AIRCRAFT ACCIDENT INVESTIGATION REPORT

CRASH

AKAGI HELICOPTER CO., LTD.

KAMAN K-1200 (ROTORCRAFT), JA6200

OKUWA-MURA, KISO-GUN, NAGANO PREFECTURE, JAPAN

AT ABOUT 13:18 JST, SEPTEMBER 20, 2021

May 10, 2024

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 Monday, September 20, 2021, while a Kaman K-1200, JA6200, operated by Akagi Helicopter Co., Ltd., was hovering for helicopter logging, its engine shut down, and the helicopter crashed. Only the captain was on board the helicopter and sustained a minor injury. The helicopter was destroyed but no fire broke out.
1.2 Outline of the Accident Investigation	On September 20, 2021, the Japan Transport Safety Board (JTSB) designated an investigator-in-charge and an investigator to investigate this accident. An accredited representative and an adviser of the United States of America, as the State of Design and Manufacture of the helicopter and the engine involved in the accident, participated in the investigation. On May 6, 2022, while this investigation was underway, the Design and Manufacturing Company of the Model T-53 Engine was changed from Company A to Company B. Comments on the draft Final Report were invited from the parties relevant to the cause of the accident and the Relevant State.

2. FACTUAL INFORMATION

2.1 History of the Flight

According to the statements of the captain, and the worker who was working to prepare for helicopter logging under the helicopter, the history of the flight is summarized as below:

Figure 1: Accident Site

Besides, according to a mechanic who conducted the pre-flight inspection, no abnormalities were found on the helicopter before departure.

On September 20, 2021, at about 13:01 Japan Standard Time (JST: UTC+ 9hr, unless otherwise stated, all times are indicated in JST on a 24-hour clock), the helicopter took off from Tonooku Operation Site, Okuwa-mura, Kiso-gun, Nagano Prefecture to helicopter logging, with only the captain sitting in the pilot seat, and started helicopter logging back and forth from the loading site in the mountain forest located east side of the Operation Site to the unloading site adjacent to the Operation Site. On the 6th transport run, the helicopter flew to the loading site located about 2 km east of the Operation Site and made a transition to an eastward hovering at a ground altitude of about 40 m over the loading site (See Figure 1).

One worker was working immediately under the helicopter, preparing to bundle the timbers to be carried out with wire and sling them on the sling cable hook.

After the transition to hovering, the captain felt the collective pitch lever momentarily vibrating in small motions with a “rasping", and heard a "whoosh" sound, with which the engine shut down, immediately after that. While transmitting by radio, “Run-away”, the captain controlled the cyclic stick to the right forward direction (valley side) to ensure the safety for the worker who was working immediately under the helicopter.

With its heading facing the valley side while contacting with the trees (southwest), the helicopter crashed into the mountains about 20 m south side from the hovering position with its nose facing downward. The helicopter’s attitude after the crash was about 70° in the nose-down direction with the roll angle of about 80° to the left. Broken pieces of the helicopter were scattered over a radius of approximately 20 m from the crash site (See Figure2).

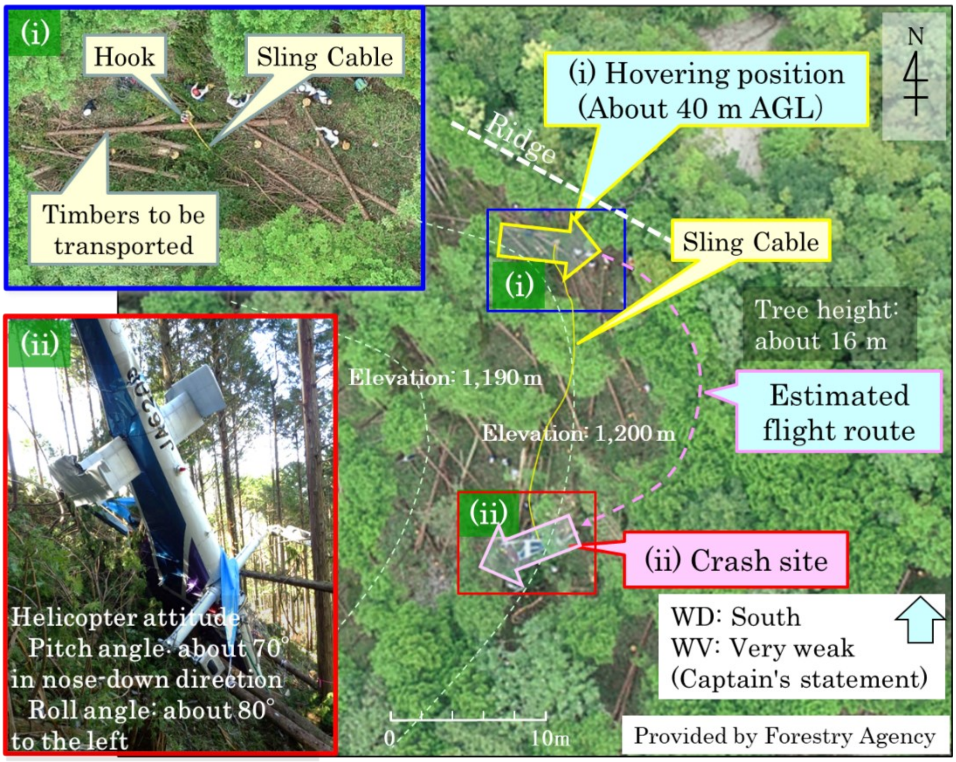


Figure 2: Estimated Flight Route and Crash Site

Immediately after hearing a "whoosh" sound of the engine shutdown and the radio from the captain, saying "Run-away", the worker visually confirmed the helicopter crashed.

After the crash, the captain took actions such as turning off the fuel supply and the battery power, then took off the seat belt, escaped through the cracked area in the front right side of the windshield from the helicopter.

The accident occurred in the mountains (35°44'01"N, 137°41'29"E) at an elevation of approximately 1,200 m in Okuwa-mura, Kiso-gun, Nagano Prefecture at about 13:18, September 20, 2021.

2.2 Injuries to Persons

Captain: minor injury

2.3 Damage

(1) Extent of Damage: Destroyed

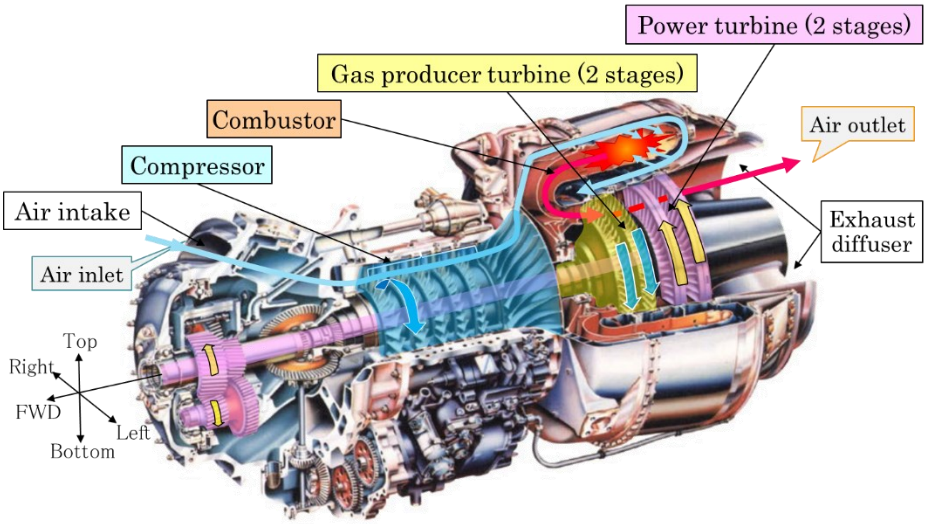
(2) Damage to the Aircraft Components (except engine, see Figure 3)

- i) Rotor blades : All four blades were fractured
- ii) Vertical fin (Rudder) : Fractured at its root
- iii) Vertical fin (Vertical stabilizer) : Damaged
- iv) Fuselage, tail boom : Damaged
- v) Windshield : Broken

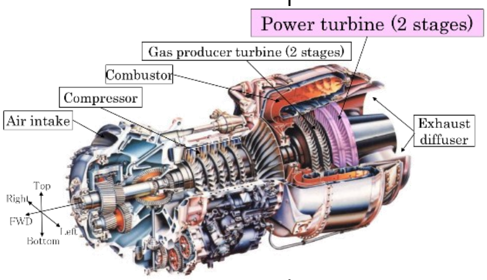
Figure 3: Damage to the Helicopter Components (except engine)

(3) Damage to the Engine

- i) The Overview of the Engine

	he engine of the helicopter is a turboshaft engine, which is composed of air intake, compressor, combustor, gas producer turbine (two stages), power turbine (two stages) and exhaust diffuser, from the fore (see Figure 4).  Figure 4: Names of Engine Parts ii) Engine Disassembly Inspection The disassembly inspection of the engine was performed at a facility in the Design and Manufacturing Company (Company A). he damage to the engine revealed by the inspection was as follow: a. External appearance of the engine The external appearance of the engine was clean and did not show any damage caused by a fire or traces of the casing penetration. b. Compressor Light scratch marks were observed in the circumferential direction on the tips of the compressor blades. c. Gas producer turbine No damage was observed to the gas producer turbine. d. Exhaust diffuser On the cross-shaped structural support struts inside the exhaust diffuser, there was a crack, which was probably caused by the impact of scattered broken pieces, and on the surface inside the exhaust diffuser, scratch marks were observed. e. Power turbine (hereinafter referred to as "PT")

The PT configuration consists of two stages such that one stage is formed by a pair of a non-rotating PT nozzle and a rotating PT rotor. (Hereafter, the forward stage is referred to as "PT1" and the backward stage as "PT2.") (See Figure 5.)



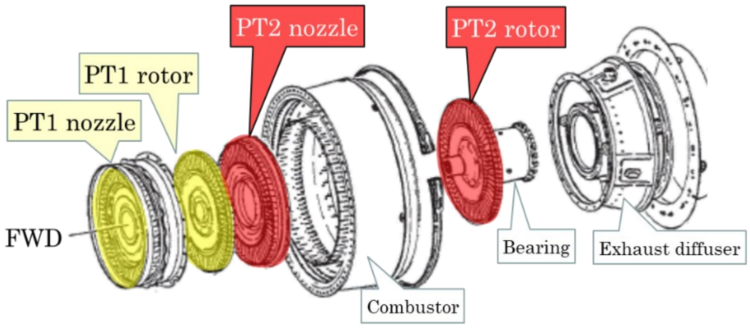


Figure 5: PT Configuration

As for PT rotor blades (Figure 6 (i)), 66 blades for PT1 and those 62 for PT2, are mounted radially around circumference of the rotor disk (Figure 6 (ii)).

The outer circumferential side of the PT rotor blades form an umbrella type shape called tip shroud (hereinafter referred to as “Shroud”) (Figure 6 (iii)), in which Shroud is structured to encircle the outer circumference of the PT rotor that would keep the seal effect against combustion gas leakage. Blade A is mounted on each odd-numbered rotor blade and Blade B on each even-numbered one. Adjacent Blade A and B form a pair (hereinafter referred to as “Pair(s)”), and Shroud is in close contact (Figure 6 (iv)), but there is a gap between each Pair called the shroud gap (Figure 6 (v)). The shroud gap between adjacent Pairs is called the "individual gap", and the sum of the individual gaps of all rotors is called "cumulative gap".

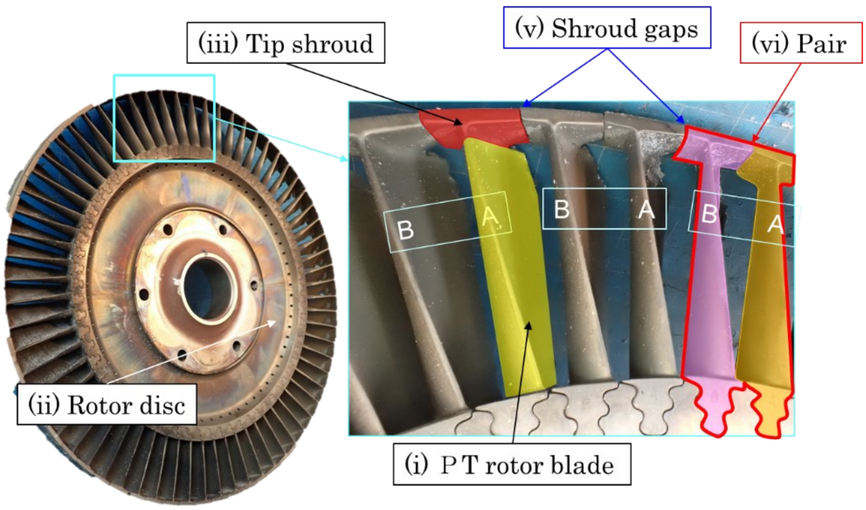


Figure 6: PT1 Rotor

(a) PT1 Nozzle

The PT1 nozzle aft flange was found separated, but no damage was observed to the PT1 nozzle airfoils.

(b) PT1 Rotor

As for the PT1 Rotor, damage was observed to the trailing edge of about half the blades and the Shroud.

(c) PT2 Nozzle

The outer periphery of the PT2 nozzle was deformed and severe damage was observed all around the trailing edge of the nozzle vane outer periphery.

(d) PT2 Rotor

The PT2 rotor blades (62 blades) were all broken, of which 43 PT rotor blades were broken at the airfoil root section, and other remaining 19 blades approximately in the intermediate positions (see Figure 7).

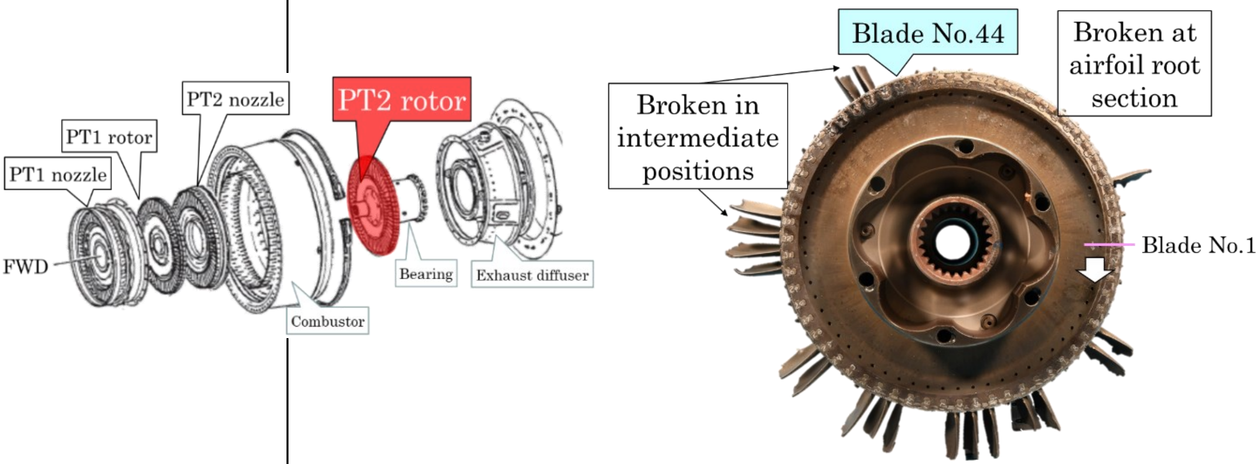


Figure 7: Damage to PT2 Rotor Blades

The visual check of the fracture surface of the PT2 rotor blades revealed that only for the blade number 44 (hereinafter referred to as “Blade 44”), approximately 1/3 of the fracture surface on the leading edge side was smooth and that on the trailing edge side was rough. Other than Blade 44, all PT rotor blades had rough fracture surfaces on all sides.

(4) Detailed Examination of Blade 44

Following the disassembly inspection, the detailed examination of the Blade 44 fracture surface was conducted using an optical microscope, a Scanning Electron Microscope (hereinafter referred to as “SEM”), and an Energy dispersive X-ray analysis. The enlarged view of the fracture surface of Blade 44 is shown in Figure 8, SEM images in Figure 9.

The result of the detailed examination revealed that Blade 44 base material was IN713C material specified in design, the smooth fracture surface on about 1/3 of the leading edge side indicated the fatigue region emanating from its origin of a sub-surface faceted region near the leading edge of the blade, in addition, a rough fracture surface on its trailing edge side was caused by the overload.

In Figure 8 and 9, the red arrows identify the direction of fatigue propagation, and the red dashed lines indicate the extent of fatigue propagation.

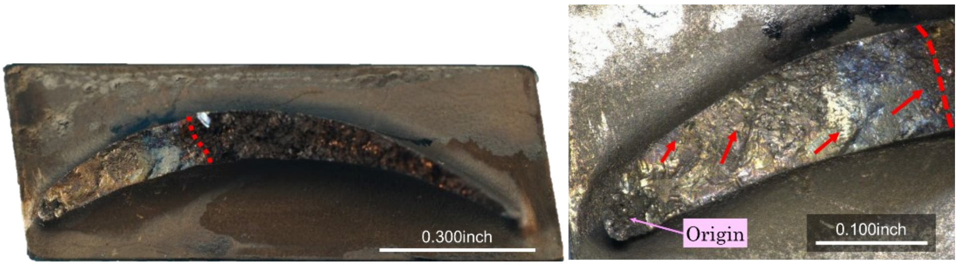


Figure 8: Enlarged View of the fractured surface of Blade 44

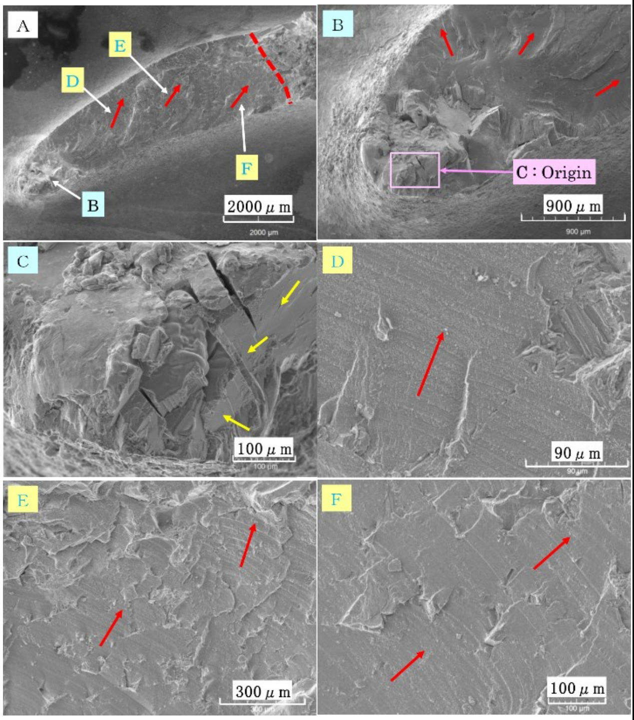


Figure 9: SEM Images of Blade 44

Figure 9A is an SEM image of the entire fatigue surface seen on approximately 1/3 of fracture region on the Blade 44 leading edge side. Among those SEM images, B shows the fatigue origin (pink arrow), C indicates the faceted region (yellow arrow) that is a fatigue origin, and D to F identify the fatigue propagation section. In the fatigue region, shell-like patterns (beach marks) suggestive of the High Cycle Fatigue (hereinafter referred to as “HCF”) propagation were observed.

According to the Design and Manufacturing Company of the engine (Company B), the HCF of the same type of engines was caused by the high frequency vibration load generated by the flutter[*1] that would occur in the PT rotor blades, which has come to be easily moved due to excessive shroud gap.

(5) Other Damage

When the helicopter crashed, 12 trees were broken off.

2.4 Personnel Information	Captain:	Age: 52
	Commercial pilot certificate (Rotorcraft)	August 9, 2000
	Type rating for single-turbine engine (Land)	August 23, 1991
	Specific Pilot Competence	

*1 “Flutter” is a dynamic instability resulting from the interplay between the elastic resilience, inertia, and aerodynamic forces of the rotor blades, and a phenomenon which manifests oscillations centered at a fixed point (rotor blade mounts) persist in proportion to the distance and, if divergent, may lead to structural destruction.

	Expiry of practicable period for flight March 26, 2023 Class 1 aviation medical certificate Validity: February 25, 2022 Total flight time 9,430 hours 54 minutes Total flight time on the type of aircraft 4,719 hours 30 minutes Total flight time in the last 30 days 23 hours 57 minutes
2.5 Aircraft Information	(1) Aircraft Aircraft type: Kaman K-1200 Serial number: A94-0020 Date of manufacture: December 2, 1996 Certificate of airworthiness: No.DAI-2020-703 Validity: March 18, 2022 Category of airworthiness Rotorcraft, Normal N/Special aircraft X Total flight time: 10,584 hours 6 minutes (2) Engine Type: Lycoming, T5317A-1 Serial number: LE81009 Date of manufacture: November 3, 1994 Number of installed equipment: 1 Total time in service: 8,633 hours 45 minutes Time in service since latest overhaul: 899 hours 48 minutes Time in service since last periodical check: 4 hours 16 minutes (3) Weight and Balance When the accident occurred, the weight and the position of the center of gravity of the helicopter were within the allowable range.
2.6 Meteorological Information	According to the statement of the captain, the weather conditions in the vicinity of the accident site were as follows: Weather: Fine, Wind direction South; Wind velocity Very weak Visibility 10 km or more
2.7 Additional Information	(1) Total Shroud Gap Growth Rate The shroud gap is considered to increase due to fretting and erosion wear over time of use. According to its Design and Manufacturing Company (Company B), based on the data on the maintenance of the same type of engines to date, an average cumulative gap growth rate (hereinafter referred to as the "growth rate") can be calculated. However, the individual gaps do not all open uniformly, but rather there are generally variations in relation to many factors such as differences in individual gaps during assembly and the effects of operation. (2) Record of 2nd Overhaul for the Engine (LE81009) On July 21, 2017, the 2nd overhaul (hereinafter referred to as “O/H”) for the engine was conducted in the maintenance facility that was certified by the Design and Manufacturing Company (Company A) (hereinafter referred to as the “Maintenance Facility”). At the 2nd O/H, the total time in service of the engine was about 7,734 hours. In addition, as for both of

	PT1 and PT2, there was no replacement history of rotor blades and rotor disc from their newly production to the 2nd O/H. The repair details and others for each PT rotor blade during the 2nd O/H are as follows: i) PT1 40 rotor blades were replaced due to a shroud gap failure (All (33) pieces of Blade A and 7 pieces of Blade B (26 blades remaining). The rotor disc was not replaced. After the repair, the cumulative gap was documented as 0.033 in., but the individual gap was not documented. And as for the shroud gaps at the time of the 2nd O/H, no as-received dimensions documented both of cumulative and individual gap. ii) PT2 The rotor blades and rotor disc were not replaced. The cumulative gap at the received was documented as 0.117 in., but the individual gap was not documented. Besides, at the inspection of the shroud gap during the 2nd O/H, the same inspector of the Maintenance Facility documented both PT1 and PT2 measurements. (3) Similar cases in the Company i) Overview of Similar cases On March 25, 2018, during ground operation of the engine, the PT rotor blades of the engine of the same type(SN: P-81029) (hereinafter referred to as "P81029") installed on Kaman Helicopter JA6184, which was owned by the Company, were fractured with a sudden big popping sound, and the engine and the airframe were damaged by the scattering debris. The total time in service of P81029 at the time was approximately 4,600 hours since newly produced, an O/H was not conducted in the past, there was no replacement history for the rotor blades and rotor disc of both of PT1 and PT2. For P81029 whose PT rotor blades were fractured, the disassembly inspection was performed at the facility of the Design and Manufacturing Company (Company A) on April 27, 2018. The Company received the inspection results in writing from the Design and Manufacturing Company (Company A). The summary of the disassembly inspection results the Company had received are as follows: a. As a result from SEM examination, it was confirmed that there was the trace of fatigue initiating from a similar location on each of five blades of all PT2 rotor blades of P81029. Based on the experience of the Design and Manufacturing Company (Company A), it is unlikely that fatigue would initiate from similar locations on multiple rotor blades when there was a problem with the materials of the rotor blades.

	b. The Company's commercial fleet records associated with operation of the same type of engines between 2008 and 2018 indicate approximately 177,500 hours have been accumulated during this timeframe. And there were two events associated with the damage to PT2 rotor blades over this period, which is equivalent to one event in 88,750 hours. According to the Engine & Propeller Directorate Continued Airworthiness Assessment Process Handbook created by the US Federal Aviation Administration (FAA), in case of in-flight shutdown and power loss event rate > 0.1/1,000 hours, it should be investigated, and corrective action should be implemented to maintain safe operation. c. The Design and Manufacturing Company (Company A) will continue the investigation to determine the cause of fatigue that led to damage to the PT2 rotor blades. ii) Records from Disassembly Inspection of P81029 Despite of checking the maintenance records in the Maintenance Facility for the disassembly inspection of P81029, the inspection results of the shroud gap were unable to be confirmed. iii) Response of the Company upon Receipt of the Disassembly Inspection Results of the Similar Case From the results of the disassembly inspection results received from the Design and Manufacturing Company (Company A), the Company determined as follows: a. It is assumed that there was a failure specific to the engine. b. It can be said that the probability of a similar failure is extremely low. c. The FAA Guideline described that in case of in-flight shutdown and power loss event rate > 0.1/1,000 hours, it should be investigated, and corrective action should be implemented, however, for the same type of engines, in-flight shutdown and the power loss event rate was 0.1/8,875 hours, thus, it is not the event that corrective action should be implemented immediately. In addition, the Company inquired of the Design and Manufacturing Company (Company A) about the necessity of additional inspections and others and received a verbal response that there were no effective additional inspections, etc., at that time. However, on May 5, 2018, the Company issued a technical news based on the Company's maintenance implementation guideline and stipulated its own measures for "Special Inspection of Engines due to Fracture of the Power Turbine Rotor Blades of the same type of Engines (hereinafter referred to as "Special Inspection of Blade Fracture") as the Company's own measures. The items to be performed during the Special Inspection of Blade Fracture are as follows: ・ Visual inspection of PT2 rotor

・ Inspection of the tip clearance of PT2 rotor blades (clearance between the circumference of Shroud and the casing)

・ Inspection of PT2 rotor for the presence of abnormal noise and binding by manually rotating

In addition, the Special Inspection of Blade Fracture just before this accident was conducted on September 15, 2021, and as of the inspection date, the total time in service of engine was approximately 8,629 hours and the time in service of engine between the inspection and the accident was 4 hours 16 minutes.

(4) Service Bulletin

On December 11, 2018, the Design and Manufacturing Company (Company A) issued a service bulletin (SB T53-0195) on "Power Turbine Rotors-Blade Shroud Gap Check" (hereinafter referred to as the "SB") as a corrective action for similar cases.

The SB is related to the inspection of the shroud gap of PT rotor blades, and the contents of the shroud gap inspection procedure described in the SB (hereinafter referred to as the "Inspection Procedure") were same as those described in the O/H manual.

The summary of the contents of the SB applicable to the PT2 of the Ozark Engine with an O/H interval of 5,000 hours is as follows:

i) Reason for issuing the SB

a. When PT rotor blade shroud gaps are excessive, single blade failures can occur.

b. Operating an engine with PT2 rotors with either excessive individual or cumulative gaps can lead to the uncontained blade failures.

ii) Compliance

In accordance with the instruction in this SB, in order to have the shroud gap inspected, engines that have not had the shroud gap inspected at the O/H or the 2,500-hour midpoint inspection must be returned to authorized service center within 500 elapsed engine operating hours from release date of this SB.

iii) Measure and record

a. The shim*2 shall be inserted in the individual gap between each pair, and doing so, do not force the shims.

b. If a 0.001 in. shim is too loose and will fall out, insert a shim that is 0.002 in. or larger and has light drag on it when inserted (Light Drag Fit method).

c. The drag of each shim shall be confirmed again after the shims are inserted in all the individual gaps, and any shim having excess drag is to be removed and a smaller shim inserted with the proper light drag on it.

*2 A "shim" is a thin plate used to fill gaps, and by sandwiching the shim between two parts, the gap can be filled, or the height can be adjusted.

d. In case that part of or all PT2 rotor blades which were not re-bladed, the allowable value of each gap shall be as follows:

(a) Individual gap

0.000 to 0.020 in.

(b) Cumulative gap

0.016 to 0.210 in.

In case of the cumulative gap exceeds the upper value, replace blades as necessary to obtain proper gap in accordance with the repair manual. In case of the cumulative gap smaller than the lower value, the blades shall be repaired or replaced in accordance with the repair manual.

(5) Maintenance Facility's Response to the SB

On June 24, 2019, the Maintenance Facility sent to the Company a notice stating that from the records at the 2nd O/H of the engine, the results of the shroud gap inspection conducted at the time met the requirement of the SB, in addition, the shroud gap inspection based on the SB shall not be necessary until the next midpoint inspection when the time in service of the engine would pass 2,500 hours since the 2nd O/H.

(6) The Company's Response to the SB

On June 24, 2019, receiving from the Maintenance Facility the notice stating that the shroud gap inspection based on the SB shall not be necessary until the next midpoint inspection when the time in service of the engine would pass 2,500 hours since the 2nd O/H, the Company recorded in the flight logbook of the engine, describing that the implementation of the SB was confirmed.

(7) Opinion Expressed by the Design and Manufacturing Company (Company B) in the Investigation after the Accident

i) Opinion on the records of the 2nd O/H of the engine

a. PT1

After the repair, the PT1 cumulative gap was documented as 0.033 in. On the other hand, the cumulative gap measured by the Design and Manufacturing Company (Company B) after the assembly with the newly produced rotor disc and all new rotor blades was approximately 0.050 in. And in comparison with this, for the PT1 whose rotor disc and part of rotor blades had not been replaced, the cumulative gap of 0.033 in. is unreasonable small, and it is difficult to believe this value to be correct.

For the PT1 rotor blades of the engine, 26 blades without replacement history remained mounted on the rotor disc used for approximately 7,734 hours. From this, it is reasonable to estimated that the PT1 cumulative gap of the engine was 0.050 in. or more, in case that all were replaced with new ones, or probably more than 0.100 in.

b. PT2

The PT2 cumulative gap was documented as 0.117 in. at the time of the received, which was unreasonably small for the cumulative gap of the PT that had been used for over 7,000 hours without any replacement, and difficult to be considered as an appropriate value.

Assuming the PT cumulative gap as 0.050 in. at its newly produced as mentioned above, if the total time in service of the engine (about 7,734 hours) is multiplied by the growth rate and added, the cumulative gap at the time of the received should be estimated to be approximately 0.3 in.

ii) Opinion Expressed by the Design and Manufacturing Company (Company B) on the Inspection Procedure

In consultation with the FAA, the Design and Manufacturing Company (Company B), chose to address the following three points in the Inspection Procedure.

a. The Inspection Procedure contained descriptions that shims shall be used for the measurement of shroud gaps, however, there was no specifications on the standards of the shim. Therefore, the Maintenance Facility used those locally fabricated shims for the measurement of shroud gaps, but those locally fabricated ones likely varied in quality.

b. In the Inspection Procedure, the “drag” when a shim is inserted was described only as “light drag”, allowing for different interpretations depending on the inspector making the measurement, which have probably resulted in variations in measurement techniques.

c. The items to be recorded at the inspection are not specified.

What items that should be recorded at the inspection (at the received and after the repair) of shroud gaps were not specifically indicated in the Inspection Procedure. In addition, the form of SB completion report to be sent to the Design and Manufacturing Company (Company A) after the inspection did not have a column to write down the results of the shroud gap inspection (see Figure 10).

This is to inform you that the service bulletin has been complied with as indicated below:

SERVICE BULLETIN ____________ REVISION ____ DATE ________

Engine Model ________ Serial# ________ Hours ________ Cycles ________

PT Rotor 1 PN ________ Serial# ________ Hours ________ Cycles ________

PT Rotor 2 PN ________ Serial# ________ Hours ________ Cycles ________

Figure 10: SB Completion Report Form Specified in the SB
(Excerpts of the part related to the records)

3. ANALYSIS

(1) Shutdown of the Engine

The JTSB concludes that it is certain that based on the statements of the captain and the worker, and the damage to the engine, the engine shut down despite of the captain not performing the engine shutdown procedure.

The engine was damaged because the Blade 44 was broken initially and broken pieces of the Blade 44 damaged other PT2 rotor blades, at this time, the engine probably shut down. Besides, it is highly probable that broken pieces of the damaged PT2 rotor blades were scattered forward and backward, causing secondary damage to the upstream PT2 nozzle and the downstream exhaust diffuser. Furthermore, it is probable that the engine rotating shaft went out of balance due to the damage to PT2 rotor, the compressor and PT1 rotor rubbed against the engine case, leading to scratch marks on the compressor and damage to the PT1 rotor.

(2) Fracture of Blade 44

The JTSB concludes that the Blade 44 was highly probable fractured because the region of the fatigue due to the HCF initiating from near the leading edge propagated to the trailing edge side, and when the fatigue region reached approximately 1/3 from its leading edge, the Blade 44 became no longer able to withstand the load and was fractured, from the features of the fractured surface.

The HCF on the Blade 44 was probably caused by the high frequency vibration that occurred due to the flutter of the Blade 44 generated as the excessive PT2 shroud gap had influenced the individual gaps of the Blade 44, which became easier to move.

(3) PT2 Shroud Gap

The JTSB concludes that at the time of the 2nd O/H received, the PT2 cumulative gap had possibly expanded to approximately 0.3 in., assuming that the cumulative gap for a new PT2 was 0.050 in. and adding up the time in service of the engine until the 2nd O/H (about 7,734 hours) was multiplied by the growth rate. From this, it is possible that the individual gaps of the Blade 44 were excessive.

However, it is certain that at the time of the 2nd O/H received, the PT2 cumulative gap examined at the Maintenance Facility resulted in 0.117 in. that was judged to be within the allowable value (0.210 in.), therefore, both rotor blades and rotor disc were not replaced.

In addition, after a year and 5 months from the 2nd O/H, the SB was issued, it is certain that the Maintenance Facility judged that the engine was not subject to the shroud gap inspection in accordance with the SB because the inspection results of the 2nd O/H of the engine were within the allowable value, and the time in service of the engine from the 2nd O/H did not pass 2,500 hours.

From this, it is certain that the PT2 was used without its rotor blades and rotor disc being replaced since it was newly produced until this accident occurred.

(4) Inspection Procedure

i) The JTSB concludes that at the shroud gap inspection conducted in the 2nd O/H of the engine, the Maintenance Facility measurement likely made incorrect shroud gap measurements for both PT 1 and PT 2, to which the following two points in the Inspection Procedure more likely contributed.

a. About shims

The Inspection Procedure contained descriptions that shims shall be used for the measurement of shroud gaps, but there were no standards of the shim specified, thus, the Maintenance Facility used the shims that they made by themselves for the shroud gap measurement. But those locally fabricated shims likely varied in quality, which more likely influenced the inspection results.

b. Drag when a shim is inserted.

In the Inspection Procedure, the drag when a shim is inserted was described only as "light drag."

It is probable that this expression would allow different interpretations depending on the inspectors, which had resulted in variations of the shroud gap measurement techniques.

ii) It is required for the Design and Manufacturing Company (Company B) to consider the Inspection Procedure, including following issues, to prevent a reoccurrence of similar accidents.

a. Specify suitable and calibrated equipment for measurements.

b. Establish specific and quantitative inspection procedure.

(5) Records of Inspection Results

The JTSB concludes that the Inspection Procedure contained descriptions that shroud gaps shall be measured and recorded, but did not describe what items should be specifically recorded, and the form of SB completion report to be sent to the Design and Manufacturing Company (Company A) after the inspection did not have a column to write down the results of the shroud gap inspection, which most likely contributed to the only partially kept records of the engine's inspection after O/H.

It is necessary for the Design and Manufacturing Company (Company B) to specifically indicate and manage the contents of inspection result records, and the preservation procedure.

4. PROBABLE CAUSES

The JTSB concludes that it is certain that the cause of this accident was that while the helicopter was hovering, the engine shut down because the Blade 44 of PT2 rotor was fractured, resulting in the crash.

The Blade 44 was fractured because the inspection result of PT2 cumulative gap was determined to be within the allowable value during the 2nd O/H and the rotor blade and disks were not replaced, which most likely caused the subsequent excessive shroud gap and the flutter on the blade, leading to the HCF and the fracture.

Regarding the judgment that the PT2 cumulative gap inspection result was within allowable value in the 2nd O/H, it is possible that the Inspection Procedure, which allowed for different interpretations, caused variations in shim tooling quality and shroud gap measurement techniques at the Maintenance Facility, resulting in inaccurate shroud gap measurements.

5. SAFETY ACTIONS

5.1 Safety Actions Required	As indicated in the ANALYSIS, it is required for the Design and Manufacturing Company (Company B) to consider, including following issues, preventive measures for a reoccurrence of similar accidents, in relation to the Inspection Procedure. (1) Specify suitable for shroud gap measurements and calibrated equipment. (2) For the Inspection Procedure, establish specific and quantitative inspection procedure. (3) Be specifically indicate and manage about the contents of shroud gap inspection result records, and the record preservation procedure.

5.2 Safety Actions Taken after the Accident	Measures Taken by the Design and Manufacturing Company (Company B) after the Accident The Design and Manufacturing Company (Company B) developed and implemented the following corrective actions to minimize the possibility of reoccurrence of similar accidents. (1) Issuance of new Service Bulletin (on April 17, 2023) The Design and Manufacturing Company (Company B) issued a new Service Bulletin (SB T5317-210) (hereinafter referred to as the "New SB"), to supersede the SB, in which the Inspection Procedure for shroud gaps was changed as follows: i) As for the measurement shims described in the Inspection Procedure of the SB, they were specified in the New SB that a feeler gauge (see Figure 11), which are materials used to measure gap widths shall be used.  Figure 11: Feeler Gauge ii) The Inspection Procedure of the SB describes the "Light Drag Fit method", in which it is stated that "a shim with the light drag on it shall be inserted when inserting the shim", however, in the New SB, the method was changed to the "Measured Firm Drag Fit method" that is the Inspection Procedure that would not allow different interpretations depending on the inspectors, and it was stated that "after inserting all feeler gauges in the shroud gap, the shroud gaps shall be measured with a feeler gauge inserted of a thickness that does not cause visible displacement when a 1 lb. minimum vertical pull shall be applied". iii) In the New SB, a format with the columns to record all individual gaps, maximum individual gap, and cumulative gap was stipulated as an appendix, in addition, it was required to send those records to the Design and Manufacturing Company (Company B) from the Maintenance Facility certified by the Design and Manufacturing Company (Company B) on the purpose of continuous data analysis. iv) The inspection interval for the Ozark Engine(with an O/H interval of 5,000 hours) was changed from 2,500 hours so far to 1,250 hours. (2) Temporary Revision of O/H manual (on July 11, 2023) The O/H manual for the same type of engines was temporarily revised to reflect the Inspection Procedure of the New SB. (3) New Training for Inspectors The Design and Manufacturing Company (Company B) established a new training program to certify inspectors to clarify and standardize the shroud gap inspection techniques.