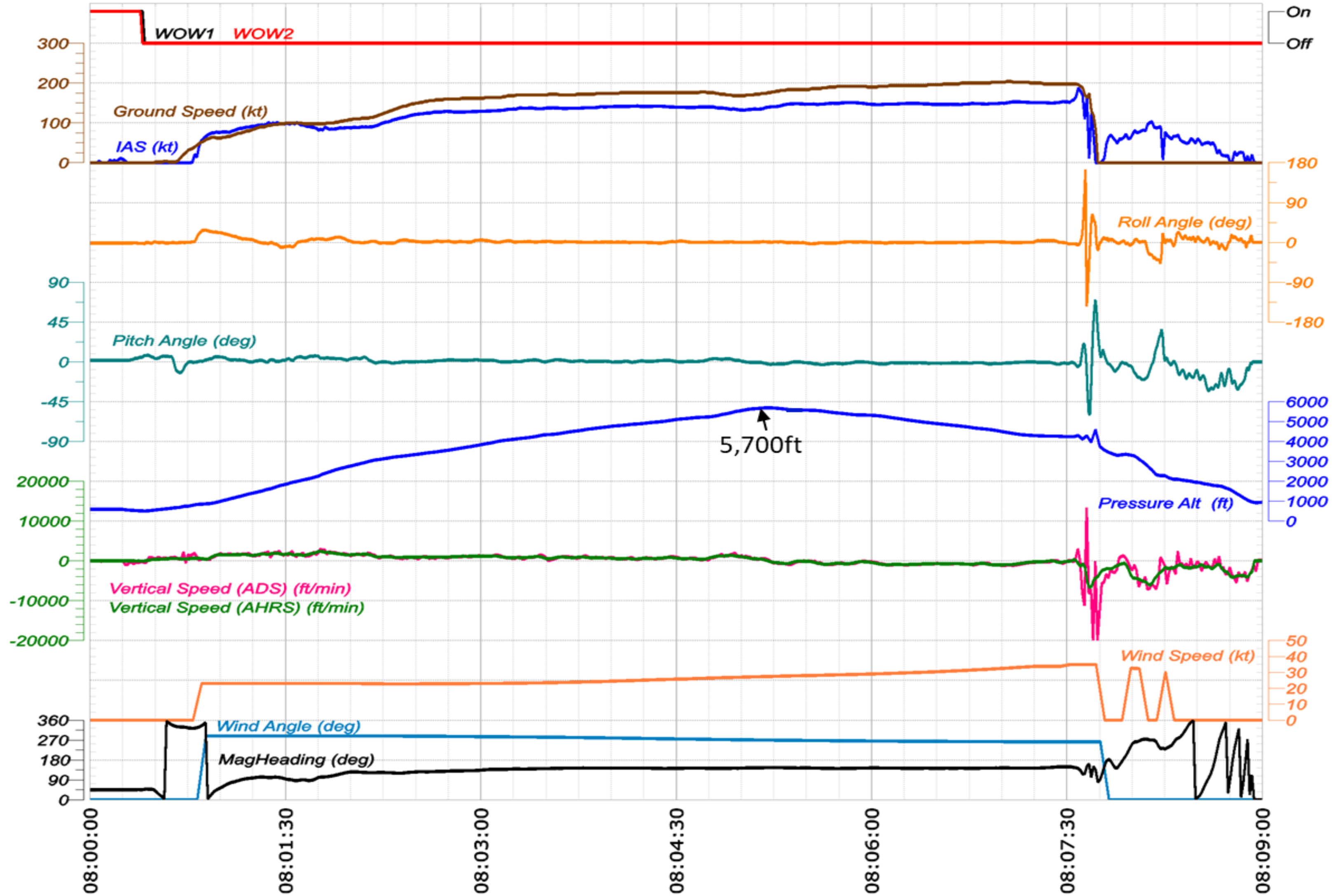
b. Try to improve the emergency operations ability through periodical trainings and conduct recurrent trainings assuming complex emergencies so as to be able to respond to multiple signs of failures.

Appended Figure 1: Three Angle View of Agusta AW 139 and Direction of Force Acting on the Tail

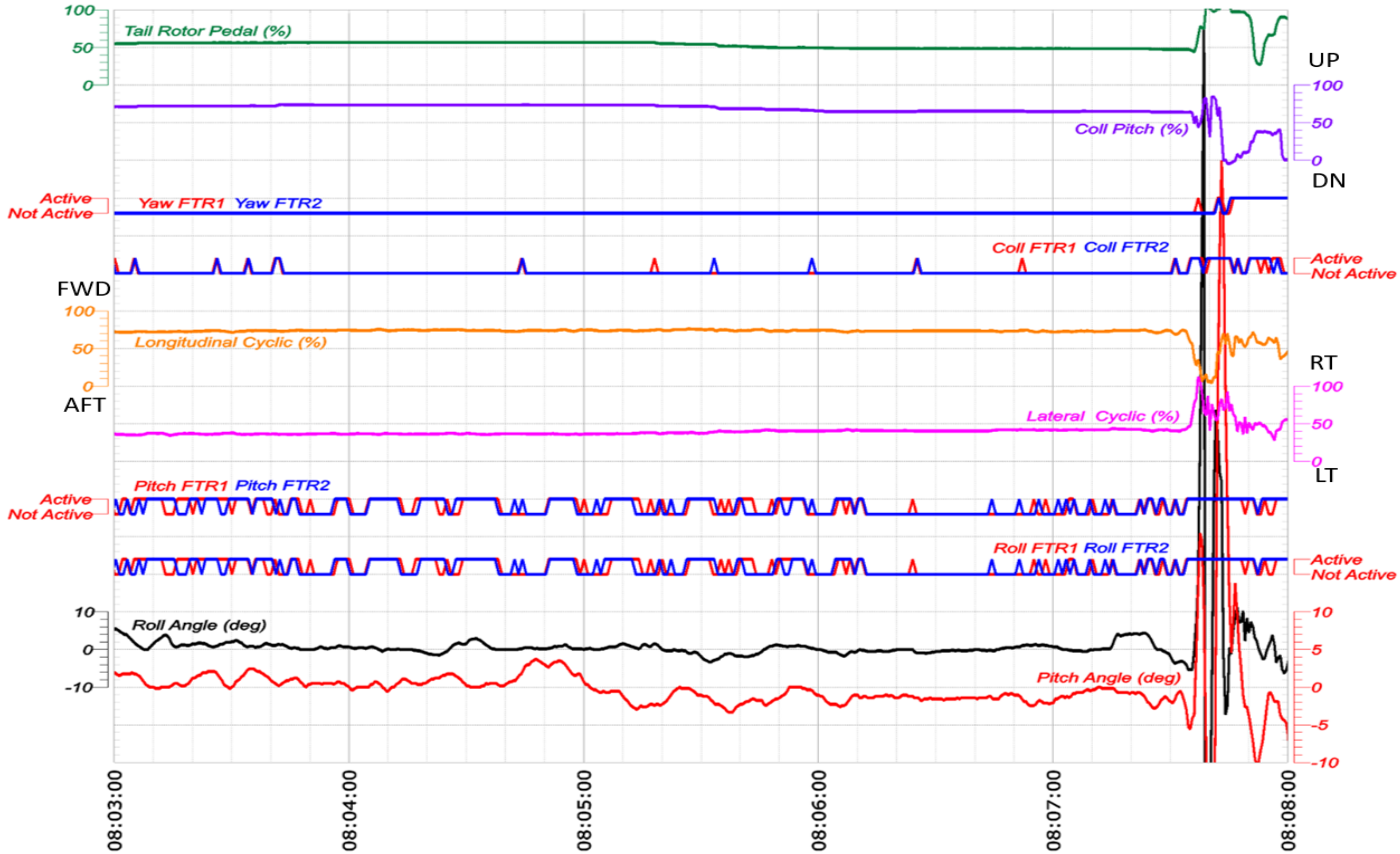


* Angle of attack of horizontal stabilizer. Left < Right

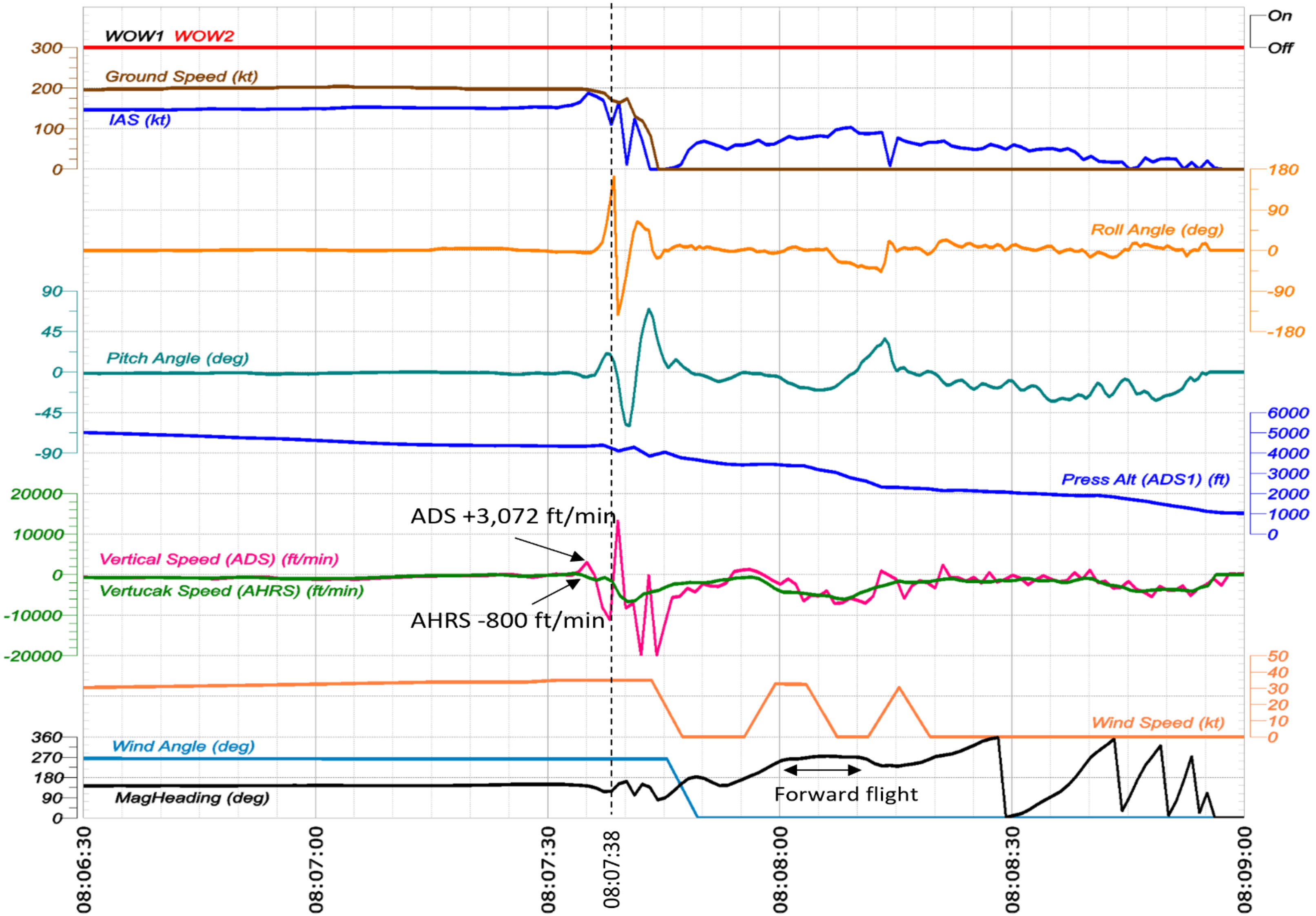
Appended Figure 2: MPFR Analysis after Take-off from Aizu Operation Site - 1



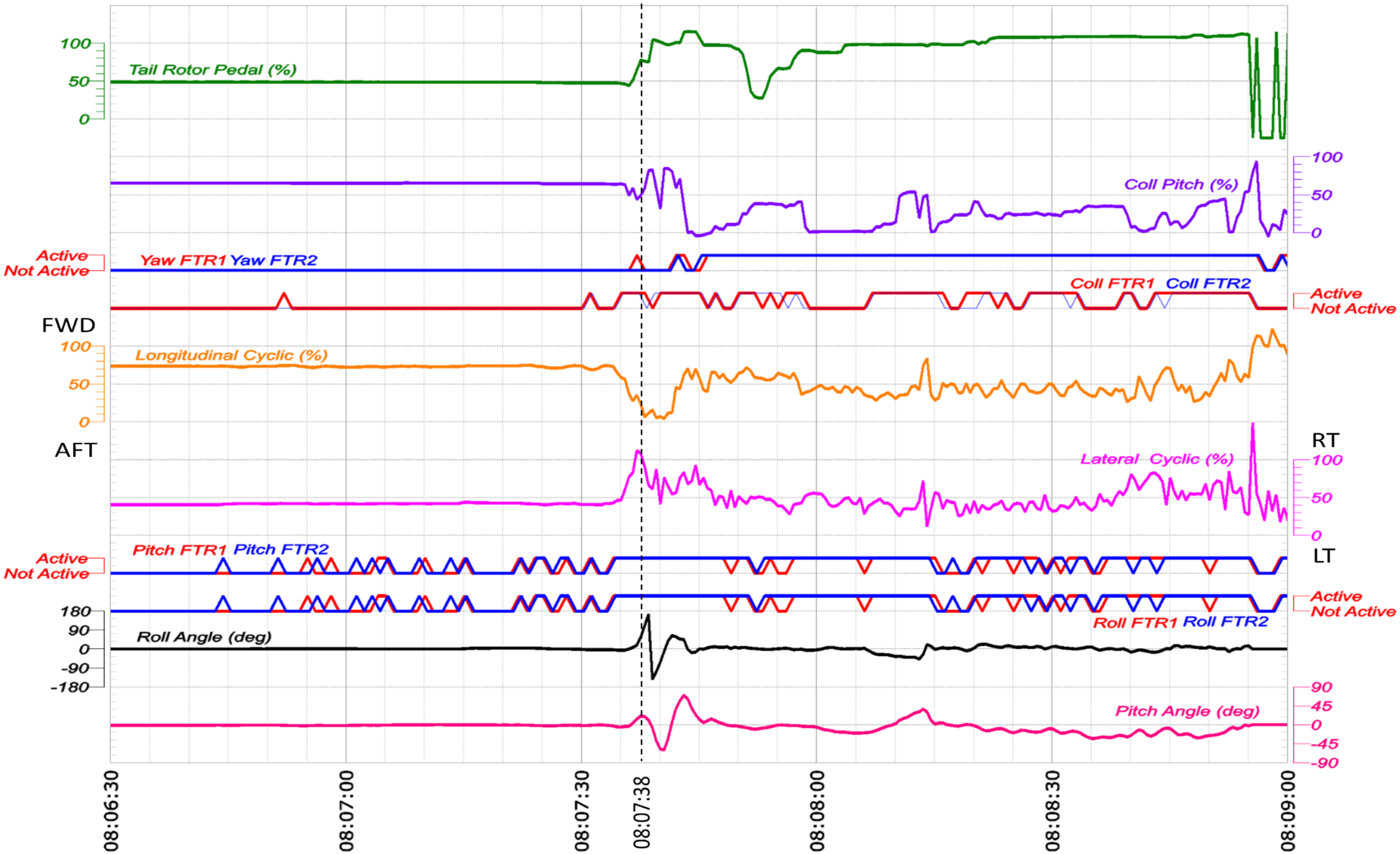
Appended Figure 3: MPFR Analysis after Take-off from Aizu Operation Site - 2



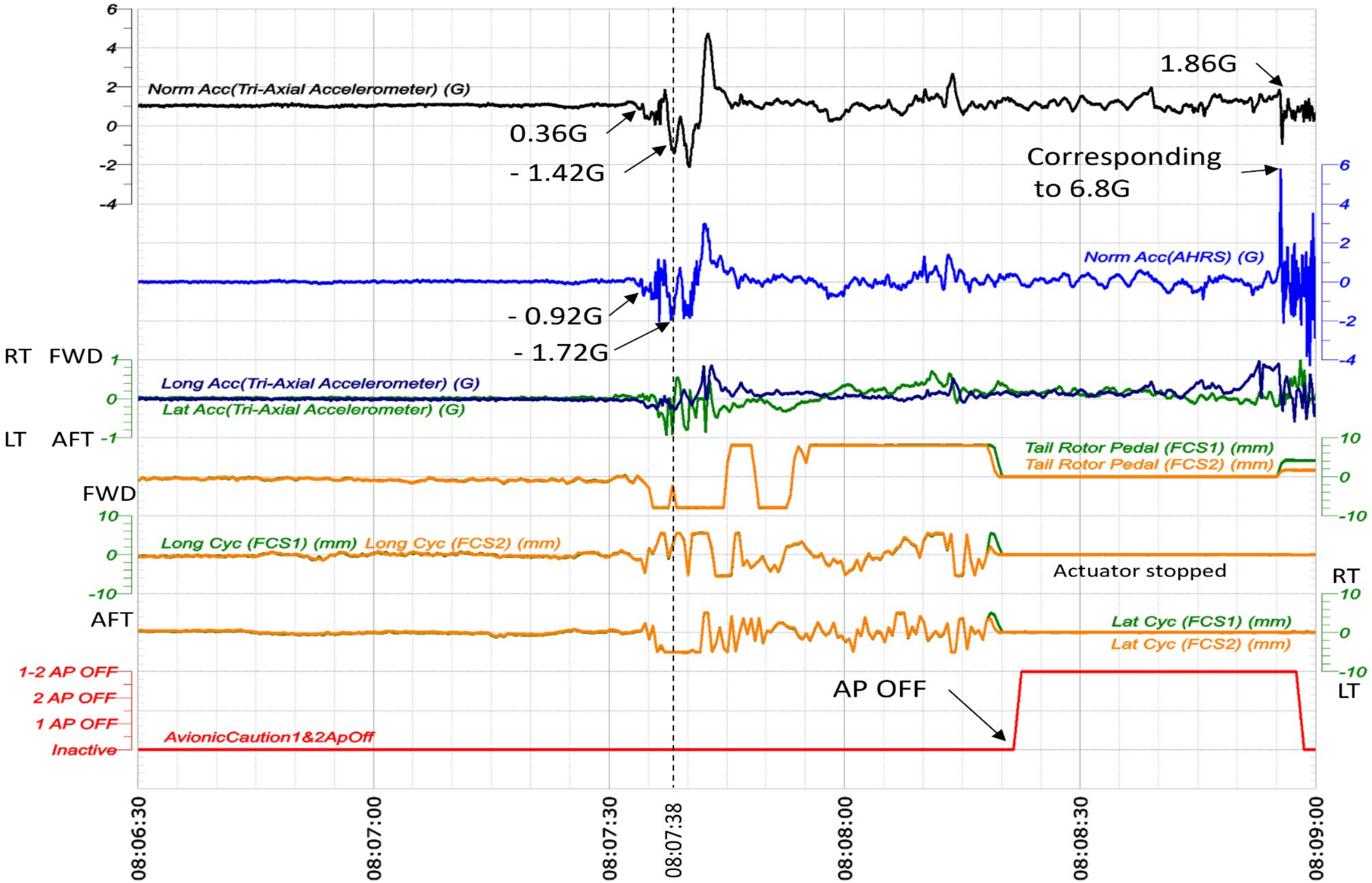
Appended Figure 4: MPFR Analysis before and after right rolling motion - 1



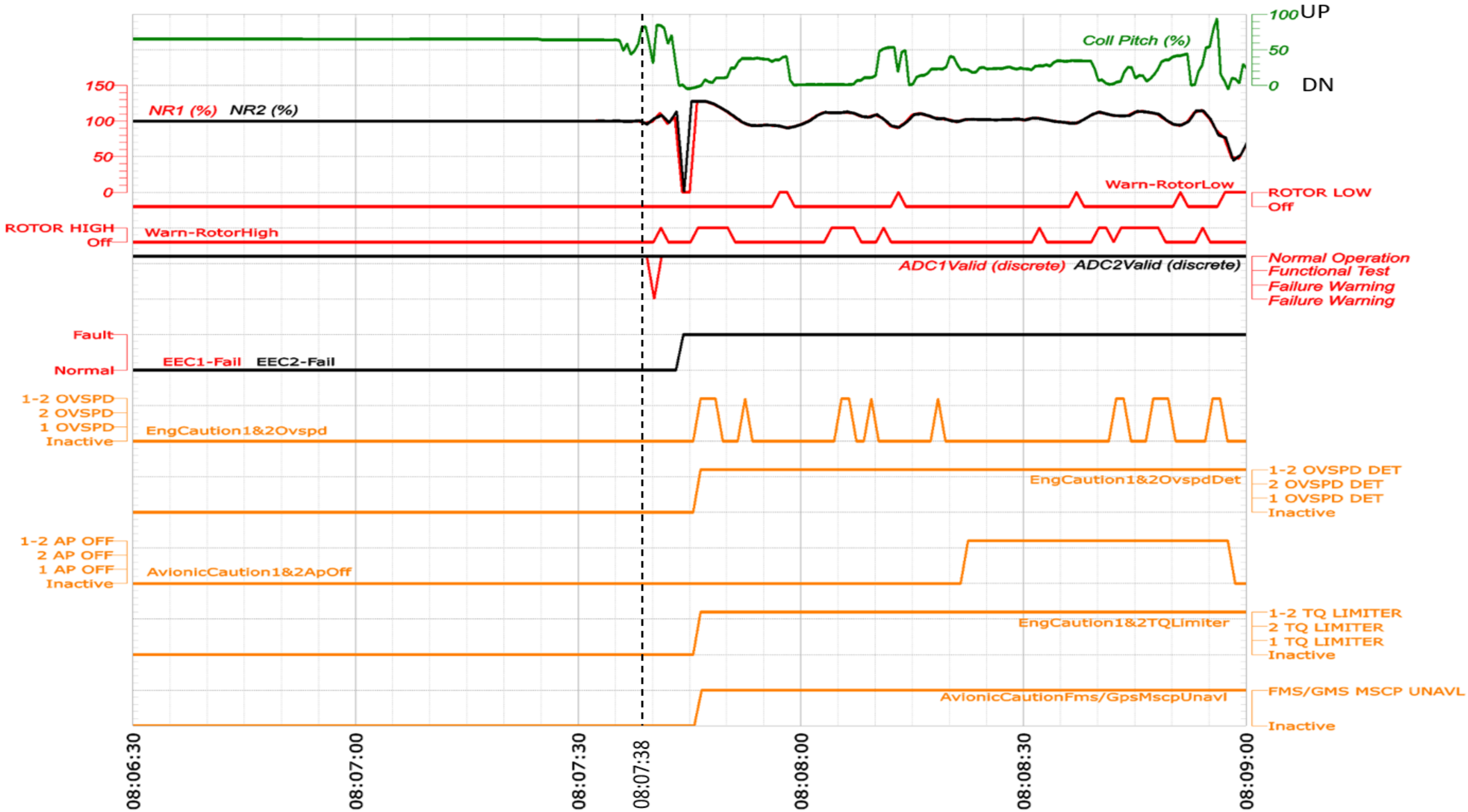
Appended Figure 5: MPFR Analysis before and after right rolling motion - 2



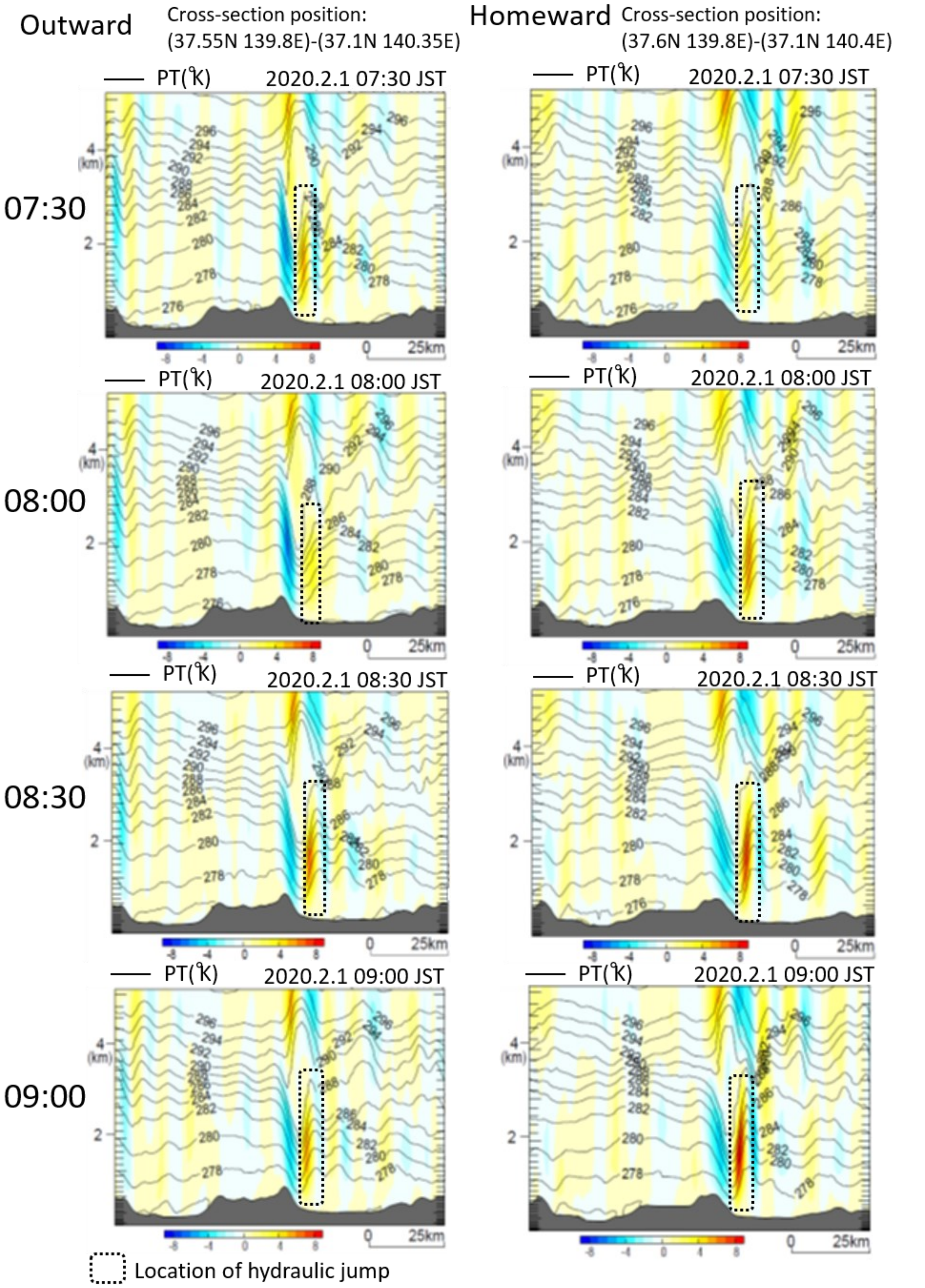
Appended Figure 6: MPFR Analysis before and after right rolling motion - 3



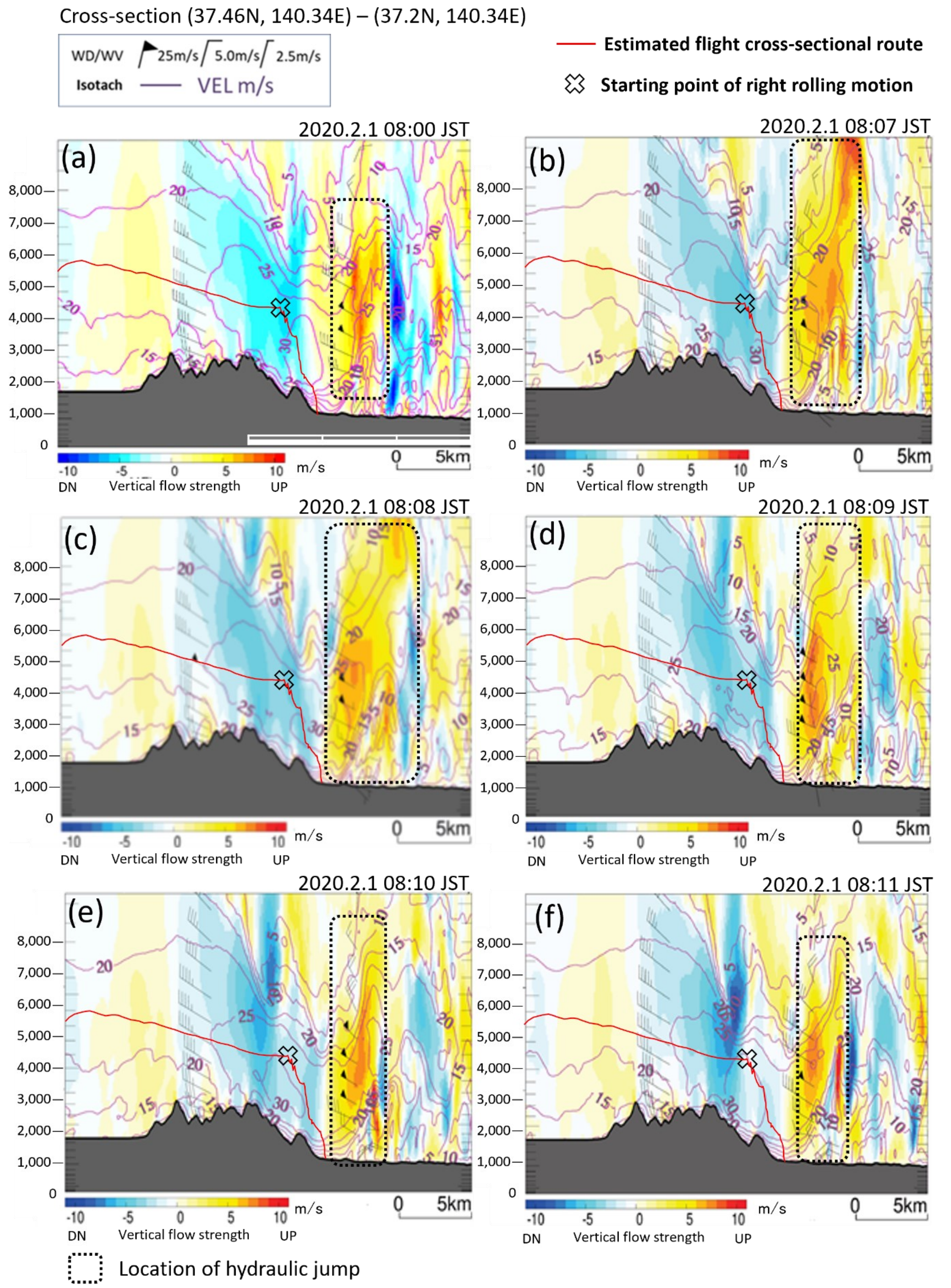
Appended Figure 7: MPFR Analysis before and after right rolling motion - 4



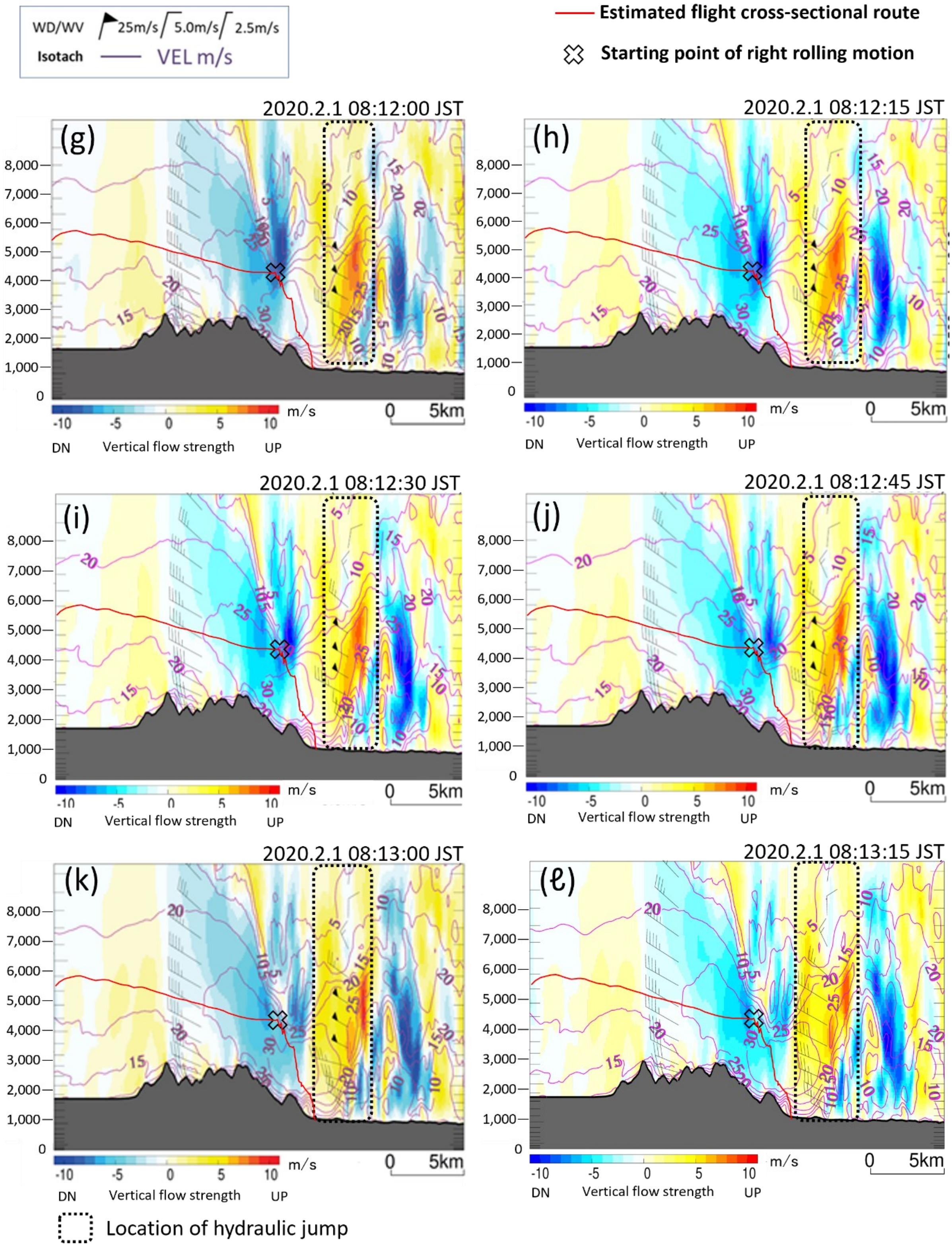
Appended Figure 8: Numerical Analysis A　Analysis with Potential Temperature Line and Vertical Flow　(Resolution 1 km)

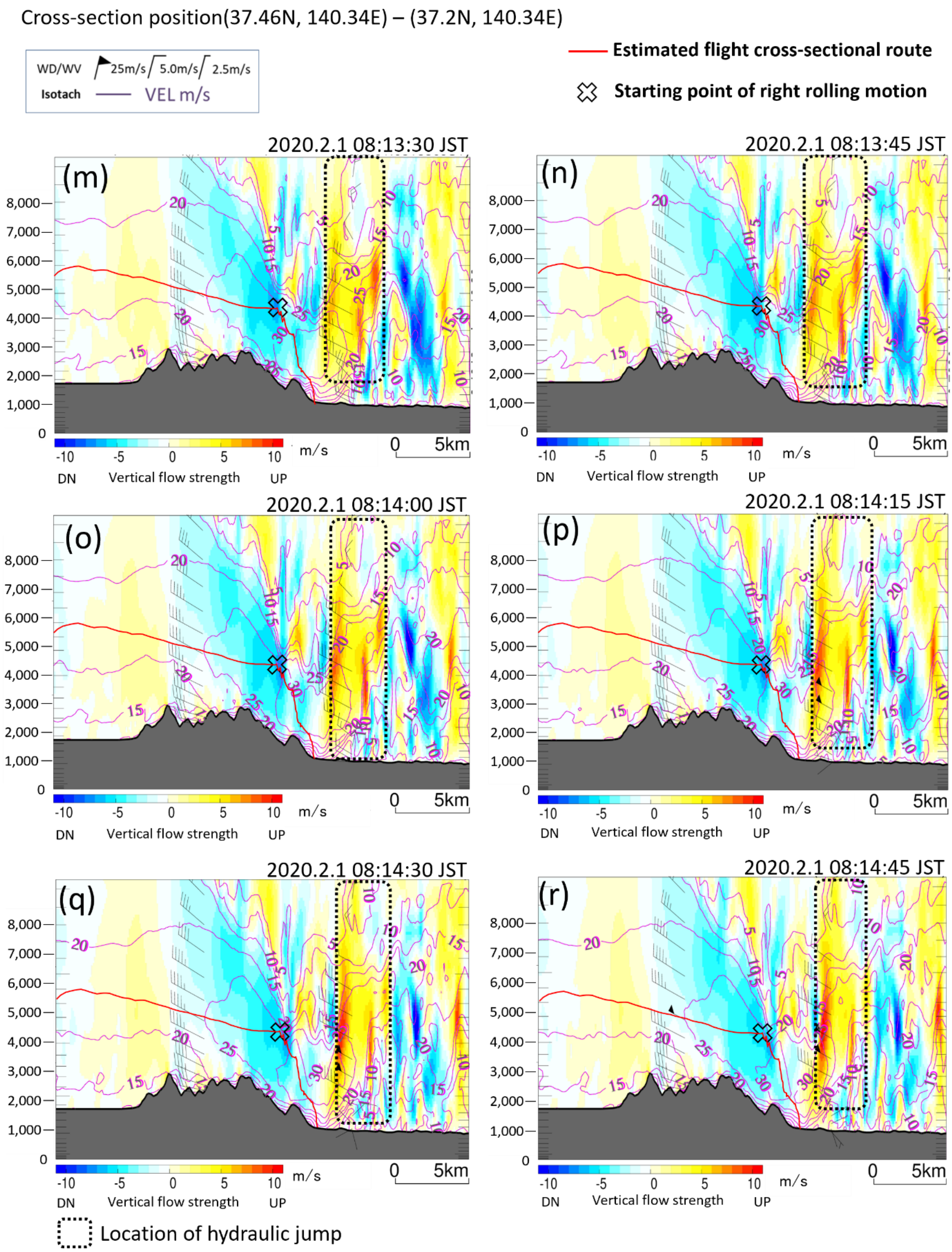


Appended Figure 9: Numerical Analysis B Analysis with Distribution of Horizontal Wind and Vertical Flow (Resolution 100 m)



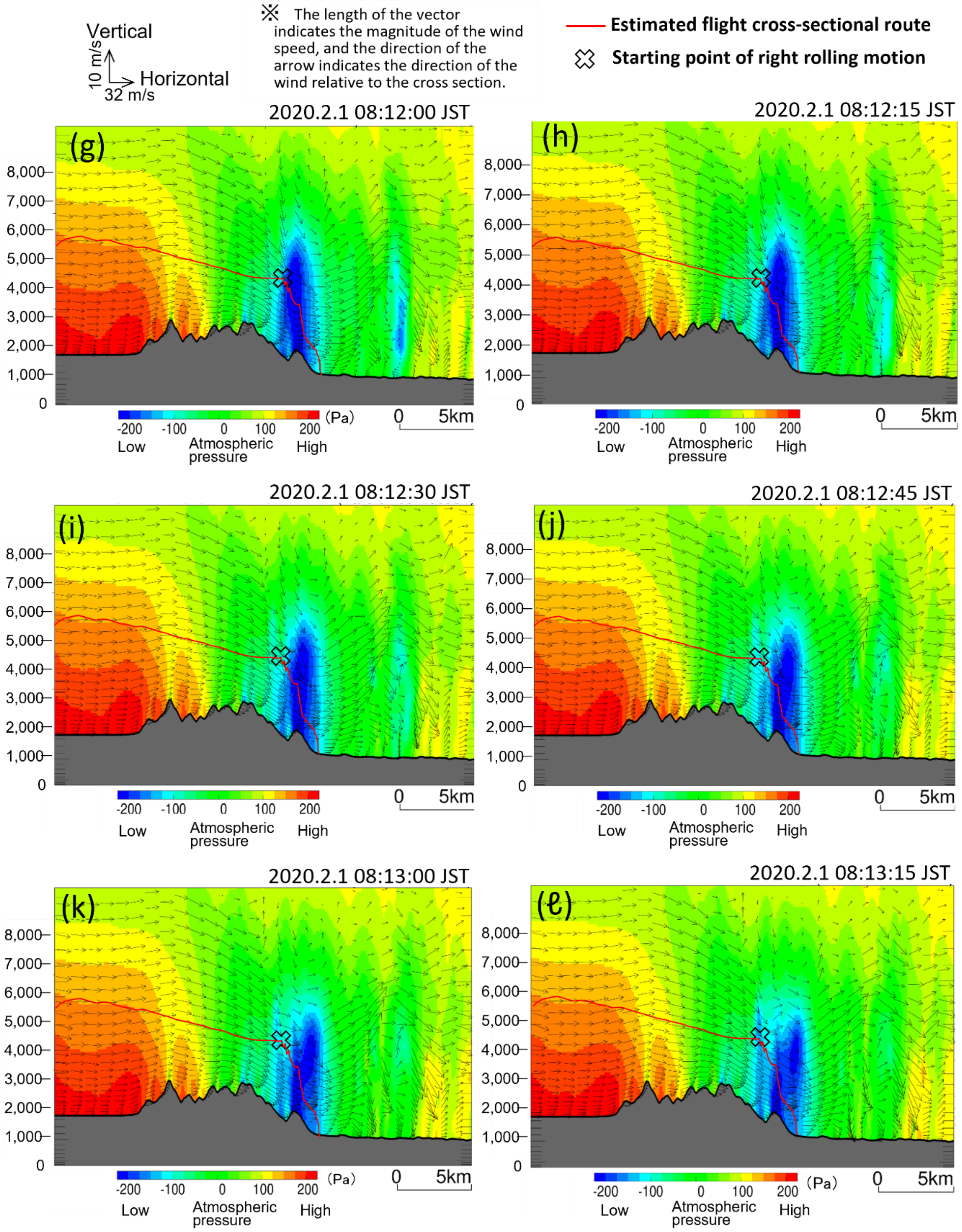
Cross-section position(37.46N, 140.34E) – (37.2N, 140.34E)



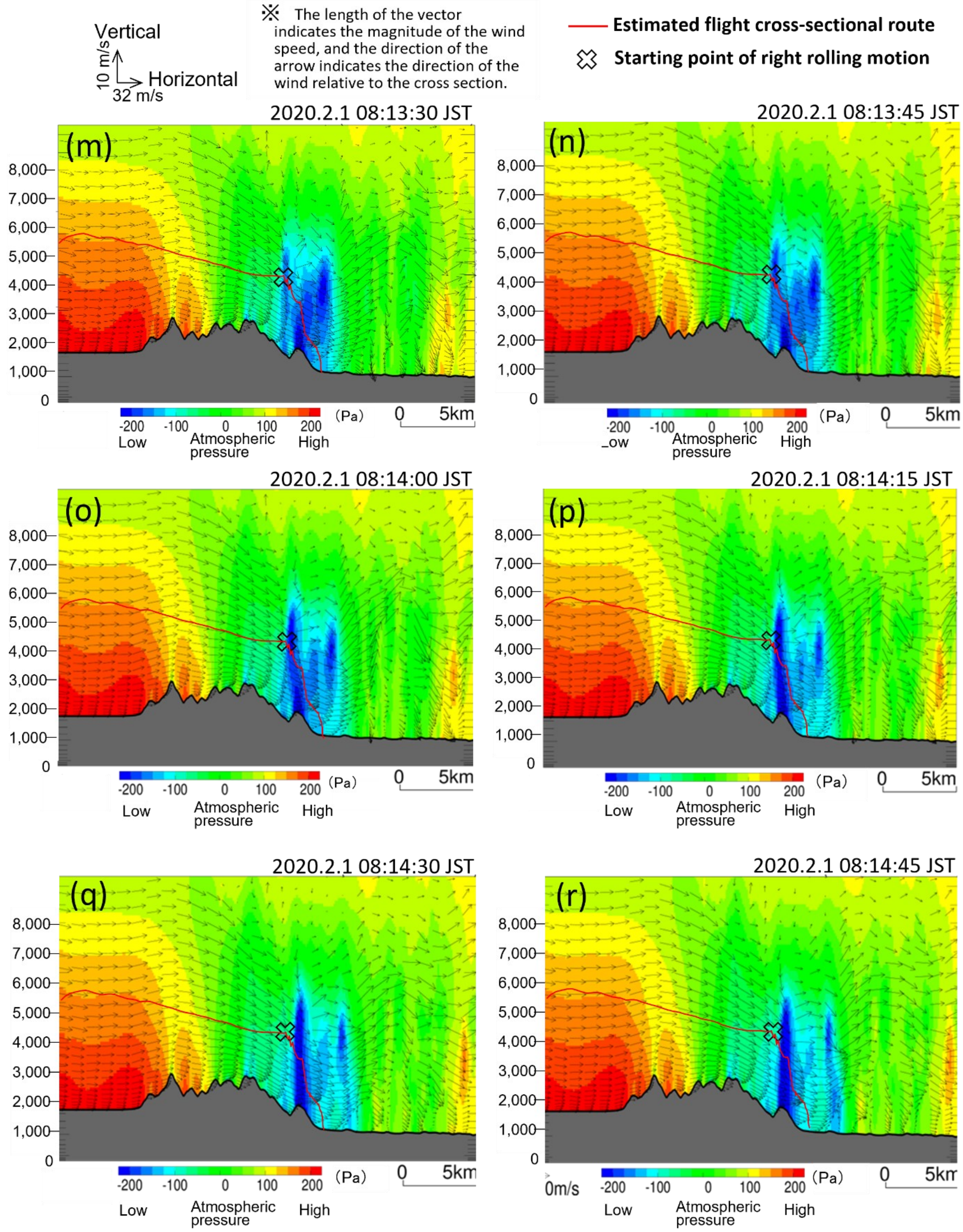

Cross-section position(37.46N, 140.34E) – (37.2N, 140.34E)
WD/WV 25m/s 5.0m/s 2.5m/s
Isotach VEL m/s
Estimated flight cross-sectional route
Starting point of right rolling motion
(m) 2020.2.1 08:13:30 JST
(n) 2020.2.1 08:13:45 JST
(o) 2020.2.1 08:14:00 JST
(p) 2020.2.1 08:14:15 JST
(q) 2020.2.1 08:14:30 JST
(r) 2020.2.1 08:14:45 JST
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-10 -5 0 5 10 m/s
DN Vertical flow strength UP
0 5km
Location of hydraulic jump

Appended Figure 10: Numerical Analysis B Distribution map of wind and Atmospheric pressure deviation along the cross-section (Resolution 100 m)

Cross-section position(37.46N, 140.34E) – (37.2N, 140.34E)



Cross-section position(37.46N, 140.34E) – (37.2N, 140.34E)



Appended Figure 11: MPFR Parameter Table

This table provides descriptions and units for the names of the graphs generated from the MPFR parameters in the report.

No.	Name	Description (English)	Unit
1	Altitude Press	Pressure Altitude	ft
2	AvionicCaution1&2ApOff	Avionic Caution Panel 1&2 Auto Pilot Off	On/Off
3	AvionicCautionFms /GpsMscpUnavl	Avionic Caution_Fms/Gps Unavl	DET/ Inactive
4	Coll FTR1	Collective Pitch Lever Force Trim Release1	On/Off
5	Coll FTR2	Collective Pitch Lever Force Trim Release2	On/Off
6	Coll Pitch	Collective Pitch	%
7	EEC1-Fail	Electronic Engine Control Fail 1	Fault/ Normal
8	EEC2-Fail	Electronic Engine Control Fail 2	Fault/ Normal
9	EngCaution1&2Overspd	Engine Caution 1&2 Over Speed	DET/ Inactive
10	EngCaution1&2TQLimiter	Engine Caution 1&2 Torque Limiter	DET/ Inactive
11	GS	Ground Speed	kt
12	IAS	Indicated Air Speed	kt
13	Lat Acc(Tri)	Lat Acc(Tri-Axial accelerometer)	g
14	Lat Cyc	Lateral Cyclic	%
15	Lat Cyc(FCS1)	Lateral Cyclic(FCS1)	mm
16	Lat Cyc(FCS2)	Lateral Cyclic(FCS2)	mm
17	Long Acc(Tri)	Long Acc(Tri-Axial accelerometer)	g
18	Long Cyc	Longitudinal Cyclic	%
19	Long Cyc(FCS1)	Longitudinal Cyclic(FCS1)	mm
20	Long Cyc(FCS2)	Longitudinal Cyclic(FCS2)	mm
21	Mag Heading	Mag Heading	deg
22	NF1 Backup	Engine 1 Free Turbine Speed	%
23	NG1	Engine 1 Gas Generator Speed	%

24	NG2	Engine 2 Gas Generator Speed	%
25	NR1	Number of Rotor speed 1	%
26	NR2	Number of Rotor speed 2	%
27	Nf2 Backup	Engine 2 Free Turbine Speed	%
28	Norm Acc(AHRS)	Norm Acc(AHRS)	g
29	Norm Acc(Tri)	Norm Acc(Tri-Axial accelerometer)	g
30	PI Left Value	Power Index Left Value	%
31	PI Right Value	Power Index Right Value	%
32	Pitch Angle	Pitch Angle	deg
33	Pitch FTR1	Pitch Force Trim Release1	On/Off
34	Pitch FTR2	Pitch Force Trim Release2	On/Off
35	Roll Angle	Roll Angle	deg
36	Roll FTR1	Roll Force Trim Release1	On/Off
37	Roll FTR2	Roll Force Trim Release2	On/Off
38	TQ1	Engine 1 Torque	%
39	TQ2	Engine 2 Torque	%
40	Tail Rotor Pedal	Tail Rotor Pedal	%
41	Tail Rotor Pedal(FCS1)	Tail Rotor Pedal(FCS1)	mm
42	Tail Rotor Pedal(FCS2)	Tail Rotor Pedal(FCS2)	mm
43	Vertical Speed(ADS)	Vertical Speed(ADS)	ft/min
44	Vertical Speed(AHRS)	Vertical Speed(AHRS)	ft/min
45	WOW	Weight On Wheel	On/Off
46	Warm-Rotor-High	Warm-Rotor-High	%
47	Warm-Rotor-Low	Warm-Rotor-Low	%
48	Wind Angle	Wind Angle	deg
49	Wind Speed	Wind Speed	kt
50	Yaw FTR1	Yaw Force Trim Release1	On/Off
51	Yaw FTR2	Yaw Force Trim Release2	On/Off