AIRCRAFT ACCIDENT INVESTIGATION REPORT

HELICOPTER DAMAGE

CAUSED BY A HARD LANDING ON THE SPOT

ALL NIPPON HELICOPTER CO., LTD.

EUROCOPTER EC 135 T2 (HELICOPTER), JA37NH

ON THE SPOT AT OKAYAMA AIRPORT

AT ABOUT 10:41 JST, MARCH 2, 2023

May 30, 2025

Adopted by the Japan Transport Safety Board

Chairperson RINOIE Kenichi
Member TAKANO Shigeru
Member MARUI Yuichi
Member SODA Hisako
Member TSUDA Hiroka
Member MATSUI Yuko

1. PROCESS AND PROGRESS OF THE AIRCRAFT ACCIDENT INVESTIGATION

1.1 Summary of the Accident	On Thursday, March 2, 2023, a Eurocopter EC 135 T2, JA37NH, operated by All Nippon Helicopter Co. Ltd., became unstable while touching down near No.1 Spot at Okayama Airport, which caused the helicopter to make a hard landing while turning right, resulting in damage to the helicopter. Three people in total, including the pilot and two passengers were on board the helicopter. One passenger sustained an injury.
1.2 Outline of the Accident Investigation	On March 3, 2023, the Japan Transport Safety Board (JTSB), upon receiving a report of the aircraft accident, designated an investigator-in-charge and an investigator to investigate the accident. An accredited representative and an adviser of the Federal Republic of Germany, as the State of Design and Manufacture of the helicopter involved in the accident, an accredited representative and an advisor of the French Republic, as the State of Design and Manufacture of the engine, participated in the investigation. Comments on the draft Final Report were invited from parties relevant to the cause of the accident and the Relevant States.

2. FACTUAL INFORMATION

2.1 History of the Flight

According to the statements of the pilot and the mechanic on board, the history of the flight was summarized as follows:

At about 09:18 Japan Standard Time (JST: UTC+9 hrs: unless otherwise stated all times are indicated in JST on a 24-hour clock), a Eurocopter EC 135 T2, JA37NH, operated by All Nippon Helicopter Co. Ltd., (hereinafter referred to as “the company”) took off from Hiroshima Heliport for news coverage, with the pilot in the right pilot seat, with the mechanic in the left pilot seat, and a camera person in the aft seat. After shooting Okayama City from the sky, the helicopter landed on Runway 07 at Okayama Airport at about 10:38 in order for refueling and started air-taxiing*1 to No.1 Spot located in front of the control tower at the airport (hereinafter referred to as “the Spot”) at about 1 m ~~altitude~~ above the ground (AGL).

After entering the apron, the helicopter started its approach with a true bearing of about 330° (see Figure 1).

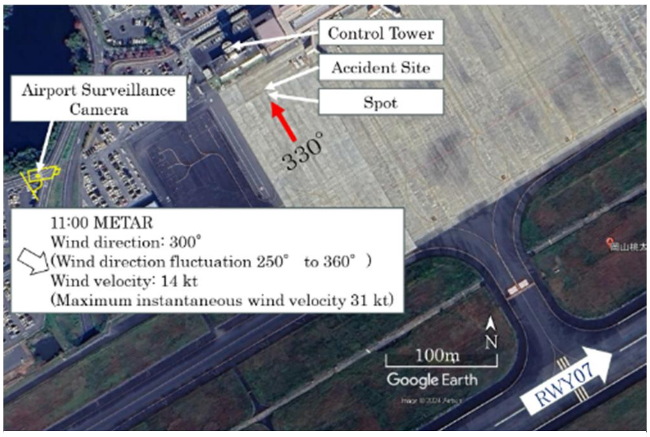


Figure 1: Situation around the Accident Site

When the helicopter approached the apron, the pilot felt a strong crosswind blowing from the left, but also felt that the helicopter was being subject to wind as if it were being pushed down from above and pushed up from below as it approached the Spot. The pilot felt that the air flow was rather unfavorable and that it would be dangerous in this situation, therefore the pilot continued the approach to the Spot by air-taxiing at about 2 m AGL. The helicopter was unstable as its altitude changed erratically up and down, shaking and rattling. Knowing from the past experience, the pilot thought that the strong wind blowing through the control tower building in front and the wind blowing through a parking lot to the left mixed to create turbulence that would affect the helicopter, and that it would not be safe to continue to advance in this situation, the pilot decided to make a landing about 20 m short of the Spot.

The pilot slowly lowered the helicopter's altitude to make a landing about 20 m short of the Spot. However, even during the descent, the helicopter's attitude was unstable due to turbulence. When the skids touched down, the helicopter’s pitch attitude was downward, as if it were pivoting around the front of the skids that had touched down, but soon returned, again pitch attitude was downward more than the first, and returned to the attitude at the time of touchdown. At this time, the pilot felt an impact as if

*1 According to the definition in Annex 2 to the Convention on International Civil Aviation, “air-taxiing" refers to the movement of a helicopter above the surface of an aerodrome, normally in ground effect and at a ground speed normally less than 20 kt.

	the helicopter bounced twice with sounds of "boom, boom". In addition, the pilot remembered feeling that the collective pitch lever (hereinafter referred to as "CP") was coming to rise, but did not know whether the CP was rising naturally or whether the pilot had raised the CP unconsciously. As the helicopter changed its pitch attitude, the pilot's left arm was fully extended and the CP was about to leave the pilot's left hand, but when the pilot felt the second "boom" impact, the pilot's upper body moved forward, allowing the pilot's hand to firmly reach the CP. The helicopter lifted off with a sharp downward pitch for the third time and suddenly began to rotate to the right. Immediately, the pilot fully applied the rudder pedal (hereinafter referred to as "the Pedal") to the left and lowered CP to its lowest position and waited for the right rotation to stop while maintaining a horizontal roll attitude, but the helicopter did not stop its right rotation and landed with a hard impact. The helicopter's touchdown position was on the apron the control tower side about 3 m from the stop bar marking at the Spot, and even after the touchdown, the helicopter continued its right rotation and came to a stop. In addition, the helicopter's emergency locator transmitter (ELT) was activated as the helicopter landed harder. According to the Okayama Airport Office, it was 10:41:15 when they received the ELT signals, which appeared to have been transmitted when the helicopter made a hard landing. According to the mechanic on board, the helicopter began to descend after the mechanic on board heard the pilot saying that the pilot would make the helicopter touch down slightly short of the Spot to reduce the influence of the wind. At this point, the mechanic on board checked the surrounding and confirmed that there were no abnormal indications on the engines instrument. At the time of the helicopter's touchdown, the mechanic on board confirmed through the left window that the left skid had touched down and was about to check the surrounding, when the helicopter suddenly began to shake, but at first, the helicopter tilted slightly forward and then returned. Next, the helicopter tilted forward significantly and returned to the original again, but the mechanic on board did barely remember anything after that. When the helicopter suddenly began to rotate, the only thing the mechanic on board could do was to try to maintain the posture by holding onto the chair with the mechanic's right hand and placing the left hand on the door recess. The landscape outside the helicopter was seen spinning abnormally fast and immediately afterwards there was a hard impact, the mechanic on board confirmed that the helicopter had come to a stop. The mechanic on board checked to see if there was a fire, but found that the engines were running, then advised the pilot to shut them down. The mechanic on board checked that there were no abnormal indications or displays on the engines instrument panel while the pilot was performing the engine shutdown procedures, and until the rotor stopped, the mechanic on board selected the flight report page, which displayed the flight time and the excess of the limit during the relevant flight to photograph it with a smartphone.

	The surveillance camera installed on the west side of the Spot at Okayama Airport recorded the video at the time of the accident (see Figure 1, and 2.7 (1) described below). The accident occurred at about 10:41 on March 2, 2023, on the Spot at Okayama Airport (34° 45' 33" N, 133° 51' 09" E).
2.2 Injuries to Persons	One passenger: minor injury
2.3 Damage to the Aircraft	(1) Extent of damage: Substantially damaged (2) Main damage to the helicopter (see Figure 2) Left aft frame as a primary structure member: buckled Right and left sides and lower surface of the fuselage: broken Left side of the forward cross tube: buckled Tail bumper and left vertical stabilizer: broken Press coverage equipment (camera and antenna): damaged No abnormalities were observed in the engine, main rotor (hereinafter referred to as "MR"), fenestron*2, rotor drive system and control system.

*2 "Fenestron" is a type of helicopter anti-torque system acting in the same way as a tail rotor. in which a series of rotating blades are shrouded within a vertical fin.

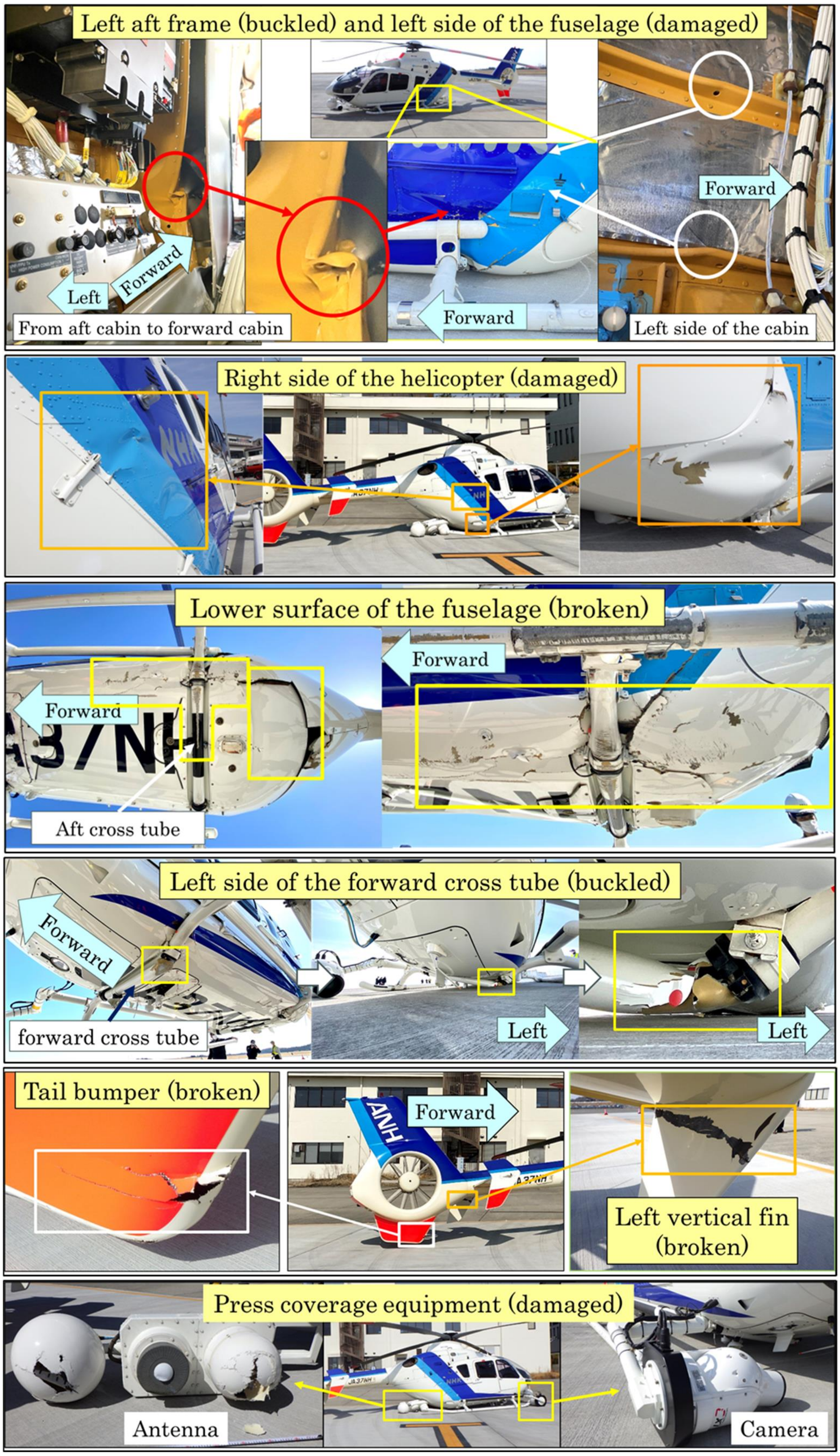
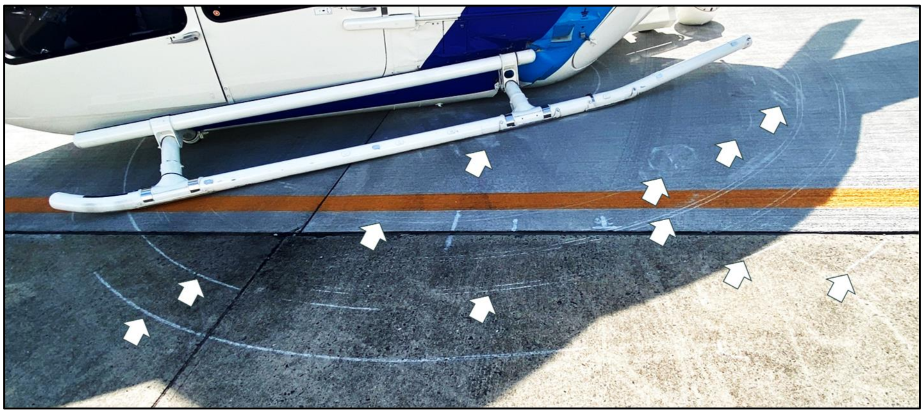


Figure 2: Damage to the Helicopter

	(3) On the surface of the apron where the helicopter had stopped, many scratch marks, including those from the skids, were confirmed (see Figure 3).  Figure 3: Scratch Marks on Apron Surface
2.4 Personnel Information	Pilot: Age 50 Commercial pilot certificate (Helicopter) October 19, 2000 Type rating for Land Multi-Turbine July 13, 2005 Pilot competency assessment/confirmation Expiration date of piloting capable period: February 10, 2024 Class 1 aviation medical certificate Validity: November 9, 2023 Total flight time 2,902 hours and 38 minutes Total flight time in the last 30 days 13 hours 43 minutes Flight time on the type of rotorcraft 477 hours 00 minute Total flight time in the last 30 days 8 hours 08 minutes
2.5 Aircraft Information	Aircraft type: Eurocopter EC 135 T2 Serial Number: 0397, Date of Manufacture: April 14, 2005 Airworthiness Certificate: No. Dai-2022-265, Validity: August 1, 2023 Total flight time: 3,357 hours and 14 minutes When the accident occurred, the weight of the helicopter was estimated to have been 2,513 kg, and that the position of center of gravity (CG) was estimated to have been at 428 cm fore-aft, and 5.0 cm right, both of which are estimated to have been within the allowable range (the maximum approved gross mass is 2,835 kg, the CG range (fore-aft) of 421 to 442 cm and the CG range (lateral) of 10.0 cm left to 10.0 cm right at accident weight).
2.6 Meteorological Information	The following are excerpts from aerodrome routine meteorological report (METAR) at Okayama Airport around the time of the accident. 11:00 Wind direction: 300°, Wind direction fluctuation 250° to 360° Wind velocity: 14 kt, Maximum instantaneous wind velocity 31 kt
2.7 Additional Information	(1) Recording of Video from Airport Surveillance Camera (hereinafter referred to as “the Video”) The Video recorded the situation from the time the helicopter approached the airport apron by air taxi until after the accident. The Video was played back slowly using general purpose software and the elapsed time during the rotation was measured.

a. From the time when the helicopter touched down about 20m short of the Spot until it lifted off

Figure 4 shows the situation from the time the helicopter touched down about 20 m short of the Spot until it lifted off, with the sequence of images of the same angle of view cut from the Video on the left, and the helicopter movement corresponding to each image illustrated and indicated on the right as a supplement. In addition, the rightmost column shows the elapsed time and the time difference between each image when the time of the helicopter's touchdown about 20m short of the Spot is set to 0 second.

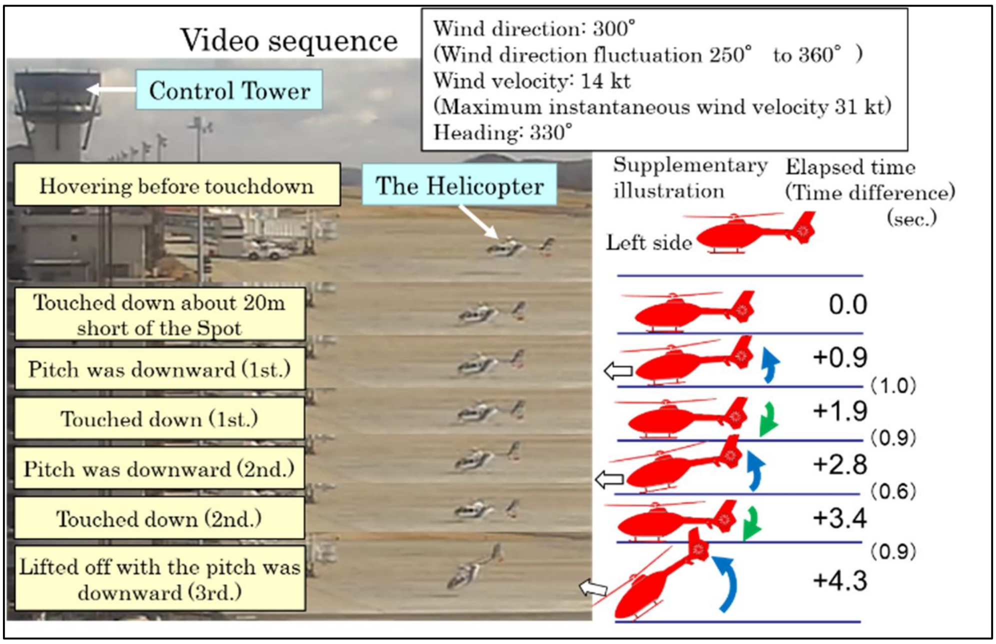


Figure 4: Situation from the Helicopter's Touchdown about 20 m Short of the Spot until the Lifting Off

According to the Video, the change to downward pitching attitude was observed three times after the helicopter's skids had touched down: the first time, about 0.9 seconds after initial touchdown, about 20 m short of the Spot, the helicopter's pitch attitude was downward, as if it were pivoting around the front of the skids, and it touched down again about one second after it had advanced slightly: the second time, about 0.9 seconds after the first touchdown, the helicopter's pitch attitude was pitch more downward than the first time, as if it was pivoting around the front of the skids, and it touched down again about 0.6 seconds after having advanced slightly: the third time, about 0.9 seconds after the second touchdown, the helicopter's pitch attitude was significantly downward (about 30°), and then it lifted off while moving forward.

On the surface of the apron, where the helicopter touched down about 20 m short of the Spot, there were contact marks confirmed in two places each to the right and left (four in all), symmetrically along the path taken by the helicopter, with those on the control tower side being clearer and deeper than the others (see Figure 5).

b. From the time when the helicopter lifted off and rotated to the right, until it landed harder

Figure 6 shows the situations when the helicopter's pitch attitude became was significantly nose down, lifted off while moving forward, then rotated to the right and landed harder.

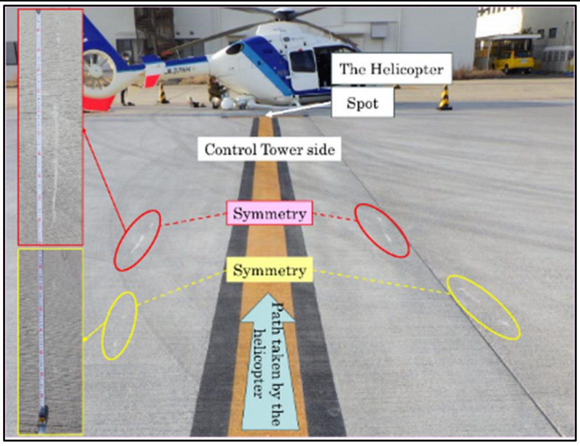


Figure 5: Contact Marks on the Apron Surface where the Helicopter Touched Down about 20 m Short of the Spot

It was confirmed that after the helicopter's pitch attitude was significantly downward and lifted off while moving forward, its attitude became level and immediately thereafter it began to rotate to the right. The right rotation of the helicopter in the air was one and a half turns (about 540°). It took 3.6 seconds from the start of the right rotation to the hard landing. The AGL during the right rotation was almost constant, and as a result of a comparison with the three angle views of the surrounding buildings, the maximum AGL was about 8 m (about 26 ft), and this was when the helicopter rotated about 270°.

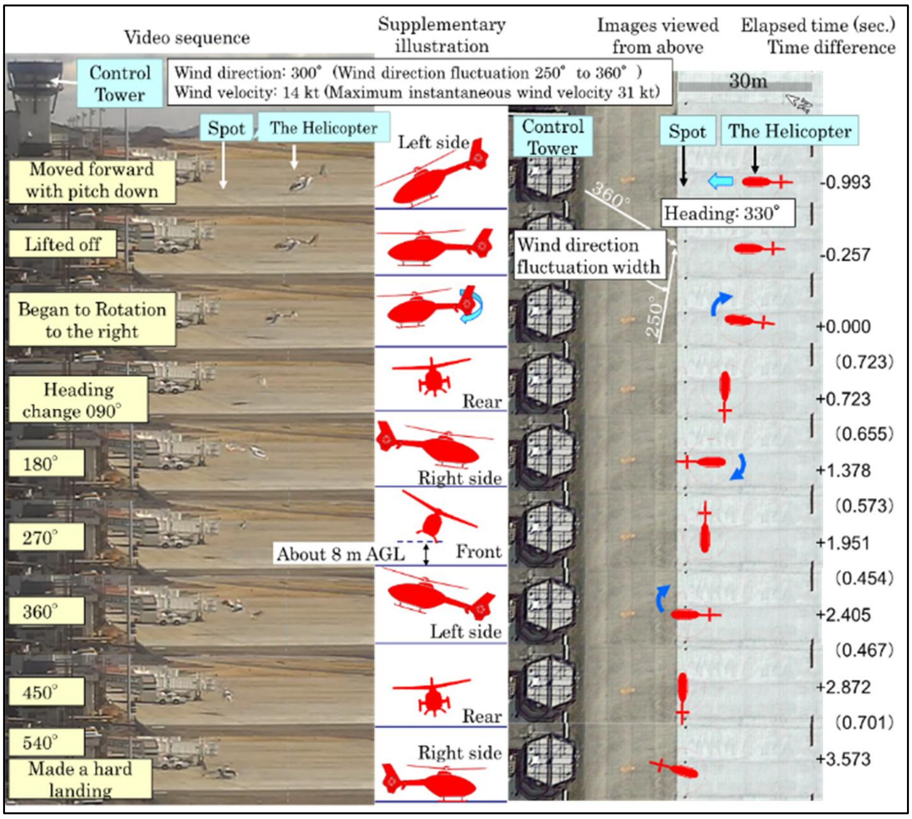


Figure 6: Situations when the Helicopter Started the Right Turn until It Made a Hard Landing

The average rates of rotation, measured at 90° intervals for the changes in heading from when the helicopters rotated right to the hard landing, were as follows:

000° to 090°: about 120°/s
090° to 180°: about 140°/s
180° to 270°: about 160°/s
270° to 360°: about 200°/s
360° to 450°: about 190°/s
450° to 540°: about 130°/s

c. From the time when the helicopter landed harder until it stopped the rotating

The helicopter made a hard landing with an almost level attitude while rotating to the right, it continued to rotate to the right and came to a stop after rotating about 270° on the ground.

(2) Altitude Changes of the Helicopter in Hovering Flight

During hovering flight, a helicopter maintains altitude by balancing the thrust gained by the rotation of the MR blades and the weight (see Figure 7).

In case of the helicopter, as the pilot adjusts the CP, the pitch angle of the MR blades changes, the engine power is adjusted to keep the main rotor r.p.m. constant, and the MR thrust changes. Thrust greater than weight by raising the CP induces a climb, while thrust less than weight by lowering the CP causes a descent.

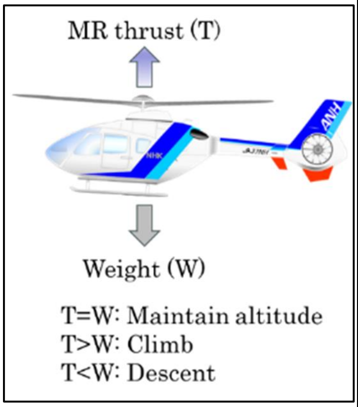


Figure 7: Altitude Change during Hovering Flight

Given these, raising the CP is necessary for the pilot to maneuver the helicopter in hovering flight into climb.

(3) Changes in Heading of the Helicopter in Hovering Flight

When viewed from above, the helicopter's MR rotates in a counterclockwise direction (see Figure 8). As the MR rotates, counteracting torque is generated to rotate the helicopter fuselage in the opposite direction to the MR. This torque is related to the engine power used to rotate the MR, therefore, as the CP is raised, power increases, which in turn increases the torque.

Fenestron, on the other hand, produces the thrust in a lateral direction, as if counteracting the torque. The helicopter's fenestron system is installed in such a way that the thrust is generated on the right side, viewed from above, the pilot is able to change the magnitude of this thrust force through the use of the pedals. On the left side of the fenestron, a wake is created.

When a pilot applies the left pedal, the fenestron thrust increases, and when the fenestron thrust is greater than the torque, the nose of the helicopter yaws to the left. Similarly, when a pilot applies the right pedal, the fenestron thrust decreases, and when the fenestron thrust is less than the torque, the nose of the helicopter yaws to the right.

When a pilot raises the CP for climbing from hovering, the torque increases accordingly. Therefore, when a pilot does not apply the left pedal, the nose of the helicopter yaws to the right.

From the above, one of the following operations is required for the pilot to rotate the helicopter in hovering flight to the right.

(a) Raise the CP without moving the pedal.

(b) Apply the right pedal.

(c) Apply the right pedal while raising the CP.

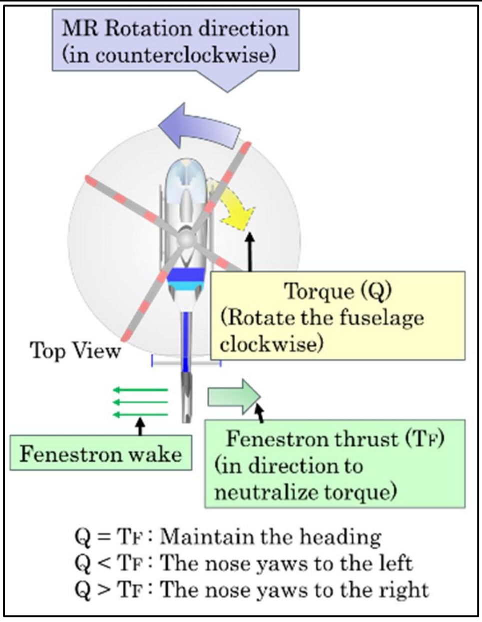


Figure 8: Heading Change during Hovering Flight

(4) A-PC: Aircraft - Pilot Coupling

Caused by interactions between the aircraft and the pilot, A-PC is an unexpected deviation in aircraft attitude and flight path, sometimes referred to as Pilot Induced Oscillation (PIO) or Pilot Assisted Oscillation (PAO).

a. Examples of A-PC in Helicopters

"Chapter 5: Helicopter Emergency Situations, Section 3: Collective Bounce" in the "Helicopter Pilot Training Manual Vol.5" (edited and published by the Helicopter Pilot Training Manual Revision Working Group in the Japan Aircraft Pilot Association in 2021, p. 257) describes the following (excerpt).

Collective bounce is a PIO (Pilot Induced Oscillation) phenomenon in the collective pitch control system, induced by the pilot control, where the aircraft suddenly oscillates up and down.

This document shows some examples of mechanisms that cause collective bounce. Raising the collective pitch abruptly during descent can cause the aircraft to climb rapidly, resulting in the pilot pushing down the collective pitch lever due to the pilot's own inertia. As a result, the pilot's body tends to float up as the aircraft suddenly descends, causing the pilot to inadvertently pull up the collective pitch lever again. This repeated up and down movement of the helicopter is known as collective bounce, which causes the vibrations to diverge and, in the worst case, makes it difficult for the pilot to control the helicopter.

The initial cause of collective bounce is not limited to the amount of movement in the collective lever. Collective bounce may result from factors such as changes in airflow, the touchdown of the sling cargo and the cyclic stick control. In any case, the collective bounce tends to be

	easily triggered by repeated collective control operations with relatively large rates, or by airframe movement. The recovery method to eliminate this condition includes: loosening holding of, letting go of the collective pitch lever, or using the collective pitch lever by "raising" or "lowering" it clearly. *As collective bounce tends to occur when there is insufficient collective pitch lever friction**3*, it can be prevented in advance by ensuring that the friction is confirmed and adjusted during the pre-flight checks. Seat belts and shoulder harnesses not only to prevent collective bounce, but should be fastened securely to the extent that they do not interfere with flight control.* According to the pilot, at the time of the accident, the CP friction was the same as in a normal flight and the pilot had the seat belt and shoulder harness properly fastened. b. Flight Manual of the Helicopter SECTION 4 "NORMAL PROCEDURES" of the Flight Manual for the Helicopter specifies operation procedures as follows (excerpts): *4.6 TAKEOFF* (Omitted) *CAUTION AN OSCILLATION, WHICH COULD BE UNINTENTIONALLY INDUCED/ASSISTED BY THE PILOT (PIO/PAO) MAY BE EXPERIENCED INFLIGHT IN TURBULENT WEATHER CONDITIONS.* *IN CASE OF PIO/PAO, RELEASE COLLECTIVE LEVER MOMENTARILY AND INCREASE COLLECTIVE LEVER BRAKE FRICTION.* *4.7 LANDING* (Omitted) *CAUTION AN OSCILLATION, WHICH COULD BE UNINTENTIONALLY INDUCED/ASSISTED BY THE PILOT (PIO/PAO) MAY BE EXPERIENCED DURING RUNNING LANDING OR HARDER VERTICAL LANDINGS.* *IN CASE OF PIO/PAO, RAPIDLY INCREASE OR DECREASE COLLECTIVE LEVER, WHATEVER SITUATION ALLOWS, UNTIL OSCILLATION HAS STOPPED.* (5) Unanticipated right yaw in helicopters*4

*3 "Collective pitch lever friction" refers to a mechanical device that adjusts the firmness of the CP's operating feel and prevents the CP from moving without the pilot's intention, also known as brake friction.

*4 "Yaw" refers to motion around the vertical axis of the fuselage, with the nose swinging to the right or left. And "unexpected right yaw of the helicopter" refers to an aerodynamic characteristic that occurs when the MR rotates in a counterclockwise direction when viewed from above.

In 2.7 (3) above, the case was presented where the heading of the helicopter in hovering flight is changed by the pilot's control. Next, unanticipated right yaw in helicopters is shown, where an uncommanded yaw occurs in helicopters.

The Advisory Circular AC90-95, Subject: UNANTICIPATED RIGHT YAW IN HELICOPTERS issued by the U.S. Department of Transportation Federal Aviation Administration (FAA) states the following (Excerpt) :

> Unanticipated right yaw, or loss of tail rotor effectiveness (LTE), has been determined to be a contributing factor in a number of accidents in various models of U.S. military helicopters. The National Transportation Safety Board (NTSB) has identified LTE as a contributing factor several civil helicopter accidents wherein the pilot lost control. In most cases, inappropriate or late corrective action may have resulted in the development of uncontrollable yaw.
>
> LTE is critical, low-speed aerodynamic flight characteristic which can result in an uncommanded rapid yaw rate which does not subside of its own accord and, if not corrected, can result in the loss of aircraft control.

With respect to LTE, the FAA Flight Standards Service “Helicopter Flying Handbook” 2019, Chapter 11, pp. 18-21, an excerpt of which reads as follows:

> LTE is not related to an equipment or maintenance malfunction but to aerodynamic forces acting on the tail rotor that alter its thrust, resulting in a loss of tail rotor effectiveness, and may occur in all single-rotor helicopters. When entering the LTE region, helicopters experience an abrupt and uncommanded yaw in the opposite direction to the direction of rotation of the MR blades.
>
> There are three main things that can create an LTE affected by the airflow relative wind (in case of a counterclockwise MR rotation when viewed from above).

a. MR Disc Vortex interference

The relative wind direction at 285 to 315° and winds at velocities of 10 to 30 kt, MR generating vortices that can blow directly into the tail rotor, interfering with the tail rotor and reducing thrust (see Figure 9, a.). As a result, the nose direction yaws to the right.

b. Weathercock Stability

In the region of 120 to 240° relative wind direction, *the helicopter* attempts to weathercock its nose into the wind and starts an uncommanded turn either to the right or left (see Figure 9, b.). Particularly when the nose direction yaws to the right, the yaw rate can accelerate rapidly as it turns in the same direction as the torque.

c. Tail Rotor Vortex Ring State (Vortex Ring State, hereinafter referred to as ”VRS”)

Winds in the range of the 210 to 330° relative wind direction cause a tail rotor wake to be pushed back, and this turbulent airflow flows into the tail rotor causing the tail rotor thrust to vary and the nose direction to yaw to the right (see Figure 9, c.). If a tail rotor is in VRS and a right yaw rate is allowed to build, the helicopter can be brought into weathercock stability and then accelerate the right turn rate.

Figure 10 shows the relative wind conditions at the time of the

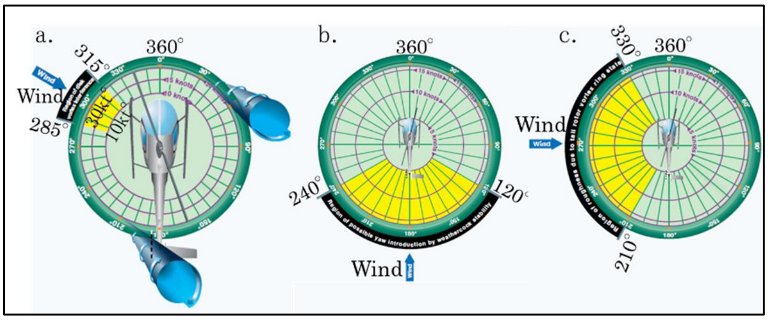


Figure 9: Wind Directions that are More Likely to Cause LTE

accident. According to the pilot's statement, the pilot felt a strong crosswind from the left when the approaching the apron.

According to Airbus Helicopters Deutschland (hereinafter referred to as "AHD"), helicopters equipped with the fenestron type tail rotor like the helicopter are unlikely to encounter VRS for the following reasons.

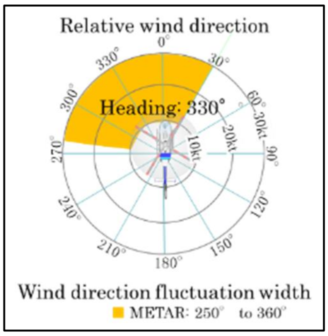


Figure 10: Relative Wind Conditions at the time of the Accident

Comparing the fenestron with an open tail rotor makes it evident that the establishment of a stable VRS condition is even more unlikely, because of the long way the vortex has to travel around the fenestron shroud and the fact that this path is obstructed at three locations around the circumference: tail boom, vertical fin and bumper. As a conclusion it can be said that aerodynamic and external influences like sidewind, high yaw rate or VRS can contribute to entering into an unanticipated yaw but the capabilities of the tail rotor – conventional or fenestron type – are sufficient to counteract and end this flight state.

(6) Training and Others in the company

The pilot regularly received flight training on the simulator of the EC 135 T2 helicopter both domestically and abroad, during which, the pilot was also trained on how to handle LTE and tail rotor drive system failure as training subjects for emergency procedures. In addition, the pilot stated that although A-PC was not simulated in the flight training simulator, the pilot had knowledge of A-PC as it was described in the Flight Manual.

(7) Verification with Full Flight Simulator

In order to verify the helicopter condition obtained from the Video in this investigation, the Full Flight Simulator (hereinafter referred to as

"FFS") of the EC 135 helicopter owned by Airbus Helicopters Japan was used for verification. For this verification, the weather conditions, aircraft weight and balance were set exactly as they were at the time of the accident.

The results of the verification were as follows:

a. Changes in wind velocity

Based on the pilot's statement that the effect of turbulence was present, the simulated helicopter movement during hovering flight was verified in case of changing wind velocity.

It was verified that when the wind velocity increased, the simulated helicopter tended to raise its nose, move backwards, and lift off, and that when the wind velocity decreased, the simulated helicopter tended to lower its nose, move forward and sink. It was also verified that the greater the variation width in wind velocity, the greater the changes in pitch attitude and altitude (see Table 1). However, even though the wind velocity changed, the simulated helicopter did not move in the touchdown condition when its CP was at the lowest position.

It was also verified that the changes in wind direction had less affected the simulated helicopter movement than changes in wind velocity.

Table 1: Simulated helicopter's Responses to Changes in Wind Velocity (Summary)

Changes in wind velocity (kt)		Simulated helicopter's Responses (Starting altitude: about 3 ft)
Before change	After change (variation width)	
12	20 (+8)	Nose up, moved backwards, and skid rearend touched down
12	29 (+17)	Nose up, moved backwards, and lifted off
20	12 (-8)	Nose down and moved forward
29	12 (-17)	After nose down, sank and touched down

b. Operation to raise CP to the maximum position.

The effect of CP raise operation, which would change the nose of the helicopter in hovering flight to the right, was verified.

It was verified that when CP was from the hovering state without the right pedal being , the simulated helicopter rotated to the right. It was also verified that the yaw rate increased as the amount of raised movement in CP increased.

The yaw rate when CP was raised to the maximum position was about 53° per second at the time of the first 90° turn of the heading. Thereafter the yaw rate gradually increased to a maximum of about 130° per second. It also took about 4.5 seconds to change the heading 360° to the right. However, as the altitude increased as CP was used, it was verified that the altitude had increased about 47 m (about 155 ft) from the starting altitude at the time of 360° turn of the heading.

c. Operation to fully apply right pedal

The effect of applying right pedal, which would change the heading of the helicopter in hovering flight to the right, was verified.

It was verified that when the right pedal was applied without moving CP from the hovering state, the simulated helicopter rotated to the right. It was also verified that the yaw rate increased as the amount of right pedal pressure applied increased.

The yaw rate, when the right pedal was fully applied, was about 34° per second at the time of the first 90° turn of the heading. Thereafter the yaw rate gradually increased to a maximum of about 134° per second. Besides, it took about 6.1 seconds to change the heading 360° to the right. Furthermore, the altitude gradually decreased as the right pedal was applied, and the altitude had dropped about 14 ft from the starting altitude at the time of 360° turn of the heading.

In addition, it was easy to stop the right rotation by applying left pedal of the opposite side to the turning direction during the right turn.

d. Fenestron drive system failure

As LTE was not simulated in FFS, the helicopter's response to a failure in fenestron drive system during hovering flight was verified as a case simulating the loss of fenestron effectiveness.

It was verified that when the values simulating the fenestron drive system failure during hovering flight were entered, the simulated helicopter suddenly rotated to the right.

The yaw rate was about 80° per second at the time of the first 90° turn of the heading. Thereafter the yaw rate increased to a maximum of about 187° per second. Besides, it took about 3.3 seconds to change the heading 360° to the right. Furthermore, it was also verified that there was little change in altitude and the rotate to the right continued at almost the same altitude.

Table 2 shows a summary of the results from a. to d. above, with the situation at the time of the accident was listed in the bottom row as a reference.

Table 2: Simulated helicopter’s Response to Flight Operations with FFS (Summary)

Inputs	Simulated helicopter’s Response		
	Maximum turn rate	Trend of altitude change	Time required to turn 360°
CP raise	About 130° per sec.	Climb	About 4.5 sec.
Applied right pedal	About 134° per sec.	Descent	About 6.1 sec.
Fenestron drive system failure	About 187° per sec.	Almost constant	About 3.3 sec.

At the time of the accident	About 200° per sec.	Almost constant	About 3.6 sec.

(8) Simulation Conducted at AHD

Based on the Video analysis and its analysis results, a simulation was conducted at AHD.

a. The following procedure was applied for the analysis of the video:

(a) The speed of the video was reduced into slow motion by a factor of four with the commercial tool.

(b) A sequence of 12 screen shots was done at specific moments of the helicopter attitude and motion:

(i) Estimated moment of "collective up" application (1 image)

(ii) Estimated moment of yaw movement starting (1 image)

(iii) Estimated moments of reaching an increment of 90° heading change compared to the respective previous screenshot (8 images)

(iv) Estimated lowest and highest position of the helicopter during the accident sequence (2 images)

(c) Based on the heading changes obtained from the 10 images from (i) to (iii) above and the time differences, the yaw rate was calculated and plotted on a graph (see Figure 11). It can be seen that a duration from start of rotation until 360° of 2.5 to 3.0 seconds.

(d) Based on (iv) above, it was estimated that the altitude gained during the turn was to have been about 5 m.

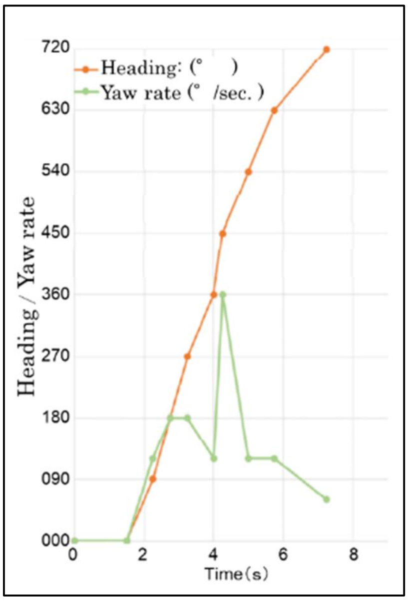


Figure 11: Heading and yaw rate from video analysis

b. Simulation Results

The simulation was attempted at AHD by inputting the helicopter's weight and balance data and the data of the weather conditions at the time of the accident into a simulation tool and creating various scenarios to recreate the helicopter movement at the time of the accident, which was obtained from the Video analysis.

The simulation results revealed that on increase in CP alone would not be sufficient to cause the right turn similar to the one at the time of the accident, and that it would bring to an excessive increase in altitude, greater than that obtained from the Video.

Figure 12 shows the simulation results that were most consistent with the Video analysis.

The upper left graph in Figure 12 shows the flight control inputs during the simulation. The CP position, which corresponds to the left axis of the graph, is shown at 0% for the lowest position and 100 % for the topmost position, and the pedal position, which corresponds to the right axis of the graph, is shown at 50% for the left and right pedals in the same position from front to back, 100% for the right pedal fully applied, 0% for the left pedal fully applied. Therefore, with the pedal position in the middle, a 50% increase in pedal input indicates that the pedals were fully applied.

The hovering state before the start of the simulation is at 0 seconds on the horizontal axis, with the CP position at about 54% and the pedal position at about 38%, thus it can be confirmed that the CP position is almost in the middle up and down, and as for the pedal position, the left pedal is in a slightly forward position.

As can be seen from the top left graph in Figure 12, the simulation scenario that most closely matched the AHD's video analysis was an

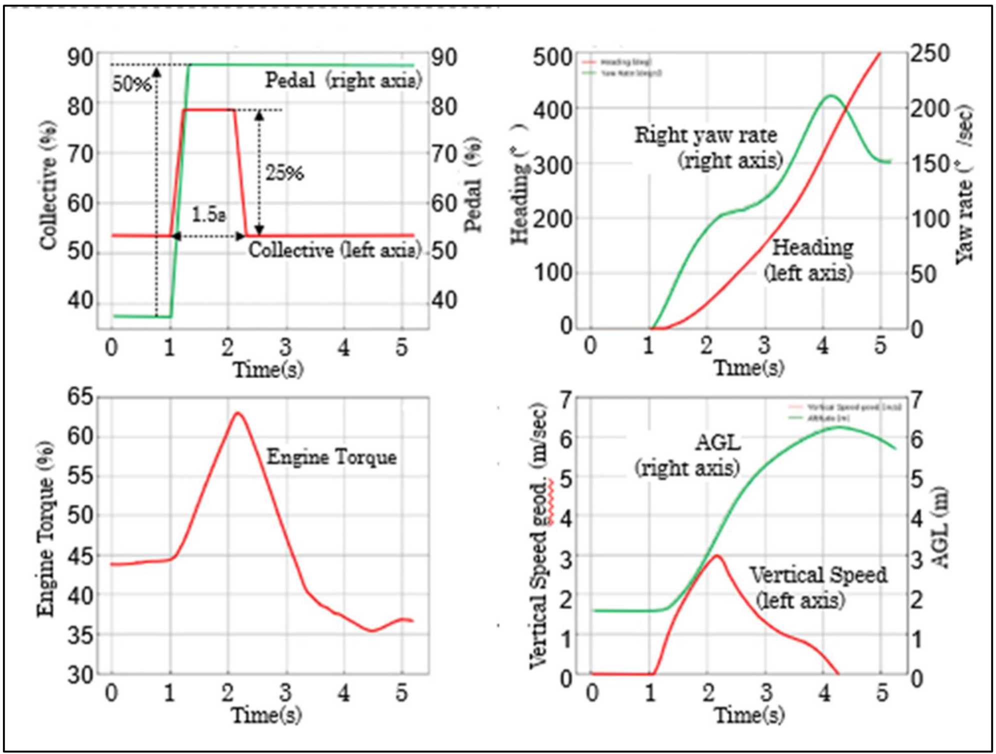


Figure 12: Results of the Simulations at AHD (Excerpt)

operation that increased the right pedal by 50% and raised the CP by 25% from the hover state and returned only the CP to its original position after about 1.5 seconds.

Table 3 shows the comparison between the simulation results and the Video analysis at AHD.

Table 3: Comparison between the Simulation Results and the Video Analysis at AHD

Parameters	Simulation	Video Analysis
Time for one full rotation (sec.)	3.3	2.5 to 3.0
Maximum altitude gain (m)	6	5
Time to the maximum altitude (sec.)	3.25	3.25

AHD evaluated the simulation results as follows:

Even though this pedal input scenario is considered as counter-intuitive it has to be assumed to be realistic based on the helicopter behavior documented in the video.

(9) Turbulence

"Chapter 4, Advanced Flight Maneuvers, Section 2, Confined Area Operations" (p.224) in the "Helicopter Pilot Training manual" describes the following. (Excerpt)

3 Turbulence

(Omitted)

(1) Ground Surface on the Leeward of Obstacles such as Hills, Forest, Buildings

The turbulence region is related to both the shape and size of the obstacles, and its strength can vary depending on the wind speed.

Caution should be exercised for the vortices created by structures and buildings. In particular, when the wind velocity exceeds 20 kt, the airstream splits into irregular vortices, affecting take-off and landings in the leeward area, which is quite far from the structures and buildings.

The location where the helicopter touched down about 20 m short of the Spot was on the apron about 50 m from the building with the Okayama Airport Branch Office, on the windward of which were buildings of varying depth and height and a wide-open car park (see Figure 13).

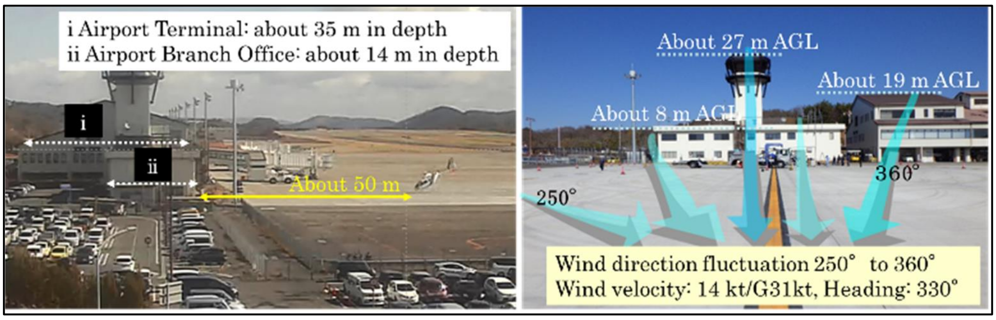


Figure 13: Geographical Situation and Wind Direction in the Area where the Helicopter Touched Down about 20 m short of the Spot

3.ANALYSIS

(1) Damage to the Helicopter

The JTSB concludes, based on the Video records, that it is certain that the accident was that as the helicopter was touched down about 20 m short of the Spot for landing, it became unstable in pitch attitude and lifted off the ground, and after lifting off the ground, it suddenly rotated to the right and made a hard landing while rotating to the right, resulting in the damage to the aircraft.

(2) Turbulence

The JTSB concludes that, based on the pilot's statement, the weather conditions around the time of the accident and the geographical situation in the area where the helicopter touched down about 20 m short of the Spot, it is most likely that there was turbulence in the vicinity of the accident site.

(3) The Helicopter Suddenly Rotate to the Right

The JTSB concludes as follows:

The situation from the time the helicopter touched down about 20 m short of the Spot, which led to the sudden right rotation, was divided into the following three phases for analysis.

- Change of pitch attitude after the helicopter has touched down about 20 m short of the Spot.
- The helicopter lifted off while moving forward with the pitch attitude was significantly downward.
- The helicopter made a sudden right rotation after the lift off.

a. Concerning change of pitch attitude after the helicopter has touched down about 20 m short of the Spot

When the helicopter touched down about 20 m short of the Spot as the pilot considered the effect of the turbulence, the pitch attitude changed repeatedly three times, which was confirmed to follow the same trend as the simulated helicopter's responses to the change in wind velocity using FFS. On this basis, it is more likely that the helicopter's pitch attitude changed due to the effect of a significant change in wind velocity (turbulence). In addition, the scratch marks at two locations each to the right and left of the apron surface (four in all) along the path of the helicopter's forward movement were most likely caused by the underside of the skids hitting the apron surface hard as the helicopter touched down again after tilting forward.

In the FFS verification, even if the wind velocity changed, the helicopter did not move in the touchdown condition when its CP was at the lowest position. Therefore, it is probable that at the time of this accident, although the skids had contacted, the CP had not been at the lowest position, which contributed to the change in pitch attitude.

In the phase when there is a sign of unstable pitch attitude when the helicopter touched down about 20 m short of the Spot, it is important to maintain the pitch attitude by moving the CP to the lowest position, or to have the helicopter climb to change the landing site to one with less effect of turbulence.

b. Concerning the helicopter lifted off while moving forward with the pitch attitude was significantly downward

According to the pilot's statement, when the helicopter's pitch attitude changed after touching down about 20 m short of the Spot, the pilot's left arm holding the CP was fully extended and the CP was about to leave the pilot's left hand, but when the pilot felt the second "boom" impact, the pilot's upper body moved forward, allowing the pilot's hand to firmly reach the CP. In view of the above, although the pilot had the seat belt and shoulder harness fastened, the pilot's upper body was moved forward and backward due to the inertia caused by the change in pitch attitude of the helicopter, as the pilot's left arm holding the CP moved the CP in interaction with the change in pitch attitude, possibly inducing A-PC (collective bounce). In addition, the second change in the pitch attitude of the helicopter was greater than in the first, therefore, the inertia force moving the pilot's upper body forward and backward also increased repeatedly, and at the third pitch change, when the helicopter's pitch attitude was significantly downward, the CP was raised to the position that would allow the helicopter to lift off, caused by A-PC, which possible resulted in the helicopter lifting off while moving forward.

When flying in the turbulence area, or if some turbulence is expected, it is effective to increase the CP friction and to fasten the seat belt and shoulder harness more firmly so that they do not interfere with the flight controls in order to prevent A-PC induction.

c. Concerning the helicopter made a sudden right rotation after the lift off

(a) Analysis of FFS verification results

Based on the results of the FFS verification in this investigation, the helicopter's yaw rate and altitude change during the right rotation were more likely to have been the same trend as when the fenestron drive system failed. And the pilot stated that although the pilot applied the left pedal during the right rotation at the time of the accident, it had no effect, and it is probable that the relative wind at the time of the accident was in conditions that could easily lead to LTE. It is therefore possible that the helicopter encountered LTE, and temporarily lost the effectiveness of the fenestron, resulting in the sudden right rotation.

(b) Analysis of the simulation results at AHD

Regarding the helicopter's sudden right rotation after the lift off, it was concluded in the results of the simulation at AHD that the simulation scenario which most closely matched the Video analysis was the operations of increasing the right pedal input by 50% from the hovering state, with 25% CP up, and returning only CP to the original position about 1.5 seconds later.

As described in b., CP was likely raised to the position which would allow the helicopter to lift off, caused by A-PC. In addition, since the pilot stated that the pilot moved CP down to the lowest position after the helicopter suddenly began to rotate to right, it is possible that before the helicopter rotated, the helicopter's CP was raised, caused by A-PC, and after the helicopter began to rotation, and if CP was lowered by the pilot, CP operations similar to those in the trend of the results of the simulation at AHD were performed.

On the other hand, with regard to the pedal operations, in the AHD simulation, it was the operation to apply 50% right pedal input, but the pilot stated that the pilot fully applied the left pedal immediately after the helicopter suddenly began to rotate to the right. It is certain, therefore, that the pedal input which was concluded to be the most closely matched to the analysis of the Video records at the time of the accident in the AHD simulation, did not match to the pilot's statement. In addition, in the FFS verification, when the nose direction was able to be controlled using pedals, it was easy to stop the right rotation by applying the left pedal even during the right rotation when the right pedal was fully applied, therefore, it is most likely that, as stated by the pilot, the right rotation would not continue when the left pedal was fully applied.

However, according to the mechanic on board's statement that when the helicopter suddenly began to rotate, it was not possible to maintain the attitude without using both hands to support it, it is highly probable that a high lateral acceleration force (G) was generated during the right rotation. Therefore, it is possible that when the helicopter began to rotate to the right with the CP raised, the pilot, who was holding the flight controls with both hands, may have inadvertently applied the right pedal while standing firmly with both feet so as not to be swayed from side to side, but as the helicopter was not equipped with a flight data recorder, the acceleration and pedal positions were unknown, thus, it could not be determined.

From (a) and (b) above, regarding the helicopter suddenly rotate to the right after the lift-off, following possibilities are considered.

- The helicopter encountered LTE after CP was raised, caused by A-PC.
- CP was raised by A-PC, CP was lowered by the pilot after the helicopter began to right rotation, and the right pedal was inadvertently applied as the helicopter began to right rotation.

However, as the helicopter was not equipped with a flight data recorder, the position of each control system was unknown and could not be determined.

It is desirable to promote the installation of Flight Data Monitoring (FDM) *5 in aircraft, which could make it possible to determine the cause of accidents and other incidents, to prevent the reoccurrence of similar accidents, and to improve pilot skills through efficient post-flight analysis.

(4) Response of the Mechanic on Board

The JTSB concludes that the check on the engine instrument panel and the flight report screen records by the mechanic on board after the helicopter touched down provided useful information to confirm that the engine had been operated normally in this investigation. And having demonstrated CRM skills, such as the situational awareness that there was no fire after the accident and making assertion to the pilot at the time of the engine shutdown, were more likely desirable actions to reduce the pilot's workload after the accident.

4. PROBABLE CAUSES

The JTSB concludes that it is certain that the probable cause of this accident was that when the helicopter was touching down for landing, the helicopter's pitch attitude became unstable, causing the helicopter to make a hard landing while rotating right, resulting in damage to the helicopter.

The helicopter lifted off, possibly because the pilot’s upper body was moving forward and backward due to the inertia caused by the unstable pitch attitude caused by the effect of the turbulence, inducing A-PC (collective bounce).

Regarding the sudden right rotation of the helicopter, it is likely that the helicopter encountered LTE (Loss of Tail Rotor Effectiveness), or possibly because the right pedal was inadvertently applied when the helicopter began to rotate to right as the CP was raised, but both could not be determined.

5. SAFETY ACTIONS

5.1 Safety Actions Require	As described in Analysis, when landing in turbulence, it is necessary for the company to inform of the method to avoid turbulence by detecting a sign of as unstable pitch attitude, the possibilities of A-PC induced by turbulence, and the preventive actions.
5.2 Safety Actions Taken after the Accident	Safety actions taken by the company after the accident (1) Provided education and training for weather, A-PC (PIO), and LTE and others, and effectiveness measurement for all crew members (including mechanics) in the company (completed on March 27, 2023).

*5 For more information on matters concerning prevention of accident of small aircraft, see the Japan Transport Safety Board Digests No. 42 "For Prevention of Accidents of Small Aircraft": Do you know flight data monitoring device (FDM)? (issued in August 2023)
(https://jtsb.mlit.go.jp/bunseki-kankoubutu/jtsbdigests_e/jtsbdigests_No42/No42_pdf/jtsbdi-42_all.pdf)

	(2) Provided hands-on training using FFS to prevent reoccurrence to all crew members in the company (completed on April 21, 2023). (3) Provided specific the pilot competence assessment and on-the-job training to return to flight duties (completed on June 13, 2023).