AA2023-8

AIRCRAFT ACCIDENT
INVESTIGATION REPORT

PRIVATELY OWNED
J A 7 7 A R

November 30, 2023

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

CRASH

PRIVATELY OWNED ROBINSON R66 (ROTORCRAFT), JA77AR

OJIRO, SHIMADA CITY, SHIZUOKA PREFECTURE

AT ABOUT 15:33 JST, DECEMBER 30, 2020

October 20, 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

1. PROCESS AND PROGRESS OF THE AIRCRAFT ACCIDENT INVESTIGATION

1.1 Summary of the Accident	On December 30 (Wednesday), 2020, a privately owned Robinson R66, JA77AR, took off from Isewan Heliport in Tsu City, Mie Prefecture, and crashed into a mountain forest near Ojiro, Shimada City, Shizuoka Prefecture, while flying toward Hodogaya Imai Temporary Operation Site, Yokohama City, Kanagawa Prefecture. Only a captain was on board the helicopter, and fatally injured in the crash. The helicopter was destroyed, but there was no outbreak of fire.
1.2 Outline of the Accident Investigation	On December 30, 2020, the Japan Transport Safety Board (JTSB), upon receiving information about the occurrence of the accident, designated an investigator-in-charge and an investigator to investigate this accident. An accredited representative and an advisor of the United States of America, as the State of Design and Manufacture of the helicopter involved in this accident participated in the investigation. Comments on the draft Final Report were not invited from the person relevant to the cause of the accident because the pilot was fatally injured in the accident. Comments on the draft Final Report were invited from the Relevant State.

2. FACTUAL INFORMATION

2.1 History of the Flight	According to the helicopter's flight plan, the Engine Monitoring Unit*1, the GPS records as well as the statements of the eyewitnesses, the ATC communications of Hamamatsu Aerodrome of the Ministry of Defense and radar track records , the history of the flight is as outlined below. On December 30, 2020, at about 14:59 Japan Standard Time (JST: UTC + 9hrs, unless otherwise stated all times are indicated in JST on a 24-hour clock), after refueling at Isewan Heliport in Tsu City (hereinafter referred to as "Isewan HP"), with only the captain sitting in the right pilot seat, the helicopter took off from Isewan HP for its ferry flight, heading toward Hodogaya Imai Temporary Operation Site (hereinafter referred to as "Hodogaya Operation Site"). (See Figure 1) (1) Summary of the Flight 14:59 Taking off from Isewan HP, the helicopter headed for Hodogaya Operation Site. (Estimated time of landing at Hodogaya Operation Site: 16:30) 15:16 The helicopter established communication with Hamamatsu Aerodrome of the Ministry of Defense Terminal Control Facility (hereinafter referred to as "Hamamatsu Radar") and started to fly according to a radar advisory *2. 15:22 The helicopter passed about 11 km south of Hamamatsu Aerodrome at an altitude of about 1,500 ft and at a ground speed of about 130 kt, and then turned to northeast. 15:29 The radar advisory by Hamamatsu Radar was terminated. About 15:31:10 When the helicopter was flying about 11 km of northwest of Shizuoka Airport at an altitude of 1,900 ft and at a ground speed of about 120 kt, its attitude became unstable. About 15:32:55 After rolling right and left, the helicopter crashed into a mountain forest with its nose down while turning to the right, as shown in Figure 2. (2) Statements of the Eyewitnesses a. Eyewitness A The eyewitness A visibly recognized the helicopter at about 500 m southwest of the crash point. The helicopter was tilted to the right while swinging its tail right and left, and then largely tilted to the left, after that, it descended in a steep angle while turning left, flew northeast and disappeared. b. Eyewitness B The eyewitness B visually recognized the helicopter at about 260 m northwest of the crash point. The eyewitness B heard a loud roaring sound

*1 The "Engine Monitoring Unit", commonly referred to as EMU, is a device that records time, engine gas generator (compressor) speed (N1), engine output shaft speed (N2), engine torque, and Measured Gas Temperature (within the turbine section) (MGT).
*2 "Radar advisory" means providing of radar vector and traffic information from air traffic control facilities based on requests from aircraft flying under visual flight rules.

from the mountains, and then the helicopter came flying low from the south, and it was flying east with its nose down largely while turning right, and disappeared.

c. Eyewitness C

The eyewitness C visually noticed the helicopter at about 100 m northwest of the crash point. The helicopter was flying at low altitude with its nose down largely while tilting to the right, heading toward the mountains in the southeast.

d. Eyewitness D

The eyewitness D was sitting in a chair outside the eyewitness D's house about 100 m east of the crash point. The eyewitness D did not see the helicopter but heard a loud banging sound, and then flying fragments of the yellow metalic parts fell beside the eyewitness D's house.

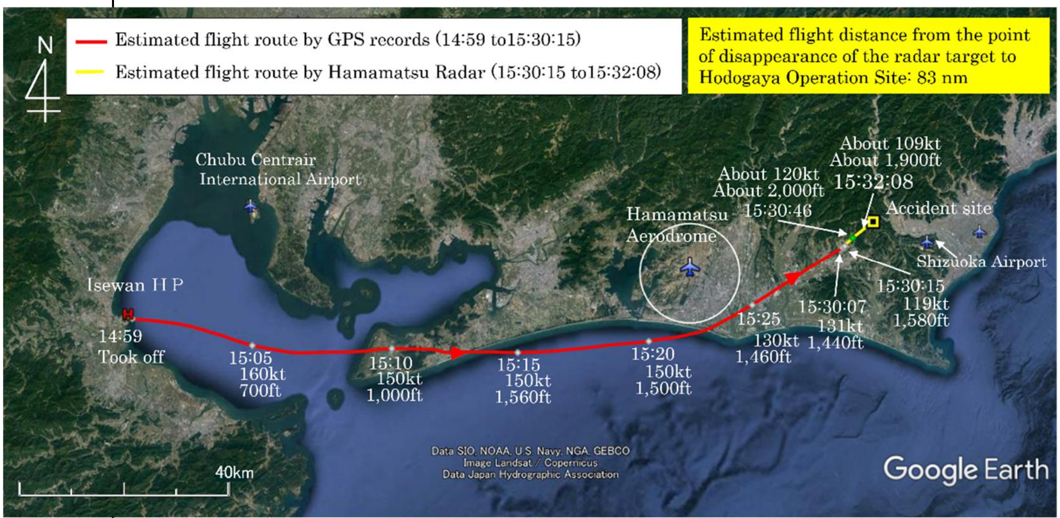


Figure 1: Estimated Flight Route of the Helicopter

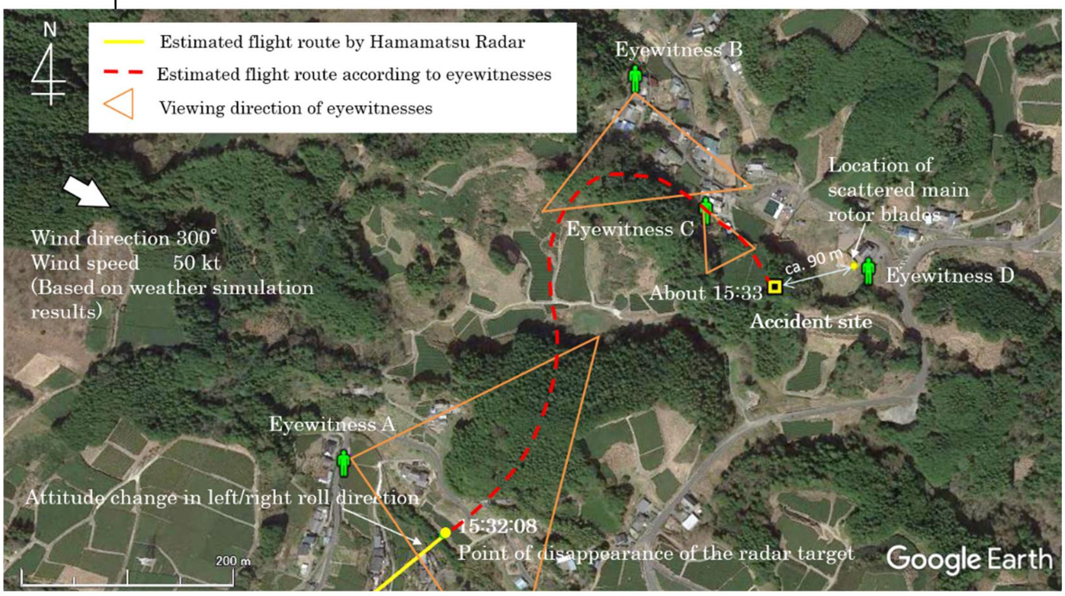


Figure 2: The Helicopter's Estimated Flight Route Immediately before the Crash

This accident occurred at about 15:33, on December 30, 2020, in a mountain forest around 11 km (Latitude 34°50'36" N and Longitude 138°04' 51" E) west-northwest of Shizuoka Airport.

2.2 Injuries to Persons	Captain: fatally injured
2.3 Damage to the Aircraft	Extent of Damage: Destroyed Fuselage: Cockpit and cabin destroyed Aft fuselage deformed Upper part of main rotor drive shaft deformed, main rotor hub*3 dented, and teeter stops*4 deformed Tail cone: Deformed, and broken at the forward horizontal stabilizer Main rotor blades: Deformed, broken and scattered Tail rotor blades: Damaged Landing gears (skid): Damaged and broken

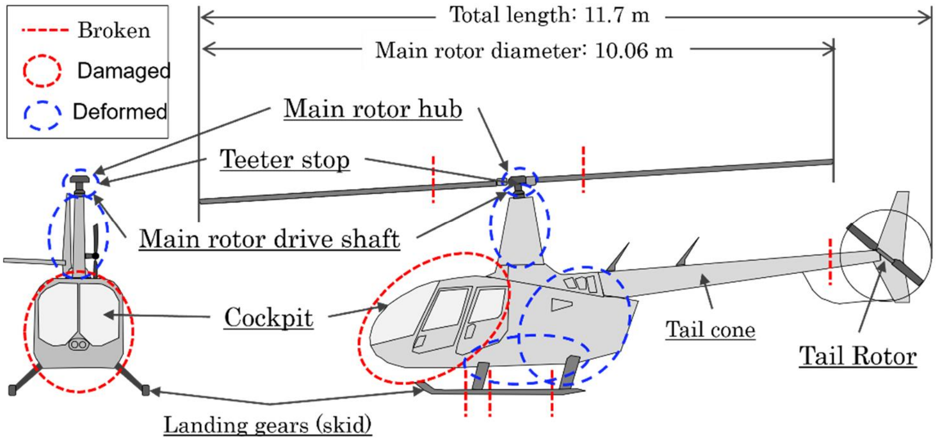


Figure 3: The Helicopter Size and Damaged Locations

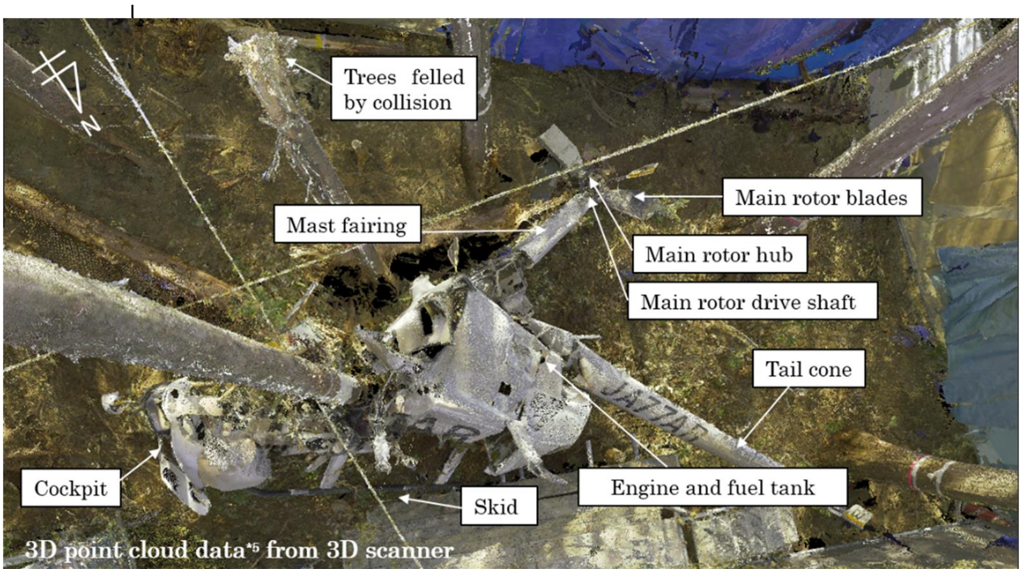


Figure 4: 3D Image of the Helicopter Damage

*3 The "main rotor hub" is the component that connects the main rotor blades to the main rotor drive shaft.
*4 The "teeter stop" is the component that buffers the impact of the contact between the main rotor blade spindle and the main rotor drive shaft when the main rotor blade spindle moves like a seesaw.
*5 The "3D point cloud data" means a representation of a large number of point data having three-dimensional coordinates representing landforms, features, etc. and attribute data representing the contents thereof in a form that allows calculation processing. Created by laser surveying and photogrammetry using drones.

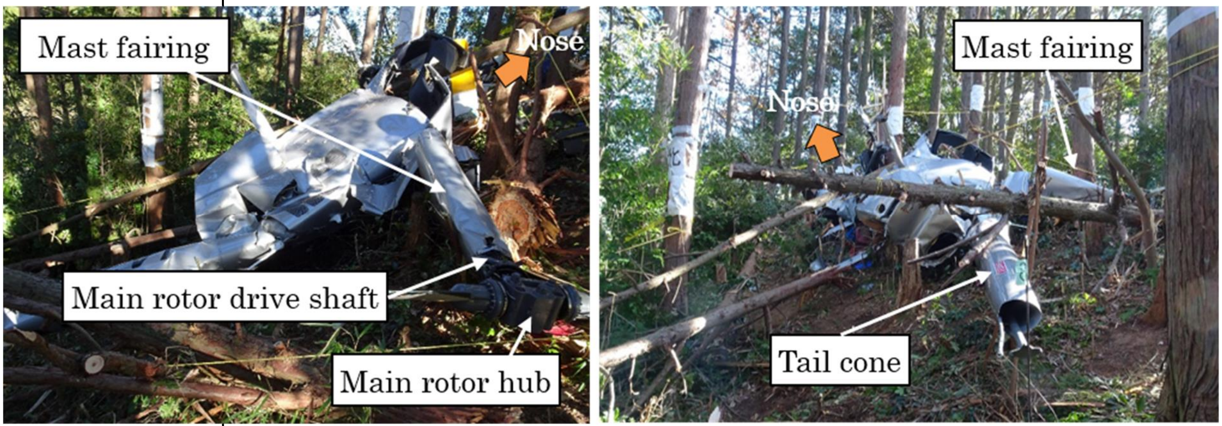


Figure 5: Damaged Helicopter in the Accident Site

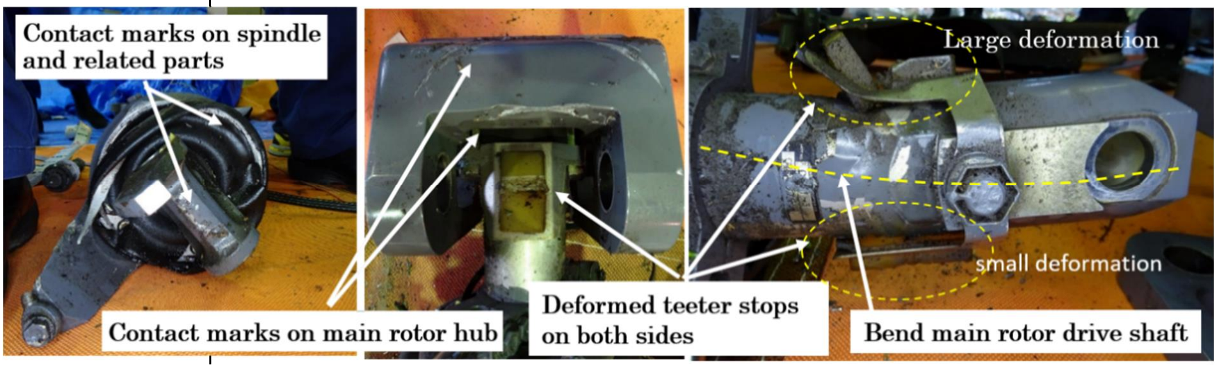


Figure 6: Contact Marks on Spindle, Main Rotor Hub, Teeter Stop and Main Rotor Drive

2.4 Personnel Information	Captain: Age 46 Commercial pilot certificate (Rotorcraft) July 24,2000 Specific pilot competence Expiry of practicable period for flight March 17, 2021 Type rating for single-piston engine (Land) July 24, 2000 Type rating for single-engine turbine (Land) August 15, 2002 Class 1 aviation medical certificate Validity date: May 15, 2021 Total flight time (including glider and fixed wing aircraft) 3,340 hours 54 minutes Flight time in the last 30 days 32 hours 37 minutes Flight time on the same type of aircraft 63 hours 52 minutes Flight time in the last 30 days 21 hours 57 minutes Total flight time on Robinson R22, R44 and R66 204 hours 03 minutes
2.5 Aircraft Information	Aircraft type: Robinson R66 Serial number: 0756; Date of manufacture: February 1, 2017 Certificate of airworthiness: No. Dai-2020-267; Validity date: August 13, 2021 When the accident occurred, the helicopter's weight is estimated to have been 1,947 lb, and the center of gravity (CG) was estimated to have been at 102.0 in. It is highly probable that both the weight and the CG were estimated to have been within the allowable range (maximum take-off weight: 2,700 lb; the CG range that corresponds to the weight at the time of the accident: 91 to 102.5 in).

2.6 Meteorological Information

(1) General Weather Conditions

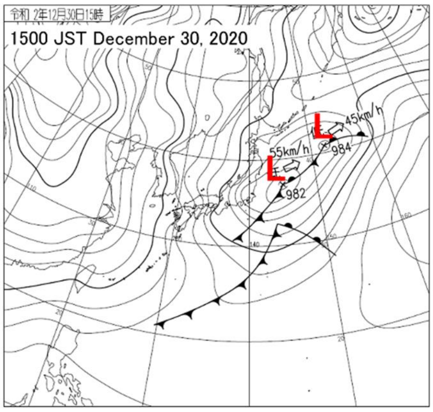


Figure 7: Surface Analysis Chart 15:00 JST December 30, 2020

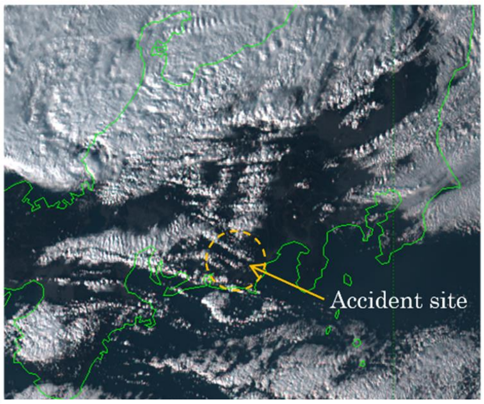


Figure 8: Meteorological Satellite Imagery (Visible) 15:00 JST December 30, 2020

According to the Japan Meteorological Agency, a weather outlook for the Tokai region on the day of the accident was as follows:

As of 15:00, a low-pressure system is developing over the sea of the east, Japan, while there is a high-pressure system prevailing over the Continent, and areas around Japan has been becoming in a winter pressure pattern with high pressure in the west and low in the east. In the Tokai regions, there is a westerly wind blowing in rounding around the south of the Japan Alps, resulting in cloud streak extending from northwest to southeast, as shown in the meteorological satellite image (visible).

(2) Aeronautical weather observations around the time of the accident for Shizuoka Airport located about 11 km east-southeast of the crash site and wind direction, wind velocity and temperature values observed on the day at the Airport observation station were as follows:

15:00 Wind direction 260°; Wind velocity 26 kt;
Maximum instantaneous wind velocity 39 kt;
Prevailing visibility 10 km or more
Cloud: Amount 1/8, Type Cumulus, Cloud base 2,500 ft
Temperature 12℃; Dew point 0℃;
Altimeter setting (QNH) 29.25 inHg;

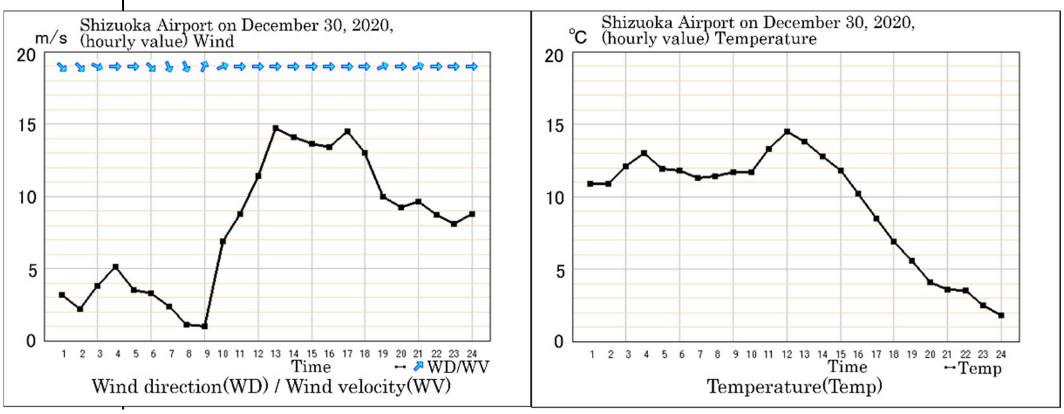


Figure 9: Wind Direction/Velocity and Temperature Observed on December 30, 2020 Observed at Shizuoka Airport Observation Station

(3) The Time of Sunset near the Destination on the Day of the Accident

Location: Imai-Cho, Hodogaya-Ku, Yokohama City, Kanagawa Prefecture

Sunset time: 16:38

2.7 Accident Site

(1) Situation around the Accident Site

To the north of the accident site lies the mountain region in northern Shizuoka Prefecture, and there is Mt. Awagatake, with an elevation of 532 m (1,745 ft), 1.2 km west of the accident site. The accident site was a small hill with cedar trees about 30 meters high. As shown in 3D point cloud data of Figure 10, in the mountain forest, there was the opening space which indicated about the same length as the main rotor with a diameter of about 10 m and the fuselage with the overall length of about 12 m. And contact marks were left on the trees at the opening space.

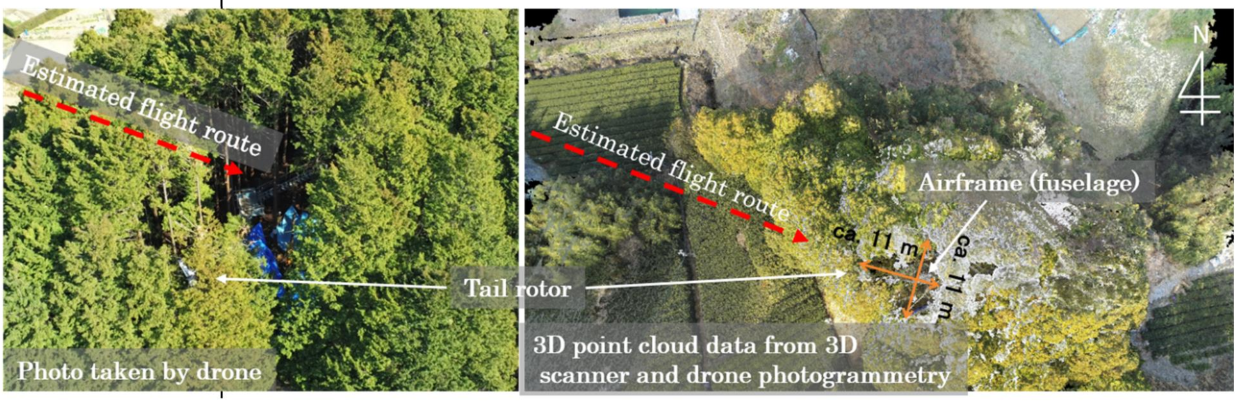


Figure 10: Size of the opening Space in the Mountain Forest at the Accident Site

(2) The Helicopter's Estimated Angle of Approach to the Accident Site

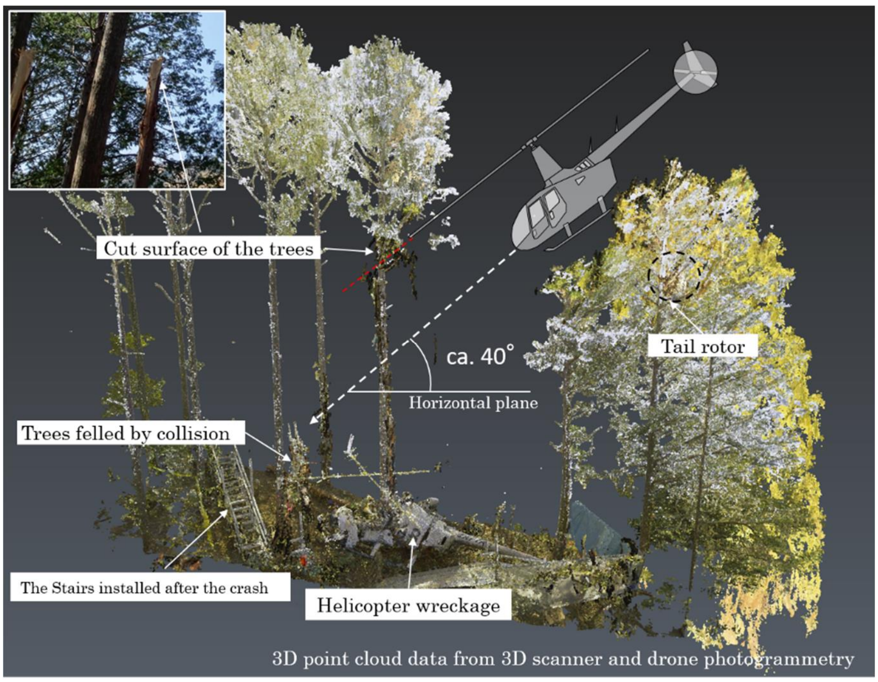


Figure 11: Estimated Approach Angle at the Time of the Crash

The tail rotor was left on the top of the trees. Both the angle the cut surface of the trees and the opening space, which was created because the helicopter had cut the trees, was about 40°. In addition, the Emergency Locator

Transmitter (ELT), which was installed in the frame of the aft fuselage, was operating due to the impact at the time of the crash (Threshold value 6 to 8 G).

2.8 Additional Information

(1) Information about GPS Device

The helicopter was equipped with a GPS device, which recorded the position information from the take-off from Isewan HP to 15:30:15 when it was three minutes before the crash, however, the position information at the time of crash was not recorded due to the damage by the crash.

(2) Emergence of Roll-shaped Thermal Convection

Under strong winds, when the temperature near the ground surface increases as heated by the sunlight, a roll-shaped thermal convection with spiral wind is generated, as shown in Figure 12. The characteristics of the winds created by heat convection are that the horizontal wind speed is weak in updrafts, and strong in downdrafts, however, the wind speed decreases at night when the temperature drops. And as shown in Figure 9, at Shizuoka Airport, the wind speed decreased from 18:00 after sunset. Additionally, in a mountain region, turbulence is more likely to further occur due to the influence of topography.

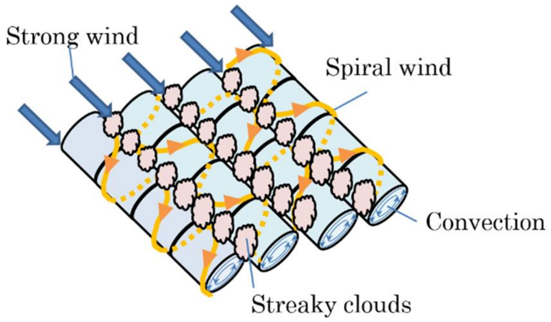


Figure 12: Roll-shaped Thermal Convection

(3) Engine Monitoring Unit (EMU) Recording of Condition just before the Crash (See Figure 13)

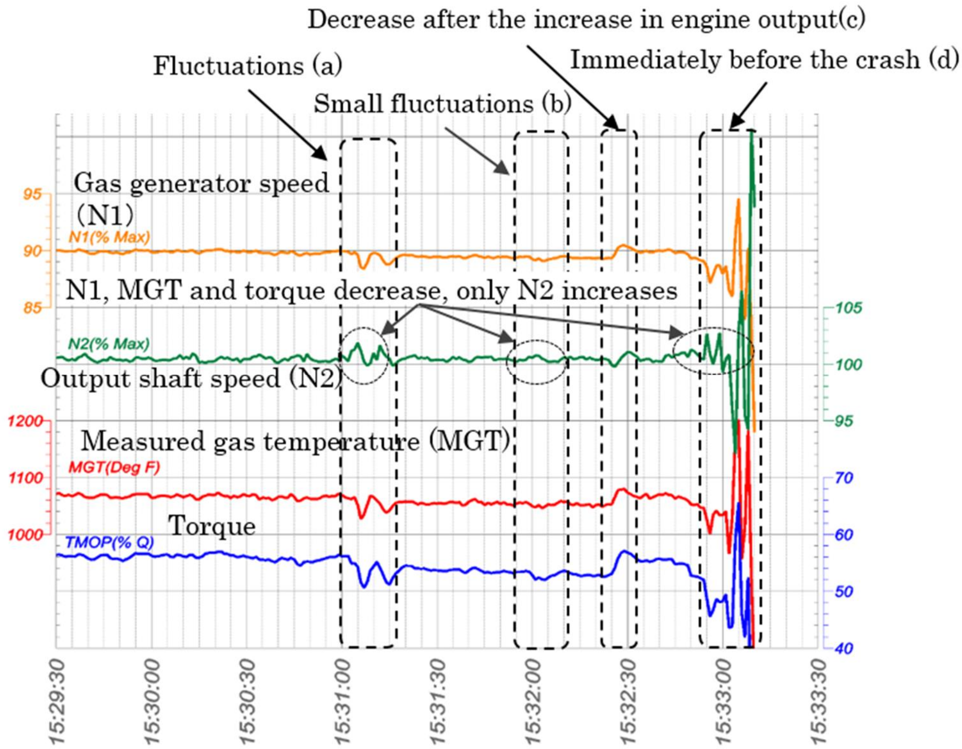


Figure 13: Engine Monitoring Unit (EMU) Recording of Condition just before the Crash

As shown in Figure 1, the helicopter climbed from an altitude of about 1,400 ft up to about 2,000 ft between 15:30:07 and 15:30:46. The Engine Monitoring Unit (EMU), recorded the fluctuations (a) in which the power significantly fluctuated up and down around 15:31:10 after the climb. The record showed that around 15:32:00, there were slight torque fluctuations (b), and the power increase from 15:32:25 to 15:32:30. In addition, the record showed that from 15:32:30 to 15:32:35, the power decreased (c), became almost stable for 20 seconds, and then significantly changed (d) between 15:32:50 and the crash. Especially, in the fluctuations (a), (b) and (d), N1, MGT and the torque decreased, only N2 increased.

(4) Mast Bumping

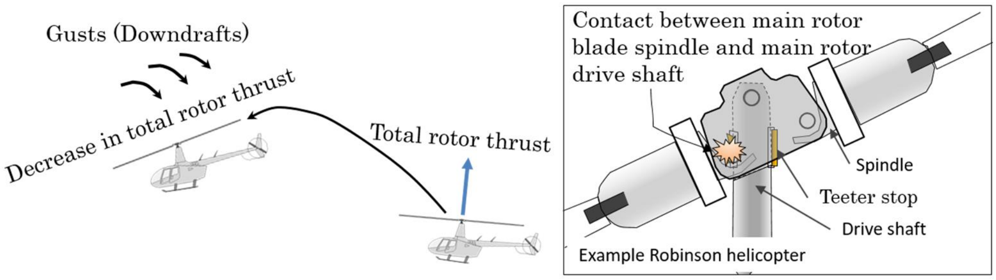


Figure 14: Mast Bumping

Mast bumping is a phenomenon where the main rotor blade spindle (or hub for Bell Helicopter type) strongly contacts or bumps the main rotor drive shaft, when a helicopter (usually often for two-bladed helicopter) having semi-rigid rotor systems*6 enters a low-G condition out of the normal condition of 1G and the attitude is not properly controlled. The excessive flapping may result in the damage to the main rotor drive shaft and the control system, making it difficult to control. Besides, as a characteristic of the occurrence of the mast bumping occurs during flight, contact marks are often left on both sides of the main rotor shaft.

Conditions that are likely to cause a mast bumping

- Improper reaction to right roll during a Low G condition
  (When viewed from above, main rotor rotates counterclockwise)
- Steep-angle descent
- Weight and balance not within the allowable range
- Forward cyclic stick at high speed
- Gusts
- Low main rotor RPM
- Take-off and Landing on a slope

In order to prevent mast bumping during Low G conditions, Section 2 Limitations in the Rotorcraft Flight Manual for Robinson R66 stipulates as follows:

*6 "Semi-rigid rotor type" refers to a rotor system in which the blades are fixed to the hub, but flapping and feathering are flexible, there are such as teeter ring type and under sling (seesaw) type.

FLIGHT AND MANEUVER LIMITATIONS

Low-G cyclic pushovers prohibited.

CAUTION

A pushover (forward cyclic maneuver) performed from level flight or following a pull-up causes a low-G (near weightless) condition which can result in catastrophic loss of lateral control. To eliminate a low-G condition, immediately apply gentle aft cyclic. Should a right roll commence during a low-G condition, apply gentle aft cyclic to reload rotor before applying lateral cyclic to stop roll.

(5) Recommended airspeed

Regarding the recommended airspeed, and the flight method in turbulence, Section 4 Normal Procedures in the Rotorcraft Flight Manual for Robinson R66 stipulates as follows:

Recommended airspeed Maximum Cruise 110 KIAS[*7]

CAUTION

Do not exceed 110 KIAS except in smooth air and then only with caution. In turbulence, use lower airspeed. If turbulence is significant or becomes uncomfortable for the pilot, use 60 to 70 KIAS.

(6) Night Facility for the Helicopter's parking at Hodogaya Operation Site

In the helicopter's parking at Hodogaya Operation Site, there was no night facility. In order to move to the helicopter's parking and perform post-flight tasks after the landing, it was necessary that the helicopter should land before the sunset.

(7) Captain's work schedule for the next day

According to the statement of the captain's family, when the captain went to work, there was no particular anomaly. The captain would inform to the family about his holidays of no duties in advance, but the family did not know that it was a holiday on the next day of the accident.

(8) Operation Management for the Helicopter

The helicopter was registered owned by co-owners consisted of 40 organizations and represented by Company A. The helicopter was operated as a private aircraft by the captain, an individual business owner who had contracted with Company B after Company B rented the helicopter from Company A. Also, the Company A and Company B had ever transported passengers without a license for air transport services. According to the president of Company B, it was the captain who decided about all the flight operation management, Company B never had forced the captain to operate the helicopter. And Company B relayed to the captain the information on the time at which aircrafts take off and land, and the passengers on board by SNS or telephone, and the captain reported to Company B about the take-off and landing which the captain had performed. In addition, the helicopter was planned to be parked at Hodogaya

[*7] "KIAS" stands for Knot Indicated Airspeed and referred to the indicated airspeed in knots.

Operation Site after the landing.

(9) Air Transport Services*8 Alert issued by the Civil Aviation Bureau

In December 2017, the Civil Aviation Bureau created and issued a leaflet to make it known thoroughly that in view of a significant risk entailed in the business using aircraft, which shall require to obtain a license, and any person who has run the business using aircraft without a license shall be liable to prison sentence of up to three years or a fine of not more than 3,000,000 yen.

https://www.mlit.go.jp/common/001599984.pdf

(10) Past Accidents Resulting from Mast Bumping

In Japan, there is one report of the accident resulting from mast bumping of Robinson helicopter which occurred on October 27, 2007.

https://www.mlit.go.jp/jtsb/eng-air_report/JA102D.pdf

3. ANALYSIS

(1) Weather Simulation

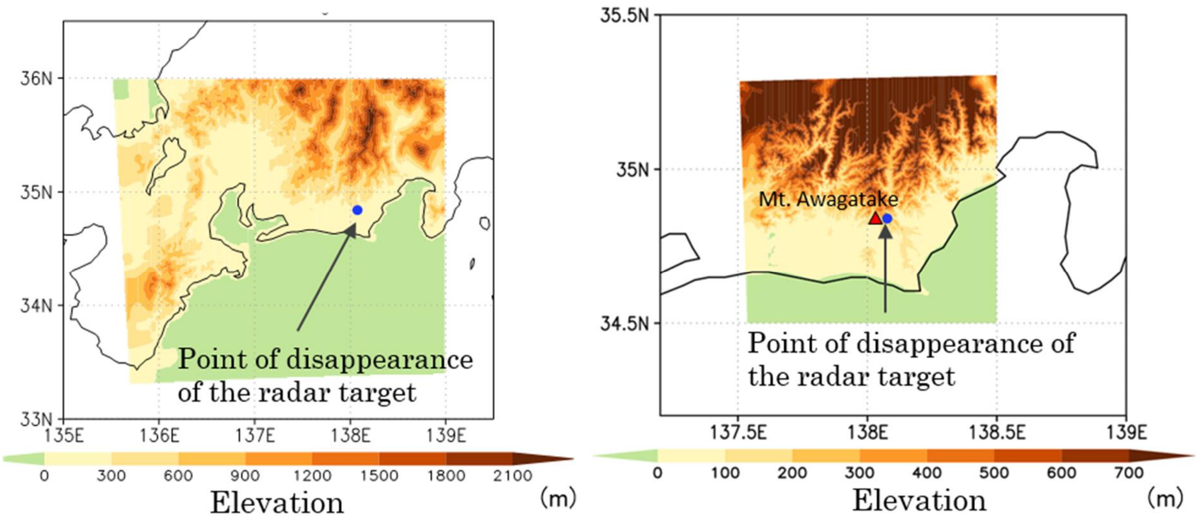


Figure 15: Computational Region of Numerical Analysis A Model Terrain (Left)
Computational Region of Numerical Analysis B Model Terrain (Right)

The JTSB concludes that as follows regarding the weather conditions of this accident by weather simulations.

As described in 2.6 Meteorological Information, on the day of the accident, areas around Japan were in a winter pressure pattern with high pressure in the west and low in the east. At around the point where the helicopter experienced a sudden change in attitude, a westerly wind was probably blowing, however, as the details about the vertical flow generated around the helicopter's flight altitude was unknown, numerical analyses A and B were conducted in the Atmosphere and Ocean Research Institute, the University of Tokyo, using two weather simulation models with a horizontal resolution of 1 km and 100 m. In this analysis, by means of the four-dimensional variation method of meso-analysis by the Japan Meteorological Agency（JMA） that was used for the initial values, it was calculated regarding non-on-the-hour observations as hourly observations on the hour, thus a time lag of up to an hour may occur.

a. Calculation condition

Default values: The JMA mesoscale analysis at 09:00 on December 30, 2020 were used for

*8 "Air transport services" mean any business using aircraft to transport passengers or cargo for remuneration upon demand.

numerical analysis A, and the output value of numerical analysis A at 12:00 on December 30, 2020 for numerical analysis B.

Boundary value: The JMA mesoscale analysis for analysis A and the output value of numerical analysis A for numerical analysis B

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

Computational region: For analysis A and B, respectively, within a 400-km (Left, Figure 15) and an 80-km (Right, Figure 15) radius centered on the point where the helicopter experienced a sudden change in attitude, and 21.1 km in vertical direction for both.

Resolution: As horizontally 1 km (analysis A) and 100 m (analysis B), 80 vertical layers are placed (the lower part of the computational region is based on a coordinate system along the terrain).

b. Results of Numerical Analysis

The left in Figure 16 shows horizontal wind velocity and the horizontal wind vector diagram from the numerical analysis B and the right in Figure 16 indicates the vertical flow, and the horizontal wind deviation from the area averaged.

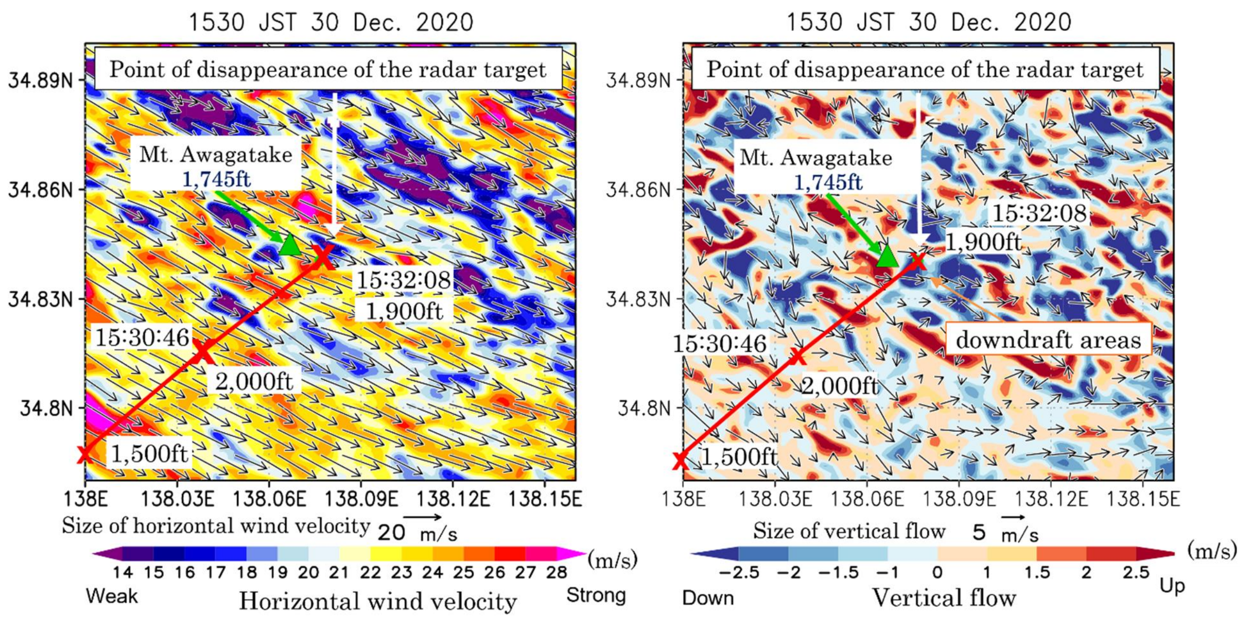


Figure 16: Horizontal wind velocity at altitude 600 m (colored areas) from analysis B (Left) Vertical flow at altitude 600 m (colored areas) and horizontal wind deviation from the area-averaged (indicated by arrows) (Right)

As shown in Figure 15 (Right), topographic features in the vicinity of the estimated flight route of the helicopter were mountainous in the north and plain in the south. Around an altitude of about 600 m (about 2,000 ft) where the helicopter was flying, as shown in Figure 16 (Left), on the southwest side, the horizontal wind was blowing from an angle of 300° at about 25 m/s (50 kt), which is indicated mainly in yellow color, and the northeast side, the horizontal wind was blowing at about 15 m/s (30 kt), which is indicated in dark blue. In addition, as shown in Figure 8: Meteorological Satellite Imagery (Visible), in the Tokai region, there are three streaky cloud lines running through the northwest to the southeast, and one of these lines is located near the accident site, and as shown in Figure 9, at Shizuoka Airport, the strong wind had continued blowing until 17:00. The horizontal wind velocity and the vertical flow in Figure 16 (Right) show a wind pattern running through northwest to southwest, and it is indicated that the wind tends to be strong in downdrafts area and weak in updrafts. It is probable that on the flight route of the helicopter, in the section between the point where the helicopter was flying at 15:30:46 and the point at 15:32:08 when the radar target, which was captured by Hamamatsu Radar and seemed be the helicopter, disappeared, there were increases and decreases in horizontal wind velocity with about 10 m/s (20 kt), and there were alternating updrafts and downdrafts with a velocity of about 2.5 m/s, therefore, a roll-shaped thermal convection with an axis running through northwest to southeast was generated, which resulted in the strong wind blowing in downdraft area and the weak wind in updraft area. Besides, as shown in Appended Figure, comparing the analysis results from 600 m to 1,000 m altitude of numerical analysis B revealed that according to the increase in altitude, in the wind velocity distribution (left column), the wind velocity increased as indicated in red, while in the vertical flow distribution (right column), the downdraft areas indicated in blue decreased. According to the increase in altitude, the likelihood of encountering downdrafts may decrease, however, since the horizontal wind velocity increases, it is probable that only increasing altitude would not be sufficient to response to the turbulence generated by a roll-shaped thermal convection.

(2) Estimated Airspeed when the Helicopter Encountered Turbulence

The JTSB concludes that as follows regarding estimated airspeed when the helicopter encountered vertical flow.

From the helicopter's flight route and ground speed, it is probable that in order to avoid the influence of mountain waves, the captain chose the route at an altitude higher than Mt. Awagatake located on the west side of the flight route, in addition, the route at around 2,000 ft in order to avoid the cumulus clouds, which were observed to be present around 2,500 ft, as described in 2.6 (2), and climbed from 1,500 ft. Based on the helicopter's actual flight track, ground speed, outside air temperature, atmospheric pressure, and wind direction and velocity from numerical analysis, the helicopter probably was flying at 110 KIAS and at a heading of about 025° in winds of 300° and 50 kt.

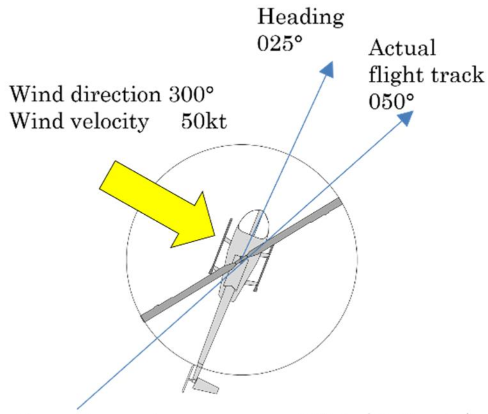


Figure 17: Estimated Airspeed

The helicopter maintained the maximum cruise speed of 110 KIAS, therefore, it is probable that the helicopter caused a low-G at the time of encountering turbulence with vertical flow, resulting in flying at the velocity that mast bumping more likely occurred.

(3) Encounter with Turbulence and Low-G Flight Condition

The JTSB concludes that as follows regarding the helicopter encountered with vertical flow and low-G flight condition.

As shown in Figure 6, the spindle assembly of the helicopter's two main rotor blades and the main rotor hub had contact marks, in addition, the main rotor drive shaft was significantly bent, the teeter stops on both sides had a difference in the size of deformation due to contact marks, which most likely resulted from a strong contact between the main rotor blade spindle assembly, hub and the main rotor drive shaft during the flight or at the time of the crash.

According to the collated results including the estimated flight path from the point at 15:30:46 to the point at which the radar target disappeared at 15:32:08, the engine monitoring unit (EMU) records in Figure 13 and the numerical analysis in Figure 16 , against the large output fluctuation region (a) from 15:31:00 to 15:31:20, the flight altitude decreased and the deviation of the vertical flow during that period exceeded 5 m/s. If the output shaft speed (N2) is in the normal 1G state, the engine output is transmitted, so the main rotor RPM is maintained at around 100%. In particular, in the output fluctuation region (a), around 15:31:05, N2 increased by about 2 to 3% while N1, MGT, and torque suddenly decreased. This is more likely that encountered turbulence with strong vertical flow, and reduced the load on the main rotor and temporarily increased the main rotor RPM.

Besides, the airspeed was maintained at about 100 KIAS until near the point at 15:32:08 when the radar target disappeared, therefore, it is probable that up to this point, the helicopter had not fallen into difficulties in flight control. On the other hand, there was a strong downdraft by numerical analysis in the vicinity of the point where the radar target disappeared, Eyewitness A visually recognized that the helicopter was changing the roll attitude from the left to the right while the tail was swaying, it is more likely that was a situation in which a mast bumping was likely to occur as the helicopter was maintained airspeed within low-G flight condition. After that, there are statements from Eyewitnesses that the helicopter largely turned left, then turned right, and descended, therefore, the helicopter probably become difficult to control in this area.

(4) Responses to Attitude Fluctuations

The JTSB concludes that as follows regarding responses to attitude fluctuations of the helicopter.

It is probable that the captain could have fully predicted the occurrence of mast bumping because he had more than 200 hours of flight experience with Robinson helicopters. And thus the captain possibly climbed to the altitude higher than Mt. Awagatake's summit without reducing the speed before passing Mt. Awagatake's downwind side where severe turbulence was expected. In addition, the captain maintained the maximum cruise speed of 110 KIAS was possibly because he considered the scheduled time of landing at Hodogaya Operation Site.

Besides, according to the statement of Eyewitness A, after the right roll, the helicopter significantly changed its attitude to the left roll, therefore, it is more likely that the cyclic stick was moved to the left after the right roll. The Caution in the Rotorcraft Flight Manual for Robinson R66 stipulates that *"Should a right roll commence during a low-G condition, apply gentle aft cyclic to reload rotor before applying lateral cyclic to stop roll"*, however, when a sudden right roll commences in a strong downdraft from the left, a pilot tends to prioritize in applying left cyclic in order to correct its tilt. For sudden right roll, the captain probably tried to correct the attitude by instantly applying left cyclic rather than gently applying aft cyclic. It is therefore probable that when the helicopter encountered turbulence, it entered a low-G flight condition, its attitude was not properly controlled, and mast bumping occurred, causing it to become uncontrollable.

During high- speed flight, an aircraft tends to respond to the external force faster and greater, therefore, before severe turbulence is encountered, as in the caution in the Pilot's Operating Handbook for Robinson R66, the airspeed should have been probably reduced to 60 to 70 KIAS.

(5) The Helicopter's Scheduled Time of Landing at Hodogaya Operation Site and Decision on Deceleration

The JTSB concludes that as follows regarding the helicopter's scheduled time of landing at Hodogaya Operation Site and decision on deceleration.

According to the statement of the captain's family, the captain possibly needed moving to Hodogaya Operation Site within the day as having a work to do on the next day of the accident. The estimated flight distance between the point where the radar target disappeared and Hodogaya Operation Site, the destination was 83 nm, and assuming an average ground speed of 110 kt, the estimated scheduled time of landing at Hodogaya Operation Site would be at 16:15, 23 minutes before sunset. There was not sufficient time to do the work for parking the helicopter after landing, therefore, the captain possibly hesitated in deciding to reduce the airspeed.

(6) Flight from Right and Left Rolling Attitude Changes to the Crash

The JTSB concludes that as follows regarding the flight from right and left rolling attitude changes to the crash.

As shown in Figure 2, the flight route from the point where the radar target of the helicopter disappeared to the crash point was about 900 m, and the helicopter flew for one minute, in addition, according to the recording on the Engine Monitoring Unit, from around 15:32:25, the torque suddenly increased, and the helicopter was more likely flying at a low speed of about 30 kt. According to the statements of eyewitnesses, the helicopter was swinging its tail right and left, and immediately before the crash, therefore, it was flying while largely tilting to the right with a large nose down, the helicopter most likely continued flying in a difficult flight control condition. Besides, if the main rotor drive shaft had been bent during the flight, the imbalance of the main rotor would rapidly result in complete separation of the entire main rotor gearbox, and the airframe will disintegrate in midair. Therefore, it is likely that the main rotor drive shaft was bent after the crash, not during the flight.

(7) Estimated Final Approach Profile at the Time of the Crash

The JTSB concludes that as follows regarding estimated final approach profile at the time of the crash.

Based on the recording on the Engine Monitoring Unit, and the main rotor blade found in the location about 90 m away from the accident site and the cutting condition of the surface of the trees, it is highly probable that the helicopter's engines were working normally, and with its engine output able be transmitted to the main rotors, the helicopter crashed into a mountain forest in an angle of about 40°.

(8) Captain's Decision on Flight Operation

The JTSB concludes that as follows regarding the captain's decision on flight operation.

At the request of Company B without a license in air transport services, the captain engaged in an aircraft operation as an individual business owner, however, the captain should have made flight decisions with safety as the top priority about whether to depart or not under a bad weather, and the flight plan.

4. PROBABLE CAUSES

The JTSB concludes that the probable cause of the accident was that during flight in a mountain region under strong winds, when the helicopter encountered a downdraft caused by a roll-shaped thermal convection and fell into a low-G condition, it is highly probable that the helicopter was resulted in the mast bumping and the loss of flight control failure when the aircraft's attitude was not properly controlled, it crashed. The mast bumping occurred leading to the loss of flight control failure was probably because the helicopter continued flying due to encountering turbulence while maintaining airspeed.

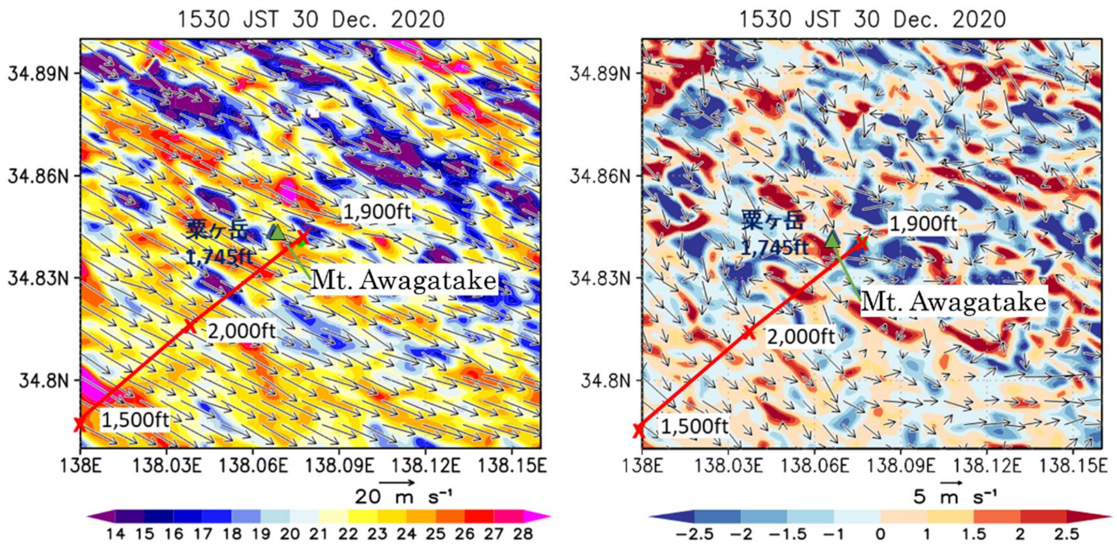
5. SAFETY ACTIONS

5.1 Safety Actions Required	(1) It is required for a pilot flying a semi-rigid rotor helicopter must keep the following in mind to prevent mast bumping that could lead to loss of control. a. In order to avoid flying in low-G flight conditions, it is necessary to take into account the area where turbulence occurs and set appropriate airspeed and flight altitude. In particular, when temperatures rise, strong downdrafts occur due to roll-shaped thermal convection, and in mountainous region, downdrafts tend to be larger than in flat areas due to the influence of the topography. So do not wait until feeling turbulence, therefore, it is important to slow down and fly before entering an area where turbulence occurs. b. When a low-G flight condition occurs, it is important to predict the occurrence of a right roll and prepare for an appropriate recovery maneuver as per the flight manual. (2) It is important for a captain to obtain the weather information necessary for the relevant flight at Confirmation before departure and make flight decisions about whether to depart or not and perform flight operation according to a reasonable flight plan, if weather conditions impeding the flight operation are expected.

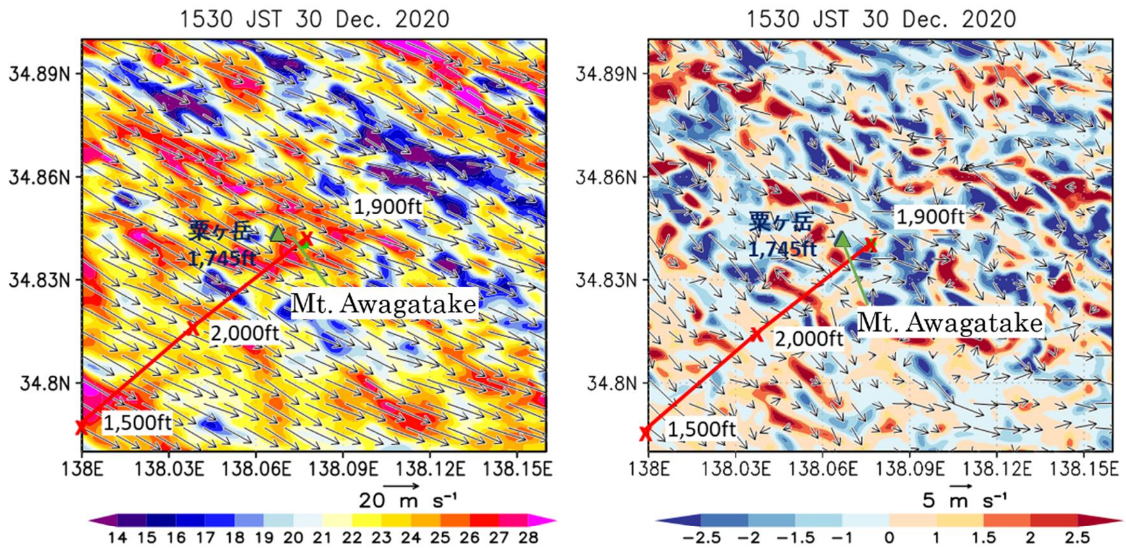
Appended Figure: Distributions of Horizontal Wind Velocity and Vertical Flow at Altitude 600 m to 1,000 m from numerical analysis B

	Horizontal wind velocity (colored areas) and horizontal wind vector	Vertical flow (colored areas) and horizontal wind deviation from the area-averaged

(Altitude 600 m)



(Altitude 800 m)



(Altitude 1,000 m)