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NTSB Investigates Loss-of-control Accidents Among Lightweight Helicopters

Robinson Helicopter Co. R22s had more fatal loss-of-control (LOC) accidents per flight hour between 1981 and 1994 than other helicopter models that also had fatal LOC accidents. Since changes were made in R22 and R44 operations and training requirements these aircraft have had no further fatal LOC accidents. Nevertheless, concern remains about the development of other highly responsive helicopters.

FSF Editorial Staff

Between 1981 and 1994, 31 Robinson Helicopter Co. (RHC) R22 and three R44 fatal accidents occurred that involved a loss of main-rotor control during in-flight operations, resulting in the main-rotor blades contacting the fuselage or tailboom of the aircraft. Most of these accidents were attributed to pilots maneuvering at less than 0.5 positive G or allowing excessive decay of main-rotor revolutions per minute (RPM). A recent U.S. National Transportation Board (NTSB) report said that 13 accident briefs have been revised to reflect the recognition that these LOC accidents may have resulted from other causes including low-rotor RPM leading to blade stall; encounters with turbulence; or large, abrupt cyclic control inputs.

The cause of these LOC accidents was questioned following a fatal helicopter accident on June 29, 1992, in which a student pilot recorded cockpit communications on a microcassette tape recorder. The pilot-in-command (PIC) was a certified flight instructor (CFI) with about 2,000 hours of flight time in the R22; the student had four hours of flight time, all in the R22. The U.S. accident, which occurred near Richmond, California, U.S., helped spur an investigation of R22 and R44 accidents.

The report said, "The recording revealed no operational difficulties during the engine start, ground checks, takeoff or the 17-minute flight en route to a practice area. The low-rotor-RPM warning horn was checked and operated normally on the ground."

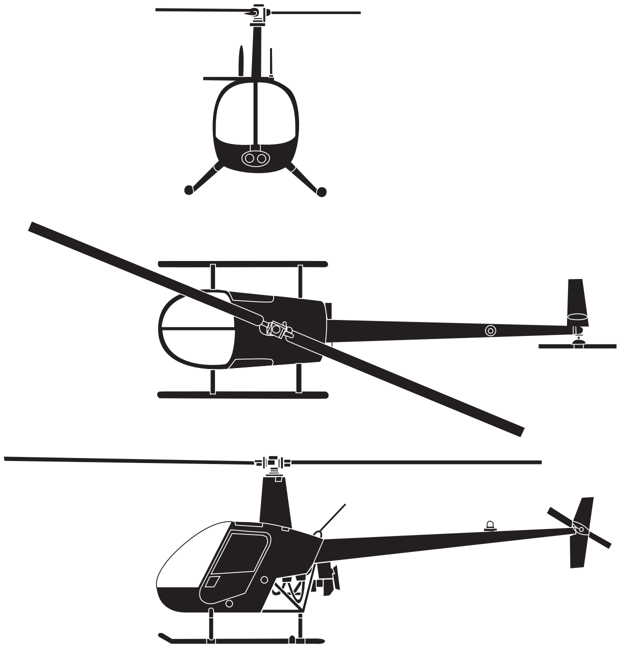
The helicopter was at 610 meters (2,000 feet) in cruise flight at 157 kilometers per hour (kph) (85 knots) when "an undetermined event interrupted the CFI's speech and culminated in the breakup of the helicopter. A wind-like background noise then became evident on the tape and muffled the student's exclamation, 'Help!'"

The main rotor blades departed their normal plane of rotation and struck the aircraft. Witnesses reported that the tailboom and main rotor separated from the helicopter in flight. Both the CFI and the student were killed and the aircraft was destroyed.

The recording revealed no pilot concern about the helicopter's operation prior to the breakup, and no unusual rotor-system noises. Sound-spectrum analysis of the recording revealed no main-rotor RPM decay; the low-rotor warning horn was not recorded before or during the breakup.

The report said that the accident occurred during daylight, in visual meteorological conditions, within the approved flight envelope and at normal RPM.

"The findings in [this] accident — coupled with the [NTSB's] difficulty in determining the causes of many similar loss of main-rotor control accidents in the past — led the [NTSB] to investigate these accidents as a group in an attempt to find



Robinson R22

The Robinson R22 is a conventional helicopter with a two-bladed semi-articulated main rotor. The R22 has a tri-hinged underslung rotor head designed to reduce blade flexing, rotor vibration and control-force feedback. A two-bladed tail rotor on the left side of the tailboom provides directional control. R22 design began in 1973, and the aircraft first flew in August 1975.

The R22 has two side-by-side seats and is powered by a single reciprocating engine mounted in the lower rear section of the main fuselage. The R22 has a maximum normal takeoff weight of 621 kilograms (1,370 pounds); a maximum cruising speed of 180 kilometers per hour (97 knots); a service ceiling of 4,265 meters (14,000 feet); and a range of 592 kilometers (368 miles) using auxiliary fuel and maximum payload with no reserves.

Source: *Jane's All the World's Aircraft*

common factors and to develop appropriate recommendations to prevent occurrence of similar accidents in the future," the report said. "The [NTSB's] special investigation initially focused on R22 accidents in which the main-rotor blade diverged from its normal path and struck the helicopter. When similar R44 accidents occurred, the special investigation was expanded to include those accidents."

The NTSB looked at various scenarios that could cause this type of LOC accident, including deficient main-rotor design; rapid RPM decay; mechanical failures; high blade angles (rotor stall); mast bumping; over-sensitive flight controls; and sensitivity to multiple or large control inputs. The NTSB did not conclusively eliminate design flaws, but said that many operators successfully fly the R22 under challenging conditions without main-rotor-blade divergence.

No evidence was found to support mechanical failure as a causal factor. Although mast bumping — the contact of a portion of the rotor system (two blades and the hub) with the mast, usually with enough force to damage the mast or cause mast failure — occurred in all of the accidents reviewed in the special investigation, the NTSB did not find that mast bumping was a causal factor in the R22 and R44 accidents.

Originally certified on March 16, 1979, the R22 is a two-seat, conventional helicopter with a standard tail-rotor system. The R22 is used by flight-training schools, police departments, pipeline patrols and the news media; the R44 is a four-place version of the R22.

Both the cyclic control and the main-rotor-blade system of these RHC aircraft incorporate unique design features. The cyclic control is a T-shaped design in which a single vertical component is located between the pilot seats and a horizontal component passes over each pilot's legs. Two cyclic control sticks are attached to the horizontal component of the "T" and are hinged to allow adjustment for pilot comfort.

Because the cyclic control sticks for each pilot are interconnected, "If the flying pilot holds the handle in a comfortable position, the handle for the nonflying pilot may be in an awkwardly high position," said the report.

The main-rotor system of the R22 uses a two-blade, rigid-in-plane design. This design uses separate flapping hinges to connect the rotor blades to the main-rotor hub. This allows the blades to move independently of one another vertically, but not horizontally. The rotor hub is hinged to the main-rotor mast and has a normal teeter limit of 12 degrees. (Teeter, or tilt is the angle formed when the plane of rotation of the main-rotor system is not perpendicular to the mast.)

When the R22 is operated with two occupants and a full load of fuel, the aircraft approaches its maximum gross weight of 621 kilograms (1,370 pounds), and therefore is operating near the maximum designed lift of the main-rotor system. When operating near maximum gross weight, "The R-22's main-rotor-blade angle of attack will be near the stall angle of attack," said the report. "According to RHC and a [computer-based mathematical model of the R22] ... large, abrupt control movements may produce main-rotor-blade stall and rapid decay of the rotor RPM. The RHC, many R22 pilots, and some [R22] test pilots have indicated that the flight controls on the R22 are more sensitive than on other light helicopters.

"That is, the R22 is highly responsive in pitch and roll to small flight-control inputs. ... The sensitivity of the R22 flight controls suggests that the greater responsiveness combined with limited pilot skills, proficiency or alertness could be a factor in some of the 31 accidents that the [NTSB] reviewed."

Recent design changes such as the inclusion of electronic fuel control governors on all new R22's and use of automatic carburetor heat control on R22 Beta 2 models, as well as other changes [see "Airworthiness Directives Aim to Reduce Pilot Workload"], have helped to reduce pilot workload during critical phases of flight.

Of the 31 R22 accidents involving main-rotor-blade divergence and subsequent tailboom or fuselage strikes, 21 occurred in the United States and two occurred in each of the following countries: Switzerland, New Zealand, Australia and Germany; all three R-44 accidents occurred in Germany.

To compare the R22 per-flight-hour rates at which these types of LOC accidents have occurred with other helicopters, the NTSB examined 500 fatal accidents involving U.S.-registered helicopters from 1981 through 1994.

The NTSB said that a rotor blade striking the tailboom or fuselage of the aircraft following LOC not precipitated by mechanical problems may be unique to the R22. The report said that all of the accidents used for comparison "involved an in-flight loss of main-rotor control; a structural failure of the main-rotor blade that did not involve pre-existing fatigue of rotor-blade materials; or loss of aircraft control or collision with terrain for unknown reasons, in the absence of structural failure, encounter with instrument meteorological conditions, or pilot impairment from drugs or alcohol."

The report said, "Ten helicopter models were involved in 43 accidents that met the above criteria as LOC accidents: the Bell 47, Bell 204, Bell 206, Bell 212, Enstrom F28, Hiller UH12, MBB [Messerschmitt-Bölkow-Blohm, now Eurocopter] BO 105, Hughes 269, Hughes 369 and the Robinson R22." Of the 500 fatal accidents that fit the criteria, the Hughes 269 had five LOC accidents; the Bell 47 had six LOC accidents; and the R22 had 23 LOC accidents (Table 1, page 4).

A fatal LOC accident rate per 100,000 flight hours was calculated for each model using FAA estimated-activity data. The NTSB included the FAA standard-error statistics associated with each helicopter model's activity estimate and determined that no particular model was subject to consistently poor reporting activity during the study period.

Because the Bell 47 and the R22 are both lightweight, two-place, low-inertia aircraft with high utilization rates, the NTSB compared the accident rates for these two helicopters for fatal non-LOC and fatal LOC accidents. The report said, "Statistically, the R22 and Bell 47 were about equally likely to be involved in non-LOC accidents, but the R22 was more likely than the Bell 47 to be involved in LOC accidents."

The report said, "The [NTSB] concluded that, compared to other helicopter models that have had fatal LOC accidents, R22s were involved in more fatal LOC accidents per flight hour [Table 1, page 4]."

With pilot flight-hour data available from 30 of the 31 R22 fatal LOC accidents, median flight hours were calculated for the pilot-in-command of each aircraft. Additionally, for dual instructional flights, median flight hours were calculated for both students and instructors. For dual-piloted flights that were not instructional, median flight hours were calculated for the pilot-in-command and for the least experienced pilot. The median flight hours of the pilots-in-command, including flight instructors, were 180 hours of helicopter flight time and 127.5 R22 hours when involved in fatal R22 loss of main-rotor-control accidents; the median R22 flight experience for the least experienced pilots who may have been manipulating the flight controls was 52.5 hours (Table 2, page 5).

The report said, "[NTSB] staff reviewed in detail six of the most recent U.S. R22 accident investigations in which the helicopter lost main-rotor control and broke up in flight to review the type and severity of the physical damage. These six accidents were chosen because their wreckage remained available for detailed examination. In each case, the flight-control system was extensively damaged above the swashplate; no prior mechanical failures were evident; and the main-rotor blades had struck the structure of the helicopter. In each case, engine failures were conclusively

Airworthiness Directives Aim to Reduce Pilot Workload

Since the NTSB's special investigation report on Robinson Helicopter Co. R22 and R44 loss-of-main-rotor-control accidents was published in April 1996, several U.S. Federal Aviation Administration airworthiness directives (ADs) for these aircraft have been adopted that either address potential causes of in-flight blade-to-fuselage contact or reduce pilot workload.

AD 97-02-14 for R22 helicopters, serial numbers 0002 to 2537, was intended "to minimize the possibility of pilot mismanagement of main rotor (M/R) revolutions-per-minute (RPM), which could result in unrecoverable M/R blade stall and subsequent loss of control of the helicopter." This AD required the low-RPM warning unit to be adjusted so that the warning horn and caution light activate between 96 percent and 97 percent RPM; required throttle/collective governors to be installed on model R22 helicopters without governors; required existing throttle/collective governors to be upgraded; and prohibited flight with the governor selected off unless an in-flight system malfunction occurs or emergency-procedures training is being conducted. This AD also requires that revisions addressing governor normal and emergency procedures be incorporated into the normal- and emergency-procedures sections of the flight manual.

Similarly, AD 97-02-15 for R44 helicopters, serial numbers 0001 through 0183 and 0189, was intended to minimize main-rotor-RPM mismanagement that could lead to loss of control of the aircraft. This AD also adjusts the low-RPM warning system to activate between 96 percent and 97 percent, and it prohibits flight with the throttle/collective governor selected off unless an in-flight system malfunction occurs or emergency-procedures training is being conducted. Flight manual revisions for governor-off flight restrictions were also required.

Although not directly linked to factors involved in LOC accidents reviewed in the special investigation, AD 97-25-05 for R22 helicopters with Lycoming 0-360-J2A equipment required installation of a carburetor that does not require manual leaning of the fuel-and-air mixture during flight. Eliminating the need to manually lean the engine reduces in-flight workload for R22 pilots.♦

ruled out, and no evidence of a precipitating flight-control failure was found." All of the control- and rotor-system components revealed evidence of overload failures; however, no component showed evidence of fatigue failure, inadequate materials or improper maintenance causal to the in-flight rotor-to-fuselage contacts (Figure 1, page 6 and Table 3, page 7).

Three FAA special certification reviews (SCRs) of the R22 were conducted between 1982 and 1994, and no discrepancies in the original certification were found.

The first SCR was completed on Oct. 24, 1982, following several fatal R22 accidents in 1981 and 1982. The report said, "The FAA's report of that review included four recommendations to the RHC for future actions: (1) conduct rotor-hub teetering and RPM-decay studies; (2) issue an operations bulletin to make operators aware of light-helicopter problems specific to helicopters similar to the R22 by focusing on RPM decay and [RPM] recovery problems, throttle-coordination problems, attention to proper maneuvers during student instruction and careful student monitoring during student solo flights; (3) issue a service bulletin and provide a kit to enable the FAA to issue a priority [AD] to make installation of a low-RPM warning light mandatory; and (4) raise the RPM limit for the activation of the low-rotor-RPM light from 91 percent to 97 percent."

As a result of the FAA recommendations following the first SCR, RHC conducted flight tests and published the results, which showed that when flown within its approved limitations, the R22 rotor system will not stall, exceed its teeter clearance or contact the tailboom.[1] Tests of aircraft response to large, abrupt cyclic inputs while in cruise flight could not be conducted for safety reasons. The report said that, in addition to conducting flight tests, RHC issued a safety notice to advise operators of the R22's sensitivities to low- rotor RPM. The FAA instituted a requirement to install a low-rotor-RPM light and raised the RPM threshold at which the warning horn annunciates to 95 percent (from 91 percent).

This first SCR said that the U.S. Federal Aviation Regulations (FARs) Part 61 guidance material, basic helicopter handbook, and flight-test guides were inadequate for students and flight instructors training in small helicopters. The SCR said that an FAA flight standards and engineering review team should be formed to recommend specific changes to these resource materials; however, the report said that no FAA flight standards and engineering review team was ever formed.

According to the NTSB report, correspondence from the manager of the FAA Western Aircraft Certification Field Office (WACO) dated Nov. 23, 1982, to the acting manager of the FAA Flight Standards Division stated that the R22 "responds rapidly to any control input, and the student *must be made aware of this*" [emphasis in original].

The NTSB reviewed records of the Los Angeles Aircraft Certification Office (LAACO) which included a memorandum dated March 29, 1983, from the manager of the FAA WACO

Table 1
U.S. Loss-of-control,1 Non-loss-of-control and All Fatal Helicopter Accidents, Flight Hours and Corresponding Accident Rates for the Years 1981–1994

Helicopter model2	Fatal Accidents				Fatal accidents per 100,000 flight hours		
	LOC	Non-LOC	All	Flight hours3	LOC	Non-LOC	All
Bell 206	2	119	121	13,369,702	0.015	0.890	0.905
Hughes 369	2	38	40	3,000,236	0.067	1.267	1.333
Hiller UH12	1	13	14	987,796	0.101	1.316	1.417
Enstrom F28	1	16	17	845,032	0.118	1.893	2.012
MBB BO 105	1	12	13	806,750	0.124	1.487	1.611
Bell 212	1	3	4	497,129	0.201	0.603	0.805
Hughes 269	5	28	33	1,992,301	0.251	1.405	1.656
Bell 47	6	44	50	2,343,215	0.256	1.878	2.134
Bell 204	1	2	3	227,683	0.439	0.878	1.318
Robinson R22	23	39	62	1,524,483	1.509	2.558	4.067
Totals	43	314	357				

[1]Loss-of-control (LOC) accidents involved an in-flight loss of main-rotor control; structural failure of the main-rotor blade that did not involve pre-existing fatigue of rotor-blade materials; or loss of aircraft control or collision with terrain for unknown reasons, in the absence of structural failure, encounter with instrument meteorological conditions or pilot impairment because of drugs or alcohol.

[2]Accidents involving Fairchild Hiller FH1100 (two fatal LOC accidents) and Brantly B2 (one fatal LOC accident) helicopters were excluded because reliable utilization data were not available. Three fatal LOC accidents involving amateur-built helicopters were also excluded.

[3]*General Aviation Activity and Avionics Survey,* U.S. Federal Aviation Administration (FAA): Washington, D.C., 1980–1992. Nine missing data values were assigned by linear interpolation. *General Aviation and Air Taxi Activity and Avionics Survey,* FAA: Washington, D.C., 1993. Preliminary 1994 data from FAA.

Source: U.S. National Transportation Safety Board which said, "The R22's low-G maneuvering characteristics are more sensitive to control inputs than other helicopters but are still acceptable and within the criteria established in the regulations. Critical situations such as mast bumping can only be created through abnormal or aggressive control inputs." [See "R22 and R44 Require Specialized Training and Experience," page 6.]

The NTSB report said that although "The [WACO memorandum] concluded that the low-G characteristics of the R22 are acceptable when the R22 is flown in a normal and reasonable manner," the memorandum suggested that the FAA give consideration to evaluating the dynamic-stability characteristics of all future helicopters; warn pilots of the dangers of low-G flight; and expand dynamic-stability testing to better establish helicopter handling qualities.

After three LOC accidents in 1987, a second SCR was conducted. The NTSB report said, "The SCR team recommended that a research program be initiated through the FAA technical center to study potential rulemaking changes in the following areas: (1) specific aircraft response rates to control inputs; (2) change in control force with cyclic and collective displacement; (3) rotor-speed-decay rates after throttle chops; and (4) speed-decay rates during autorotation touchdown." The NTSB said that no information was found to show that the FAA took action in response to these recommendations.

Following more R22 accidents and NTSB safety recommendations, the third SCR of the R22 was issued in January 1994. This SCR recommended that research should be conducted to gather data on rotor-decay rates to help establish a minimum standard, and to collect data to support new rulemaking about allowable response rates to abrupt control inputs. The NTSB found no evidence that the FAA took action in response to these recommendations.

On July 22, 1994, the FAA issued a special airworthiness alert (SAA) warning that abrupt cyclic inputs and high-speed maneuvering should be avoided by R22 pilots; on Jan. 17, 1995, R44s were included in the updated SAA.

The report said, "The [NTSB] is concerned that although some actions were taken to address the safety concerns related to the R22, the FAA could not show that those actions were taken as a direct result of the SCR recommendations or that a process existed to ensure that the SCR recommendations were followed up on." The NTSB recommended that the FAA review the process and procedures used to bring safety recommendations presented in internal documents, including special certification reviews, to closure.

On July 21, 1994, an NTSB safety recommendation said, "The [NTSB] recommends that the [FAA] issue an immediate [AD] to reduce the R22 'never-exceed airspeed' (V_{ne}) to an airspeed that would provide an adequate margin of operating safety below the airspeeds at which loss of main-rotor control accidents have occurred, until the reason for in-flight main-rotor-blade divergent behavior is established and design changes are approved and implemented, as necessary." The NTSB also recommended that wind-tunnel and modeling tests of the R22 should be conducted to help identify the cause of main-rotor-blade divergence.

In July 1994, an FAA Aircraft Certification Panel (technical panel) recommended installation of electronic engine-RPM governors for the R22 (similar to those installed on the R44); prohibition of normal flight operations with the governor

Table 2
Median Flight Hours in R22s, All Helicopters and All Aircraft of the Flying Pilot at the Time of the Accident, for Worldwide R22 Accidents in Which the Main Rotor Contacted the Airframe

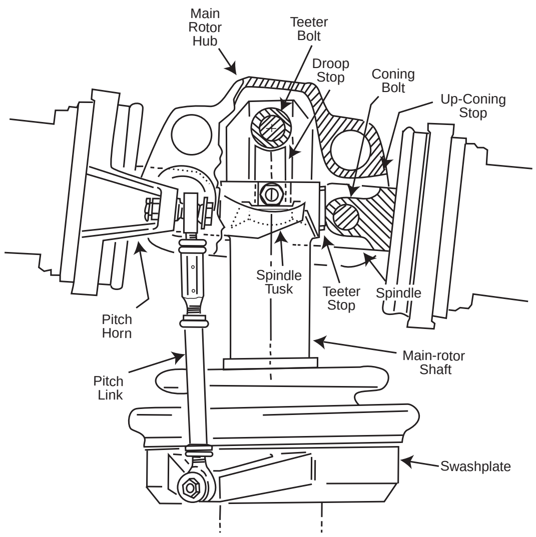
Type of operation and pilot	Number of accidents[1]	Median flight hours: R22	All helicopters	All aircraft
All flights				
Pilot-in-command	30	127.5	180	790
Least experienced pilot[2]	30	52.5	76	290
Dual-instructional flights				
Instructor	9	451	451	772
Student	9	4	4	190
Non-dual-instructional flights				
Pilot-in-command	21	85	123.5	792

[1]Flight hours data were available for 30 of the 31 accidents.

[2]The least experienced pilot was the pilot who had accumulated the fewest flight hours in the R22. For the dual-instructional flights, the least experienced pilot was the student; for the non-dual-instructional flights, the least experienced pilot was the pilot-in-command.

Source: U.S. National Transportation Safety Board

R22 Main-rotor Hub and Assembly



Source: U.S. National Transportation Safety Board

Figure 1

switched off; an increase in the low-RPM warning threshold; an audible low-RPM warning system; and an increase in minimum power-on RPM limits to 97 percent.

Simulation studies were conducted on the R22 main-rotor system, and the report said, “The mathematical model sufficiently simulates the R22 rotor-system behavior in the normal operating range, and … the results suggest that large, abrupt, and multiple control inputs could lead directly to a mast-bumping event or high blade angles-of-attack, either of which could lead to loss of main-rotor control.”

On Jan. 10, 1995, several ADs and a special airworthiness information (SAI) bulletin were issued. The bulletin advised pilots of R22s and R44s to fly within the envelope and to avoid flight in high winds or at high altitudes. The ADs, which have been updated since the release of the NTSB report as AD 95-26-04 and AD 95-26-05, state that flight is prohibited in surface winds exceeding 25 knots, when surface-wind-gust spreads exceed 15 knots, and when turbulence is moderate, severe or extreme. They give recommended flight procedures for encounters with greater-than-moderate turbulence, information on main-rotor stall and mast bumping, methods for avoiding mast-bumping conditions, and emergency procedures for right rolls in low-G conditions, uncommanded pitch roll, or yaw resulting from flight in turbulence and inadvertent encounters with turbulence greater than moderate.

The NTSB, in a Jan. 6, 1995, safety recommendation concerning R22 and R44 LOC accidents, said, “Qualified pilots were unable to recognize and correct low main-rotor RPM or anomalous main-rotor behavior before uncontrollable blade pitch and excessive blade divergence followed.” The FAA alerted its Flight Standards inspectors in a Jan, 18, 1995, flight standards information bulletin about the NTSB’s concerns.

Special Federal Aviation Regulation (SFAR) 73, dated March 1, 1995, established special rules for R22 and R44 pilot flight training and currency requirements. [See “R22 and R44 Require Specialized Training and Experience.”]

The report said, “Large, abrupt control inputs when the R22 is in a steady-state condition with an already existing teeter could cause the teeter limit (12 degrees) to be exceeded, followed by a mast strike and subsequent loss of main-rotor control.”

Because the R22 is used extensively in training, the NTSB also expressed concern that the awkward position of the cyclic control

R22 and R44 Require Specialized Training and Experience

Special Federal Aviation Regulation (SFAR) 73-1, effective from Dec. 31, 1997, through Dec. 31, 2002, superseded SFAR 73, which, in March 1995, set forth requirements for specialized training and aeronautical experience for pilots of R22 and R44 aircraft that are above and beyond Part 61 requirements.

According to the SFAR, anyone flying a Robinson model R22 or R44 must complete awareness-training on energy management, mast bumping, low-rotor RPM (blade stall), low-G hazards and rotor-RPM decay. This awareness training must be conducted by a certified flight instructor (CFI) who has completed the same awareness training and who has at least 200 flight hours in helicopters and 50 flight hours in the R22 or R44; 25 R22 flight hours can be applied toward the total of 50 R44 flight hours required. The CFI must also have received enhanced training on autorotation procedures, instruction on engine and rotor-RPM control without use of the governor, low-rotor-RPM recognition and recovery training, and instruction on the effects of low-G maneuvers and proper recovery procedures in an R22, R44 or both. The instructor must demonstrate an ability to provide general subject-matter instruction and flight training as required by this SFAR and must be authorized by endorsement from an FAA aviation safety inspector or authorized designated examiner.

After receiving awareness training, a licensed helicopter pilot must have a logbook endorsement by a CFI who, by completing the requirements above, is authorized to do so.

Individuals who successfully completed RHC’s safety course after Jan. 1, 1994, can obtain an endorsement from an aviation safety inspector in lieu of completing the awareness training outlined above.

In addition to awareness training, the SFAR specifies that, to fly as pilot-in-command (PIC) of an R22 or R44, pilots holding a rotorcraft category and helicopter class rating must have at least 200 flight hours in helicopters, at least 50 hours of which are in the R22 or R44; or must have at least 10 hours of dual instruction in the appropriate aircraft by an instructor certified in accordance with the above requirements. The 10 hours of dual flight instruction must include the same training on autorotation procedures, RPM control, low-RPM recognition and low-G maneuvering specified above for CFIs. For R44 qualification, 25 flight hours of the 50-hour requirement may be obtained in the R22, and five hours of dual instruction received in the R22 may be credited toward the 10-hour dual-flight-instruction requirement.

For pilots without a rotorcraft category and helicopter class rating, 20 hours of dual instruction in the appropriate aircraft, including the specific training outlined above, are required prior to solo flight.♦

Table 3
R22 Component Comparisons of Wreckage from Six U.S. Accidents

	Malabar, Florida 01/30/92	**Maricopa, Arizona 03/04/92**	**Mt. Pleasant, Tennessee 05/06/92**	**Richmond, California 06/29/92**	**Martinez, California 09/30/92**	**Knightdale, North Carolina 09/28/94**
Hub	Indents in hub from spindle tusks	Strong indents in hub from spindle contact	Slight indents in hub from spindle tusks	Indents in hub from spindle tusks	Indents in hub from spindle tusks	Indents in hub from spindle tusks
Spindles	Both tusks sheared	One tusk sheared	Both tusks sheared	Both tusks sheared	One tusk twisted at the tip	One tusk sheared
Droop stops	Slightly compressed and distorted	Crushed and deformed	Slightly compressed and distorted	Bolt hole deformed; stops crushed	One crushed with bolt hole deformed	Crushed and deformed
Pitch-change links	Both fractured at upper adjustment threads	Both fractured at upper adjustment threads	Both fractured at upper adjustment threads	Both fractured at upper adjustment threads	One fractured at blade horn, other at upper adjustment threads	Both fractured at upper adjustment threads
Swashplate assembly	Chord arm fractured; upper swashplate intact	Intact	Scoring on chord arm from blade horn; upper mast-tube fitting fractured	Fractured at chord arm and upper swash-plate	Chord arm had deep lateral indents	Scoring on chord arm
Upper main-rotor shaft	Slight indentations from hub contact	Torsional twisting and bending, and contact from hub	Contact from hub; 25-inch bend in upper main-rotor shaft below hub	Contact from hub with slight bending of shaft	Contact from hub with slight bending of shaft	Separation above swashplate; no torsion
Transmission and main-rotor mast	Fractured at upper trans-mission cap	Fractured at upper trans-mission cap	Intact upper transmission cap and shaft	Fractured at upper trans-mission cap	Fractured at upper trans-mission cap	Intact; case fractured
Lord mounts	Intact	Impressions in transmission deck	Intact	Transmission deck distorted and bent	Transmission deck distorted and bent	Transmission deck distorted and bent
Main-rotor blades	Both blade chords fractured through to main spar	One blade fractured 48 inches from blade tip	One blade slightly coned upwards; other severely curled down and fractured 22 inches from blade horn	One blade fractured 24 inches from hub, rivet impressions along blade to 49 inches from tip	One blade fractured 16 inches from tip	One blade fractured 39 inches from tip
Tailboom	No indications of blade strike	Severe torsional twisting and separation at fuselage	No indications of blade strike	Tailcone severed and missing aft of first bay; first bay exhibits slap to left side	Severe torsional twisting and separation at fuselage; blade strike 53 inches from forward end	Tailboom severed; blade strikes in two places
Cockpit	Left passenger door struck by main rotor blade	Strike from main-rotor blade at left door, airframe and forward skid	Left forward door frame and bulk-head struck by main-rotor blade	No indications of blade strike	Right skid and right upper windscreen struck by main-rotor blade	Plexiglas strike

Source: U.S. National Transportation Safety Board

for the nonflying pilot might make guarding the cyclic during training flights difficult. Based on the Richmond, California, accident, data from a 1976 Bell Helicopter study,[2] and the results of the R22 rotor-system computer model, the NTSB report concluded that a "low-inertia main-rotor blade can diverge from normal rotation to strike the body of the helicopter in just a few revolutions of the blade. This would take less than 0.5 second when the blade is operating at a normal rate of 530 RPM. Thus, unless the instructor is actually holding the cyclic handle and preventing a large, abrupt input, there is insufficient time for the instructor to react once a student makes such an input."

The NTSB said that many factors including RPM decay followed by blade stall, turbulence, insufficient pilot skill or lack of pilot proficiency could be causes of main-rotor-blade divergence. The report said, "Because of the high responsiveness of the R22 to cyclic input and the rapidness with which the rotor blade could diverge and strike the fuselage, it is possible that diversion of attention to tasks such as retrieving charts, tuning radios or turning to look at something could result in a control input and subsequent change in aircraft attitude that requires corrective action to which even an experienced pilot may inadvertently respond with a large, abrupt movement of the cyclic control."

SFAR 73-1 said, "Since the SFAR was issued in 1995 ... there have been no accidents or fatalities involving R22 or R44 aircraft associated with low-G operations or main-rotor contact with the airframe. Although there is not yet sufficient historical data to statistically demonstrate that the almost three-year period of no fatal accidents of this type is a result of SFAR 73, it is the judgment of the FAA after reviewing all available information that this is the case."

The report said, "The absence of such accidents also supports the proposition that most of the accidents were caused by large, abrupt control inputs and the corrective actions taken should help prevent such accidents." Concluding that SFAR 73 should be made permanent, the report said, "There is a need to continue the special operating rules for flight instructors and student, low-experience and nonproficient pilots to ensure the safe operation of the helicopter."

The NTSB said that for future certification of highly responsive helicopters, operational requirements, student-pilot training requirements and instructor-pilot requirements similar to those imposed on the R22 and R44 should be included in the certification process. "The FAA should require helicopter manufacturers to provide data on the response of helicopters to large, abrupt cyclic inputs as part of the certification process and require operational limitations or other measures for those helicopters that are more responsive, such as the R22," said the report.

The report said that, in conjunction with the U.S. National Aeronautics and Space Administration (NASA), the FAA should continue to develop computer models of lightweight helicopters, using flight tests and whirl-tower tests as needed for model verification, to create a national resource tool for the study of flight-control systems and main-rotor-blade dynamics, and to facilitate the dissemination of information should any unusual main-rotor-blade system characteristics be found.♦

Editorial note: This article was adapted from *Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents*. Report no. NTSB/SIR-96/03. April 1996. The 107-page report includes figures and appendixes.

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