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Cracked R22 Main-rotor Blade Results in Warning on Vibration

The U.K. Air Accidents Investigation Branch said that the blade was near catastrophic failure because of the crack, which was 80 millimeters (three inches) long, in a main-rotor blade root-end fitting.

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FSF Editorial Staff

About 0855 local time on May 14, 2002, a Robinson R22 Beta helicopter was on a photographic surveying flight near Maxey, Cambridgeshire, England, when the pilot decided to end the flight because of an increasingly severe vibration that he believed involved the main-rotor head. The pilot landed the helicopter at a nearby airport, where maintenance personnel found an 80-millimeter-long (three-inch-long) crack in a main-rotor-blade root-end fitting, near the root end. The helicopter was otherwise undamaged, and the pilot and his passenger — the photographer, who was the helicopter's owner — were not injured.

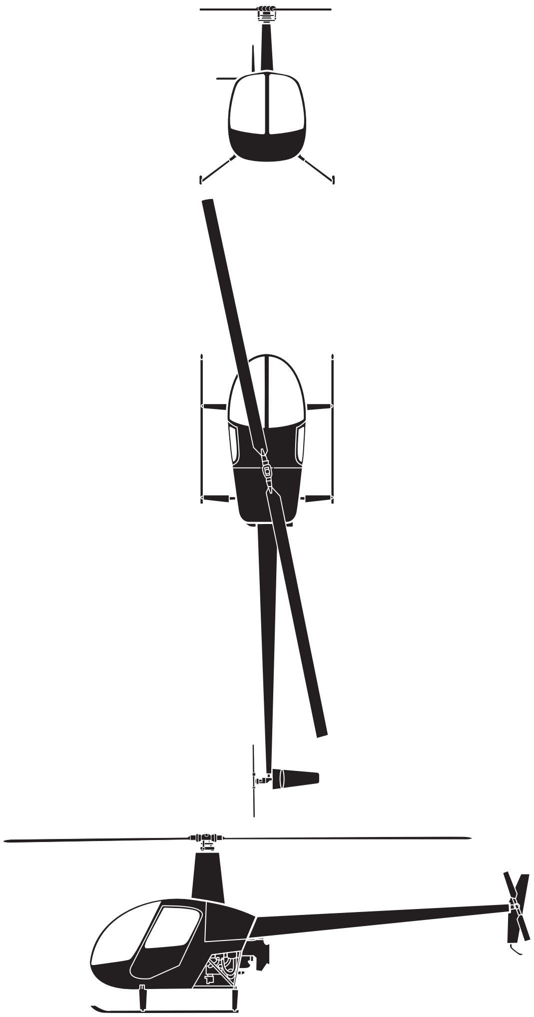
The U.K. Air Accidents Investigation Branch (AAIB), in its final report, said, "The crack was caused by a fatigue process, which had initiated at multiple origins at the lower leading edge corner of this forged-aluminum root fitting. No prior instances of fatigue cracking have been known to occur at this location. Crack initiation was attributed to a particularly adverse combination of factors, including transverse scoring and significant local erosion of material. … This had been caused by hand-grinding operations to remove excess adhesive during manufacture."

The area where the crack occurred was "an area of likely stress concentration due to a section change of the forged-aluminum-alloy root fitting," the report said.

"The significance of damaging the surface was apparently not understood by the operatives involved, nor was it detected by inspection before being hidden from view by filler and finish paint layers during subsequent stages of manufacture."

The report said that the crack meant that the blade was "extremely close to the point of catastrophic failure."

The morning of the incident, the pilot flew the helicopter from his home to Maxey, where the owner boarded for the planned photographic survey. The helicopter was used primarily for this purpose, with the owner operating the camera from the



Robinson R22 Beta

The Robinson R22 Beta is a light two-seat helicopter with a two-blade main rotor and a two-blade tail rotor. The R22 first was flown in 1975, the R22 Alpha was certificated in 1983, and the R22 Beta was certificated in 1985.

The helicopter has one 119-kilowatt (160-horsepower) Textron Lycoming O-320-B2C piston engine. The main fuel tank has a usable capacity of 72.5 liters (19.2 gallons); an auxiliary fuel tank has a capacity of 39.8 liters (10.5 gallons). The main rotor blades are made of bonded metal with a stainless-steel spar and leading edge, an aluminum-alloy skin and an aluminum-alloy honeycomb core; the rotor is equipped with a tri-hinge underslung rotor head to reduce blade flexing, rotor vibration and control-force feedback. The main-rotor diameter is 7.7 meters (25.2 feet).

Empty weight is 379 kilograms (835 pounds); maximum takeoff and landing weight is 621 kilograms (1,370 pounds).

Maximum rate of climb at sea level is 1,200 feet per minute. Hovering ceiling in ground effect is 6,970 feet.

Maximum level speed is 97 knots. Range at sea level with auxiliary fuel, maximum payload and no fuel reserves is 319 nautical miles (592 kilometers).♦

Source: Jane's *All the World's Aircraft, U.K. Air Accidents Investigation Branch Report EW/C2002/05/04.*

left seat. During the flight to Maxey, the pilot felt vibration, as he had on the previous flight in the helicopter.

After the takeoff from Maxey, the vibration worsened, and the pilot flew the helicopter to Sywell Aerodrome in Northampton, where the helicopter was maintained.

"Some 20 minutes into the flight, the vibration became markedly worse, but with Sywell now in sight, the pilot decided to continue," the report said.

The pilot said later that he had not been overly concerned because he had felt similar vibrations in other types of helicopters.

After the helicopter was landed, a maintenance test pilot inspected the helicopter and found oil contamination around the rotor head. While investigating the source of the leak, he found the crack in the main-rotor blade. The report said that the test pilot was "appalled at the extent of the crack" and that he grounded the helicopter until completion of the AAIB investigation.

The incident pilot had 13,500 flight hours, including 8,000 flight hours in R22s, 250 flight hours in the previous 90 days and 64 flight hours in the previous 28 days.

The helicopter was manufactured in 1991 and was flown initially in Finland. In 2000, a major overhaul was performed, and the helicopter was purchased for use in aerial photography in England. When the incident occurred, the helicopter had accumulated 747 flight hours since overhaul, and 2,747 flight hours since new. The main-rotor blades on the helicopter were manufactured by the Robinson Helicopter Co. (RHC) and were delivered as a matched pair in February 2000, when they were installed on the incident helicopter during the major overhaul. No repairs had been performed on the blades since manufacture, and the blades had been operated normally — without abnormally high flight-maneuvering loads or the occurrence of any event that would have caused physical changes to make the blade more susceptible to fatigue cracking.

Maintenance records showed that during an annual inspection about 8.6 hours before the incident, maintenance personnel had performed several tasks involving the main-rotor system, including an inspection for blade-root cracks.

During a routine test flight after annual maintenance, a test pilot felt an airframe vibration. The vibration was apparent after liftoff to a hover and during low-altitude maneuvering at low airspeeds. After the helicopter was accelerated, the vibration was reduced.

After the test flight, maintenance personnel used several techniques to attempt to eliminate the vibration; the owner said that after the helicopter was returned to him on April 2, 2002, the helicopter "felt smoother than at any time since he purchased it," the report said.

"During the first four sorties following the annual inspection, extending over some five flight hours, the aircraft had remained exceptionally smooth," the report said. "However, during the next flight, the pilot noted the onset of a slight rotor vibration, albeit at a level which caused him no particular concern. On subsequent flights, these vibrations became more severe, culminating in the diversion to Sywell on [May 14]."

The R22's main-rotor blade is comprised of a top skin and bottom skin made of aluminum alloy surrounding a core of aluminum honeycomb, a "hollow D-section leading-edge spar" made of stainless steel, and a forged aluminum-alloy root-end fitting. A section of the root-end fitting is bonded to the top skin and bottom skin. Two other sections extend further into the blade; the larger of these sections is attached to the rear of the hollow spar by several nuts and bolts and adhesive bonding, and the smaller section is bonded to the top skin and bottom skin. The skins are reinforced near the root-end fitting by aluminum-alloy doublers, and an aluminum-alloy cap is bonded to the end of the hollow spar; an adhesive fillet blends the root end of the cap to the root-end fitting, the report said.

Examination of the crack revealed that it apparently had begun at the leading edge of the blade root-end fitting and spread toward the trailing edge, "turning progressively inboard as the crack developed," the report said.

"The crack had extended a distance of approximately 9.0 centimeters [3.5 inches] beyond the leading edge on the lower surface of the fitting and approximately 7.0 centimeters [2.8 inches] on the upper surface," the report said. "The crack had evidently penetrated through the full thickness of the forging over a significant proportion of the cross-section and had opened up sufficiently to produce a discernible step-like discontinuity across the fracture at the leading edge."

Microscopic Cracks Found Next to Fracture

The examination of the crack also revealed a number of microscopic cracks in the paint next to the fracture. Those cracks apparently resulted from abnormally high strain that may have been associated with growth of the main crack or another unknown event, the report said.

Examination of the cracked blade revealed that the spindle-bearing assembly in the root-end fitting contained none of the oil that, under normal circumstances, would have filled it.

"Any oil originally inside the cavity was likely to have been driven out through the crack under centrifugal loading," the report said. "This was almost certainly the source of the oil contamination of the rotor head noted when the aircraft had landed immediately after the incident."

The investigation did not reveal any condition affecting the airframe, engine or transmission that might have caused abnormal loading of the main-rotor system.

Surface Cracks Found in Other Main-rotor Blade

An examination of the incident helicopter's other main-rotor blade revealed microscopic surface cracks in the paint at the leading edge. The cracks resembled the minor paint cracks noted on the failed blade, but they were fewer in number and not so wide; the report said that, "overall, the character of these cracks was consistent more with paint shrinkage due to aging than to strain, but the possibility of the latter could not be totally ruled out."

Inspections of the main-rotor blades on other R22s revealed similar surface cracks in the same area; those cracks also were not as wide or as deep as those on the incident helicopter.

The report said that before this incident, several other incidents had been reported involving fatigue failure of R22 main-rotor-blade root-end fittings. In each of those incidents, however, the crack had developed from the bore of the inboard spar-attachment bolt hole; the report said that this was "an explicable failure mode in an area of known stress concentration" and that in at least one of those incidents, the blade may have exceeded its permitted service life.

Because this incident was the first involving fatigue failure in the root-end fitting inboard of the spar, the failure may have been caused by a factor specific to that blade, such as damage to the blade or a defect associated with an environmental factor or flight condition, the report said.

The report said that estimates were that the total propagation time was five hours 22 minutes of flight time, and "if it is assumed that a comparable period would have been required for initiation of the crack, then this would suggest a total period of growth — comprising initiation and active propagation — of approximately 10 [flight hours] to 11 [flight] hours.

"The potential significance of the vibration problem identified during the annual inspection check flight was considered in some detail," the report said. "At a superficial level, the apparent correlation between the 11 hours of run time since the aircraft's return to service and the estimated crack-growth time of 10 [flight hours] to 11 [flight] hours, together with the reported absence of a prior vibration problem, suggests that some event might have occurred during the annual inspection that may have set in train the initiation process. However, the characteristics of the vibration problem suggest that the crack was present at that time and that its presence was actually the cause of the vibration problems encountered during the annual inspection. The failure to identify any mechanical cause for the vibration, despite extensive investigation and the fact that a 'head-shift' [a procedure that moved the rotor system's center of mass] was ultimately required to effect a cure, implies that a fundamental change in the balance of the rotor assembly had already taken place. This, after some 735 satisfactory flight hours with no changes having been made to the rotor system during that time, suggests strongly that some physical change had taken place in the rotor system over a relatively short period of time immediately prior to the annual inspection.

"Such a crack in a blade will potentially alter its stiffness characteristics, which in turn will cause [the blade] to adopt a different position under load, when compared with the pre-cracked state and/or under static conditions, causing a rotor imbalance when the rotor is running."

The report said that the vibration that was found during the annual inspection was caused by the shift of the center of the mass of the rotor system away from the rotor-mast axis and that the shift was caused by the root-end-fitting fatigue crack, early in its development. The head shift moved the center of mass far enough to temporarily end the vibration, which reappeared five flight hours later when the continuing spread of the crack caused an additional shift in the center of mass.

"It is probable that the vibration was not noticed prior to the annual inspection because the pilot flew the aircraft regularly and consequently did not notice the gradual deterioration, whereas the annual check pilot, who came to the aircraft afresh, detected it immediately," the report said.

The report said that if no cause is found for any significant main-rotor vibration and if the vibration recurs shortly after balancing operations are performed, a main-rotor-blade crack should be considered as a cause of the problem.

The "Safety Tips" section of the *Pilot's Operating Handbook (POH)* says, "A change in the sound or vibration of the helicopter may indicate an impending failure of a critical component. Make a safe landing and thoroughly inspect aircraft before flight is resumed."

Pilot Criticized Own Judgment

The incident pilot said that when he felt the vibration, he did not consider that the cause might be a cracked main-rotor blade.

Later, the pilot said that his judgment had been questionable.

"Pilots of all rotorcraft should be acutely aware of the potentially catastrophic rate of propagation of fatigue cracks should they develop in a main-rotor blade," the report said. "Once a crack has progressed to the extent that a discernible vibration results, the rate of crack growth is likely to increase dramatically, especially so during the final stages of growth. This is when the vibration produced in the main-rotor system will feed back into the cracked blade, raising still further the cyclic stresses which drive the crack. In this circumstance, there will be a [significant] risk of catastrophic blade failure occurring within a time frame of minutes, or possibly even seconds. In any situation involving a severe, or indeed, any perceptible escalating main-rotor vibration, pilots should be advised to interpret these symptoms as indicative of imminent blade failure and land immediately, or as soon as possible should an immediate landing be likely to result in an accident."

During the investigation of the incident, on June 16, 2002, the manufacturer said that it would "take the appropriate steps … to inform operators of the potential significance of rapid loss of rotor balance and the implications of employing head shift operations to effect a cure."

Safety Alert Issued After Incident

Other actions included the following: investigating the history of other blades that were subjected to the shot-peening process at the same facility, ensuring that the shot-peening process is performed correctly, changing the blade clean-up process during manufacture to ensure that the shot-peened layer "is not compromised by removal of surface material and that the surface finish is of an acceptable standard" and educating the production staff on the importance of surface finish. The manufacturer's actions also included implementing inspection procedures to check for the quality of the surface finish and for inappropriate surface attrition, examining samples of blade root-end fittings from in-service blades and/or time-expired/damaged blades to "extend understanding of the character of, and incidence of, [shot-peened] layer and surface-finish discrepancies and reviewing options for replacing blades in service, if necessary."

On June 25, 2002, the manufacturer issued the following R22 safety alert:

> *Unusual vibration can indicate a main-rotor blade crack.*
>
> A catastrophic rotor-blade fatigue failure can be averted if pilots and mechanics are alert to early indications of a fatigue crack. Although a crack may be internal to blade structure and not visible, it will likely cause a significant increase in rotor vibration several flight hours prior to final failure.

If a rotor is smooth after balancing but then goes out of balance again within a few flights, it should be considered suspect. Rapidly increasing vibration indicates imminent failure and requires immediate action.

If main-rotor vibration increases rapidly or becomes severe during a flight, land immediately.

Do not attempt to continue flight to a convenient destination. Have the rotor system thoroughly examined by a qualified mechanic before further flight. If [the] mechanic is not sure whether a crack exists, contact RHC."

On June 27, 2002, AAIB drafted a position paper that included the following:

- "It was likely that a significant number of blades in service would contain transverse scores … similar to those seen on the cracked blade";
- "The apparently widespread incidence of aging cracks in the filler, at the leading edge just inboard of the spar, would tend to reduce any concern which might otherwise be shown by operators regarding any cracking in this area";
- "Any attempt to remove the filler to facilitate inspection could potentially result in further scoring of the surface, which could possibly lead to the initiation of fatigue cracks"; and,
- "The apparently short time interval between crack initiation and blade failure does not give confidence that a normal inspection regime would detect the embryonic cracks in adequate time."

AAIB Recommended 'Priority Airworthiness Action'

The position paper also said that "priority airworthiness action should be taken to ensure that operators are made aware of the potential significance of sudden changes in main-rotor blade balance and that operators should regard any blades requiring rebalancing … as potentially being cracked" and that "steps should be taken urgently to identify all those blades built from root forgings sent for shot-peen treatment at or around the same time as the cracked blade … and that these blades should be located and removed from service for inspection."

As a result of the investigation, AAIB issued the following safety recommendations:

- "It is recommended that the FAA [U.S. Federal Aviation Administration], as the primary certificating authority for the R22 helicopter, require the manufacturer of the R22 helicopter to establish an inspection procedure capable of identifying blades containing cracks originating in the main-rotor-blade root-fitting leading edge region;
- "It is recommended that the FAA require the manufacturer of the R22 helicopter to devise an inspection method which will identify on in-service blades the type of root fitting surface abrasion damage found on both a cracked blade and several non-cracked sample blades, that is potentially capable of initiating fatigue cracking. … [; and,]
- "It is recommended that the FAA confirm that the manufacturer of the R22 helicopter has adjusted their manufacturing processes of the main-rotor blade, since the discovery of a large crack on an in-service main-rotor blade, to preclude abrasion damage of the shot-peened surface treatment during the adhesive clean-up process and ensure that the depth of the shot-peened layer on the blade-root fitting conforms to the manufacturer's specifications."

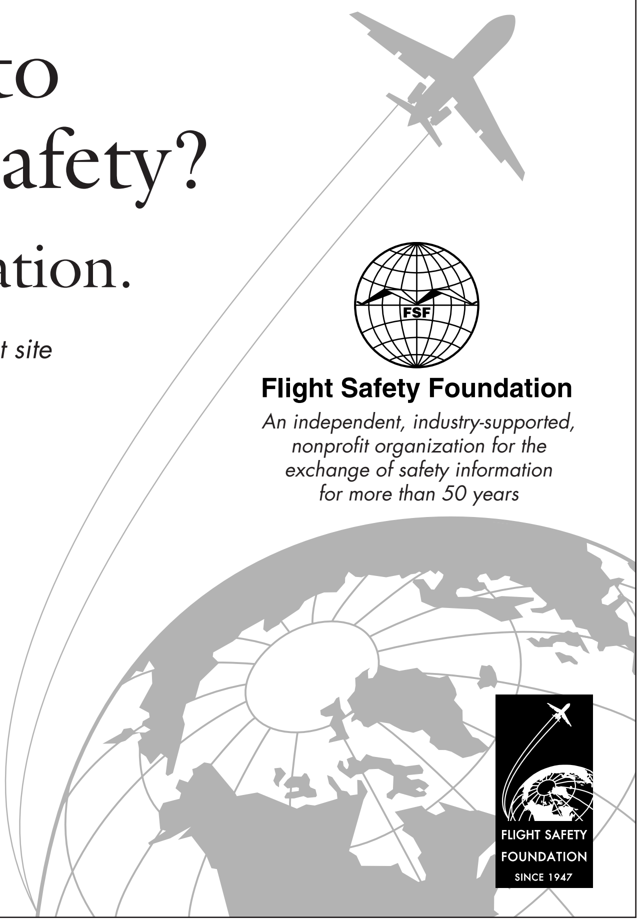
FAA said in response that it had issued a special airworthiness alert bulletin, SW-04-36, on Dec. 17, 2003, recommending that operators comply with RHC service letter (SL) 21A, which included instructions for conducting an acceptable inspection for cracks of the blade-root area without damaging the root-end fitting. FAA also said that procedural changes implemented by the company meant that blades produced after November 2001 should not have abrasion scratches.[1]

"The depth of the [shot-peened] layer is not in question, and the quality control system at RHC has not found any reason for concern," FAA said. "Also, RHC redesigned the root fitting of the blade to be more robust in that area. The newly designed blades, part number A016-4, will be the only new blades available and will eventually replace the older-style blades."♦

[This article, except where specifically noted, is based on U.K. Air Accidents Investigation Branch incident report no. EW/C2002/05/14. The 24-page report includes photographs.]

Note

1. Downey, David A. Memo to the manager, Recommendation and Analysis Division, U.K. Air Accidents Investigation Branch. Jan. 12, 2004. Downey is the manager of the Rotorcraft Directorate, Aircraft Certification Service, U.S. Federal Aviation Administration.



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