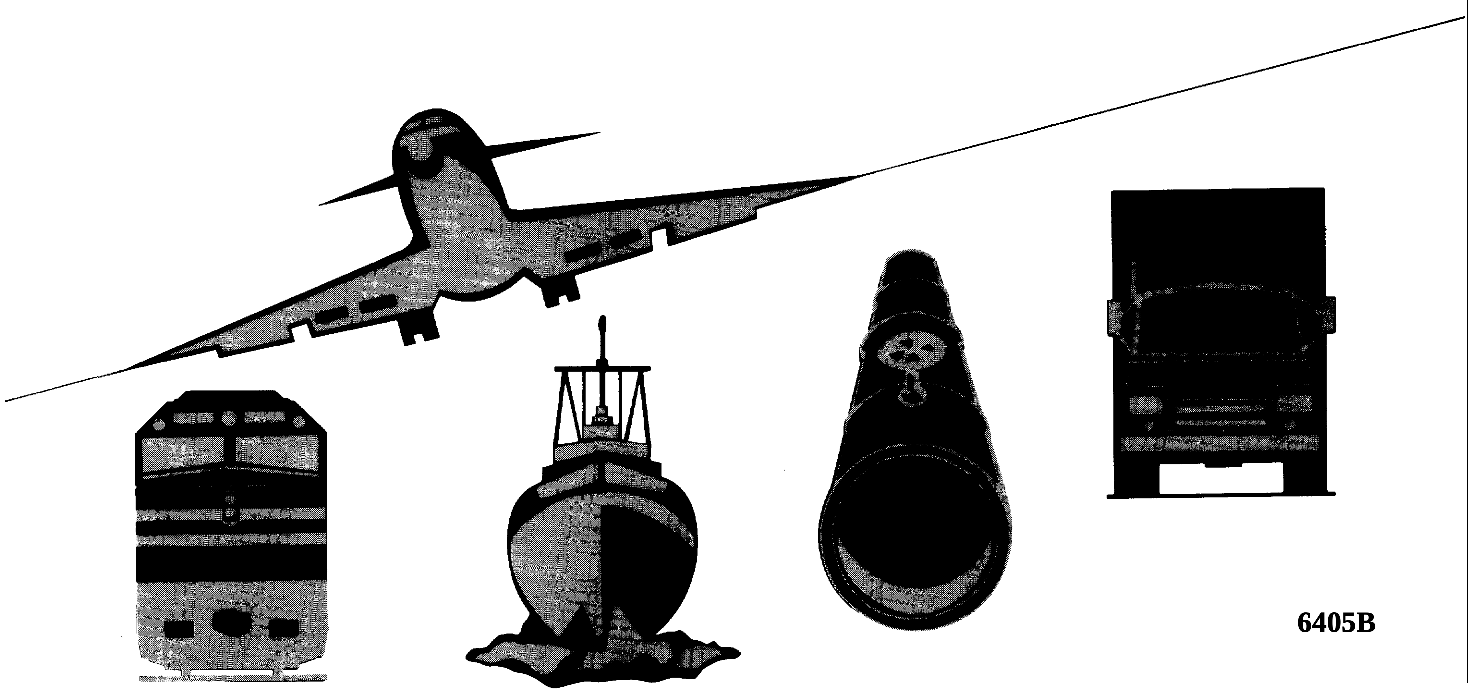
PB96-917003
NTSB/SIR-96/03

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

ROBINSON HELICOPTER COMPANY R22 LOSS OF MAIN ROTOR CONTROL ACCIDENTS



6405B

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Information about available publications may be obtained by contacting:

National Transportation Safety Board
Public Inquiries Section, RE-51
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(202)382-6735
(800)877-6799

Safety Board publications may be purchased, by individual copy or by subscription, from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703)487-4600

NTSB/SIR-96/03 PB96-917003

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

ROBINSON HELICOPTER COMPANY R22 LOSS OF MAIN ROTOR CONTROL ACCIDENTS

Adopted: April 2, 1996
Notation 6405B

Abstract: This report examines the loss of main rotor control accidents involving Robinson Helicopter Company R22 helicopters, When similar accidents occurred involving the Robinson R44 helicopters, the scope of the report expanded to include those accidents. The safety issues discussed in the report include the need for appropriate measures to reduce the probability of loss of main rotor control accidents; the need for continued research to study flight control systems and main rotor blade dynamics in lightweight, low rotor inertia helicopters; the need for operational requirements to be addressed during future certification of lightweight, low rotor inertia helicopters; and the need for the Federal Aviation Administration (FAA) to review and revise, as necessary, its procedures to ensure that internal recommendations, particularly those addressed in special certification reviews, are appropriately resolved and brought to closure. Safety recommendations concerning these issues were made to the FAA and the National Aeronautics and Space Administration.

this page intentionally left blank

CONTENTS

Executive Summary

The National Transportation Safety Board's special investigation of accidents involving loss of main rotor control by the Robinson Helicopter Company (RHC) R22 was prompted, in part, by an accident that occurred during an instructional flight near Richmond, California, on June 29, 1992. The flight instructor had 2,000 hours in the R22, and the student had 4 hours. The findings in that accident—that the helicopter was being operated at normal main rotor revolutions per minute (rpm) within the approved flight envelope and with no indication of weather being a factor—coupled with the Safety Board's difficulty in determining the causes of many similar loss of main rotor control accidents in the past, led the Safety Board to investigate these accidents as a group in an attempt to find common factors and to develop appropriate recommendations to prevent occurrence of similar accidents in the future.

For this special investigation, the Safety Board reviewed fatal accidents involving certificated helicopters; reexamined the available wreckage of the R22 from the Richmond accident and other accidents; reviewed the Federal Aviation Administration's (FAA) original certification process, certification requirements, and subsequent reviews of the R22 certification; and reviewed the Safety Board's recommendation history for the R22. In addition, the Safety Board analyzed various potential scenarios that could lead to loss of main rotor control.

During the Board's special investigation, the FAA implemented several operational changes, primarily to ensure that pilots of the R22 and flight instructors were better trained and more proficient and that flights in R22s in certain adverse weather conditions were restricted. There have been no loss of main rotor control R22 accidents in the United States since the changes were implemented more than a year ago.

The following issues are addressed in this special investigation report:

- The implementation of appropriate measures to reduce the probability of loss of main rotor control accidents.

- The need for continued research to study flight control systems and main rotor blade dynamics in lightweight, low-rotor inertia helicopters.

- The establishment of operational requirements to be addressed during future certification of lightweight, low rotor inertia helicopters.

- The need for the FAA to review and revise, as necessary, its procedures to ensure that internal recommendations, particularly those addressed in special certification reviews, are appropriately

resolved and brought to closure.

As a result of this special investigation, recommendations concerning these issues were made to the FAA and the National Aeronautics and Space Administration (NASA).

this page intentionally left blank

Chapter 1 - Introduction

On June 29, 1992, at 1242 Pacific daylight time, a Robinson Helicopter Company R22 helicopter, N83858, operated by the Sierra Academy of Aeronautics, Inc., lost main rotor control and broke up in flight during an instructional flight near Richmond, California.[1] Witnesses observed the tailboom and main rotor separate from the helicopter in flight. A certificated flight instructor (CFI) was providing a primary flight lesson to his student, who was recording her lesson (cockpit interphone and radio communications) with a microcassette tape recorder. 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[2] warning horn was checked and operated normally on the ground.

While en route and following a climb, the CFI instructed the student to perform a left turn. According to the recording, the student completed the turn using a shallow bank. While cruising southbound at 2,000 feet, with no prior indication of an anomaly, 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 helicopter rapidly descended and crashed into San Pablo Bay, 3 miles northwest of Richmond, California. The CFI, who had accumulated about 2,000 hours of R22 flight time, and the student pilot were killed. The student pilot had 4 hours of total flight time, all in the R22 as a pre-solo student.

The record of the flight provided by the audiotape showed that neither pilot had voiced any concern about the operation of the helicopter before the breakup. The low rotor rpm warning horn did not activate before or during the breakup sequence. The Safety Board's sound spectral analysis of the audiotape indicated that the helicopter was being operated at normal main rotor rpm. No unusual rotor system noises were heard before the event. The analysis of the audiotape indicated that the main rotor rpm did not decay before the breakup. Analysis of the recorded primary and secondary air traffic control radar data found that the initial breakup had occurred at 2,000 feet mean sea level. The helicopter's indicated airspeed, calculated from available radar data, was normal for cruise flight.

The wreckage was recovered from San Pablo Bay; examination of the wreckage produced no evidence of preimpact control system or airframe failures that might have initiated the breakup. Evidence of control interference was not found. The swashplate, spindle bearings, and engine exhibited no signs of preimpact damage. The main rotor mast assembly, with the main rotor blades attached, was recovered about 970 feet north of the main wreckage. The assembly had separated from the upper portion of the helicopter's transmission housing. One main rotor blade was found curled 39^{o} upward, and both main rotor blades exhibited multiple red paint smears that appeared to match the tailboom paint. The aft portion of the tailboom (aft of the first

---

[1]For more detailed information, read Brief of Accident File 1003, accident number LAX92FA267.

[2]Revolution of the blade per minute.

bay area) was not recovered. However, a main rotor blade had left its impression in the crushed left side of the tailboom's first bay area. Both pitch change links[3] exhibited bending overload failures, and the spindle tusks[4] were fractured from each spindle, consistent with damage resulting from the divergence of the main rotor blades from their normal plane of rotation. (Pitch change links and spindle tusks are addressed later in the report in Chapter 2.)

The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. The circumstances of the accident did not suggest failure or inability to maintain adequate rotor rpm, nor did they support that low-G maneuvering (that part of the flight envelope generally accepted to be less than 0.5 positive G) precipitated the event.[5]

Since 1981, the Safety Board has investigated or researched 31 R22 and three R44[6] accidents (domestic and foreign) involving an in-flight loss of main rotor control and contact of the main rotor blades with the tailboom or fuselage of the helicopter.[7] Because of the circumstances of the accident near Richmond, California, and the Safety Board's difficulty in determining the specific reasons for the loss of control of the main rotor blade and the precise mechanism by which the blade severs the fuselage, the Safety Board conducted this special investigation to identify common factors in these accidents and to recommend appropriate measures to prevent future accidents.

---

[3]Pitch change links are metal links that connect the swashplate to the pitch horn of the blades to control the blade angle-of-attack. See Figure 1.

[4]A tusk is the inner portion of the blade spindle that contacts the droop stops during start-up or shut down. It is designed to prevent the blades from drooping too low when centrifugal and aerodynamic forces are too low to support the blade in the plane of rotation.

[5]In the 1980s, low main rotor rpm and low-G maneuvering were associated with several R22 accidents as determined by the FAA, RHC, and the Safety Board.

[6]The R44 is a four-place version of the R22.

[7]The Safety Board'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. (See Appendix A for a summary of each R22 accident and Appendix B for a summary of the R44 accidents.) The Safety Board's review of R22 accident reports disclosed that 13 of the reports did not contain sufficient information to adequately support the previously issued probable causes. The Safety Board has revised the probable causes of these accidents and changed the corresponding Brief of Accidents accordingly (see Chapter 5 for more discussion).

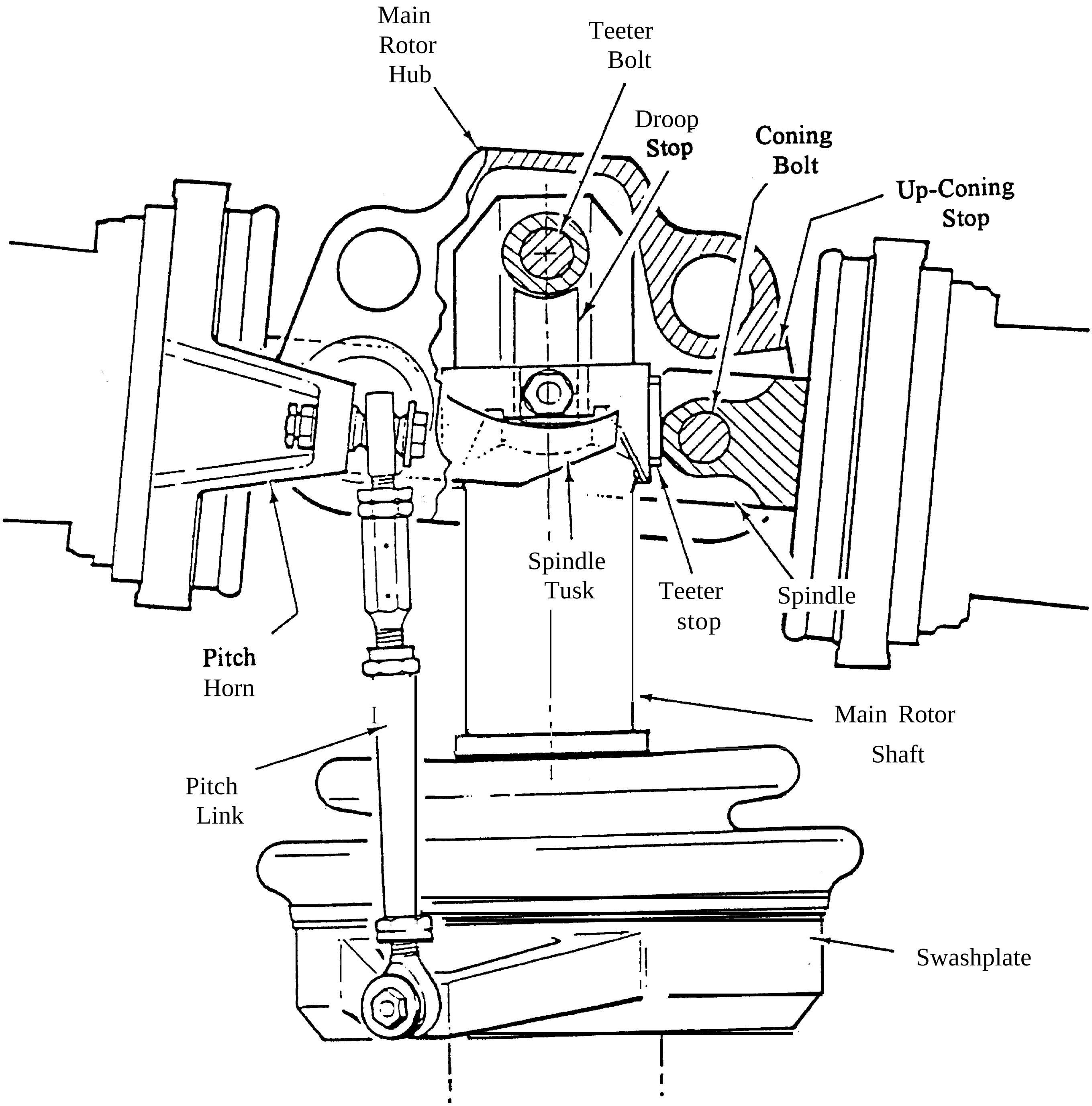


Figure 1 Main Rotor Hub and Assembly

Chapter 2 of the special investigation contains a description of the R22 design and manufacture. Chapter 3 provides an overview of fatal accident data involving certificated helicopters; the chapter also provides data related to pilot experience and some general characteristics of loss of main rotor control accidents investigated by the Board. Chapter 4 tracks the involvement of the Federal Aviation Administration (FAA) with the R22, related technical studies, and actions taken to reduce the potential for loss of main rotor control accidents. Chapter 5 contains a summary discussion of the issues and further actions needed. The last section of Chapter 5 presents the Safety Board's findings and safety recommendations made as a result of this special investigation.

Chapter 2 - R22 Design

General Description

The Robinson R22 helicopter is a two-place, light utility aircraft powered by a four-cylinder Textron Lycoming 0-320 reciprocating engine (see Figure 2). The helicopter has design features common to some helicopters but has several innovative design features unique to the R22 (and R44).

Flight Control System

The R22's flight control system is similar to those in other conventional helicopters in directional, lift, and maneuvering controls. The R22 uses a standard tail rotor system and tail rotor pedals for directional control. The collective and cyclic control mechanisms[8] are also standard for controlling lift, steady flight, and maneuvers.

However, the cyclic control is shaped differently from those in other helicopters. The R22's cyclic control is shaped like a "T," with a vertical component between the pilot seats. The top part of the "T" is angled slightly upwards from the center to the outboard ends to provide leg-to-handle clearance for the nonflying pilot. The handles are attached vertically to the outboard ends of the "T" for each pilot. The top part is hinged to the vertical component to allow the vertical position of the handles to vary. It was noted that if the flying pilot holds the handle in a comfortable position, the handle for the nonflying pilot may be in an awkwardly high position. However, the FAA has reviewed the R22 cyclic control system effectiveness from a human performance perspective and found it satisfactory. The FAA has also evaluated and approved the supplemental type certificate for an alternative R22 cyclic control that has a more conventional design.

[8]Collective is the flight control, located on the pilot's left side, that controls total lift of the rotor system. The collective changes the angle-of-attack of both main rotor blades equally. The cyclic is the flight control that the pilot grips with the right hand to control the tilt of the main rotor system and thus the direction of flight. The cyclic consists of push-pull tubes to a non-rotating swashplate, converted to rotating swashplate via bearings, to the pitch change links to control the pitch of the blades.

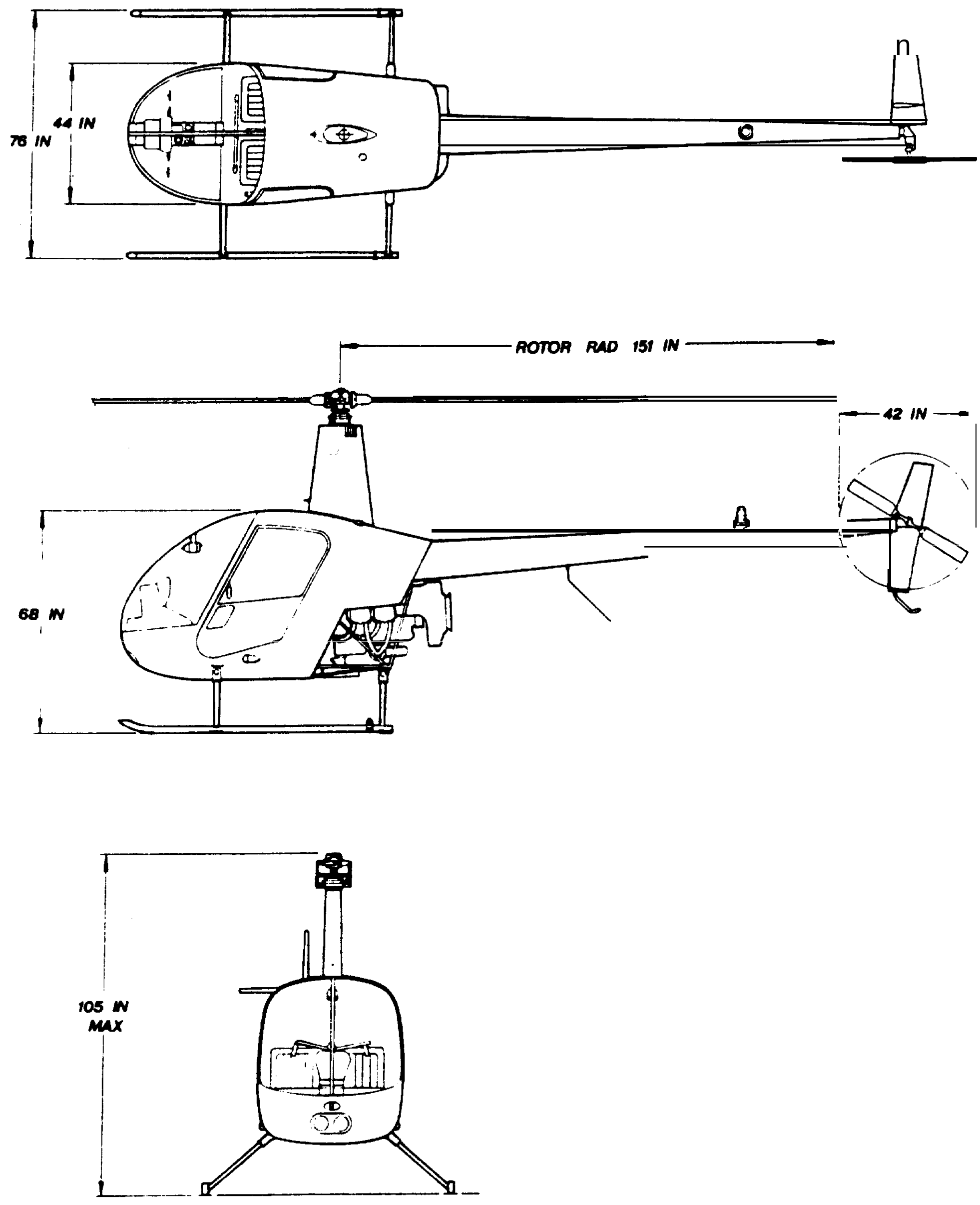


Figure 2--Three-Dimensional View of Robinson Helicopter Company

Main Rotor System

The main rotor system utilizes a two-blade, rigid-in-plane design.[9] The rotor blades are connected to the main rotor hub (see Figure 1) through individual flapping hinges.[10] The flapping hinges are part of a teetering main rotor hub that is hinged to the main rotor mast. In most two-bladed semi-rigid systems, the advancing blade flaps up, causing the retreating blade to flap down; however, the R22 main rotor blades are individually hinge-pinned and therefore can flap independently relative to each other. The total diameter of the R22 main rotor disc (two opposite blades connected by the hub) measures 25 feet, 2 inches, and each blade weighs approximately 26 pounds.

The R22 uses main rotor blades designed according to National Advisory Committee for Aeronautics (NACA) 63-015 airfoil specifications. The R22 main rotor blades are constructed at the RHC's manufacturing facility with a 7.2-inch chord (width of blade) and are each 12.58 feet long.

The R22 is operated at close to its maximum gross weight (1,370 pounds) with two people on board and a full tank of fuel, resulting in operations routinely conducted near the upper limit of the helicopter's operating envelope. This condition requires that the helicopter be operated near the maximum design lift capability of the main rotor system. To gain the needed lift, the R22's main rotor blade angle-of-attack will on occasions be near the stall angle-of-attack during normal operations. According to RHC and a simulation study conducted by the Georgia Institute of Technology (Georgia Tech),[11] large, abrupt control movements may produce main rotor blade stall and rapid decay of the rotor rpm.

Flight Control Responsiveness

The RHC, many R22 pilots, and some 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. In fact, in a February 13, 1984, memo from an FAA helicopter test pilot to the FAA Supervisor, Flight Test Section, ANM-176W, the writer stated that, "The aircraft in general is very quick. The aircraft reaction per inch of control input is high, making pilot-induced oscillations (PIO) and overcontrolling tendencies much more

---

[9]The rigid-in-plane term is used to describe the difference between the semi-rigid and the RHC design. The rigid-in-plane design allows the blades to move independent of each other in the vertical but not the horizontal plane of rotation. Hence, if one blade accelerates, the other blade will mirror the acceleration, but if one blade flaps (up or down), the other blade is not influenced directly.

[10]Flapping is the vertical movement of the blade as a result of aerodynamic forces. Coning is the upward bending of the blades caused by the resultant forces of lift and centrifugal force.

[11]See Chapter 4 for more details about the simulation study.

noticeable than in other helicopters." Further, a 1994 report of a special certification review (SCR)[12] by the FAA stated that, "Informal interviews were conducted with individuals from the operational community who were familiar with the R22. These individuals, who consisted of FAA flight standards pilots, FAA certification test pilots and operators of the R22, frequently expressed the opinion that this helicopter is very sensitive, requiring the pilots to be attentive at all times. However, those individuals interviewed stated that the aircraft did not have any unusual handling characteristics." Some pilots have stated that this greater responsiveness to control inputs causes R22 pilots to be highly alert, sharpening their piloting skills. However, 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 Board reviewed.

The Safety Board was unable to compare the response rates of the R22 to cyclic control input with the response rates of other helicopters because the data in the flight regimes of importance[13] to this investigation for other helicopters were not readily available. In fact, such data are difficult to obtain. Flight tests and computer simulations, which are quite extensive, are the best source of such data, and because of the lack of an FAA requirement for such data, they are not always available.

The Safety Board compared flight control response rate data of the R22 to Department of Defense helicopter military specification MIL-H-8501A requirements. The data showed that although the R22 is very responsive, it could meet the military's standards for flight control response during instrument approaches.

Original Certification

The RHC began its concept design phase for the R22 helicopter in 1974. Following the concept design phase, an application for certification (for research and development, with limitations) was issued by the FAA on January 6, 1975. After the R22 helicopter was flight-tested, the FAA issued Type Certificate No. H10WE to the RHC on March 16, 1979, approving the R22 design. Following the R22, the RHC requested certification of the R22 Alpha and was granted certification on October 12, 1983. The R22 Beta model was approved by the FAA on August 12, 1985, with the R22 Mariner (equipped with floats) shortly after. The R22 helicopter is built at the RHC factory in Torrance, California, under Production Certificate No. 424WE, which was granted to the RHC by the FAA on March 6, 1981. There have been more than 2,550 R22s built, and about 850 are registered in the United States.

According to a 1989 FAA study of rotorcraft operations, about 80 percent of the R22 flight hours logged that year were for instructional flights, 5 percent were for personal flying, and the

[12]See Chapter 4 for more information about the SCR.

[13]The flight regimes of importance to this investigation are those involving flight into turbulence, low-G maneuvers, low main rotor rpm maneuvering, and large, abrupt pilot inputs.

remainder were for business or corporate purposes, including aerial application and observation.

Recent Robinson Helicopter Company Design Changes

According to the RHC, all R22 helicopters produced after serial number 2510 have an electronic fuel control governor[14] as standard equipment, and a kit became available to install the new governor in other models of the R22 about August 1995. The electronic governor reduces pilot workload, especially in critical times. It also prevents underspeeds, thereby preventing rotor stall under certain conditions, and it prevents overspeeds that can overstress the rotor system.

In addition to the new governor, other design changes, according to the RHC, have been developed or are under development that could lessen pilot workload. RHC announced in February 1996 the availability of the newly certificated R22 Beta 2, which incorporates the Lycoming O-360 engine. The O-360 will deliver about 13 percent more horsepower in some instances. The extra horsepower will aid in maintaining or recovering rotor rpm more rapidly if the rpm becomes too low. The larger engine will incorporate an automatic carburetor heat control. The carburetor heat control could be set at takeoff, and when changes are required in flight, the movement of the collective would cause an increase or decrease in the carburetor heat control. This also reduces pilot workload at critical times, and also ensures that the carburetor heat will be automatically reduced providing maximum power upon landing.

A new main rotor blade for the R22 is also being developed. According to the RHC, the new blade would have the same dimensions as the present blade but would have a stainless steel outer covering similar to that in use on the R44. The use of stainless steel provides increased inertia in both the rotational and flapping directions leading to better rotor system performance. After completion of testing on the new blade and FAA approval of the R22 main rotor blades, the RHC plans to install the new blades on each production helicopter and modify each R22 when it is returned to the RHC for its 2,000 hour overhaul.[15] A certification date has not been set for the new R22 model utilizing the stainless steel main rotor blades.

Obviously, design changes that reduce pilot workload (especially during critical phases of flight) or enable the pilot to keep his or her attention focused outside of the cockpit will improve the safety of the operation of the R22, or any other aircraft.

---

[14]Device sustaining main rotor rpm by varying the throttle with inputs from the ignition system.

[15]The RHC encourages operators to return their R22s to the RHC factory for a complete overhaul at 2,000-hour intervals. The Safety Board is not aware of any other manufacturer with a similar program.

Chapter 3 - Accident Data and Accident Investigation Review

Since the first R22 in-flight loss of main rotor control accident, which occurred near Livermore, California, on November 11, 1981, the Safety Board has investigated or reviewed investigative data from 31 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. Consequently, three R44 accidents involving an in-flight loss of main rotor control and contact of the main rotor blades with the tailboom or fuselage of the helicopter have also been reviewed. Twenty-one of the accidents were domestic accidents; ten occurred in other countries. The Safety Board participated in R22 and R44 investigations in England, Germany, and Switzerland, and reviewed data files and reports received from Germany, Switzerland, England, Australia, and New Zealand.

The following characteristics were common to the 31 R22 and three R44 accidents:

- an in-flight breakup or main rotor blade contact to the airframe occurred in flight before collision with any object or terrain;
- there was no evidence of an initiating airframe or engine component malfunction;
- flight into adverse weather such as low visibility or ceilings was not involved; and
- pilot impairment from drugs or alcohol was not involved.

The Safety Board wanted to compare how often these types of accidents occurred per flight hour in R22s with the rate at which these accidents occurred in other helicopters. The Board did not attempt to calculate accident rates using the foreign R22 accidents because comparable activity data (flight hours) were not available for foreign operations. Instead, the Board concentrated on the U.S. R22 helicopter accidents for which information was available in the Safety Board's aviation accident data base.

The Board did not compare only accidents in which the main rotor blade contacted the airframe by helicopter model because blade contact with the airframe following a loss of control for non-mechanical reasons may be unique to the R22, while other helicopters might react differently when subjected to similar loss of control conditions. That is, a large, abrupt pilot input might lead to the loss of control of an R22, subsequent airframe contact by the main rotor and a fatal crash, while a similar pilot input might lead to loss of control without main rotor/airframe contact in another helicopter model but still involve a fatal crash. To permit a more appropriate comparison, the Board examined fatal helicopter in-flight loss of control accidents regardless of main rotor/airframe contact, provided that the loss of control was not attributable to a preexisting mechanical condition or an encounter with weather.[16] For the purpose of making comparisons, certain loss of control accidents were selected by the Board for study. These accidents, which will be referred to as 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 preexisting 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.

From 1981 through 1994, the Safety Board investigated 500 fatal accidents involving U.S.-registered helicopters. Ten helicopter models were involved in 43 accidents that met the above criteria as LOC accidents:[17] the Bell 47, Bell 204, Bell 206, Bell 212, Enstrom F28, Hiller UH12, MBB BO 105, Hughes 269, Hughes 369, and the Robinson R22. These ten helicopter models were involved in 357 of the 500 fatal accidents during the time period.

For each helicopter model, the fatal LOC accident rate per 100,000 flight hours was calculated using FAA estimated activity data for each model.[18] The accident rates for fatal non-LOC and all fatal accidents were also calculated per 100,000 flight hours. This information is summarized in Table 1.

---

[16]Encounters with instrument conditions were not included because R22s are not approved for flight in instrument conditions, and because accidents involving such encounters are usually related to the instrument flight skills of the pilot.

[17]Safety Board records include one additional LOC accident involving a Brantly B-2, and two involving a Fairchild-Hiller FH1100 helicopter. However, relatively few of these helicopters are in service; consequently, sufficiently reliable estimates of aircraft utilization were not available to calculate accidents rates. Further, three additional comparison accidents involving amateur-built helicopters were also excluded.

[18]*General Aviation Activity and Avionics Survey*, Federal Aviation Administration: Washington, DC, 1981-1992. *General Aviation and Air Taxi Activity and Avionics Survey*, Federal Aviation Administration: Washington, DC, 1993. *General Aviation and Air Taxi Activity Survey*, Federal Aviation Administration: Washington, DC, 1994. Data for 5 flight hour values were missing. These values were estimated by linear interpolation.

Table 1-U.S. Loss of control[1] (LOC), non-loss of control (non-LOC), and all fatal helicopter accidents, flight hours, and corresponding accident rates for the years 1981-1994. by helicopter model.

Helicopter model[a]	Fatal Accidents			Flight hours[b]	Fatal Accidents per 100,000 flight hours		
	LOC	Non-LOC	All		LOC	Non-LOC	All
Bell 206	2	119	121	13,369,702	0.015	0.890	0.905
Hughes 369	2	38	40	3,00,236	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 due to drugs or alcohol.

[a] 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.

[b] *General Aviation Activity and Avionics Survey,* Federal Aviation Administration: Washington, D.C. 1980-1992. Nine missing data values were imputed by linear interpolation. *General Aviation and Air Taxi Activity and Avionics Survey,* Federal Aviation Administration: Washington, D.C., 1993. Preliminary 1994 data from Federal Aviation Administration, Washington,

As shown in Table 1, seven of the 10 helicopter models had only one or two LOC accidents during the period examined. The Hughes 269 had five LOC accidents, and six such accidents involved the Bell 47. However, the Robinson R22 was involved in 23 LOC accidents during the period, 21 of which involved loss of main rotor control. In fact, per flight hour, the R22 was involved in the most LOC, non-LOC, and total fatal accidents.

The Safety Board recognizes that the aircraft activity data gathered and reported by the FAA are based on a survey. The data are subject to reporting and measurement error. Each year, the FAA reports the standard error statistic associated with each activity estimate for each model. It did not appear that any particular model was subject to consistently poor reporting during the period studied.

Finally, the Safety Board decided to compare the accident history of the R22 with the Bell 47. Although it is an older design, the Bell 47 was selected for this last comparison because, like the R22, it is a relatively lightweight, two-place, low inertia, helicopter that is also used extensively for training. Both the R22 and Bell 47 have similar high utilization rates, and the standard errors associated with these utilization estimates are low and comparable. The Safety Board used these standard error statistics to estimate the upper and lower bounds of the accident rates for each helicopter.[19]

Using these estimates of flight hours, the Bell 47 accident rates ranged from 0.155 to 0.729 fatal LOC accidents per 100,000 flight hours, compared to 0.964 to 3.300 for the R22. Accident rates for fatal non-LOC accidents ranged from 1.342 to 5.346 for the Bell 47, and from 1.635 to 5.589 for the R22. It is important to note that these intervals overlap for non-LOC accidents, but not for LOC accidents. That is, the lower bound rate of LOC accidents for the R22 is notably greater than the upper bound rate of LOC accidents for the Bell 47. 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.

From its statistical review of fatal helicopter accidents that occurred between 1981 and 1994, the Safety Board concludes that, compared to other helicopter models that have had fatal LOC accidents, Robinson R22s were involved in more fatal LOC accidents per flight hour.

Characteristics of Accidents Involving Loss of Main Rotor Control

The Safety Board compiled pertinent data from each of the 31 worldwide R22 in-flight loss of control accidents involving main rotor airframe contact. Only eight of the accidents involved winds or gusts known to be greater than 15 knots. In two accidents, the wind conditions at the accident site were not known. Wind data for most of the other accidents were obtained from the location of the closest-known official weather observatory. Of the 31 flights,

[19]The estimated 99 percent confidence interval for total flight hours during the period ranges from 822,983 to 3,879,368 for the Bell 47, and from 697,759 to 2,385,420 for the R22.

18 were conducted for personal business, nine involved dual flight instruction,[20] and three involved unaccompanied students. Only one of the accident flights involved commercial operation other than flight instruction. Further details of the accidents are contained in the summaries of the cases in Appendix A.

The Board was specifically interested in the flight experience of the pilots involved in these 31 accidents. The Safety Board used available records to compute the median time in R22s, total time in all helicopters, and total time in all aircraft for the pilots involved in each of the 31 accidents. In Table 2, these median flight hours are summarized by type of pilot assumed to be flying. Median flight hours are given for the pilots-in-command for all of the 31 accidents, for both the instructors and the students in the dual instructional flights, for the pilots-in-command of the non-dual-instructional flights, and for the least experienced pilot. For the dual instructional flights, least experienced pilot was the student; for the non-dual-instructional flights, it was the pilot-in-command.

Accident Investigation Review

Safety Board staff reviewed in detail six of the most recent R22 accident investigations[21] 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. (See Chart 1.) 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 ruled out, and no evidence of a precipitating flight control failure was found.

The Safety Board's materials laboratory examined components from these R22 accidents. The lab examined pitch change links, masts, mast supports, drive assemblies, main and tail rotor blades, hubs, droop stops, spindles, flight control tubes, bearings, and other pertinent items. In all cases, the laboratory personnel found no evidence of fatigue failure, inadequate materials, or improper maintenance. All of the R22 control and rotor system components examined in the Board's materials lab revealed evidence of overload failures. No evidence suggested a failure of the parts as causal to the in-flight rotor/fuselage contacts.

---

[20]This groups a "demonstration" flight for a non-pilot and a flight involving a flight instructor and another rated pilot (in which the exact purpose was unknown) with other accidents that were dual-instructional flights.

[21]Malabar, Florida, 1/30/92 (MIA92FA072); Maricopa, Arizona, 3/4/92 (LAX92FA137); Mt. Pleasant, Tennessee, 5/6/92 (ATL92FA096); Richmond, California, 6/29/92 (LAX92FA267); Martinez, California, 9/30/92 (LAX92FA410); and Knightdale, North Carolina, 9/28/94 (ATL94FA179).

Table 2-Median flight hours in R22s, all helicopters, and all aircraft of the pilots assumed to be handling the helicopter at the time of the accident, for the 31 worldwide R22 accidents in which the main rotor contacted the airframe.

		Median flight hours in		
Type of operation **Pilot**	**Number**[a]	**R22s**	**All helos**	**All aircraft**
All flights				
Pilot-in-command	30	127.5	180	790
Least experienced pilot[b]	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

[a]Flight hours data were available for 30 of the 31 accidents.
[b]The least experienced pilot was the pilot who had accumulated the fewest flight hours in the R22. For the dual instructional flights, it was the student; for the non-dual-instructional flights, it was the pilot-in-command.

Chart #1 **Robinson R22 Accident Wreckage Component Comparisons**

	MALABAR 01/30/92	MARICOPA 03104/92	MT PLEASANT 05/06/92	RICHMOND 06/29/92	MARTINEZ 09/30/92	KNIGHTDALE 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 adj. 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 swashplate	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° 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
TX & M R MAST	Fractured at upper trans. cap	Fractured at upper trans. cap	Intact upper trans. cap and shaft.	Fractured at upper trans. cap	Fractured at upper trans. cap	Intact. Case fractured
LORD MOUNTS	Intact	Impressions in trans. deck	Intact	Trans. deck distorted and bent	Trans. deck distorted and bent	Trans. deck distorted and bent
MAIN ROTOR BLADES	Both blade chords fractured through to main spar	One fractured 48" from blade tip	One slightly coned upwards, other severely curled down and fractured 22" from blade horn.	One blade fractured 24" from hub, rivet impressions along blade to 49" from tip	One fractured 16" from tip	One fractured 39" from blade 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 1st hay. First bay exhibits slap to left side	Severe torsional twisting and separation at fuselage; blade strike 53" 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 bulkhead struck by main rotor blade	No indications of blade strike	Right skid and right upper windscreen struck by main rotor blade	Plexiglas strike

The Safety Board has determined that most of the damage occurred after the main rotor blades began to diverge from their normal plane of rotation. The angles of the blade strikes to the fuselage could not have been achieved unless the hub had teetered[22] past its normal limits to the point of contacting or breaking the main rotor shaft or mast. In addition, the blades would have had to have been significantly out of plane for the spindle tusks to have contacted the droop stops or for the pitch change links to have failed. Divergent main rotor behavior could have overloaded the pitch change links.

A hub can become overteetered in a number of ways. Mechanically, the blade pitch control system could fracture or could separate. Typically, these failures should produce identifiable signatures in the wreckage. None were found.

In addition to the mechanically induced mechanism for overteetering, large, abrupt flight control inputs could directly induce overteetering or high blade angles, which in turn could induce mast bumping.[23]

The Safety Board is aware of only two cases in which an R22 exhibited signs of significant mast bumping in which the helicopter was able to land. Therefore, once mast bumping occurs, the margin for maintaining structural integrity is very small. Once overteetering and mast bumping occurs, structural failure of the main rotor mast or shaft is highly likely and would be quickly followed by overload of the pitch control system of the blade. The available wreckage from all six accidents is consistent with this scenario.

---

[22]The angle formed when the plane of rotation of the main rotor system is not aligned perpendicular to the mast. The angle is measured from the horizontal portion of the hub and the mast.

[23]Mast bumping occurs when a portion of the rotor system (two blades connected by the hub) exceeds the teetering limit and strikes the mast of the helicopter, usually with sufficient force to cause mast deformation or mast failure.

Chapter 4 - FAA Oversight

Certification Reviews

The R22 has been the subject of three FAA special certification reviews (SCRs).[24] Following several R22 fatal accidents that occurred in 1981 and 1982, an SCR of the R22 by the FAA, with the participation of RHC personnel, was completed on October 24, 1982. 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 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 airworthiness directive (AD) to make installation of a low rpm warning light mandatory; and (4) raise the rpm limit for activation of the low rotor rpm light from 91 percent to 97 percent. No discrepancies in the original certification were found.

As a result of this SCR, the RHC conducted flight tests and published a report on the results.[25] In addition, the RHC issued a safety notice to advise operators of the R22's sensitivities to low rotor rpm. The FAA raised the rpm threshold at which the warning horn (and newly installed light) would be required to annunciate to 95 percent (from 91 percent) and issued an AD mandating the installation of a low rotor rpm warning light.

The Safety Board noted that the SCR included a statement that, "The certification rules relating to [flight] characteristics, policy, guidance and advisory circulars will be reviewed for applicability to small FAR 27 rotorcraft. Especially, the 1-[second] delay time in correcting for power loss, control response and [aircraft] dynamic stability during maneuvers." The SCR recommended the following:

> The airman certification rules, FAR 61, guidance [material], [flight] test guides and the basic helicopter handbook, AC61-13B, should be revised to reflect the safety needs of small rotorcraft as learned from the R22 accident records. The current rules and practice [are] inadequate for students and [flight] instructors training in small helicopters. Pilot certification and [flight instructor] ratings in

---

[24]The SCRs provided to the Safety Board followed the format specified in FAA Orders 8110.4 (p. 21 and p. 167, dated 1/31/77) and Rotorcraft Directorate Standard Procedures (dated 10/1/92).

[25]Main Rotor Hub Teeter Angle and Rpm Decay Survey. October 26, 1982. (RHC RTR-073. See Appendix C for relevant excerpts.)

rotorcraft are currently insufficient and unsafe. An FAA [flight standards] and engineering review team will be formed[26] to recommend specific changes.

On November 23, 1982, the Manager of the Western Aircraft Certification Field Office (WACO) wrote to the Acting Manager of the FAA Flight Standards Division that RHC flight tests showed that, "the R22 had no unusual flight characteristics when flown within the operating limitations....Attempts to achieve a rapid rotor decay could only be accomplished with throttle chops....The aircraft does have a relatively high roll rate sensitivity....The aircraft responds rapidly to any control input, and the student must be made aware of this.[emphasis in original]" The letter ends, "In conclusion, the R22 helicopter is a safe, airworthy aircraft when it is flown within its operating limitations. It is highly responsive to small control inputs and as a result must be treated gently by its operator (as any helicopter must be). The aircraft has a low inertia rotor system which will decay rapidly during throttle chop maneuvers,[27] but control is maintained throughout the transient rotor droop, and rpm builds quickly back to power-off levels.[28] It is an aircraft which can foster good helicopter flying techniques in the student pilot."

The Safety Board reviewed the records of the Los Angeles Aircraft Certification Office (LAACO) concerning action taken as a result of the SCR and found an internal FAA memorandum, dated March 29, 1983, directed to the Manager, Helicopter Policy and Procedures Staff, ASW-110 from the manager of the FAA WACO, ANM-170. In that memorandum, the manager of the WACO addressed the low-G maneuvering problem of the R22 and stated that, "This office is of the opinion that the R-22'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." He further stated that, "The FAA, however, has not addressed its problem as perhaps it should have. We have found nothing published by the FAA which describes the problem of helicopter control during low g maneuvering and the appropriate recovery techniques."

The memo also stated that quantitative dynamic stability testing data were obtained on the recent FAA-monitored refly (repeat of flight testing previously conducted) and that consideration should be given to evaluating the dynamic stability characteristics of all future helicopters. The memo concluded that the low-G control characteristics of the R22 are acceptable when the R22 is flown in a normal and reasonable manner. The memo recommended that the FAA initiate action to warn pilots of the dangers of low-G flight and expand dynamic stability testing to better establish helicopter handling qualities. The Safety Board's subsequent review of the FAA records

---

[26]To the Board's knowledge, no FAA team was ever formed.

[27]A throttle chop maneuver is one in which a pilot intentionally reduces the throttle to simulate engine failure.

[28]Power-off levels range from 459 to 561 rpm. This range is considered acceptable for autorotative rpm.

found no documentation of any FAA action taken as a result of the FAA memorandum. However, the Safety Board notes that such dynamic testing was performed on the R44.

On January 25, 1988, the manager of the FAA's Southwest Region, Aircraft Certification Division, requested another SCR of the R22. (In 1987, there were three accidents involving the R22 involving in-flight loss of control.) The SCR was completed on March 23, 1988, and found that the R22 met all requirements of 14 CFR Part 27.[29] The review found no new areas of concern. After the review, 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 Safety Board could not find any records indicating that the FAA had ever addressed the merits of or conducted research in response to any of the 1988 SCR team recommendations.

On January 18, 1994, following additional accidents and Safety Board recommendations, the FAA LAACO issued another SCR of the R22. The review found, as in the two previous certification reviews, that the R22 met all 14 CFR Part 27 certification requirements. The FAA concluded that the R22 is used extensively by training facilities and that the flight characteristics, sensitivity to flight control inputs and high rotor rpm decay rate, are inherent to this aircraft because of its low gross weight. The FAA also concluded that structural and mechanical integrity of the rotorcraft did not appear to be an issue and that the rotor rpm decay rate is similar to other helicopters. The SCR report recommended that a research and development (R&D) program be established to provide data to support rulemaking and recommended that the program include rotor decay rates related to a minimum standard, and allowable rotorcraft response rates to abrupt control inputs. Additionally, it was suggested that a method of tracking accident rates be established. During the Board's special investigation, no evidence was found that the FAA had established such an R&D program or determined that such a program was unnecessary.

On May 3, 1996, the FAA provided to Safety Board staff a copy of a Research Project Initiative (RPI) that had not been signed, had no RPI number, and had no approval attached to it. The Safety Board could find no evidence that the RPI had been funded. The FAA also provided documentation of other actions taken by the FAA from 1982 through 1995 concerning the R22. However, the documentation did not link these actions to the recommendations made in the SCRs nor provide evidence of any procedures that would have brought the recommendations to closure. In fact, the FAA's May 3, 1996, letter to the Board states that, "While present documents do not specifically detail follow-up procedures, they are being revised to do so."

---

[29]In a May 3, 1996, letter to the Safety Board's Office of Aviation Safety from the FAA"s Associate Administrator for Regulation and Certification, the 1988 SCR was classified as an internal review and not an SCR.

Recent FAA Actions

On July 22, 1994, the FAA published a special airworthiness alert (SAA) addressing the operation of R22 helicopters. Among other things, the SAA cautioned R22 pilots to avoid abrupt cyclic inputs and to reduce maneuvering speeds to the extent possible. (The alert was updated and expanded to address the R44 and reissued on January 17, 1995, and was distributed to pilots and operators of the R22 and R44.)

Also, in response to the Board's July 1994 safety recommendations, the FAA convened an Aircraft Certification Panel (technical panel) in July 1994 to study the R22 loss of main rotor control accidents and to recommend appropriate action to prevent these types of accidents. The panel was directed to consider the appropriateness of reducing the R22 helicopter "never exceed airspeed" (V_{ne}), the subject of Safety Board Safety Recommendation A-94-143.[30] In addition, the panel was to conduct research to determine possible deficiencies and their remedies with respect to aircraft design, operating procedures, operating limitations, and 14 CFR Part 27 airworthiness certification criteria, the subject of another Safety Board recommendation, A-94-144. In November 1994, the technical panel selected the Georgia Institute of Technology (Georgia Tech) to perform simulation studies of the R22 main rotor system. (The Georgia Tech simulation studies are discussed in more detail later in this section of the report.)

While the FAA's technical panel and Georgia Tech were conducting the research outlined above, the FAA initiated other actions to reduce the potential for pilot actions resulting in loss of main rotor control accidents in R22 and R44 helicopters. On January 10, 1995, the FAA issued Priority Letter ADs 95-02-03 and 95-02-04 prohibiting flight of the R22 and R44 in surface winds greater than 25 knots, gusting winds greater than 15 knots, and in moderate, severe, or extreme turbulence. These ADs were amended and re-released as ADs 95-04-14 and 95-04-13 on March 2, 1995.[31]

On January 10, 1995, the FAA also issued a special airworthiness information (SAI) bulletin to all pilots and operators of the R22 and R44. The bulletin warned airmen to operate the R22 and R44 within the helicopters' normal flight envelopes and to avoid excess winds, altitudes, and other conditions unfavorable to the helicopters. The FAA issued a flight standards information bulletin on January 18, 1995, to all FAA Flight Standards inspectors to advise them of

---

[30]The Safety Board recommendations referenced in this special investigation report are contained in Appendix D. All safety recommendations that were issued before this special investigation report and that were in an "open" status have been either closed superseded, closed acceptable alternate action, or closed acceptable action. (Appendix D also contains the Safety Board's letters to the FAA in which the recommendations were closed.)

[31]ADs 95-04-14 and 95-04-13 were identical to the previously issued ADs except that the requirement for turbulence to be based on area forecasts was deleted because area forecasts cover widely varying areas that usually contain mountainous as well as flat terrain. The ADs were further amended in January 1996 to reduce the unintended effect on experienced R22 and R44 pilots.

the information contained in the Safety Board's recommendation letter of January 6, 1995, and the SAI. On February 15, 1995, the FAA issued a flight standardization board (FSB) report for the R22 and R44. The FSB recommended stringent requirements for all future training in the two helicopter models. The FSB also recommended future research into several areas of helicopter hardware and operations, including revision of 14 CFR Part 27 to consider main rotor system inertia in single-engine helicopters.

On February 23, 1995, the FAA issued Special Federal Aviation Regulation (SFAR) 73, promulgating special rules for pilots operating under 14 CFR Part 61.[32] The SFAR alters the normal biennial flight review requirements by requiring R22 and R44 pilots to perform proficiency flight reviews in the R22 and R44, as appropriate; increasing the amount of dual training required before a pilot may receive his or her private pilot-helicopter certificate; and mandating special awareness training specific to the R22 and R44 helicopters. The SFAR expires on December 31, 1997, or sooner if superseded or rescinded.

In June 1995, the technical panel released its report, dated March 17, 1995, to the Safety Board. The report summarizes the panel's actions and outlines recommendations for further design changes, operating limitations, and future actions. Specifically, the panel recommended the following: (1) that the R22 be reconfigured with an electronic engine rpm governor similar to that previously installed in the R44;[33] (2) that the low rpm warning threshold be increased to activate at a higher rpm and the audio warning be added through the R22's intercom system; (3) that the operating limitations be changed to increase the minimum power-on rpm limit to 97 percent; (4) that the cyclic control be removed for all passengers in the left seat; and (5) that normal flight operations with the governor switched off be prohibited. The technical panel further recommended that the simulation and modeling program initiated by Georgia Tech be continued until Safety Board concerns and any deficiencies discovered by simulation were satisfied.

Flight Testing of the R22 and R44

As a result of the several R22 accidents involving excessive teetering and blade contact with the tailboom, RHC conducted in 1982 a series of flight tests to ensure that adequate teetering clearances existed during all normal flight regimes and that the rotor decay rates were not excessive. The flight tests consisted of throttle chops and flight control inputs. Parameters of pitch, roll, and teeter angle were recorded as were other parameters such as main rotor rpm, airspeed, altitudes, and acceleration. Pitch and roll rate responses to cyclic input were calculated.

---

[32]SFAR No. 73; Part 61—*Certification: Pilots and Flight Instructors,* issued February 23, 1995.

[33]As previously noted, according to the RHC, all new R22 helicopters produced after serial number 2510 have the new governor as standard equipment, and a kit became available to install the electronic governor in other models of the R22 about August 1995.

The tests determined that the margin of tailboom clearance was satisfactory during all maneuvers and that adverse flight characteristics were not obtained during any of the maneuvers, even those outside the normal flight envelope. Following power changes, a reduction of the collective stick resulted in a positive response of the rpm, and the helicopter remained controllable with normal inputs. The RHC concluded that the R22 rotor system would not stall, exceed its teeter clearance, or contact the tailboom when the aircraft is flown within its approved limitations.

The tests showed that, during cruise, the cyclic is forward and to the right of neutral while the rotor plane is tilted aft and to the left, about 5^{o}. Changes to the cyclic generally produce like changes in the tilt of the rotor plane. For example, if the cyclic is moved aft and left from the cruise position, the tilt of the rotor plane can be expected to increase in the aft and left direction.

During July 1995, the FAA participated in flight tests of the R44 at the RHC facilities in Torrance, California. The R44 was fully instrumented to record information from the main rotor system, helicopter performance information, and flight control positions. The flight tests were accomplished to confirm that the R44 can be operated safely. According to the FAA, the results indicated that the R44 could safely perform any nominal flight activity without main rotor divergence tendencies. The flight tests comprised engine power reductions, push-overs, and normal flight training maneuvers.

A Safety Board staff review of the flight test results showed that some of the flight test maneuvers were performed with large control inputs and at substantial input rates. A standard used by one helicopter manufacturer is to input 10 percent of the total control input available in 0.1 second. The R44 was subjected to a 10 percent cyclic push in 0.17 second continuing to 25 percent in 0.4 second.

The FAA reported that all flights were flown consistent with flight test procedures and that at no time was the safety of the flight questionable. Unfortunately, because tests were not (and could not safely be) conducted to determine the helicopters' response to large, abrupt cyclic inputs while in steady state flight with the cyclic already forward and to the right (normal high speed forward flight), the results of the flight tests did not provide the data needed to determine the mechanism for the blade diverging into the body.

Georgia Tech Study

The FAA awarded a grant to the Georgia Tech School of Aerospace Engineering to develop a computer-based mathematical simulation of the R22 to allow the study of the aircraft and rotor system dynamics. The development of a simulation model had been recommended by the Safety Board and the FAA's R22 technical panel. The objective of this effort was to use the simulation to study the effects of flight control inputs, rotor rpm stall, low-G maneuvers, and turbulence on the operation of the helicopter and the three-hinge rotor system. A final report of the study was provided to the Safety Board in the first week of March 1996.

Georgia Tech researchers stated to the Safety Board that the research was concluded in December 1995 when the available funds were expended and before the mathematical model was thoroughly validated by comparison to flight test data. Modeling of such a complex system required more resources than had been allotted for the project. According to the researchers, more research, including future testing that produces excessive flapping or rotor divergences, is needed to fully validate the mathematical modeling of the R22 in the areas of flapping and divergent tendencies.

The FAA then opted to simulate induced tail rotor strikes through the use of large flight control inputs and large gusts. FAA and Georgia Tech experts described the simulated flight control inputs as extreme and the gusts like an encounter with a sharp thermal-induced gust. Although some of the more severe flight control inputs or gusts did result in tailboom contacts, Georgia Tech engineers pointed out that the model appeared to be numerically unstable in that induced roll rates were not properly damped. Therefore, calculated roll excursions were artificially large, and the tailboom contacts were not considered valid. However, each main rotor strike was preceded by mast bumping and/or extremely high blade angle of attacks.

In effect, the simulations, based on the nature of the modeling, became invalid when roll rates became large, the blade angle of attacks became high, or once the rotor hub contacted the mast. In addition, rotor decay histories could not be evaluated because the model was based on a constant rotor speed rather than an engine/power-based model that would react to rotor blade aerodynamic performance factors. Also, the FAA decided to forgo a methodical buildup of control inputs and evaluated large control movements; it is unknown if smaller control inputs would have produced mast bumping. Typical pilot control inputs while reacting to flight dynamics were not modeled.

Although the Georgia Tech mathematical model of the R22 was not developed sufficiently to explain the divergent behavior of the rotor system, the researchers stated that the trends that the model exhibited inside the validated flight envelope show that the R22 model is a useful tool in analyzing rotor stability and transient response within the normal operating envelope and verifying the theory that pushovers and rotor stall may lead to rotor/airframe contact. The Safety Board believes that the mathematical model sufficiently simulates the R22 rotor system behavior in the normal operating range, and that 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.

Chapter 5 - Summary Discussion

The Board examined various potential scenarios that could lead to an in-flight rotor/fuselage contact, including the following: an unstable main rotor design; too rapid rotor rpm decay; mechanical failures; high blade angles (rotor stall); mast bumping; over-sensitive flight controls; or sensitivity to multiple or large control inputs.

During this investigation, the Safety Board found no direct evidence of an unstable blade or rotor system design. The extensive operational history, the wreckage evidence, flight tests, and computer simulations indicate that a dynamically unstable main rotor system is unlikely. Although the Board cannot conclusively eliminate the possibility of a deficient design, many professional pilots continue to operate the R22 and R44 in difficult conditions without inducing loss of control of the main rotor blade. For example, the R22 is used by police departments, pipeline spotters, and the news media, often under challenging operating conditions.

The Safety Board originally determined that the probable causes of most of the past R22 accidents were the result of pilots allowing the main rotor rpm to decay or low-G maneuvering. The absence of preexisting material defects in the rotor system, the FAA's assurance that all relevant certification standards had been met, and the belief that the certification standards were adequate led the Safety Board to that determination. However, the Safety Board's investigation of the Richmond, California, accident presented evidence of an in-flight loss of main rotor control with normal rpm until the breakup began. In the other accidents, the rotor system rpm at the moment of loss of control is unknown. Further, the majority of the evidence in most of the accidents is not consistent with pilot maneuvers that would result in a low-G condition before the loss of control. Therefore, the Safety Board has revised 13 of the Briefs of Accidents to more accurately reflect the known and unknown factors in these accidents.

Indications of mast bumping were present in all of the loss of main rotor control accidents discussed in the Board's special investigation report, although the mast bumping generally did not result in significant damage at the point of contact with the mast. The Safety Board does not believe that mast bumping was the precipitating causal event in the R22 and R44 loss of main rotor control accidents.

A number of situations could have led to the mast bumping in the R22 and R44 accidents. Unstable blade or rotor system design has been considered, as were rotor blade stall; low-G maneuvers; large, abrupt control inputs; and turbulence. Large, abrupt control inputs can lead directly to mast bumping or induce blade stall, which, in turn, can lead to mast bumping. Turbulence may produce blade stall or lead pilots to make large control inputs. Some low-G maneuvers initially result from deliberate control inputs, but at times these may be followed by larger control inputs during recovery from the low-G situation that may lead to a loss of main rotor control.

Given that the R22 helicopter is very responsive to control inputs, the Board became concerned that many of the loss of control accidents involved large control inputs leading to the loss of main rotor control and subsequent in-flight airframe contact by the main rotor. The Safety Board notes that large, abrupt control inputs when the R22 is in a steady-state condition with an already existing teeter could cause the teeter limit (12^o) to be exceeded, followed by a mast strike and subsequent loss of main rotor control.[34] Although the Georgia Tech mathematical model of the R22 was not developed sufficiently to demonstrate this conclusively, the results of the studies suggest that large, abrupt cyclic movements can lead to blade stall and/or mast bumping.

The Board notes that this is not new information; an earlier study on teetering rotor systems by Bell Helicopter also highlighted that large flapping amplitudes could be expected with large, abrupt control inputs.[35] The report stated that blade flapping can increase rapidly from acceptable to excessive angles in only one or two revolutions. The Bell Helicopter report further stated, in part:

> Control inputs were a source of high flapping when made rapidly and with large amplitude. If the cyclic control is applied faster than the helicopter will respond, high flapping will result in proportion to this input....Most conditions which cause excessive flapping result from rapidly developing phenomena such as blade stall, landing loads, or abrupt, large control inputs. Blade flapping increases rapidly from acceptable to excessive angles in only one or two rotor revolutions, leaving little, if any, reaction time for the pilot to correct the situation.
>
> The pilot is the ultimate controller of conditions that generate excessive flapping. The danger of large, abrupt control inputs in flight conditions near retreating blade stall, or low g-levels, should be emphasized in training. Flight maneuvers which are acceptable when the aircraft is held within its operational envelopes may result in excessive flapping if any of those envelopes are exceeded.

Further, because R22s are used extensively for training, the Safety Board attempted to determine if limited pilot experience and the training environment might have been common factors in some of the loss of main rotor control accidents. Although many accidents involved low-time pilots, the Board cannot be certain in many of the dual-instructional accidents whether the student or the flight instructor was manipulating the flight controls immediately preceding the loss of control. In many of these accidents, student pilots were probably operating the flight controls, but instructor pilots may have been demonstrating maneuvers. Although flight instructors should be able to prevent a student pilot from improperly manipulating the controls by

---

[34]Again, the Safety Board is aware of only two incidents in which an R22 experienced a mast strike and recovered.

[35]*Rotor Blade Flapping Criteria Investigation.* December 1976. Prepared for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory by Bell Helicopter Textron, Ft. Worth, Texas.

guarding the controls, the Board is concerned that flight instructors may not always or properly guard the cyclic flight control during long periods of instructional flight because of the somewhat awkward position of the cyclic-T handle for the nonflying pilot. Based on the Richmond, California, accident, the Bell Helicopter study, and the Georgia Tech study, the Board concludes that the 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 seconds 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 Safety Board recognizes that all of the loss of control accidents may not have resulted from a single scenario. Some may have involved low rotor rpm leading to blade stall, and some may have involved turbulence. The high responsiveness of the helicopter to flight control input combined with possible lack of pilot skills, knowledge, proficiency, or alertness could also offer possible explanations for some of the subject accidents. Further, 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.

Although the Board could not identify a particular cause that led to the in-flight rotor blade contact with the fuselage of the R22s, during the investigation, the FAA did implement numerous operational changes, primarily to ensure that pilots and flight instructors were more knowledgeable of specific R22 operational hazards and were better trained, and that flights in adverse weather conditions by low-experienced pilots were limited. There have been no in-flight rotor/fuselage contacts of the R22 in the United States in the past year since the changes were implemented. Although the Safety Board cannot conclude that the operational changes will eliminate all in-flight rotor strikes, the absence of such accidents since these actions were implemented suggests that they have been effective. 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. Because the R22 appears to be more responsive to control inputs than other helicopters normally used in training or routinely used by low-time pilots, the Board concludes that there is a need to continue the special operating rules for flight instructors and student, low-experience, and non-proficient pilots to ensure the safe operation of the helicopter. Therefore, the Safety Board believes that the FAA should ensure that SFAR 73, the FSB specifications, and the ADs applicable to the operation of the R22 and R44 are made permanent.

The Board is also concerned that in the future, other highly responsive helicopters are likely to be designed and built that may have characteristics similar to the R22. Consequently, the Safety Board believes that as a part of the certification process for highly responsive helicopters, the FAA should establish operational requirements, student pilot training requirements, and instructor pilot requirements, such as those imposed on the R22 and R44, to ensure that pilots at all levels of qualification and skills can adequately operate the helicopter. The Safety Board concludes that although the response rate of the R22 to cyclic input is not unsafe so long as the special operating rules remain in place, there is a need for the FAA to consider the responsiveness of helicopters (especially lightweight, high performance helicopters such as the R22) as part of the certification process to determine if special operating rules or guidance are necessary. Thus, the Safety Board believes that the FAA should require helicopter manufacturers to provide data on the response of helicopters to large, abrupt cyclic inputs as a part of the certification process and require operational limitations or other measures for those helicopters that are more responsive, such as the R22.

The Safety Board is aware of the complexity, difficulty, and potential hazards associated with flight tests and full-scale wind tunnel testing. However, further research into lightweight helicopter behavior would benefit the helicopter industry and create a national resource tool that would aid certification of future helicopter models, especially those that are lightweight and highly responsive. Therefore, the Safety Board believes that the FAA, in conjunction with NASA, should continue the development of the simulator model of lightweight helicopters, using flight tests and whirl tower tests as needed to validate the model, to create a national resource tool for the study of flight control systems and main rotor blade dynamics.

As indicated above, the FAA did ultimately implement several operational changes regarding pilot and flight instructor knowledge and training in the R22. Although these changes appear to have improved R22 safety, the Safety Board will continue to monitor any future R22 and R44 accidents.

Also, records made available to the Safety Board suggest that resolution of internal recommendations made during the SCRs has not been documented and may not have been accomplished in response to those SCRs. The Safety Board believes that the FAA should review the process and procedures by which the FAA's aircraft certification offices and management resolve or bring to closure safety recommendations that are presented in internal documents, including SCRs, assuring that each recommendation is properly reviewed and that the results of the review are properly documented.

Findings

1. The Federal Aviation Administration's special certification reviews concluded that the Robinson Helicopter Company R22 met the certification standards of 14 CFR Part 27 when it received its type certificate on March 16, 1979.

2. Between 1981 and 1994, the R22 experienced fatal accidents involving loss of control, including accidents involving loss of main rotor control at rates much greater than other helicopters.

3. Between 1981 and 1995, at least 31 R22 accidents and three R44 accidents (domestic and foreign) have involved a loss of main rotor control. The investigations of these accidents did not identify any precipitating progressive mechanical failures or material defects. The cause of the loss of main rotor control in many of the accidents most likely stems from a large, abrupt pilot control input to a helicopter that is highly responsive to cyclic control inputs.

4. The median flight hours of the pilots-in-command, including flight instructors, were 180 hours helicopter and 127.5 R22 hours of flight experience when involved in fatal R22 loss of main rotor control accidents. However, the median R22 flight experience for the lowest time pilots who may have been manipulating the flight controls was 52.5 hours.

5. Because the R22 is likely more responsive to cyclic control inputs than other helicopters normally used in training or by low-time pilots, special training requirements for both student pilots and flight instructors are needed.

6. As part of the certification process, manufacturers have not been required to provide data on the responsiveness of helicopters to cyclic inputs.

7. Flight instructors probably do not have sufficient time to react to R22 students' large, abrupt flight control inputs; therefore, they must guard the cyclic closely to prevent such inputs.

8. There have been no in-flight main rotor loss of control accidents in the United States involving the R22 or R44 helicopter since early 1995, when the Federal Aviation Administration issued airman information alerts, airworthiness directives, a flight standardization board report, and Special Federal Aviation Regulation 73, all of which pertain to the operation of the R22 and R44 helicopters.

9. Mathematical modeling of the R22 main rotor system conducted by the Georgia Institute of Technology suggests that large, abrupt cyclic control inputs may result in mast bumping or blade angles-of-attack greater than the stall angle; however, the mathematical model was

not developed sufficiently to demonstrate that flight control inputs would lead to loss of control of the main rotor.

10. Further research into lightweight helicopter behavior would benefit the helicopter industry and create a national resource tool that would aid in the certification of future helicopter models, especially those that are lightweight and highly responsive.

11. Federal Aviation Administration (FAA) staff made several internal recommendations related to the R22 accidents and special certification reviews (SCRs). Based on documents provided by the FAA under subpoena and in subsequent correspondence, the Safety Board 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.

Recommendations

As a result of this special investigation, the National Transportation Safety Board made the following safety recommendations:

To the Federal Aviation Administration—

> Ensure that Special Federal Aviation Regulation 73, the Flight Standardization Board specifications, and the airworthiness directives applicable to the operation of the R22 and R44 are made permanent. (Class II, Priority Action) (A-96-9)
>
> Establish, for future certification of highly responsive helicopters, operational requirements, student pilot training requirements, and instructor pilot requirements, such as those imposed for the R22 and R44, necessary to ensure that pilots of all levels of qualification and skills can adequately operate the helicopter. (Class II, Priority Action) (A-96-10)
>
> Require helicopter manufacturers to provide data on the response of helicopters to flight control inputs to be used as part of the certification process, and require operational limitations or other measures for those helicopters that are highly responsive. (Class II, Priority Action) (A-96-11)
>
> In conjunction with the National Aeronautics and Space Administration, continue the development of the simulator model of lightweight helicopters, using flight tests and whirl tower tests as needed to validate the model, to create a national resource tool for the study of flight control systems and main rotor blade dynamics. If any unusual main rotor blade system characteristics are found, ensure that the information and data gathered are disseminated to the appropriate agencies and industry. (Class II, Priority Action) (A-96-12)
>
> Review the process and procedures by which the Federal Aviation Administration's aircraft certification offices and management resolve and bring to closure safety recommendations that are presented in internal documents, including special certification reviews, and take appropriate action, if necessary, to ensure that each recommendation is properly reviewed and that the disposition of the recommendations is properly documented. (Class II, Priority Action) (A-96-13)

To the National Aeronautics and Space Administration:

> In conjunction with the Federal Aviation Administration, continue the development of the simulator model of lightweight helicopters, using flight tests and whirl tower tests to validate the model, to create a national resource tool for the study of flight control systems and main rotor blade dynamics. If any unusual

main rotor blade system characteristics are found, disseminate the information and data gathered to the appropriate agencies and industry. (Class II, Priority Action) (A-96-14)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JAMES E. HALL
Chairman

ROBERT T. FRANCIS II
Vice Chairman

JOHN A. HAMMERSCHMIDT
Member

JOHN J. GOGLIA
Member

GEORGE W. BLACK, Jr.
Member

April 2, 1996

APPENDIX A-Summary Reports of R22 Loss of Main Rotor Control Accidents

Case No.	Date	Location	Registration No.	Robinson Serial No.	NTSB Accident No.
1.	11-11-81	Livermore, CA	N9073Q	0227	LAX82FA012
2.	09-25-82	Nashville, TN	N9072V	0212	ATL82FA285
3.	09-30-82	Paige, TX	N9063Z	0147	FTW82FA402
4.	10-06-82	Santa Ana, CA	N8358B	0302	LAX83FUA01
5.	03-14-83	St. Louis, MO	N9024Z	0038	MKC83FA076
6.	12-25-84	Huntsville, AL	N8475K	0391	ATL85FA067
7.	05-05-85	San Angelo, TX	N83745	0320	FTW85FA207
8.	01-05-86	Grenchen, Switzerland	HB-XOC	0327	None
9.	03-22-86	Memphis, TN	N9069S	0181	ATL86FA097
10 .	05-10-86	E. Fishkill, NY	N8511Z	0415	NYC86FA127
11 .	03-16-87	Scottsdale, AZ	N2256M	0498	LAX87FA147
12.	06-03-87	S. Windsor, CT	N2287L	0512	MNYC87FA160
13.	11-03-87	Moraga, CA	N8475A	0389	LAX88FA032
14.	08-01-89	Whitford Forest, New Zealand	ZK-HYX	0666	None
15.	11-23-90	Simi Valley, CA	N80783	1319	LAX91FA037
16.	01-04-91	Hukerenui, New Zealand	ZK-HDC	1535	None
17.	07-05-91	Phoenix, AZ	N23039	1846	LAX91FA288
18.	09-08-91	Welford, England	G-BSHF	1382	None
19.	10-27-91	Obrigheim, Germany	D-HEXE	1156	None
20.	01-30-92	Malabar, FL	N2313G	2015	MIA92FA072
21.	03-04-92	Maricopa, AZ	N8413Q	0354	LAX92FA137
22.	05-06-92	Mt. Pleasant, TN	N191KC	1818	ATL92FA096
23.	06-15-92	Julia Crk, Australia	VH-HBK	0546	None
24.	06-29-92	Richmond, CA	N83858	0337	LAX92FA267
25.	09-30-92	Martinez, CA	N8069X	1364	LAX92FA410
26.	03-28-93	Wissen/Sieg, Germany	D-HUPS	1944	None
27.	08-10-93	Honolulu, HI	N4017J	1443	LAX93FA318
28.	06-08-94	Martin, England	G-PUDD	0863	DCA94RA060
29.	09-28-94	Knightdale, NC	N83112	2446	ATL94FA179
30.	12-27-94	Zurich, Switzerland	HB-XZW	2387	DCA95RA011
31.	07-17-95	Brighton Downs Station, Australia	VH-BEI	2494	None

Robinson R22 In-flight Breakup Accident Data

	Date	Location & Registration	Fatal	PIC R22/Helo/All Certificates Held/ Helo Rating (yes, no)[1]	Student R22/Helo/All	Flight Purpose	Prevailing Wind Velocity/ Gusts	Tailboom/ Cockpit Strike Mast Contact[2]	Aircraft TT	Serial Number
1	**11/11/81**	**Livermore, CA** N9073Q	**2**	**750/1,040/12,200** S, M, C, I, FI, ATP/ Yes	0/0/190	Personal	Calm	Tailboom Tx-S	20.2	0227
2	9/25/82	**Nashville, TN** N9072V	**2**	**30/65/1,046** S, M, C, I, FI,/ Yes		Personal	6 Kts	Tailboom TX-S	648	0212
3	9/30/82	Paige, TX N9063Z	1	85/85/290 S/Yes		Personal	12 Kts	Tailboom M-D	34	0147
4	10/06/82	Santa Ana, CA N8358B	1	37/37/4,777 S, **M, C, I,/ No**		Solo X-Country	5 Kts	Tailboom **M-S**	13.5	0302
5	**03/14/83**	St. Louis, MO N9024Z	2	110/334/748 S, **M, C,** I, FI/ Yes	1/1/1 None/No	Instructional	8 Kts	Tailboom ND	339	0038
6	12/25/84	Huntsville, AL N8475K	1	Unknown S, M, C, I, FI, ATP/ Yes		Personal	8 Kts	Cockpit Tx-S	377	0391
7	05/05/85	San Angelo, TX N83745	2	115/133/2,433 S, M, C, I, ATP/ Yes		Practice	11 Kts	Tailboom Tx-S	1478	0320

[1] Single-Engine Land: S; Multiengined Land: M; Private: P; Commercial: C; Instrument: I; Flight Instructor: FI; Helicopter: H, Airline Transport: ATP

[2] M-S: Separation of upper main rotor mast; M-D Significant deformation of upper main rotor mast; TX-S: Separation of main rotor mast at the top of the transmission; ND: Information not available.

	Date	Location & Registration	Fatal	PIC R22/Helo/All Certificates Held/ Helo Rating (yes, no)[3]	Student R22/Helo/All	Flight purpose	Prevailing Wind Velocity/ Gusts	Tailboom/ cockpit Strike Mast Contact[4]	Aircraft TT	Serial Number
8	01/05/86	Grenchen, Switzerland HB-XOC	2	75/75/75		Personal	10-15Kts /30 Kts	Tailboom ND	658	0327
9	03/22/86	Memphis, TN N9069S	2	229/306/2370 S, M, C, I/ Yes		Personal	8 Knots	Tailboom Tx-S	1805	0181
10	05/10/86	E. Fishkill, NY N8511Z	1	61/67/435 S, M, C, I/ Yes		Personal	6 Knots	Tailboom Tx-S	984	0415
11	03/16/87	Scottsdale, AZ N2256M	2	180/180/180 S, C, FI/ Yes	34/76/245 S/ No	Instructional	4 Knots	Tailboom ND	202	0498
12	06/03/87	S. Windsor, CT N2287L	2	451/451/451 S, C, FI/ Yes	15/15/15	Instructional	Calm	Tailboom M-D	1288	0512M
13	11/03/87	Moraga, CA N8475A	2	456/582/772 P, S, C, FI/ Yes	118/142/265 S, C, FI/ Yes	Instructional	6 Knots	Tailboom M-D & Tx-S	371	0389
14	08/01/89	Whitford Forest New Zealand ZK-HYX	2	276/282/286 P/ Yes		Personal	10 Knots	Tailboom Tx-S	727	0666
15	11/23/90	Simi Valley, CA N80783	1	37/37/160 P, S/ No		Solo	18 Knots	Tailboom & Cockpit ND	743	1319
16	01/04/91	Hukerenui, New Zealand ZK-HDC	2	47/153/213 P/ Yes		Personal	20 Knots	Cockpit M-S	18	1535

[3] Single-Engine Land: S; Multiengined Land: M; Private: P; Commercial: C; Instrument: I; Flight Instructor: FI; Helicopter H; Airline Transport: ATP

[4] M-S: Separation of upper main rotor mast; M-D: Significant deformation of upper main rotor mast; TX-S: Separation of main rotor mast at the top of the transmission; ND: Information not available.

	Date	Location & Registration	Fatal	PIC R22/Helo/All Certificates Held/ Helo Rating (yes, no)[5]	Student R22/Helo/All	Flight Purpose	Prevailing Wind Velocity/ Gusts	Tailboom/ Cockpit Strike Mast Contact[6]	Aircraft TT	Serial Number
17	07/05/91	Phoenix, AZ N23039	1	500/500/6,656 S, C, I/ Yes		Traffic Watch	8 Knots	Tailboom ND	51	1846
18	09/08/91	Welford, England G-BSHF	1	2/275/2,473 C / Yes - lapsed		Practice	Light/Vari	Tailboom & Cockpit ND	Unknown	1382
19	10/27/91	Obrigheim, Germany D-HEXE	1	43/ 43/ Unknown Student		Practice	Calm	Tailboom ND	1156	1156
20	01/30/92	Malabar, FL N2313G	2	9/53/2,929 S, M, C, I, FI, ATP/ Yes	1/1/1,199 S, M, C, I, FI/ Yes	Instructional	15 Kts/ 20 Kts	Cockpit Tx-S	85	2015
21	03/04/92	Maricopa, AZ N8413Q	1	292/292/31,000 S, M, I, FI, ATP/ Yes		Personal	9 Kts/ 20 Kts	Tailboom Tx-S	117	0354
22	05/06/92	Mt. Pleasant, TN N191KC	2	57/57/116 P/ Yes		Personal	10 Kts/ 20 Kts	Cockpit M-D	466	1818
23	06/15/92	Julia Creek, Australia VH-HBK	1	772/?/1,035 C/ Yes		Ferry	Calm	ND *M-S*	Unknown	0546
24	06/29/92	Richmond, CA N83858	2	2,000/2,000/2,200 S, C, FI/ Yes	4/4/4	Instructional	11 Kts	Tailboom Tx-S	15	0337
25	09/30/92	Martinez, CA N8069X	2	234/234/234 C, FI/ Yes	0/0/0	Flight Demonstration	14 Kts	Cockpit Tx-S	787	1364
26	03/28/93	Wissen/Sieg, Germany D-HUPS	2	114/114/114 Yes		Personal	10 Kts	Tailboom ND	206	1944

[5] Single-Engine Land: S; Multiengined Land: M; Private: P; Commercial: C, Instrument I; Flight Instructor: FI; Helicopter H; Airline Transport: ATP

[6] M-S: Separation of upper main rotor mast; M-D. Significant deformation of upper main rotor mast; TX-S: Separation of main rotor mast at the top of the transmission; ND: Information not available.

	Date	Location & Registration	Fatal	PIC R22/Helo/All Certificates Held/ Helo Rating (yes, no)[7]	Student R22/Helo/All	Flight Purpose	Prevailing Wind Velocity/ Gusts	Tailboom/ Cockpit Strike Mast Contact[8]	Aircraft TT	Serial Number
27	08/10/93	Honolulu, HI N4017J	2	140/140/4,350 **S, M, C, I, ATP/ Yes**		Personal	16 Knots	**Cockpit M-D**	5	**1443**
28	06/08/94	Martin, England G-PUDD	**2**	**5,200/7,170/8,257 ATP/ Yes**	**22/40/4,000**	**Instructional**	**15 Kts/20 Kts**	**Tailboom Tx-S**	**1093**	**0863**
29	09/28/94	Knightdale, NC N83112	1	**305/373/790 S, M, C, I, FI/ Yes**		**Business**	**Calm**	**Tailboom M-S**	**150**	**2446**
30	12/27/94	Zurich, Switzerland HB-XZW	**2**	**30/91/91 /Yes**		**Personal**	**18 Kts/36 Kts**	**Tailboom Tx-S**	**Unknown**	**2387**
31	07/17/95	Brighton Downs Station, Australia VH-BEI	1	**792/794/794** /Yes		**Business**	**Strong** Gusts	**Tailboom & Cockpit** Tx-S	Unknown	2494
#			**PIC Median Flight Experience R22/Helo/All**		**Student Medians R22/Helo/All**					
30			127.5/180/790		22/31/658					

[7] **Single-Engine Land S; Multiengine Land: M; Private: P; Commercial: C, Instrument: I; Flight Instructor FI; Helicopter H; Airline Transport: ATP**

[8] **M-S: Separation of upper main rotor mast M-D Significant deformation of upper main rotor mast TX-S: Separation of main rotor mast at the top of the transmission; ND: Information not available.**

1. Livermore, California

On November 11, 1981, about 1520 Pacific standard time, N9073Q, a Robinson R22HP, operated by Cheyenne Aviation, Inc., crashed in Livermore, California, during an instructional flight. The flight had departed Livermore Airport to the north and was last observed about 500 feet above ground level (agl), 4 miles north-northwest of the airport. A witness reported that the weather was visual meteorological conditions (VMC) with 15 miles visibility and calm winds. Witnesses observed the helicopter begin a shallow right turn when they heard a loud noise after which the tailboom and one main rotor blade separated. According to the witnesses, the helicopter then began turning rapidly, and crashed to the ground. The fuselage and landing skids were destroyed by impact and postimpact fire damage. The tailboom and main rotor blade were located along the wreckage path about 710 feet from the main wreckage.

The flight instructor held an airline transport pilot certificate and an instructor's certificate with an endorsement for rotorcraft-helicopter. He had a total of 12,200 hours of flight experience, 1,040 of which were in helicopters and 750 in the R22 helicopter. The student held a private pilot certificate, with an endorsement for multiengine land airplanes. He had no previous helicopter experience.

The Safety Board found the mast separated and bent approximately 10^{o}, 8 inches above the transmission splines. One main rotor blade had separated about 18 inches outboard of the coning hinge, and the outboard section of the blade was bent upward and aft. The other main rotor blade was bent upward about 90^{o}, and the outboard spar was bent aft. The tailboom exhibited evidence that a main rotor blade had intersected it just aft of the rotating beacon. The forward tailboom section was crushed and deformed, and had separated at the forward and aft manufacturing rivet lines. In addition, both tail rotor blades had separated from the hub about 3 inches outboard of the attachment bolts. The directions of the fractures indicated that the blades had been contacted by a main rotor blade during the aft tailboom separation sequence; the fractures were typical of overload forces.

The main rotor assembly was examined. The swashplate assembly rotating star rotated smoothly, and the rotating scissors were fractured at the mast clamp in overload. Both pitch change links exhibited bending overload failures at the upper adjustment threads. The flight controls were examined. All separations in the flight control system between the cockpit, main rotor head, and tail rotor assembly were the result of impact damage. The flight controls exhibited no evidence that a preimpact malfunction or failure had occurred. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

2. Nashville, Tennessee

On September 25, 1982, about 1310 eastern standard time, a Robinson R22, N9072V, registered to Aero International Helicopter, Inc., broke up in flight during a personal flight near Nashville, Tennessee. Witnesses reported hearing a slapping and cracking sound followed by pieces separating from the helicopter. The helicopter crashed into a residential area, and investigators found wreckage scattered over an area 700 feet long and 500 feet wide. The pilot and passenger were killed. The pilot held a flight instructor's certificate with an endorsement for rotorcraft-helicopter, with a total of 1,046 hours of flight time, 65 of which were in helicopters and 30 in the Robinson R22 helicopter. The pilot had received a weather briefing from Nashville flight service station at 1248, indicating that the local weather conditions were 8 miles visibility, winds from 030^{o} at 6 knots, the temperature was 68^{o} F, and the dewpoint was 59^{o} F.

The tailboom had separated into four sections and the tail rotor assembly was 200 feet from the main wreckage. There was evidence that a main rotor blade had struck the tailboom three times and severed the aft 3 feet of the tailboom. There was also evidence of contact between the main rotor hub and mast. The hub damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). Both main rotor blades were bent downward; one blade was separated about 2 feet outboard of the coning bolt and exhibited an overload fracture. The main rotor mast also separated at the upper transmission attachment flange and exhibited bending and torsional damage. The flight controls were examined for possible evidence of a progressive failure. All fractures examined in the main and tail rotor control systems were typical of overload and exhibited damage consistent with impact forces. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the tailboom. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

3. Paige, Texas

On September 30, 1982, about 1307 central daylight time, N9063Z, a Robinson R22 operated by Tejas Helicopters crashed near Paige, Texas, during a personal cross-country flight. After the helicopter's annual inspection, the aircraft mechanic/pilot departed Clover Field in Houston, Texas, about 1130 en route to the R22's home base at Tim's Airpark. The helicopter was last seen in cruise flight traveling westbound over U.S. highway 290, when motorists heard a loud noise then witnessed pieces of the helicopter falling from the helicopter. The pieces seen by one witness were later identified as the tailboom and tail rotor assembly. The tailboom was located on the north side of highway 290. The main wreckage, which included the fuselage, engine, transmission, main rotor assembly, and landing skids, crashed on highway 290, and was scattered about 117 feet to south side of highway 290. The pilot, holder of a private pilot certificate with a helicopter rating, was killed. His logbook indicated a total of 290.1 hours of flight experience, 84.6 of which were in the R22. Visual meteorological conditions were reported, with 3,000 foot broken clouds, 15 miles visibility, and winds from 130^{o} at 12 knots. Multiple electrical transmission lines crossed highway 290, near the crash site; the wires revealed no evidence of having been struck by the helicopter.

The Safety Board's examination of the wreckage found that one main rotor blade had separated at the attachment of the blade spar to the root fitting. A Safety Board metallurgist reported that the blade separation resulted from gross overstress caused by excessive bending. The blade and highway surface exhibited evidence that showed that the blade contacted the highway during the crash sequence. The other main rotor blade remained attached to the main rotor hub and was bent upwards 180^{o} about 18 inches outboard of the blade root fitting. The tailboom exhibited evidence that a main rotor blade had struck the left side of the tailboom aft of the rotating beacon. The main rotor blade also contained white paint transfer matching the white paint on the tailboom. A forward section of tailboom also contained evidence that it had been struck by a main rotor blade, and the other tailboom sections were separated at the manufacturing rivet lines. Rotational scoring was noted on the interior tail rotor driveshaft and tailboom.

The main rotor mast was partially separated at the top of the transmission. The upper mast between the swashplate and main rotor hub exhibited severe indentations. The inboard edges of the main rotor hub contained indentations in positions corresponding to the tusks normally attached to the main rotor spindles. The damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). A complete disassembly of the engine revealed no anomalies with the internal engine components. Examination of the flight controls revealed the collective control was in the "full up" position with the friction lock applied and the throttle control was jammed in the "full open" position. The Safety Board could find no evidence of preimpact failure or evidence of a specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the tailboom. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

4. Santa Ana, California

On October 6, 1982, about 1008 Pacific daylight time, N8358B, a Robinson R22 operated by Madison Manufactured Housing, crashed near Santa Ana, California, during a solo cross-country flight. The flight had departed John Wayne Airport, Newport, California, at approximately 1002 on the pilot's first solo flight in the R22 helicopter. Witnesses saw the helicopter pitch nose up, then nose down, and then saw a main rotor blade strike the cockpit, followed by the main rotor mast separating from the helicopter. The helicopter was observed to descend nose low and hit the ground on the second fairway of the Riverview Golf Course, Santa Ana, California. The helicopter burst into flames upon impact. The wreckage debris encompassed an area that included the entire second hole of the Riverview Golf Course, an equipment yard of a foundry (located south of the second green), an adjacent tennis court, and a recreation field. Debris was also located on the roof of the foundry. The pilot, who held a commercial certificate with an instrument rating but was a student in helicopters, was killed. A review of the pilot's logbook revealed that he had accumulated a total of 4,777 hours of flight time, 37 of which were in the Robinson R22 helicopter. The weather at John Wayne Airport (5 miles from the accident site), at 0945 hours was reported to be partially obscured, 1/2 mile visibility with haze, winds from 160° at 5 knots.

The Safety Board's examination of the cabin windscreen and landing gear found that a main rotor blade had entered the cockpit through the right side of the roof and struck the windscreen retainer below the magnetic compass. The instrument panel, the left tail rotor control pedals, the left cabin floor, and lower forward section of the cabin all exhibited damage consistent with a main rotor blade strike, and were found separated from the main wreckage and scattered throughout the wreckage path. The left skid and portion of the aft cross tube also exhibited damage consistent with a main rotor blade strike, and were located approximately 307 feet from the initial impact area. A 20-inch section of the outboard end of a main rotor blade was found 306 feet east of the main rotor assembly. The inboard leading edge of the adjoining section of main rotor blade exhibited impact damage 89 inches from the blade horn, and blood was found on the upper surface of the blade 58 inches from the blade horn. Examination of the fractured section of main rotor blade by a Safety Board metallurgist revealed that the blade separation was a result of gross overstress.

Examination of the main rotor assembly revealed that the upper main rotor shaft separated between the main rotor hub and swashplate. The main rotor hub contained paint transfer and semicircular gouge marks inside the hub, in positions corresponding to the tusks normally attached to the main rotor spindles. The hub damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). The cyclic and collective control systems were examined. Both control assemblies exhibited impact and postcrash fire damage; no evidence of an in-flight failure or malfunction was found. A complete disassembly of the engine revealed no anomalies with the internal engine components. The Safety Board found no evidence of a mechanical failure that allowed the main rotor blades to diverge from their normal flightpath plane and strike the fuselage and, therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

5. St. Louis, Missouri

On March 14, 1983, about 1420 central standard time, N9024Z, a Robinson R22 operated by Helicopters, Inc., crashed into the Mississippi River near St. Louis, Missouri, during an instructional flight. The flight had originated at East St. Louis, Illinois, about 45 minutes before the accident. The helicopter was seen in cruise flight at about 300 feet agl traveling north over the river.

Several people witnessed the accident. One witness, located on the 22nd floor of an office building near the accident site, said the helicopter wobbled as if buffeted by the wind. The helicopter was then observed to roll to the right and begin spinning, followed by a loud noise and the separation of the tail rotor. The witness then observed bluish/white-colored smoke as the helicopter rapidly descended. The witness also reported that he observed the main rotor separate before the helicopter fell into the river. A witness located on the 17th floor of an office building near the accident site said the front of the helicopter pitched nose down and the tail flipped over. She said she saw a long, thin, shiny object separate from the helicopter. Another witness located on the east side of the river said he observed the helicopter at about 200 to 300 feet when he heard a loud pop and witnessed the main rotor and possibly the transmission and engine separate from the helicopter. Several witnesses located on the west shore of the river heard a loud bang, then saw pieces separating from the helicopter before the helicopter descended out of control into the Mississippi River. A pilot and first mate of a tugboat operating near the vicinity of the crash reported observing an object about the size of a small car that fell into the river several hundred feet from their boat and sank immediately. They recovered a wallet and two seat cushions, which were later identified as being from the helicopter. The river was searched by local authorities until March 18, 1983, but the helicopter wreckage and the bodies of the victims were never found. Visual meteorological conditions prevailed at the time of the accident. The closest weather reporting station, 4 miles southeast of the accident site, reported 12 miles visibility and winds from 290^{o} at 8 knots.

The pilot held commercial pilot and flight instructor certificates with an endorsement for rotorcraft-helicopter, with a total of 748 hours of flight time, 334 of which were in helicopters and 110 in the Robinson R22 helicopter. According to the owner of N9024Z, the accident flight was the student's second instructional flight; the student did not have a pilot certificate. The Safety Board could not determine the probable cause of this accident.

6. Huntsville, Alabama

On December 25, 1984, approximately 1615 central standard time, N8475K, a Robinson R22 Alpha, operated by Executive Air, Inc., broke up in flight near Huntsville, Alabama, during a personal flight. The flight had originated at Decatur, Alabama, at 1330. Before the accident, the helicopter was seen in cruise, at 400 to 600 feet elevation, heading west. One witness reportedly heard a loud noise and observed the helicopter falling vertically. Another witness stated he observed a puff of black smoke and saw parts separating from the helicopter. Both the pilot and passenger were killed. The weather at the time of the accident was reportedly clear with 15 miles visibility, winds from 010^{o} at 8 knots, and no reported gusts.

The pilot held an airline transport pilot certificate with commercial pilot privileges in rotorcraft. The pilot also held airman ratings for airplane multiengine land, sea, and glider, and he held an airframe and powerplant mechanic certificate. The pilot's flight logs and reported flight experience was so inconsistently reported that the Safety Board was unable to determine his total flight experience or his relevant experience in helicopters.

The Safety Board's examination of the wreckage found parts of the helicopter scattered over an area 400 by 700 feet. The pilot's body was found 141 feet from the fuselage. The pilot's seat cushion and windscreen centerpost (with the compass attached) were also located 365 feet and 85 feet east of the main wreckage, respectively. There was evidence that one main rotor blade had struck the windscreen about 2 feet left of the centerpost and traveled aft to the rear of the left passenger's seat. One of the main rotor blades exhibited downward bending and evidence that the blade had contacted the fuselage. The main rotor mast separated at the top of the transmission in an overload fracture, resembling the fracture of the transmission upper cap. The upper main rotor mast was bent above the swashplate, where the main rotor hub contacts the shaft. One of the droop stops was fractured and the other droop stop was deformed. The main rotor shaft and droop stop damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). Both pitch change links were fractured at the top of the jam nut and upper adjustment threads and exhibited overload fractures.

The tail rotor driveshaft exhibited torsional twisting, and rotational scorings on the inside of the tailboom were consistent with tail rotor rotation at impact. A complete disassembly of the engine revealed no anomalies with the internal engine components. Examination of the flight controls revealed that the collective control was found between 3/4 to the full-up position. No indication of preimpact malfunction or failure was found throughout the control system. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

7. San Angelo, Texas

On May 5, 1985, at approximately 1630 central daylight time, a Robinson R22, N83745, operated by American Helicopters, Inc., broke up in flight during a practice flight 3 miles south of San Angelo, Texas. The commercial helicopter pilot, who was preparing to take a certified flight instructor (CFI) helicopter check flight, and a passenger were killed. The pilot had accumulated 2,433 total flight hours, 133 of which were in helicopters and 115 in the R22.

The helicopter, including the fuselage, engine, transmission, and skids, came to rest on its left side, with considerable crushing to the fuselage. Portions of the fragmented windshield and tailboom came to rest in a soft plowed field 1,200 feet west of the main wreckage, along the helicopter's flightpath. The tailrotor gear box was located approximately 600 feet west of the main wreckage. Reconstruction of the tailboom showed that a main rotor blade had struck the tailboom at three separate locations. The first strike occurred approximately 2 feet forward of the tail rotor. The second and third strikes were measured at 4 feet from the tail rotor, and 2 feet from the tailboom attachment to the fuselage. The tail rotor driveshaft and tail rotor push-pull tubes were severely bent and exhibited a strike from a main rotor blade. Both main rotor blades contained multiple areas of blue paint transfer, leading and trailing edge damage, and chordwise scratches on the surface of the blades.

The main rotor mast separated in overload at the upper transmission cap. The upper main rotor mast and hub assembly remained intact with the spindles attached to the hub and the blade horns secured to the main rotor blades. The transmission and free-wheeling unit were free to turn manually with no binding or anomalies. Disassembly of the engine revealed no evidence of mechanical malfunction, and the carburetor throttle was observed in the full open position.

Examination of the collective and cyclic control tubes revealed overload fractures due to impact and no evidence of fatigue or preimpact failure. The Safety Board was unable to define the event that caused the main rotor blades to divert from their normal plane of rotation and strike the tailboom. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

8. Grenchen, Switzerland

On January 5, 1986, about 1551 local time, a Robinson R22 helicopter, registered in Switzerland as HB-XOC, crashed near Grenchen, Switzerland, after an in-flight separation of the tailboom. The pilot and his wife were on a personal flight and had planned to fly round trip from Basel-Mulhausen to Grenich, Switzerland. Witnesses reported observing the helicopter in a wide gradual turn and heard a loud noise, "like hearing a machine gun burst," and subsequently witnessed pieces of the tailboom break apart in flight. The helicopter entered a steep descent as it fell to the ground. Pieces of the tailboom and tail rotor were found about 150 meters from the main wreckage. The private helicopter pilot and his wife were killed, and the helicopter was destroyed. The pilot had accumulated 75 pilot flight hours, all of which were in the R22 helicopter.

The investigation by the Swiss Air Accidents Investigation Branch (AAIB) found that the that the right and left cabin doors were located 10 and 15 meters from the fuselage. The winds in the vicinity were reported from the southwest at 10 to 15 knots, gusting to 30 knots. A friend of the pilot's stated that he had informed the pilot of gusty conditions over the Jura Mountains, west of the intended flight route, before the pilot's departure. The pilot reportedly replied that if the winds were too gusty he would divert his flight from his intended route to avoid adverse conditions. AAIB reported that the reason for the loss of control and subsequent crash of the R22 helicopter was that the main rotor blade struck and severed the tail assembly. It did not determine what factors may have led to the accident.

9. Memphis, Tennessee

On March 22, 1986, about 1415 central standard time, a Robinson R22 helicopter, registration N9069S, broke apart during a personal flight 8.5 nautical miles west of its point of origin at Memphis International Airport. The flight had departed at 1247. Both occupants of the R22 were killed, and the helicopter was destroyed. The pilot-in-command had accumulated 2,370 pilot flight hours, 306 of which were in helicopters and 229 in the R22. The main wreckage (cockpit, skid assembly, and engine) came to rest on a level plowed field. The tailboom and tail rotor assembly had separated from the fuselage, and pieces were located 412 feet northwest of the main wreckage. Visual meteorological conditions reportedly prevailed with the sky clear, visibility 15 statute miles, winds from 230^{o} at 8 knots, and the temperature 55^{o} F at the time of the accident.

The helicopter's paint scheme was white, blue, and yellow. Examination of the wreckage revealed that the tailboom had separated at the second bay aft of the fuselage attachment point. The leading edges of the main rotor blades exhibited blue and yellow paint transfer. The separated sections of tailboom structure exhibited diagonal impacts from left to right (viewed from aft looking forward) at three locations. One main rotor blade droop stop and both pitch change links were fractured in overload. The upper main rotor mast exhibited indentations corresponding to hub contact. The base of the main rotor mast was fractured in overload and separated at the top of the transmission. Physical evidence indicated that the bending of the upper main rotor shaft occurred before the fracture of the transmission cap, and secondary to the main rotor blades traveling beyond their normal flapping range. An instability of the main rotor, rocking of the mast, and extreme pitch divergence of the main rotor blades appeared to precede the fractures of the main rotor flight control system.

The helicopter's cyclic and collective controls were examined. There was no evidence of fatigue or preimpact failure of control system components. A partial disassembly of the engine revealed no evidence of engine internal mechanical malfunction. The Safety Board was unable to define the event that caused the main rotor blades to divert from their normal plane of rotation and strike the tailboom. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

10. East Fishkill, New York

On May 10, 1986, at approximately 1220 eastern daylight time, a Robinson R22 Alpha, N8511Z, broke up in flight while on a visual flight rules (VFR) flight from Hyde Park, New York, to Danbury, Connecticut. The pilot had departed Hyde Park about 1212. The helicopter was destroyed and the commercial certificated pilot was killed. The last entry in the pilot's logbook indicated that he had accumulated 435 total flight hours, 67 of which were in helicopters and 61 in the R22. A helicopter pilot who had witnessed the R22's departure requested the tower to inform N8511Z that the helicopter's cowl door was open in the back and to land the helicopter. The pilot of N8511Z acknowledged but continued the flight.

Witnesses to the crash reported a loud "pop" and seeing pieces falling from the helicopter. The severed section of tailboom was the first piece of the helicopter along the 584-foot long wreckage path. The main wreckage exhibited evidence that a main rotor blade had struck the tailboom at several locations. The main rotor assembly was separated from the mast at the top of the transmission and was located next to the fuselage. A cabin door and pieces of plexiglass were found 15 feet southwest of the main wreckage.

Parts of the wreckage were examined by a Safety Board metallurgist for evidence of possible preimpact failure of a control system or flight component that might have initiated the breakup. The examination of the top of the transmission case and lower main rotor mast revealed signatures typical of overstress separation. The upper main rotor shaft also exhibited features typical of a bending overstress separation. One of the pitch change links was fractured at the lower rod end, and the other remained attached to the fractured swashplate arm. Both fracture surfaces exhibited evidence of overstress separations. Examination of the main rotor spindles revealed deformed tusks on each spindle consistent with the blades traveling beyond the design limits. The droop stops were also found crushed and deformed and exhibited the effects of repeated pounding.

The Safety Board's metallurgist also examined the helicopter's collective and throttle controls. The right collective stick was fractured at the crosstube adjacent to the weld that attached the stick to the crosstube. The fracture surface exhibited a flat shiny region typical of fatigue cracking; however, the fatigue crack did not propagate through the total fracture surface. A closer examination of the fatigue region with a scanning electron microscope revealed intermittent patches of ductile dimples adjacent to the fatigue area, suggesting that the stresses propagating the fatigue crack may have been relatively high. The fracture features beyond the fatigue zone were typical of overstress separation.

The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

11. Scottsdale, Arizona

On March 16, 1987, at 1117 mountain standard time, a Robinson R22 Alpha helicopter, N2256M, operated by Arizona Wing and Rotor, broke up in flight during an instructional flight at Scottsdale, Arizona. A witnesses reported observing the helicopter in hover flight at about 400 feet agl. The helicopter was then observed to turn slowly to the left and lose altitude, then to turn 360° as the nose lowered about 45°, and to rapidly descend in a spin. The witness subsequently reported a loud noise and observed pieces separating from the helicopter as it crashed to the ground. The helicopter was destroyed, and the certificated flight instructor and student were killed. The flight had departed Scottsdale Airport about 30 minutes earlier and was operating in the traffic pattern practicing touch-and-go landings. The pilot-in-command had accumulated 180 pilot flight hours, all of which were in the R22. The student pilot had accumulated 245 pilot flight hours, 76 of which were in helicopters and 34 in the R22. Visual meteorological conditions reportedly prevailed at the time of the accident. Winds near the accident site were reported from 120° at 4 knots; visibility was 30 miles, and the temperature was 48° F.

Pieces of the helicopter wreckage were found scattered over a 270-foot area on a level undeveloped field adjacent to a paved road, approximately 1/2 mile north of Scottsdale Airport. Sections of the red and white tailboom were located west and north of the main wreckage. Two sections of the tail rotor assembly were located northwest of the main wreckage. The first section measured 18 inches and was located at about 150 feet, and the second section included the forward end of the tailrotor driveshaft and damper and was found 250 feet from the main wreckage. The main wreckage consisted of the fuselage, engine, transmission, main rotor assembly, and 24 inches of the tailboom that remained attached to the fuselage. Examination of the main rotor blades showed evidence of impact damage and red paint transfer on the bottom surface of the blades. Both main rotor blade pitch bearings were found to rotate freely, and control continuity was established to the swashplate assembly. The cyclic and collective control system exhibited no evidence of fatigue or preimpact failure. The tail rotor driveshaft turned and exhibited no evidence of binding or preimpact failure. Disassembly of the engine revealed no evidence of mechanical failure or anomalies before impact. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the tailboom. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

12. South Windsor, Connecticut

On June 3, 1987, at approximately 1120 eastern daylight time, a Robinson R22 Mariner, N2287L, equipped with fixed flotation gear, operated by Northeast Helicopters, broke up in flight during an instructional flight near South Windsor, Connecticut. A witness near the accident site stated that he heard a loud ping, then observed pieces falling from the helicopter, and the main rotor blades appear to fold upwards before the crash. The CFI and student pilot were killed. The 22-year old CFI had accumulated 451 total flight hours, all of which were in the R22. The student pilot had accumulated 15 pilot flight hours, all of which were in the R22.

Fragmented portions of the tailboom were found 300 feet from the main wreckage. The tailboom exhibited evidence of two severe strikes to its left side. The strikes were consistent with the size and shape of the main rotor blade leading edge. Inspection of the main rotor blades revealed evidence of yellow paint transfer along the main rotor blade leading edges. Examination of the engine revealed no evidence of mechanical malfunction or anomalies before impact. The collective and cyclic control system was examined, and there was no evidence of preimpact failure. Therefore, the probable cause of the accident is listed as undetermined in the Board's brief of the accident.

13. Moraga, California

On November 3, 1987, at approximately 1338 Pacific standard time, N8475A, a Robinson R22 Alpha operated by Helicopter Adventures, Inc., broke up in flight during a dual instructional flight near Moraga, California. The CFI and commercial helicopter pilot student, who was preparing to revalidate his CFI helicopter certificate, were killed. Witnesses reported observing the helicopter hovering at 400 feet agl when they heard the engine noise suddenly decrease, and a loud pop. The witnesses said they observed parts, "like sparklers," fall off the helicopter as it fell to the ground. The flight had originated 8 miles southwest, in Concord, California, about 1230, after having been refueled with 100LL fuel. The weather at Concord, 8 miles northeast of the accident site, at 1245 was reported as 15,000 feet scattered clouds, 15 miles visibility, temperature 67^{o} F, dewpoint 48^{o} F, winds from 060^{o} at 6 knots, altimeter 30.02.

The pilot-in-command was a full-time flight instructor. On May 13 through May 16, 1987, the pilot had attended a Flight Instructor Safety Course given by the Robinson Helicopter Company in Torrance, California. The RHC "Instructor/Pilot Evaluation" sheet for the pilot reported that at the time of the course, the pilot's basic flying skills were good; however, his weak areas included: high flares, poor heading control, and late pitch pulls during hovering autos. The RHC instructor stated that some of these problems were worked out, and reported "I don't feel he's unsafe." The RHC instructor also reported that the pilot's difficulty with proficiency was a result of having accumulated only 150 flight instructor hours at the time of the evaluation. A review of the instructor pilot's logbook revealed that, at the time of the accident, he had accumulated 236 flight instructor hours in the R22. The pilot's logbook documented 772 total flight hours, 582 of which were in helicopters and 456 in the R22. The other pilot's logbook revealed that he had accumulated 265 total flight hours, 142 of which were accrued in helicopters and 118 in the R22.

The main wreckage was found in the center of a dried-up cattle pond surrounded by a grass pasture and rolling foot hills that were 150 to 300 feet higher than the center of the pond. The main wreckage included the fuselage, engine, transmission, tailboom, and both rotor systems. The wreckage exhibited extensive vertical crushing and deformation. The left side of the cockpit, including the door, lower half of the left windscreen, and both left and right side cockpit windscreens, were separated from the main wreckage and found along the wreckage path. The most distant piece, identified as the cockpit procedures checklist, was found about 1,750 feet from the main wreckage. Portions of the fragmented windshield and left fuselage came to rest in the pasture 500 feet from the main wreckage, along the helicopter's flightpath. Reconstruction of the fuselage wreckage revealed evidence that a main rotor blade intersected the forward cockpit 12 inches left of the centerpost and continued through the left side of the cockpit to the left rear door post. The left rudder pedal and left seat cyclic cross tube exhibited indentations that matched the leading edge profile of the main rotor blade. An outboard section of one of the main rotor blades was found wrapped around the left side of the cockpit with the leading edge of the blade resting against the forward left skid crosstube. The blade exhibited extensive leading edge damage, chordwise scoring, and deformation over the outboard half of the blade.

The upper main rotor mast and hub assembly remained intact with the spindles attached to the hub and the blade horns secured to the main rotor blades. Both main rotor blades remained attached to the blade horns. The upper end of the main rotor driveshaft, between the hub and swashplate, exhibited torsional twist and deformation of the shaft, at about a 90^{o} angle (relative to the vertical position of the shaft). The main rotor mast contained an overload fracture at a point just above the attachment to the transmission. The internal rotor driveshaft remained intact and attached to the gear system in the transmission. The engine was rotated and the accessory gear and valve train continuity was established throughout the engine. Disassembly of the engine revealed no evidence of mechanical malfunction or overspeed. Continuity was established throughout the tail rotor drive system, and no unusual operating signatures were found.

Examination of the collective and cyclic control tubes found control system continuity from the cockpit throughout the helicopter, and no evidence of fatigue or preimpact failure.

A toxicological analysis of urine specimen taken from the PIC revealed minute traces of marijuana metabolites at a level of approximately 100 ng/ml; however, there was no evidence of alcohol or drug substances found in the pilot's blood. The toxicologist concluded that there was no evidence found of "current influence" of the drug. The student pilot's blood specimen revealed less than 1 meg/ml of caffeine, and the urine specimen revealed cocaine metabolite. The Safety Board found that there was insufficient evidence to conclude that drugs had affected either pilot's ability to operate the aircraft. The Safety Board was unable to define the event the caused the main rotor blades to divert from their normal plane of rotation and strike the tailboom. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in main rotor blade contact with the cockpit area.

14. Whitford Forest, New Zealand

On August 1, 1989, at about 1522 local time, a Robinson R22 Beta helicopter, registered in New Zealand as ZK-HYX, crashed near Whitford Forest, New Zealand, after an in-flight separation of the tailboom. After departing from Ardmore Aerodrome, the pilot had informed Ardmore Tower that he and his passenger were proceeding to Whitford Forest and indicated that the duration of the flight would be about 20 minutes. The private helicopter pilot and passenger were killed, and the helicopter was destroyed. The pilot had accumulated a total of 286 flight hours, 282 of which were in helicopters and 276 in the R22 helicopter. The pilot had flown a helicopter only twice in the 4 months preceding the accident. The weather at Ardmore Aerodrome, 10 km south-south-west of the accident site at 1500 hours, was reported to be 2 octas cumulus at 3,500 feet, 60 km visibility with haze, winds from 50^{o} at 10 knots. Subsequent analysis of the weather data suggested that a prevailing northeast wind may have produced "moderate turbulence close the hills with down draughts in the lee of the ridges." It was believed that the flight was conducted at low altitude.

The investigation by the New Zealand Transport Accident Investigation Commission (TAIC) found that the tailboom, vertical and horizontal stabilizers, and the tail rotor assembly were located in the tops of trees 80 to 100 meters from the fuselage. The severe "near vertical" impact of the fuselage on a steep hillside bent the left skid of ZK-HYX upwards, and splayed the right skid outwards. The under structure and engine were forced upwards and the mast assembly was fractured at its base and was bent to the left. Both main rotor blades remained attached to the rotor head. The TAIC reported that the damage to the blades was characteristic of low rotational energy at the time of ground impact. One main rotor blade had revolved 180^{o} in its pitch bearing, and was bent "upwards" when positioned correctly in relation to the opposite blade, which was bent "downwards." The TAIC reported that both pitch change links had bent before failure. It also reported that there was no significant evidence of mast bumping but the rotor mast was bent slightly at the top, and the metal droop stops (that limit the downward movement of the main rotor blades) had sheared in overload. The examination found no defect in the main rotor head or blades that was considered to have contributed to the cause of the accident.

The TAIC's examination found that a main rotor blade had struck the tailboom dislodging the anticollision beacon and caused the aft section of tailboom and driveshaft assembly to separate. Severe damage to the inboard end of the middle section of the tailboom and matching paint smears on the main rotor blades indicated that this section had been struck by the blades while the helicopter was still in flight. The TAIC reported that is was evident that at the time of separation, the tail rotor was being driven with considerable rotational energy. Heavy scoring was on the internal skin in the area of the fuselage/tailboom attachment indicating continued rotation of the transmission drive when the strike occurred. Both tail rotor blades were dented over the final 125 mm of their outboard ends. The TAIC found that the relative symmetry of the damage areas on each blade and the severity of denting, with the absence of "rotational" marking, suggested that the outer portion of the tail rotor had struck a branch or tree trunk.

The TAIC reported that no evidence suggested that the cyclic, collective, or tail rotor controls had been obstructed in any way, and established continuity of these control systems. The lower engine compartment was substantially damaged on impact. The carburetor bowl was broken off but both floats were intact. The fuel and engine oil filters were free of contamination, and the engine sump contained an ample supply of oil. The main and auxiliary fuel tanks were ruptured; however, a quantity of fuel remained in the line to the fuel selector. The TAIC's examination of the airframe and engine found no evidence of a preimpact mechanical defect or failure in any component of ZK-HYX.

The TAIC concluded that although there was evidence that at least one main rotor blade had struck and separated the aft section of the tailboom in flight, it was unable to establish the cause of the accident with certainty. The TAIC reported the probable cause of the accident was "a decision by the pilot to descend the aircraft below the minimum approved height above the ground in order to demonstrate maneuvers at which he had no recent practice." The TAIC reported that contributing factors may have included turbulence and the effects of a glass of wine that the pilot had consumed about 3 hours before the accident flight.

15. Simi Valley, California

On November 23, 1990, about 1603 Pacific standard time, N80783, a Robinson R22 Beta operated by Orbic Helicopters, Inc., broke up in flight near Simi Valley, California, during a solo flight. The flight had originated at Van Nuys Airport, Van Nuys, California, at approximately 1535. No one witnessed the in-flight breakup; however, one person reported hearing the rotor blades make a "thwack-thwack-thwack" sound, and then observed a plume of smoke where the wreckage was subsequently located. The helicopter was destroyed by impact forces and by postimpact fire. The wreckage debris encompassed an oval-shaped area 300 feet long, on 25^{o} up-sloping hilly terrain. The private pilot (airplane) who was a "student" helicopter pilot, was killed. The weather at Van Nuys Airport (15 miles from the accident site) at 1546 hours was reported to be 25 miles visibility with winds from 340^{o} at 18 knots.

The pilot's logbook recorded a total of 160 hours of pilot flight time, 37 of which were in helicopters--all in the Robinson R22 helicopter. The student pilot's flight instructor had reportedly authorized the student to fly from the Van Nuys Airport to a practice area, near the crash site. The student pilot had been directed to practice takeoffs to a hover, traffic patterns, and normal approaches to landings. According to the flight instructor, the pilot had been a "better-than-average" student and had not experienced any unusual problems learning to fly the helicopter.

The Safety Board's examination of the wreckage found that a main rotor blade had struck and severed the tailboom. Pieces of the tailboom and the intact tail rotor assembly were located approximately 165 feet from the main wreckage. Fragmented pieces of the helicopter's plexiglass windscreen were located along the wreckage path, an estimated 100 yards from the fuselage. The upper section of the left door frame was also found separated from the fuselage and located about 135 feet from the main wreckage. The section of separated door contained a smearing of black paint that matched the color of paint found on the leading edge of the main rotor blades. Both main rotor blades were found bent in the aft direction and exhibited impact damage to the blades, and leading edge and chordwise scoring. Examination of the collective and cyclic control tubes, swashplate assembly, and main rotor pitch change links revealed no evidence of preimpact failure. The examination of the engine revealed no anomalies or preimpact damage to the internal engine components. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in main rotor blade contact to the tailboom and cockpit.

16. Hukerenui, New Zealand

On January 4, 1991, at about 1233 local time, a Robinson R22 Beta helicopter, registered in New Zealand as ZK-HDC, broke up in flight during a personal flight near Hukerenui, New Zealand. Witnesses about 150 meters from the accident site observed the helicopter flying normally between 50 and 100 feet above the ground when they heard a loud noise. Immediately afterward, several items, including the main rotor, separated from the helicopter, and the helicopter descended to the ground and caught fire. The private helicopter pilot and passenger were killed, and the helicopter was destroyed. The pilot had accumulated a total of 213 flight hours, 153 of which were in helicopters and 47 in the R22 helicopter. The weather at the accident site was determined to be a variable scattered cloud base of 2,500 to 3,000 feet, with visibility in excess of 30 km, and winds from the southwest at 20 to 25 knots. Light or moderate turbulence in the area was considered likely.

The investigation by the New Zealand TAIC found the accident site to the windward side of a row of tall pine trees and downwind of an unobstructed expanse of rolling pasture land. The wreckage of ZK-HDC was located in a flat paddock. The TAIC reported that the left door, pieces of the canopy, the magnetic compass, the passenger's handbag, landing light fragments, and a metal clip (used to retain the rubber boot of the main rotor blade) were among the debris found some 150 meters before to the helicopter's ground impact location. The main rotor blades remained attached to the main rotor head assembly and were located 50 meters north of the burned fuselage. The upper section of the main rotor driveshaft was fractured and exhibited a torsional overload failure. The TAIC reported that it found no significant damage to the leading edge of either main rotor blade, and the blade damage was characteristic of low rotational energy at the time of ground impact. One blade exhibited evidence of striking the cockpit canopy along a line between a point immediately above the forward upper corner of the right door to a midpoint on the forward edge of the left door's "transparency." The other main rotor blade had rotated about 180^o in pitch before it also struck the canopy with its trailing edge. Mast bumping was evident on the pitch stops. The right door was found about 1 meter to the north of the rear end of the tailboom.

The examination of the helicopter's tail rotor driveshaft revealed that it had failed in overload with the tail rotor operating normally when impact occurred. The tail rotor blades had been bent symmetrically at right angles, close to their hubs with no significant damage to their leading edges.

The TAIC found most of the helicopter's instruments and cockpit area damaged by postimpact fire; however, examination of the rotor and engine tachometer revealed an impact-captured main rotor speed of 100%, and an airspeed indication of 52 knots. The positions of the collective and throttle could not be established because they were destroyed by fire. The TAIC's examination of the engine and transmission were impeded by fire damage. The examinations revealed no defects that would have led to an in-flight power loss.

The TAIC report discussed the possibility and consequences of abrupt pull-ups and push-overs and low-G maneuvering, citing the R22 Pilot Operating Handbook and RHC Safety Notice "SN-11." However, the report contained no information that suggested that low-G maneuvering was observed by anyone before the accident. The TAIC analysis speculated that the pilot may have been flying low to avoid crosswinds and to look for friends who were driving the same route. As the terrain rose and fell along the flightpath, the TAIC suggested that the pilot may have followed the terrain and thus encountered a low-G condition, precipitating the accident.

The TAIC reported the probable cause of the accident was that "the pilot failed to recognize that he had inadvertently entered a low-G flight regime which caused the aircraft to roll. Consequently, he endeavored to right the aircraft by applying left cyclic without first restoring positive loading to the main rotor blades." The TAIC found that the pilot's inexperience in the R22 and his lack of awareness of the helicopter's vulnerability to low-G flight were factors that contributed to the accident. Consequently, the TAIC recommended to the Air Transport Division of the Ministry of Transport that it "review the flight test requirements for ratings on the R22 aircraft to ensure appropriate knowledge of this peculiarity of the Robinson R22 aircraft's behavior and the appropriate technique is understood by all applicants."

17. Phoenix, Arizona

On July 5, 1991, at approximately 1639 mountain standard time, N23039, a Robinson R22 Beta, operated by Skyview Traffic Watch, Inc., broke up in cruise flight near Phoenix, Arizona. The commercial helicopter pilot, who was conducting routine local traffic reporting, was killed. Witnesses reported observing the helicopter cruising between 300 and 500 feet agl when they heard a loud bang and observed pieces falling from the helicopter. One witness observed the helicopter's main rotor blades fold upward as it fell to the ground. The flight had originated about 1631, at the Scottsdale Municipal Airport, Scottsdale, Arizona. The weather at Scottsdale Airport, 6 miles southeast of the accident site, at 1656 was 15,000 feet scattered clouds, 40 miles visibility, with winds from 260^{o} at 8 knots.

The pilot held a commercial pilot certificate, and was rated for airplane single-engine land, instrument airplane, and rotorcraft-helicopter. The pilot also held a flight instructor certificate for helicopters. On May 10, 1991, the pilot had attended a Flight Instructor Safety Course given by the Robinson Helicopter Company in Torrance, California. The RHC "Instructor/Pilot Evaluation" sheet for the pilot indicated that the pilot was "a good conservative pilot" who "exercised good judgement throughout the flight." The pilot's logbook indicated 6,656 total flight hours, 500 of which were in helicopters, all in the R22.

N23039 had collided with a residence initiating a fire that gutted the interior of the residence and severely burned the helicopter wreckage. The majority of the helicopter main wreckage was located in the living room and included the fuselage, engine, transmission, tailboom, and both rotor systems. The tailboom and tail rotor system were located in an adjacent atrium, and were separated from the main wreckage by the living room wall. The left skid, the windscreen bubble, and the left door were separated from the main wreckage, and found scattered over a distance of about 1,400 feet to the northeast of the main wreckage. A fragment of clear plastic, similar to the windscreen bubble material, was found near the accident site and exhibited a red smudge on its surface.

Remnants of model toy rockets identified as Estes B6-4 and A8-3 stages, also colored red, were located in a vacant lot near the accident site. The plastic fragment and model rockets were chemically examined by Truesdail Laboratories, Tustin, California, to determine if the smudge matched the red surface of the rockets. The paint smudge on the plastic was determined to be alkyd (multipurpose paint) and did not match the material of the rocket, which was found to be polystyrene.

Following the examination at the accident site, the wreckage was recovered and moved to the Robinson Helicopter Company where it was examined on two other occasions. No evidence was found of any control system failures or malfunctions or of any material defects of the components or systems destroyed by postimpact fire. The examination of the main rotor mast and droop stops revealed indentations where the main rotor hub makes contact with the mast. The hub and droop stop damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). The engine and accessories were examined. Fuel was observed in the accelerator pump port of the carburetor, and normal electrode wear signatures were on the spark plugs. No metal contamination was found in the engine oil screen. The engine crankshaft rotated and continuity of the gear and valve train was established. The disassembly of the engine revealed no evidence of mechanical malfunction.

The Safety Board was unable to define the event the caused the main rotor blades to divert from their normal plane of rotation and strike the cockpit. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in main rotor blade contact to the cockpit.

18. Welford, England

On September 8, 1991, about 1600 local time, a Robinson R22 Beta helicopter, registered in England as G-BSHF, broke apart during a practice flight about 1,500 feet agl, over the village of Weston-on-Avon. Witnesses reported observing the helicopter in straight-and-level flight traveling southwest when it began to yaw suddenly to the right and left. A loud noise like a bang or pop followed, and the helicopter was observed to pitch nose-down as the tail rotor assembly and sections of the tailboom separated from the helicopter. The witnesses said they then observed the helicopter's main rotor blades flailing and one of the blades separated as the helicopter entered a vertical dive and crashed to the ground. The pilot was killed, and the helicopter was destroyed. The pilot held commercial pilot licenses for both fixed wing and helicopter, and a flight instructor's certificate. His flight experience was 2,473 total flight hours, 275 of which were in helicopters and 2 in the R22. The main wreckage (cockpit, skid assembly, and engine) came to rest upright on level ground. The tailboom and one main rotor blade had separated from the fuselage, and the rotor blade and tailboom pieces were located 200 meters north of the main wreckage. The U. K. Air Accidents Investigation Board (AAIB) investigated the accident.

Examination of the wreckage on site and later at the AAIB facility at Farnborough, England, did not reveal any preimpact defects in the structure, flight controls, engine, or transmission. The droop stops were distorted due to the downward bending of the main rotor blades. Several strikes to the tailboom by a main rotor blade were evident. The initial strike was in the region of the warning arrows and "DANGER" decal at the rear of the tailboom. Subsequent high energy strikes had also occurred with the blade contacting the tailboom at about a 45^{o} degree angle forward of the initial strike. There was also evidence of a main rotor blade strike to the left side of the cabin area. The AAIB could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe.

19. Obrigheim, Germany

On October 27, 1991, about 1421 local time, a Robinson R22 helicopter, registered in Germany as D-HEXE and operated by Helicopter Service Mitte, crashed near Obrigheim, Germany, after the tailboom separated in flight. The student pilot had been operating the helicopter on a solo cross-country flight, from Egelsbach, Germany, via Baden-Baden and Mosbach, and returning to Egelsbach, Germany. Witnesses reported that they observed the helicopter flying over a shallow valley that had a power line suspended across the intended flight-path. Shortly before overflying the power line, the helicopter was observed to turn steeply to the left and crash into an uphill sloping grassy area. The student pilot, who had logged a total of 43 flight hours in the R22, was killed, and the helicopter was destroyed. The weather at the time and location of the accident was reported as calm winds, visibility greater than 10 kilometers, and clear sky.

The R22 helicopter was equipped with an altitude scriber. The German Accidents Investigation Bureau's examination of a plotted graph of D-HEXE's flightpath and altitude before impact revealed an almost level flight, followed by a rapid descent to the final impact.

The German Accidents Investigation Bureau's examination of the wreckage revealed that one of the helicopter's main rotor blades had struck and severed the tailboom. The examination revealed that the actuator for the clutch was found in the full extend position; however, the clutch actuator was not believed to have contributed to the in-flight breakup because the electric motor for the clutch was found separated due to impact forces. The examination of the helicopter's cockpit annunciator lights concluded that the lamps for "Low Rotor RPM," and "Clutch" were probably not illuminated. The examination of the wreckage did not reveal any evidence of mechanical failure or malfunction, and the German Accidents Investigation Bureau reported that it closed the accident file without having determined a probable cause.

20. <u>Malabar, Florida</u>

On January 30, 1992, about 1355 eastern standard time, N2313G, a Robinson R22 Beta operated by Melborne Helicopters, Inc., crashed in Malabar, Florida, during an instructional flight. The flight had originated in Melborne, Florida, approximately 20 minutes before the accident. Witnesses near the accident site stated that they heard a loud bang, looked up, and observed one rotor blade broken and part of the cabin area missing. According to the witnesses, the helicopter then yawed left and crashed into palm trees. The main wreckage came to rest at the base of two palm trees; both occupants were killed. Witnesses on the ground reported that the engine ran until impact. The pilot held airline transport pilot and flight instructor certificates, with a helicopter rating. He had logged a total of 2,929 hours of flight time, 53 of which were in helicopters and 9 in the R22. The R22 student held commercial pilot and flight instructor certificates, was rated in airplanes, and had accumulated 1,199 hours of flight time, 1 hour of which was in the R22. The closest weather station, 6 miles north, reported 7 miles visibility and winds from 230^{o} at 15 knots, gusting to 20 knots.

The main rotor mast had failed at the attachment to the top of the transmission. Both fracture surfaces exhibited bending overload in the forward left direction, as viewed from above. The examination of the main rotor blades revealed that the outboard end of the blade was bent downward about 100^{o} and that an area of heavy abrasion was 28 inches inboard from the blade tip. The forward door frame on the left side of the helicopter exhibited damage consistent with the abrasion found on the blade's leading edge. Indentations on either side of the hub were observed in positions corresponding to the tusks normally attached to the main rotor spindles. The hub damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). The pitch change links remained attached to the upper swashplate assembly and exhibited bending overload separations at the upper rod end bearings. The blade horn flanges exhibited scoring and compression damage consistent with the lateral impressions on the chord arm. The flight controls were examined, and control continuity was established. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in a main rotor blade contact with the cockpit.

21. Maricopa, Arizona

On March 4, 1992, at approximately 1535 mountain standard time, N8413Q, a Robinson R22, broke up in flight while cruising about 5 miles northeast of Estrella Sailport near Maricopa, Arizona. The helicopter was destroyed, and the airline transport pilot (a former airline captain) was killed. The last entry in the pilot's logbook was dated January 1, 1992, and indicated that he had accumulated 31,000 total flight hours, 292 of which were in helicopters--all in the R22. No one witnessed the accident.

The pilot was last seen departing Estrella Sailport in his R22. A CFI who had witnessed the R22's departure stated that at approximately 1520 [the accident pilot] had completed his "by-the-book preflight" and departed for his home at Stellar Airpark. The crash site was located on the direct course line between the Estrella and Stellar airports. The severed left door was the first piece of the helicopter found along the 475-foot-long wreckage path. The main wreckage exhibited evidence that a main rotor blade had entered the left side of the cockpit and severed a portion of the left forward skid. One of the main rotor blades revealed damage approximately 48 inches from the tip. The left door and left forward airframe exhibited a severe strike and yellow paint transfer consistent with the shape and painted surface of the main rotor blade. The damage to the left forward skid was consistent with a main rotor blade strike while the blade was being driven at a downward angle (as referenced with the main rotor hub) of approximately 70^{o}.

The wreckage was examined for evidence of possible preimpact failures of the control system or airframe that might have initiated the breakup; however, none were found. The top of the transmission case was fractured (360^{o}) and exhibited signatures of both compression and tension. The left rear transmission mount and right forward mount bolt made an impression in the surface of the engine shroud consistent with a rocking motion of the transmission in the left-rear to right-forward direction. The main rotor shaft exhibited torsional twisting and bending directly below the mount for the main rotor hub. The pitch change links exhibited bending overload failures at the upper adjustment threads. The pitch change links and spindle tusks were fractured in overload, consistent with damage resulting from the divergence of the main rotor blades from their normal plane of rotation. The droop stops were found crushed and exhibited the effects of repeated pounding. The main rotor hub was disassembled and examined at the Robinson Helicopter Company in Torrance, California, under the supervision of a Designated Manufacturing Inspector Representative (DMIR) and the Safety Board. Examination of the main rotor hub and main rotor spindles revealed multiple indentations, adjacent to where the spindle tusks are installed, consistent with the blades traveling to the design limits in the up and down direction (flapping). The Safety Board's probable cause of this accident was destructive mast bumping for an undetermined reason.

22. Mt. Pleasant, Tennessee

On May 6, 1992, at 1630 central daylight time, N191KC, a Robinson R22 helicopter owned by Kansas Copter and Wings, broke up in flight about 3 miles south of Mount Pleasant, Tennessee. Witnesses reported hearing a loud bang, and shortly afterwards, the helicopter came to rest in a pasture. The pilot had notified Jackson Automated Flight Service Station that he planned to depart Jackson, Tennessee, under VFR en route to Tullahoma, Tennessee, and that he intended to fly at 3,000 feet mean sea level (msl). The pilot then obtained a preflight weather briefing. Visual meteorological conditions prevailed at the time of the accident. Winds near the accident site were reported between 7 and 15 knots, gusting to 20 knots. The pilot had accumulated 116 total flight hours, 57 of which were in the R22.

The helicopter wreckage was scattered over an area 1,500 feet long and 100 feet wide. Sections of the left door frame were recovered from a field 1,100 feet southwest of the main wreckage. Examination of the left door frame revealed paint transfer and rotor blade leading edge indentations. Examination of the wreckage revealed the main rotor shaft exhibited about a 25^{o} bend directly below the main rotor hub, corresponding with the full downward teetering of the main rotor hub. Both spindle tusks were sheared, and indentations and chipped primer on either end of the hub were observed in positions corresponding to the spindles, and consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). No evidence could be found of main rotor coning. The pitch change links remained attached to the upper swashplate assembly and exhibited bending overload separations at the upper rod end bearings. The examination of the main rotor blades revealed blue paint transfer on one of the blades upper surface and leading edge from 43 to 46 inches from the tip of the blade. The left door frame, left cyclic hand grip, and left side of the lower fuselage at the aft bulkhead exhibited damage consistent with a strike from the main rotor blade and consistent with the abrasion found on the blade's leading edge. In addition, the left skid cross tube (located directly below the damaged left door frame and bulkhead) exhibited damage consistent with a strike from the main rotor blade. The examination of the cyclic and collective control system revealed no evidence of fatigue or a preimpact failure. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in main rotor blade contact to the cockpit area.

23. Julia Creek, Australia

On June 15, 1992, about 0705 local time, a Robinson R22 Beta helicopter, registered in Australia as VH-HBK, crashed near Julia Creek, Australia, after of the main rotor hub and tailboom separated during an intended ferry flight. The pilot was killed, and the helicopter was destroyed. The pilot held a commercial helicopter pilot certificate and had accumulated 1,035 pilot flight hours, 772 of which were in the R22 helicopter. The weather at the time and location of the accident was reported as fine and calm.

No one witnessed the accident. When the helicopter failed to arrive at its intended destination a search commenced. The wreckage was found the following morning close to the intended route for the ferry flight. The Australian Bureau of Air Safety Investigation (BASI) established that the helicopter was in cruise flight when the R22 broke apart. The main rotor hub with blades attached was found about 140 meters from the burnt-out fuselage.

BASI established that the main rotor mast exhibited a torsional overload separation between the swashplate and hub assembly. One of the droop stops had been subjected to a compressive force of sufficient magnitude to fracture its elastomeric retaining strap. Examination of the control linkages indicated that they had failed in overload.

No known aircraft were operating in the area at the time of the accident with which the helicopter might have conflicted. Information from other local aircraft operators indicated that large concentrations of birds were not uncommon in the area at that time of the year. However, not withstanding the severe fire damage to the fuselage, no evidence of a bird strike was found. The drive train between the engine and transmission were examined at the accident site and later in a workshop. The inspection revealed no abnormalities or faults that could have contributed to the accident. BASI found the following factors relevant to the in-flight separation of the main rotor hub and subsequent crash of the helicopter: "1. For reasons which could not be determined, a mast bump occurred during flight; and 2. The main rotor mast failed due to torsional overload as a result of the mast bumping."

24. Richmond, California

On June 29, 1992, at 1242 Pacific daylight time, N83858, a Robinson R22 HP helicopter, operated by the Sierra Academy of Aeronautics, Inc., broke apart in flight during an instructional flight near Richmond, California. Witnesses reported observing the tailboom and main rotor separate from the helicopter in flight. A CFI was providing a primary flight lesson to his student, who was recording the lesson (cockpit interphone and radio communications) with a microcassette tape recorder. 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. While en route, the CFI instructed the student to perform a left turn. According to the recording, the student completed the turn using a shallow bank. While cruising southbound at about 2,000 feet, the CFI began talking, but in mid-word, with no prior indication of an anomaly, 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 helicopter rapidly descended and crashed into San Pablo Bay, 3 miles northwest of Richmond, California. The CFI, who had accumulated about 2,000 hours of R22 flight time, and the student pilot were killed.

The record of the flight provided by the audiotape showed that neither pilot voiced any concern with the operation of the helicopter before the breakup. The low rotor warning horn did not activate before or during the breakup sequence. The Safety Board's analysis of the audiotape revealed that during most of the flight the main rotor sound signature was measured between 17.5 and 18 Hz, equivalent to a main rotor speed of 525 to 540 rpm.[36] No unusual rotor system noises were heard before the event that resulted in the in-flight breakup. The Safety Board's sound spectrum analysis of the audiotape indicated that the main rotor rpm did not decay before the breakup. Analysis of the recorded primary and secondary air traffic control (ATC) radar data supported an in-flight breakup scenario with the initial breakup occurring at 2,000 feet msl. The helicopter's indicated airspeed (IAS) was calculated from available radar data to have been about 85 knots (in cruise flight) when the main rotor blades suddenly departed from their normal rotational plane and struck the tailboom.

After recovery from San Pablo Bay, the wreckage was examined for evidence of possible preimpact control system or airframe failures that might have initiated the breakup, but none were found. No evidence was found of control interference, and the swashplate, spindle bearings, and engine exhibited no signs of preimpact damage. The main rotor mast assembly, with the main rotor blades attached, was recovered about 970 feet north of the main wreckage. The assembly had separated from the upper portion of the helicopter's transmission housing. One main rotor blade was found curled 39^{o} upward and both main rotor blades exhibited multiple red paint smears that appeared to match the tailboom paint. The aft portion of the tailboom (aft of the first bay area) was not recovered. However, a main rotor blade had left its impression in the crushed left side of the tailboom's first bay area. Both pitch change links exhibited bending overload failures, and the tusks were fractured from each spindle, consistent with damage resulting from the divergence of the main rotor blades from their normal plane of rotation. This accident was unique among other R22 in-flight loss of main rotor control accidents in that the audio recording documented the event, and analysis of the audiotape showed that the failure occurred with main rotor rpm in the normal R22-powered operating range. The Safety Board

[36] Normal R22 main rotor speed for powered flight is 495 to 530 rpm.

determined the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undetermined reason, which resulted in rotor contact to the tailboom.

25. Martinez, California

On September 30, 1992, at approximately 1445 Pacific daylight time, N8069X, a Robinson R22 Beta, operated by Helicopter Adventures, Inc., broke up in flight during a demonstration flight near Martinez, California. A witness reported hearing five or six popping and thumping sounds emanating from the helicopter, and heard the engine accelerate and then quit. The witness looked up and observed the helicopter descending in a 45^{o}, nose-down attitude with the rotor blades distorted and one main rotor blade appearing more vertical than the other. The CFI, who was conducting an intended 30-minute demonstration flight, and the prospective student were killed. The 28-year-old CFI had accumulated 234 total flight hours, all in the R22, and had completed the Robinson Helicopter Company's R22 Flight Instructor Safety Course on February 15, 1992.

Fragments of the broken windshield were found 1,800 feet from the main wreckage. An aircraft boom microphone and part of a headset were located about 450 feet east of the accident site. The wreckage revealed evidence of a main rotor blade strike to the right front portion of the cockpit windshield. The forward tip of the right skid tube also displayed damage consistent with a glancing blow by the main rotor blade. One main rotor blade exhibited abrasion and black paint transfer 29 inches from the blade tip on the blade's leading edge that matched the paint on the helicopter's right skid. The tailboom had also suffered a rotor strike to its left side, 53 inches from the where it attached to the fuselage. The 2-inch deep strike contained white paint similar to the white paint on the main rotor blade. The dimensions of the damaged area were consistent with the size and shape of the main rotor blade leading edge. Interior inspection of the tailcone revealed circular scoring of the tail rotor driveshaft and scratches to the interior tailcone structure, consistent with substantial rotation and operation of the tail rotor driveshaft at impact. The main rotor shaft exhibited an 8^{o} bend near the top of the transmission and exhibited an overload fracture at the transmission upper cap. The base of the mast also contained an overload fracture (360^{o}). Indentations on either side of the hub were observed in positions corresponding to the tusks normally attached to the main rotor spindles. The hub damage was consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). The pitch change links remained attached to the upper swashplate and exhibited bending overload separations at the upper adjustment threads. The cyclic control yoke was found bent upwards about 45^{o} in a "V" shape at the connection to the vertical tube. Both collective controls and transverse torque tube remained intact and exhibited no evidence of fatigue or separation. The Safety Board was unable to find evidence of any preimpact airframe or engine malfunction. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for undetermined reasons, which resulted in rotor contact to the fuselage and passenger.

26. Wissen/Sieg, Germany

On March 28, 1993, about 1750 local time, a Robinson R22 Beta helicopter, registered in Germany as D-HUPS and owned by the pilot, crashed near Wissen/Sieg, Germany, after the tailboom separated in flight. The intended flight was a local personal flight from an airfield in Siegerland, Germany. Witnesses reported they observed the helicopter flying straight and level over a power line before it lost several parts from the structure and hit the ground in a steep impact angle. The pilot and passenger were killed. The pilot held a private pilot certificate and was rated in helicopters, with a total of 114 hours of flight time, all of which were in the R22. The weather at the time and location of the accident was reported to be winds from 070^{o} at 10 knots, visibility greater than 10 kilometers, and clouds 4/8 in more than 5,000 ft, temperature 2^{o} Celsius, dewpoint -14^{o} Celsius.

The German Accidents Investigation Bureau's examination of the wreckage revealed that a main rotor blade had struck and severed the tailboom about 19 inches forward of the tail rotor but was unable to determine the reason for the main rotor divergence that led to the contact with the tailboom. The Bureau was unable to recover the tailrotor and severed section of tailboom aft of the strike and its examination revealed no evidence of engine failure or mechanical defect. The accident file remains open as the German Accidents Investigation Bureau is, "hoping to learn more about this type of accident in the R22."

27. Honolulu, Hawaii

On August 10, 1993, about 1806 Hawaiian standard time, N4017J, a Robinson R22 Beta helicopter, crashed into the Pacific Ocean about 8 miles southeast of Honolulu, Hawaii, during an intended pleasure flight. The airline transport pilot and his wife were killed. The pilot had logged 4,350 total flight hours and 140 hours in helicopters, all in the R22. An endorsement in his logbook indicated that the pilot had successfully completed the Robinson Helicopter Company Safety Course and biennial flight review in Torrance, California, on March 12, 1993. According to a CFI who had instructed him, the pilot was proficient with emergency procedures in the R22.

A witness kayaking in the ocean approximately 1/4 mile offshore indicated that the helicopter "appeared to be operating properly when all of a sudden it went down into the water." Another witness located aboard a catamaran said he saw "the front rotor blades' shaft bend toward the right side of the helicopter" and hit the helicopter body. The helicopter crashed into the water 50 to 75 feet from the catamaran. The last recorded radar data showed N4017J at an altitude of 500 feet above the ocean, 1/4 mile off the southeast coast of Oahu, and the radar track indicated that it was cruising at about 90 knots just before radar contact was lost.

Examination of the retrieved wreckage revealed that one main rotor blade was bent downward and had entered the left forward section of the cockpit. The main rotor hub exhibited deep gouges where the droop stop tusks contacted the hub; the droop stop tusks were sheared. The upper transmission and lower mast remained intact; however, the upper main rotor shaft was bent approximately 30°, consistent with an aerodynamically divergent blade striking the body of the helicopter during powered flight. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for an undermined reason, which resulted in rotor contact with the airframe.

28. Martin, England

On June 8, 1994, about 1139 local time, a Robinson R22 helicopter, registered in England as G-PUDD and operated by Bizzi-B Helicopters, broke apart during an instructional flight about 1,500 feet agl near Martin, England. A witness about 1 1/4 mile from the accident site reported that he saw the helicopter flying normally and then heard a loud noise and observed the helicopter falling vertically to the ground with the main rotor assembly separated from the helicopter. The instructor pilot and student were killed, and the helicopter was destroyed. The instructor had accumulated 8,257 pilot flight hours, 7,170 of which were in helicopters and 5,200 in the R22. The helicopter student held an airline transport pilot certificate (airplane) with approximately 4,000 hours of total flight time, including 40 hours in helicopters and 22 in the R22. The investigation established that the helicopter was cruising at about 80 knots (nautical miles per hour) before the accident. The main wreckage (cockpit, skid assembly, and engine) came to rest inverted on level ground. The tailboom had separated from the fuselage, and pieces were located 300 feet south of the main wreckage. The main rotor mast and rotor assembly had separated at the top of the transmission and were located about 100 feet from the main wreckage. The Safety Board and the FAA participated in the AAIB's investigation of the accident.

Examination of the wreckage revealed that the fourth tailboom bay aft of its fuselage attachment point was struck twice by the main rotor blades. One of the main rotor blades exhibited red paint transfer 10 inches from its tip that matched the red "DANGER" sign where the tailboom was struck. The blade was fractured 22 inches from the blade horn and was bowed approximately 8 inches downward. The other main rotor blade exhibited severe bending and twisting, and was fractured 14 inches from the blade tip. Examination of the tail rotor drive assembly showed no indications of preimpact failure.

The main rotor gear box (transmission), main rotor mast, and main rotor assembly were examined, but no evidence of an initiating failure was found. The transmission upper cap and lower mast exhibited multiple overload fractures indicative of the mast rocking in flight. The mating main rotor shaft exhibited an overload bending failure, and the upper portion of the shaft contained a 4° bend directly below the main rotor hub. Physical evidence indicates that the bending of the upper main rotor shaft occurred before the fracture of the transmission cap, and secondary to the main rotor blades traveling beyond their normal flapping range. One side of the upper swashplate was fractured at the outer arm, and the corresponding pitch change link was also fractured. Examination of the recovered pieces indicated overload failures, with the arm of one main rotor blade horn striking the failed pitch change link. An instability of the main rotor, rocking of the mast, and extreme pitch divergence of the main rotor blades appeared to precede all of the fractures of the main rotor flight control system. The AAIB could find no engineering reason that would account for the apparent main rotor blade divergence that resulted in the strikes of the tailboom.

29. Knightdale, North Carolina

On September 28, 1994, about 0947 eastern daylight time, N83112, a Robinson R22 Beta helicopter operated by Raleigh Helicopters, broke apart during a business flight near Knightdale, North Carolina. Witnesses at Raleigh East Airport, Knightdale, North Carolina, reported that the pilot's takeoff and initial climb out at 0945 were normal; however, seconds after the departure, the pilot of N83112 radioed in an excited voice "I've got a," and no further transmission was received. Witnesses near the accident site stated that they observed the helicopter flying west at an altitude between 200 and 300 feet when it appeared to "fishtail" and a sputtering sound was heard. The helicopter was then observed to disappear into trees, followed by a fireball rising from the area where the helicopter was last viewed. The pilot was killed, and the helicopter was destroyed. Visual weather conditions prevailed at the time and location of the accident. The commercial pilot had accumulated 790 total flight hours, 373 of which in helicopters and 305 in the R22.

The main wreckage was located 1 1/2 miles west of the Raleigh East Airport and was adjacent to Norfolk and Southern Railroad tracks. The helicopter debris was scattered over an area 850 feet long and 100 feet wide. Portions of the fragmented windshield were found 250 feet from the main wreckage, and pieces of the tailrotor driveshaft were located about 600 feet from the main wreckage. The main rotor assembly, with both blades attached, was located 31 feet north of the main wreckage. The main wreckage consisted of the impact-damaged fuselage, engine, transmission, main rotor assembly, and skids. The wreckage exhibited severe fire and heat damage, and the postimpact fire had partially destroyed the cockpit section of the airframe and engine compartment. Detailed examination of the wreckage revealed that a main rotor blade had struck the cockpit windshield and the tailboom. The main rotor blades exhibited upward bending. Main rotor blade S/N 8262C exhibited fractures 7 feet, 3 inches from the tip of the blade. The fractures in the blade's skin and spar were typical of overstress separations. The other main rotor blade, S/N 8246C, exhibited red and gray paint smears on the upper skin and along the leading edge of the blade. The paint smears matched the paint scheme on the tailboom.

The main rotor hub and spindles were examined. The tusk for the spindle from blade S/N 8262C was fractured in overstress shear; the tusk from blade S/N 8246C remained attached to the spindle. The hub and spindles exhibited damage consistent with the rotor blades traveling beyond their design limits in the up and down direction (flapping). The main rotor driveshaft exhibited an overload separation between the swashplate and main rotor hub. The pitch change links exhibited bending overstress separations at the upper adjustment threads.

On-site and followup examination of the engine did not reveal any evidence that would indicate a loss of power before the tailboom separation and loss of control. The Safety Board was unable to find evidence of any preimpact airframe or engine malfunction.

Following the on-site investigation, pieces from the main rotor blades, transmission, tail rotor assembly, and main rotor head were sent to the Safety Board's materials laboratory for examination. The main rotor blades were examined for bonding between the skin and honeycomb structure. Samples from undamaged portions of the main rotor blades were examined and showed no evidence of adhesive separation or voids. No evidence was found to indicate a precipitating mechanical or material failure of any helicopter system. The Safety Board determined that the probable cause of this accident was a divergence of the main rotor from its normal plane of rotation for undetermined reasons, which resulted in rotor contact with the tailcone.

30. Zurich, Switzerland

On December 27, 1994, about 1434 local time, a Robinson R22 Beta helicopter, registered in Switzerland as HB-XZW and operated by B. B. Helikopter, crashed into an apartment building in Zurich, Switzerland, after an in-flight separation of the tailboom. The pilot had been operating the helicopter for pleasure. Witnesses reported that they observed the helicopter roll right and then left, and the tail structure "wig-wagged." The witnesses then heard a loud bang and observed pieces of the tail structure separate from the structure. The helicopter was then observed to pitch forward and fall vertically onto the upper balcony of the apartment building. Pieces of the tailboom and tail rotor were found about 1/4 mile from the accident site. The private pilot and passenger were killed, and the helicopter was destroyed. The Safety Board and FAA participated in the Swiss AAIB's investigation of the accident.

The pilot's experience included 91 flight hours, all in helicopters, with 30 hours in the R22. The pilot had received his type rating in the R22 on December 17, 1994, and had accumulated 5 hours in the R22, 2 weeks before the accident. Zurich ATC had cleared HB-XZW to the Katzensee VFR check point on the pilots' approach to Zurich airport. Before the crash, witnesses observed the helicopter in level flight at about 1,000 feet agl, and stated that the helicopter's engine sounded normal. Radar data indicate that the helicopter was traveling at approximately 80 knots before the event. Winds at Zurich, at the time of the accident, were reported from 250^{o}, at 18 knots, gusting to 36 knots. The pilot had acquired a weather report before his flight that indicated that winds were 12 knots; however, the report was a general weather report for all of Switzerland, and not specific to Zurich.

Examination of the wreckage revealed that one of the main rotor blades exhibited red paint transfer that matched the color of the tailboom, 1 inch from the blade tip and extending 52 inches inboard along the leading edge of the blade. The tailboom exhibited compression of bays 3-5 and a swipe on the right side of the boom, which resulted in missing and chipped red paint. The spindle tusks were fractured and exhibited overload separation fractures. Both pitch change links were fractured at the upper adjustment threads, and one arm of the stationary swash plate was fractured; however, the corresponding pitch change link remained attached to the fractured arm. The pitch change link and swashplate arm fractures exhibited overload separations, and no evidence of fatigue. A preliminary examination of the engine revealed that the flywheel exhibited damage to the teeth consistent with the engine operating at impact. The governor switch (located on the pilot's collective control) was in the "on" position, and the cyclic control was fractured at the inboard side of the pilot's "T" handle control. Examination of the helicopter's control tubes revealed no evidence of preimpact failure or fatigue. Small specimens of bird feathers were found at two remote locations on the main rotor blade, which exhibited red paint transfer, and on the engine casing. No other evidence of bird remains or bird blood was found adjacent to the feathers or on any other location of the helicopter. In addition, there was no report of birds in the vicinity at the time of the accident. The reason for the main rotor divergence that led to the contact with the tailboom has not been determined and the investigation of the accident is continuing. The Safety Board received the Swiss AAIB's draft factual report on April 2, 1996.

31. Brighton Downs Station, Australia

On July 17, 1995, about 1950 local time, a Robinson R22 Beta helicopter, registered in Australia as VH-BEI, crashed near Brighton Downs Station, Australia, after one of the main rotor blade contacted the cockpit and tailboom in flight. The flight had originated about 185 nautical miles south-east of the accident site near Headingly Station, Australia. The pilot was positioning the helicopter for cattle herding to be accomplished the following day. The pilot was killed, and the helicopter was destroyed. The pilot held a helicopter pilot certificate and had accumulated 794 pilot flight hours, 792 of which were in the R22 helicopter. The weather at the time and location of the accident was reported as strong gusting winds from the south/south east with wide spread clouds.

The Australian Bureau of Air Safety Investigation (BASI) found the R22 helicopter wreckage scattered over 1,000 meters and the tailboom was found 300 meters from the cabin. The tailboom exhibited evidence that it had been struck by a main rotor blade. The cabin landed right side up and was compressed from impact forces to about a meter in height. The rotor system and main rotor blades separated from the transmission, and were found next to the cabin.

The Australian BASI is continuing their investigation of the accident. The reason for the main rotor blade divergence has not been determined.

APPENDIX B-Summary Reports of R44 Loss of Main Rotor Control Accidents

Case No.	Date	Location	Registration No.	Robinson Serial No.	NTSB Accident No.
1.	04-02-94	Hanover, Germany	D-HTOP	0013	
2.	12-08-94	Speyer, Germany	D-HPHS	0107	DCA95RA005
3.	05-08-95	Riesa, Germany	D-HFSD	0101	DCA95RA034

1. Hanover, Germany

On April 2, 1994, about 1345 local time, a Robinson R44 helicopter, registered in Germany as D-HTOP, crashed about 8 miles east of Hanover, Germany, during an intended pleasure flight. The private pilot and his wife were killed. The pilot was qualified in fixed-wing airplanes and helicopters. His total flight experience was not known, but he had logged 110 hours of R22 flight time. This was the pilot's first unsupervised flight after receiving more than 5 hours of R44 instruction and his R44 type-rating checkout. The Safety Board and the FAA participated in the German Accidents Investigation Bureau's investigation of the accident.

The investigation revealed that the main rotor blades struck the cockpit area of the fuselage. The evidence indicates that the helicopter yawed sharply due to the blade strike, and the structure of the tailboom wrinkled and then failed, resulting in separation of the tailboom. The main rotor mast shows evidence of being bumped by the main rotor blades, and the main rotor system separated from the helicopter. No precipitating mechanical failure of the helicopter was found. The investigation did not determine the reason for the main rotor blade divergence that resulted in the rotor striking the body of the helicopter during powered flight.[37]

2. Speyer, Germany

On December 8, 1994, about 1405 local time, a Robinson R44 helicopter, registered in Germany as D-HPHS and operated by Luftfahrt-Geseltschaft-Mannheim, broke apart during an instructional flight about 2,000 feet agl, near Speyer, Germany. The flight was intended to be a continuation of the second pilot's R44 type-rating training.[38] Witnesses near the accident site reported that they heard a loud noise and observed the helicopter falling to the ground with parts of the helicopter separating from the structure as it fell. The instructor pilot and student were killed, and the helicopter was destroyed. The instructor had accumulated 2,885 pilot flight hours in helicopters, 123 of which were in the R44. The R44 student held a commercial pilot certificate (airplane and helicopter) with flight time in the smaller, but similar, Robinson R22 and several hours in the R44. The Safety Board and the FAA are participating in the German Accidents Investigation Bureau's continuing investigation of the accident.

Radar data and the history of flight indicate that the helicopter was cruising about 80 knots (nautical miles per hour) before the accident. The main wreckage (cockpit, skid assembly, and engine) came to rest inverted on level ground. The tailboom had separated from the fuselage, and pieces were located 1,400 feet north of the main wreckage. The main rotor mast and

---

[37] For more detailed information, refer to the German FUS Accident File 3x047-94.

[38] German regulations require that pilots obtain a minimum of 5 hours of flight time in the specific model before acting as pilot-in-command.

rotor assembly remained attached to the transmission assembly. One main rotor blade had broken chordwise, approximately 2 feet from the root, and the outer portion of the blade was located about 1,200 feet south of the main wreckage.

Examination of the wreckage revealed that a main rotor blade had struck the front cockpit structure of the helicopter and that the other main rotor blade had struck the second tailboom bay causing the tailboom in the fourth tailboom bay aft of the fuselage to separate. One of the main rotor blades exhibited scoring that matched the windshield attachment screws of the center support in the nose of the fuselage. The other main rotor blade exhibited scoring that matched a row of similarly scored rivets on the left side of the tailboom. One main rotor blade was fractured about 2 feet from the blade horn and was found 1,400 feet from where the fuselage came to rest. The other main rotor blade exhibited severe bending and twisting, and was fractured in several places. Examination of the tail rotor drive assembly showed no indications of preimpact failure.

The main rotor gear box (transmission), main rotor mast, and main rotor assembly were examined. The main rotor shaft exhibited evidence of mast bumping but no evidence of an initiating material failure was found. The evidence indicates that the mast bumping occurred secondary to the main rotor blades traveling beyond their normal flapping range. The transmission upper cap and entire mast assembly were integral to the transmission and helicopter structure. Both sides of the upper swashplate were fractured at the outer arms, and the corresponding pitch change links were also fractured. Examination of the recovered pieces of pitch change links indicated overload failures. The structural damage of the Plexiglas and cockpit structure indicated low blade momentum during the in-flight strike. An instability of the main rotor, rocking of the mast, and extreme pitch divergence of at least one of the main rotor blades appeared to precede all of the fractures of the main rotor flight control system. The reason for the main rotor pitch divergence has not been determined.

3. Riesa, Germany

On May 8, 1995, about 1745 local time, a Robinson R44, registered in Germany as D-HFSD, and operated by Herkules-Flugservice GmbH, experienced an in-flight separation of the main rotor during a familiarization flight 50 kilometers west of Riesa, Germany. The pilot occupying the left seat had completed the mandated R44 awareness training 1 week before this flight. Witnesses near the accident site reported they heard a loud noise and observed parts of the helicopter separate in flight before the helicopter crashed into a level plowed field. The instructor helicopter pilot and three other commercial helicopter pilots were killed, and the helicopter was destroyed. The pilot-in-command had accumulated approximately 10,000 hours in helicopters, 115 hours of which were in the R44, and 52 in the R22. The right seat pilot held a commercial helicopter pilot certificate and had accumulated about 1,850 hours in helicopters, 6 hours of which were in R22 helicopter, and 1,800 in the MI-8 helicopter. He did not have previous R44 experience. Both passengers held commercial helicopter certificates and were experienced with the Robinson helicopters. The Safety Board and the FAA are participated in the German Accidents Investigation Bureau's investigation of the accident.

The flight had originated at Kassel Calden, home base of the operator, and flew to Bradenburg and Nardt where the helicopter landed safely. The pilot had reported his intention to land at the Riesa Airport at 1815 local time for fuel.

The main wreckage (cockpit shell, skid assembly, engine, and forward tailboom) came to rest on its left side on level ground. The aft tailboom assembly came to rest about 30 meters from the main wreckage. The main rotor had separated at the upper main rotor shaft and was located 180 meters west of the main wreckage. Several pieces of the instrument panel and the Plexiglas windscreen were located close to the main rotor assembly.

Examination of the wreckage revealed that a main rotor blade had struck the right side of the cockpit windscreen centerpost and had sliced through the instrument panel and the lower left side of the cockpit. One of the main rotor blades had separated in three sections and exhibited scoring and blue paint transfer that matched the color of the paint on the helicopter and a row of similarly scored rivets on the cabin centerpost. The lower left side of the fuselage structure was severed 15 inches below the left forward door frame and from the nose of the cockpit to the forward crosstube of the helicopter skid assembly, along the inboard side of the left passenger seat. The left outboard rudder pedal and left cyclic arm also exhibited contact by the main rotor blade.

Examination of the main rotor hub assembly revealed damage corresponding to a main rotor blade pitch horn. The corresponding main rotor pitch horn exhibited severe scoring on the interior surface of the horn. Its pitch change link was fractured in tension overload at the upper adjustment threads. The upper main rotor hub revealed counter-clockwise smearing on both sides of the upper hub where the blade horn had contacted the hub, as the main rotor blade rotated a minimum of 180^{o} about the hub. The main rotor blade's spindle tusk was found intact; however, the other main rotor blade's spindle had fractured in overload at the base of tusk, and the hub exhibited a gouge where the tusk had fractured as it gouged into the hub. The other main rotor blade horn was fractured at the blade collar, and the upper hub exhibited severe gouges that corresponded to the main rotor blade horn pivoting about the hub, resulting in a fracture of the blade horn. The droop stop retaining bolt was also sheared. The main rotor mast exhibited a torsional overload failure 11 inches from the teetering hinge. One-sixteenth-inch deep indentations were observed on both sides of the upper shaft 3 1/2 inches below the center of the teetering hinge, which corresponded to the location of the spindles if they had traveled excessively and bumped the shaft. The structure that houses the main rotor mast exhibited bending on the left (as viewed from aft looking forward) at the point of separation of the main rotor shaft.

Examination of the flight control system revealed overload failures of the support tubing for the jack shaft, the forward cyclic bracket, and the forward bellcrank integral to the rudder pedal controls. All other control tubes showed impact damage but remained intact and attached to their respective components. The examination of the main rotor gear box (transmission) revealed no evidence of damage or preimpact failure. The examination of the cooling fan and alternator revealed circular scoring consistent with the engine operating at impact. The examination of the tail rotor blades revealed fragments of the helicopter's Plexiglas windscreen imbedded in the aluminum honeycomb core of the blade.

On May 12, 1995, the German Accidents Investigation Bureau issued safety recommendation 3X114-0/95 to the Luftfahrt-Bundesamt (LBA), the aviation regulatory agency of Germany, to stop the operation of all R44 helicopters that are certified in Germany. After discussions with the FAA, the LBA placed limitations on the R22 and R44 similar to those placed by the FAA in early 1995.

APPENDIX C-Main Rotor Hub Teeter Angle and Rpm Decay Survey

ROBINSON HELICOPTER COMPANY

RTR-073

26 October 1982

MAIN ROTOR HUB TEETER ANGLE AND RPM DECAY SURVEY

By: [signature] Approved: [signature]

Checked: ______ Checked: ______

R E V I S I O N S

Rev	Date	By	Approved	Pages Affected & Comments
A	11/5/82	[signature]	[signature]	Revised proposal and added flight test results.
B	1/20/83	[signature]	[signature]	Revised pages 10 - 11. Added page 16a.

ROBINSON HELICOPTER COMPANY	RTR 073	PAGE 10
		REV

TABLE V

SUMMARY OF LEVEL FLIGHT CONDITIONS

FLT. NO.	COND. NO.	AIRSPEED KCAS	RPM %	MAP IN. Hg	% RIGHT STICK	% FWD. STICK	COL. PITCH AT .75R DEGREES	MAX. TEETER ANGLE ± DEGREES	ALTIT.
1	20	30	104	17.2	60.8	—	6.3	2.48	△1
1	22	40		16.5	60.8	—	6.0	3.21	
1	24	60		18.0	62.3	—	6.7	3.36	
1	26	80		21.2	62.3	52.5	8.1	4.39	
1	28	90		23.0	59.3	55.9	9.1	4.37	△1
3	30	100		23.0	69.2	60.0	8.1	4.71	△2
3	32	111	104	23.0	66.2	61.0	8.3	5.33	△2
1	19	30	97	17.0	64.6	44.1	6.4	2.65	△1
1	21	40		16.5	69.8	—	6.5	3.26	
1	23	60		18.0	70.5	—	7.2	3.89	
1	25	80		22.0	69.0	58.8	8.6	4.29	
1	27	90		N/A	68.3	62.7	9.6	4.75	△1
3	29	100		23.0	67.7	64.5	9.2	5.13	△2
3	31	111	97	23.0	67.7	66.0	9.2	5.25	△2

△1 PRESSURE ALTITUDE = 3500 FT.
DENSITY ALTITUDE = 4200 FT.

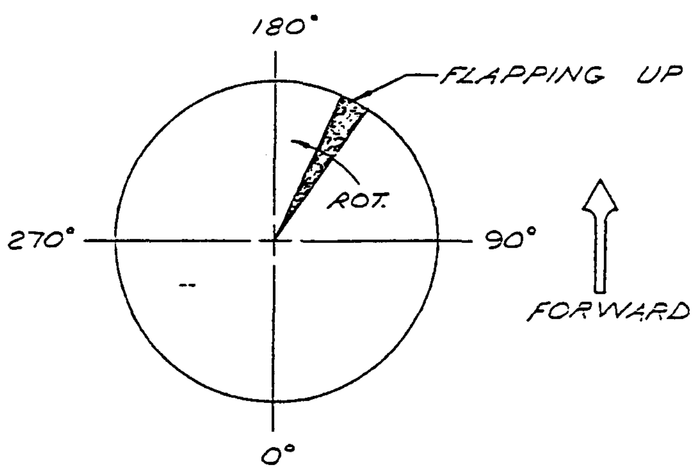
△2 PRESSURE ALTITUDE = 2000 FT.
DENSITY ALTITUDE = 2930 FT.

ROBINSON HELICOPTER COMPANY		PAGE 16
	RTR 073	REV A

TABLE XI AZIMUTH LOCATION OF MAXIMUM TEETER ANGLE

FLT. NO.	COND. NO.	DESCRIPTION	AZIMUTH LOCATION
6	27	LEVEL FLIGHT @ .9 V_{NE}	145.3°
6	37a	L. ROLL W/ 45° BANK @ .9 V_{NE}	155.5°
6	43a	R. ROLL W/ 45° BANK @ .9 V_{NE}	140.9°
6	23	LEVEL FLIGHT @ .6 V_{NE}	152.7°
6	35a	L. ROLL W/ 45° BANK @ .6 V_{NE}	152.7°
6	41a	R. ROLL W/ 45° BANK @ .6 V_{NE}	153.9°

ALL MANEUVERS PERFORMED AT 97% RPM



National Transportation Safety Board
Washington, D.C. 20594

December 12, 1995

Frank Robinson
President
Robinson Helicopter Company
2901 Airport Drive
Torrance, California 90505

Dear Mr. Robinson:

As you know, the National Transportation Safety Board (NTSB) is performing a special investigation on the Robinson R22 helicopters and will be issuing a report detailing its findings. We plan to include in that report two tables from the October 26, 1982, Main Rotor Hub Teeter Angle and RPM Decay Survey, RTR-073, submitted by your company to the Federal Aviation Administration (FAA) in conjunction with the R22 certification process.

Specifically, the tables that we plan to include in the report are Table V., Summary of Level Flight Conditions, page 10, and Table XI., Azimuth Location of Maximum Teeter Angle, page 16. Copies are enclosed for your convenience. This information is needed to adequately explain several steady state and flight control positions.

Included on the cover page of the Main Rotor Hub Teeter Angle and RPM Decay Survey is a notation stating that the document contains proprietary technical and commercial trade secrets. Therefore, we are now providing Robinson Helicopter with an opportunity to comment on the inclusion of this information in the NTSB report. We would appreciate a response within ten days and will give it careful consideration.

Thank you for your cooperation.

Sincerely,

John B. Drake
Chief, Aviation
Engineering Division

Enclosures

ROBINSON
HELICOPTER COMPANY
2901 Airport Drive, Torrance, California 90505
■ PHONE (310) 539-0508 ■ FAX (310) 539-5198

December19, 1995

NATIONAL TRANSPORTATION SAFETY BOARD
Attn: John B. Drake
Chief, Aviation Engineering Division
Washington, DC 20594

Dear Mr. Drake:

Robinson Helicopter Company does not object to the NTSB including Table V and Table XI from RTR 073 in the forthcoming NTSB report on the R22 helicopter.

If we can be of any further assistance in this regard, please let me know.

Yours truly,

ROBINSON HELICOPTER COMPANY

Frank Robinson
President

FDR: map

APPENDIX D-Applicable Safety Recommendations and Related Correspondence

National Transportation Safety Board
Washington, D.C. 20594
Safety Recommendation

Date: July 21, 1994

In reply to refer to: A-94-143 through -145

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D. C. 20591

On June 8, 1994, about 1139 local time, a Robinson R22 helicopter, registered in England as G-PUDD and operated by Bizzi-B Helicopters, broke apart during an instructional flight about 1,500 feet above ground level, near Martin, England. A witness about 1 1/4 mile from the accident site reported that he saw the helicopter flying normally and then heard a loud noise and observed the helicopter falling vertically to the ground with the main rotor assembly separated from the helicopter. The instructor pilot and student were fatally injured and the helicopter was destroyed. The instructor had accumulated 8,400 pilot flight hours, of which 5,200 hours were in the R22. The helicopter student held an airline transport pilot certificate (airplane) with approximately 4,000 hours of total flight time, including 22 hours in the R22. The investigation established that the helicopter was cruising at about 80 knots (nautical miles per hour) before the accident. The main wreckage (cockpit, skid assembly, and engine) came to rest inverted on level ground. The tailboom had separated from the fuselage and pieces were located 300 feet south of the main wreckage. The main rotor mast and rotor assembly had separated at the top of the transmission and were located about 100 feet from the main wreckage. The Safety Board and the Federal Aviation Administration (FAA) participated in the U. K. Air Accidents Investigation Board's investigation of the accident.

Examination of the wreckage revealed that the fourth tailboom bay aft of its fuselage attachment point was struck twice by the main rotor blades. One of the main rotor blades exhibited red paint transfer 10 inches from its tip that matched the red "DANGER" sign where the tailboom was struck. The blade was fractured 22 inches from the blade horn and was bowed approximately 8 inches downward. The other main rotor blade exhibited severe bending and twisting, and was fractured 14 inches from the blade tip. Examination of the tail rotor drive assembly showed no indications of preimpact failure.

The main rotor gear box (transmission), main rotor mast, and main rotor assembly were examined but no evidence of an initiating failure was found. The transmission upper cap and lower mast exhibited multiple overload fractures indicative of the mast rocking in flight. The mating main rotor shaft exhibited an overload bending failure, and the upper portion of the shaft contained a 4° bend directly below the main rotor hub. Physical evidence indicates that the bending of the upper main rotor shaft occurred before the fracture of the transmission cap, and secondary to the main rotor blades traveling beyond their normal flapping range. One side of the upper swashplate was fractured at the outer arm and the corresponding pitch change link was also fractured. Examination of the recovered pieces indicated overload failures, with the arm of one main rotor blade horn striking the failed pitch change link. An instability of the main rotor, rocking of the mast, and extreme pitch divergence of the main rotor blades appeared to precede all of the fractures of the main rotor flight control system. The reason for the main rotor pitch divergence has not been determined and the investigation of the accident is continuing.

On August 10, 1993, about 1806 Hawaiian standard time, a Robinson R22 helicopter, N4017J, crashed into the Pacific Ocean about 8 miles southeast of Honolulu, Hawaii, during an intended pleasure flight. The airline transport pilot and his wife received fatal injuries. The pilot had logged 4,350 total flight hours and 140 hours of R22 flight time. An endorsement in his logbook indicated that the pilot had successfully completed the Robinson Helicopter Company Safety Course and biennial flight review in Torrance, California, on March 12, 1993. According to a certified flight instructor (CFI) who had instructed him, the pilot was proficient with emergency procedures in the R22. A witness kayaking in the ocean approximately 1/4 mile offshore indicated that the helicopter "appeared to be operating properly when all of a sudden it went down into the water." Another witness located aboard a catamaran said he saw "the front rotor blades' shaft bend toward the right side of the helicopter" and hit the helicopter body. The helicopter crashed into the water 50 to 75 feet from the catamaran. The last recorded radar data showed N4017J at an altitude of 500 feet above the ocean, 1/4 mile off the southeast coast of Oahu, and the radar track indicated that it was cruising at about 90 knots just before radar contact was lost. Examination of the retrieved wreckage revealed that one main rotor blade was bent downward and had entered the left forward section of the cockpit. The main rotor hub exhibited deep gouges where the droop stop tusks contacted the hub; the droop stop tusks were sheared. The upper transmission and lower mast remained intact; however, the upper main rotor shaft was bent approximately 30°, consistent with an aerodynamically divergent blade striking the body of the helicopter during powered flight. The Safety Board was unable to establish the exact cause of the main rotor blade divergence.[1]

On June 29, 1992, at 1242 Pacific daylight time, a Robinson R22 helicopter, N83858, operated by the Sierra Academy of Aeronautics, Inc., experienced an in-flight breakup during an instructional flight near Richmond, California. Witnesses reported observing the tailboom and main rotor separate from the helicopter in flight. A CFI was providing a primary flight lesson to his student, who was recording the lesson (cockpit interphone and radio communications) with a microcassette tape recorder. 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 revolutions per minute (rpm) warning horn was checked and

---

[1] For more detailed information, read Brief of Accident File #1420 (attached).

operated normally on the ground. While en route, the CFI instructed the student to perform a left turn. According to the recording, the student completed the turn using a shallow bank. While cruising southbound at about 2,000 feet, the CFI began talking, but in mid-word, with no prior indication of an anomaly, 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 helicopter rapidly descended and crashed into San Pablo Bay, 3 miles northwest of Richmond, California. The CFI, who had accumulated about 2,000 hours of R22 flight time, and the student pilot were fatally injured.

The record of the flight provided by the audiotape showed that neither pilot voiced any concern with the operation of the helicopter before the breakup. The low rotor warning horn did not activate before or during the breakup sequence. The Safety Board's analysis of the audiotape revealed that during most of the flight the main rotor sound signature was measured between 17.5 Hz and 18 Hz, equivalent to a main rotor speed of 525 to 540 rpm.[2] No unusual rotor system noises were heard before the event that resulted in the in-flight breakup. The Safety Board's sound spectrum analysis of the audiotape indicated that the main rotor rpm did not decay before the breakup. Analysis of the recorded primary and secondary air traffic control (ATC) radar data supported an in-flight breakup scenario with the initial breakup occurring at 2,000 feet mean sea level (msl). The helicopter's indicated airspeed (IAS) was calculated from available radar data to have been about 85 knots in level, cruise flight when the main rotor blades suddenly departed from their normal rotational plane and impacted the tailboom.

After recovery from San Pablo Bay, the wreckage was examined for evidence of possible preimpact control system or airframe failures that might have initiated the breakup, but none were found. No evidence was found of control interference, and the swashplate, spindle bearings, and engine exhibited no signs of preimpact damage. The main rotor mast assembly, with the main rotor blades attached, was recovered about 970 feet north of the main wreckage. The assembly had separated from the upper portion of the helicopter's transmission housing. One main rotor blade was found curled 39° upward and both main rotor blades exhibited multiple red paint smears that appeared to match the tailboom paint. The aft portion of the tailboom (aft of the first bay area) was not recovered. However, a main rotor blade had left its impression in the crushed left side of the tailboom's first bay area. Both pitch change links exhibited bending overload failures and the tusks were fractured from each spindle, consistent with damage resulting from the divergence of the main rotor blades from their normal plane of rotation. This accident was unique among other R22 in-flight loss of main rotor control accidents in that the audio recording documented the event, and analysis of the audiotape showed that the failure occurred with main rotor rpm in the normal R22-powered operating range. The Safety Board could find no evidence of the specific event that caused or allowed the main rotor blades to diverge from their normal flightpath plane and strike the airframe.[3]

---

[2] Normal R22 main rotor speed for powered flight is 495 to 530 rpm.

[3] For more detailed information, read Brief of Accident File #1003 (attached).

In the three accidents described above, the in-flight breakups occurred while the helicopters were being operated at cruise speeds well within the aircraft's defined operating envelope. In all cases the pilots were experienced and the investigation indicates that they had been adequately trained in the R22. The Safety Board has found no evidence that the pilots were improperly operating the helicopters. In addition to these three accidents, the Safety Board has investigated 18 others that have occurred since 1981 involving an in-flight breakup of an R22 helicopter. In all of these, the breakup occurred when the main rotor blades diverged from their normal plane of rotation and struck the airframe.

The R22 main rotor system is unique. The two-bladed, semi-rigid main rotor system includes rotor blades that are connected to the main rotor hub through coning (flapping) hinges.[4] The main rotor hub is connected to the main rotor shaft (mast) through an additional hinge so that the hub teeters with influence from main rotor blade movement. In other two-bladed, semi-rigid systems, the advancing blade flaps up, causing the retreating blade to flap down; however, each R22 main rotor blade flaps independently of the other blade's vertical movement. The chord and diameter of the main rotor blades measure 7 inches and 25 feet, 2 inches, respectively, and each blade weighs approximately 26 pounds. The main rotor rpm is much higher, and the rotor inertia is very low by comparison to other two-bladed rotor systems.

When in forward flight, the dynamic speed of the air over the rotor blade is the rotational speed of the blade algebraically added to airspeed. Thus, the airflow over the advancing blade is greater than the airflow over the retreating blade, and at a given pitch the rotor would create asymmetrical lift. To compensate, the lift generated by the advancing blade results in movement of the teetering hinge and tilting of the main rotor hub, such that the angle-of-attack (AOA) of the advancing main rotor blade is reduced and the AOA of the retreating blade is increased to balance the lift in the rotational plane. Thus, as the helicopter's forward airspeed increases, the advancing blade's AOA decreases as the retreating blade's AOA increases. However, if the AOA on the retreating blade exceeds the critical AOA, the blade will stall (retreating blade stall). The combination of large changes in the AOA of the main rotor blades, high forward airspeed, and high gross weight (high gross weight requires more lift, which increases the AOA of the main rotor blades) creates instabilities in the main rotor system as the retreating blade becomes stalled. The Safety Board is concerned that these instabilities are a potential contributing cause of blade divergence. Other aerodynamic characteristics (Mach tuck, drag divergence, pitch moment oscillations, and negative blade damping) also could have devastating effects on a low-inertia, high rpm rotor system. Therefore, the Safety Board is concerned that adequate testing may not have been accomplished to resolve any potential adverse aerodynamic characteristics of the rotor system.

The Safety Board is aware of other potential blade characteristics that this design would be likely to encounter. The construction of the R22 main rotor blade is unlike most other

---

[4]Coming is the upward bending of the blades caused by the resultant forces of lift and centrifugal force. Flapping is the vertical movement of the blade as a result of aerodynamic forces.

helicopter blades in that there is no mid-chord shear web. The main rotor blade is constructed with a leading edge stainless steel D-shaped bar (spar), which is also designed to be the load-carrying structure. The honeycomb and blade skin is adhesively attached to the leading edge spar. The Safety Board is not aware of any wind tunnel testing using this blade design. The R22 main rotor blade was modified shortly after certification with weights in each main rotor blade tip. The weight was designed to improve the low inertia problem and aid in autorotational landings.

The R22 main rotor rpm will rapidly decay following a loss of power. The Robinson Helicopter Company has reported to Safety Board staff that it attributes most R22 loss of main rotor control accidents to pilot-induced low rotor rpm, or low-G maneuvering. The following physical evidence refutes these theories: In all three of the above accidents, there was physical evidence of main rotor blade strikes to the tailboom or cockpit under substantial operating power; the overload fractures of the spindles, pitch change links, transmission cap, and bending of the upper main rotor shaft all indicate that significant force was required to cause this damage; and the location and angle at which the strikes occurred revealed that the blade was not at its normal plane of rotation at the time of the strike to the helicopter body.

The Safety Board is aware that the R22 has demonstrated compliance with the certification requirements and that previous certification reviews have not uncovered evidence of noncompliance with certification standards or of a deficiency that would explain accidents such as those discussed above. However, because of the violent nature of the accidents and the evidence of possible main rotor involvement, the Safety Board believes that the FAA should, in conjunction with the National Aeronautics and Space Administration (NASA) and Robinson Helicopter Company, conduct further testing to evaluate the R22 main rotor and control system. The testing should include wind tunnel and computer modeling to evaluate the main rotor design, main rotor performance in cruise flight, rotor stability and other possible areas in which main rotor divergence or instabilities may have occurred on accident flights. The Safety Board is concerned that the unique design of the R22 may result in flight characteristics that are not adequately addressed by Title 14 Code of Federal Regulations (CFR) Part 27 standards. The Safety Board is concerned that the R22 main rotor control system may allow flight characteristics that were not flight or ground-tested under 14 CFR Part 27 standards, allowing anomalies in the main rotor system to go undetected during the original certification process.

Because the Richmond, California, accident occurred abruptly and with no apparent warning to the flightcrew, it was of particular concern to the Safety Board. That accident and the 20 other similar R22 in-flight breakup accidents examined by the Safety Board indicated that there may be undesirable aerodynamic characteristics of R22 main rotor blades that can result in one or both blades diverging from their normal plane of rotation (see Appendix A for the list of accidents). The Safety Board is concerned that the stability of the R22 main rotor blades is compromised by an inherent rotor system design deficiency that may allow loss of control of the rotor system when operating the helicopter within the currently defined flight envelope and in a manner that would seem normal in other light helicopters. The Safety Board is aware of the importance of the R22 as a training and light utility helicopter. However, until the cause of the accidents, like those cited above, is determined, the flight envelope should be restricted.

In each of the in-flight breakups described above, the helicopter was being operated at a speed close to that recommended for cruise. The R22 flight manual indicates 83 knots as maximum range airspeed, and the Robinson Helicopter Training Manual specifies 75 knots as the recommended cruise speed. The FAA-approved never exceed airspeed (V_{ne}) is 102 knots. The Safety Board believes that, as an interim measure, while the cause of the in-flight breakup accidents is being determined, the maximum R22 operating speed should be reduced to a speed lower than the cruise speeds at which the accidents have occurred in the past.

The Safety Board has paid particular attention to the R22 main rotor blades and the rotor head because its special investigation has revealed that the in-flight breakup accidents were more likely caused by failures that initiated at the main rotor, rather than in the transmission, its mounts, or the main rotor control system. Because of its investigative findings, the Safety Board requested Material Review Records (MRRs) for the main rotor blades involved in the accidents but has not yet received those records. The Safety Board's review of an MRR of rotor blades not involved in an accident caused the Board to become concerned with the disposition and subsequent approval of blades containing defects, as illustrated by that MRR. The MRR examined showed that the Designated Engineering Representative (DER) employed by the Robinson Helicopter Company approved the use of main rotor blades for use on new helicopters when those blades did not pass design inspection requirements. The proper design, manufacture, testing, and approval of main rotor blades are crucial to the airworthiness of a helicopter. Defects in main rotor blades should be carefully examined and any blade not meeting the original design limits should be rejected. The Safety Board does not know the circumstances under which the approval was granted by the DER but is concerned about the appearance of the action.

A DER is the quality assurance link between the FAA and the manufacturer. The Safety Board believes that to ensure product integrity and safety during the design and development of an aircraft, the FAA must closely monitor the manufacturing process. The DER has the authority, granted by the FAA, to approve deviations during the manufacturing of a component that will be installed on an aircraft. The Safety Board was concerned to learn that the only FAA-designated DER currently at the Robinson Helicopter Company was also the president of the company. (A previously assigned DER left the company on September 3, 1993, and has not been replaced.) The Safety Board is concerned that the potential exists for any senior company officer, especially its president, to have a conflict of interest that could influence the performance of his or her duties as a DER. The president of any company has a financial interest in the success of the company and has other duties that could conflict with his or her responsibilities as a DER. Therefore, the Safety Board believes that it is essential that the FAA promptly review the appointment of any DER who is both a senior company officer and a DER.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue an immediate airworthiness directive to reduce the Robinson R22 helicopter "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. (Class I, Urgent Action) (A-94-143)
>
> In conjunction with the National Aeronautics and Space Administration and Robinson Helicopter Company, conduct wind tunnel and modeling tests to examine flight parameters of the R22 helicopter to determine the helicopter's design characteristics that are related to main rotor divergent behavior; and if any abnormal rotor system performance characteristics are found, take the necessary actions to assure proper dissemination of the information and to modify the R22 design. (Class I, Urgent Action) (A-94-144)
>
> Examine the appropriateness of the Designated Engineering Representative (DER) assignment at the Robinson Helicopter Company and at other small manufacturers where senior executives are assigned DER responsibilities, and take necessary actions to eliminate any conflict of interest with DER responsibilities. (Class II, Priority Action) (A-94-145)

Acting Chairman HALL, and Members LAUBER, HAMMERSCHMIDT, and VOGT concurred in these recommendations.

By Jim Hall
Acting Chairman

Appendix A, R22 Loss of Main Rotor Control Accidents

APPENDIX A

R22 Loss of Main Rotor Control Accidents

Date	Location	Registration No.	Robinson Serial No.	NTSB Accident No.
11-11-81	Livermore, CA	N9073Q	0227	LAX82FA012
09-25-82	Nashville, TN	N9072V	0212	ATL82FA285
10-06-82	Santa Ana, CA	N8358B	0302	LAX83FUA01
12-25-84	Huntsville, AL	N8475K	0391	ATL85FA067
05-05-85	San Angelo, TX	N83745	0320	FTW85FA207
03-22-86	Memphis, TN	N9069S	0181	ATL86FA097
05-10-86	E. Fishkill, NY	N8511Z	0415	NYC86FA127
03-16-87	Scottsdale, AZ	N2256M	0498	LAX87FA147
06-03-87	S. Windsor, CT	N2287L	0512M	NYC87FA160
11-03-87	Moraga, CA	N8475A	0389	LAX88FA032
11-23-90	Simi Valley, CA	N80783	1319	LAX91FA037
07-05-91	Phoenix, AZ	N23039	1846	LAX91FA288
09-23-91	Point Judith, RI	N950CW	1637	NYC91FA254
01-30-92	Malabar, FL	N2313G	2015	MIA92FA072
03-04-92	Maricopa, AZ	N8413Q	0354	LAX92FA 137
05-06-92	Mt. Pleasant, TN	N191KC	1818	ATL92FA096
05-08-92	Anaheim, CA	N8064E	1264	LAX92FA206
06-29-92	Richmond, CA	N83858	0337	LAX92FA267
09-30-92	Martinez, CA	N8069X	1364	LAX92FA41O
08-10-93	Honolulu, HI	N4017J	1443	LAX93FA318
06-08-94	Martin, England	G-PUDD	0863	DCA94RA060

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

File No. - 1420   8/10/93   HONOLULU,HI   A/C Reg. No. N4017J   Time (Lcl) - 1806 HST

---

asic Information----
Type Operating Certificate-NONE (GENERAL AVIATION)
Type of Operation -PERSONAL
Flight Conducted Under -14 CFR 91
Accident Occurred During -CRUISE

Aircraft Damage
DESTROYED
Fire
NONE

Injuries

	Fatal	Serious	Minor	None
Crew	1	0	0	0
Pass	1	0	0	0

---

ircraft Information----
Make/Model - ROBINSON R-22 BETA
Landing Gear - SKID
Max Gross Wt - 1370
No. of Seats - 2

Eng Make/Model - LYCOMING O-320-B2C
Number Engines - 1
Engine Type - RECIPROCATING-CARBURETOR
Rated Power - 160 HP

ELT Installed/Activated - NO -N/A
Stall Warning System - NO

---

nvironment/Operations Information----
eather Data
Wx Briefing - UNK/NR
Method - UNK/NR
Completeness - UNK/NR
Basic Weather - VMC
Wind Dir/Speed- 080/016 KTS
Visibility - 20.0 SM
Lowest Sky/Clouds - UNK/NR SCATTERED
Lowest Ceiling - NONE
Obstructions to Vision- NONE
Precipitation - NONE
Condition of Light - DAYLIGHT

Itinerary
Last Departure Point
LANAI,HI
Destination
SAME AS ACC/INC

ATC/Airspace
Type of Flight Plan - VFR
Type of Clearance - NONE
Type Apch/Lndg - NONE

Airport Proximity
OFF AIRPORT/STRIP

Airport Data
Runway Ident - N/A
Runway Lth/Wid - N/A
Runway Surface - N/A
Runway Status - N/A

85

-Personnel Information----
Pilot-In-Command
Certificate(s)/Rating(s)
COMMERCIAL,ATP
SE LAND,ME LAND
HELICOPTER

Age - UNK/NR
Biennial Flight Review
Current - YES
Months Since - 5
Aircraft Type - R-22

Medical Certificate - VALID MEDICAL-WAIVERS/LIMIT
Flight Time (Hours)
Total - 4350
Make/Model- UNK/NR
Instrument- UNK/NR
Multi-Eng - UNK/NR
Last 24 Hrs - UNK/NR
Last 30 Days- UNK/NR
Last 90 Days- UNK/NR
Rotorcraft - 140

Instrument Rating(s) - AIRPLANE

-Narrative----
UT 10 MI FROM THE DESTINATION, THE PILOT RADIOED APPROACH CONTROL TO ENTER THE TCA. HE WAS GIVEN A TRANSPONDER CODE THE CONTROLLER, BUT DID NOT ACKNOWLEDGE THE TRANSMISSION. WITNESSES NEAR THE ACCIDENT SITE REPORTED HEARING A LOUD PLOSION", OR A METAL TO METAL SOUND, AND THEN OBSERVED THE HELICOPTER IN AN UNCONTROLLED DESCENT. ONE WITNESSES SAID ROTOR DISK TILTED AND STRUCK THE AIRFRAME. POST-CRASH EXAMINATION REVEALED THAT ONE MAIN ROTOR BLADE HAD ENTERED FORWARD LEFT SIDE OF THE CABIN.

Brief of Accident (Continued)

File No. - 1420   8/10/93   HONOLULU HI

rence #1   AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
of Operation   CRUISE - NORMAL

ng(s)
ROTOR SYSTEM - UNDETERMINED

rence #2   IN FLIGHT COLLISION WITH TERRAIN/WATER
of Operation   DESCENT - UNCONTROLLED

ing(s)
TERRAIN CONDITION - WATER

Probable Cause

National Transportation Safety Board determines that the Probable Cause(s) of this accident was:
ERGENCE OF THE MAIN ROTOR FROM ITS NORMAL PLANE OF ROTATION FOR AN UNDETERMINED REASON(S) WHICH RESULTED IN ROTOR
ACT WITH THE AIRFRAME.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

[illegible] A/C Reg [illegible] Time (Lcl) - 1242 PDT

Basic Information----

Type Operating Certificate-NONE (GENERAL AVIATION)
Type of Operation -INSTRUCTIONAL
Flight Conducted Under -14 CFR 91
Accident Occurred During -CRUISE

Aircraft Damage: DESTROYED
Fire: NONE

	Injuries			
	Fatal	Serious	Minor	None
Crew	2	0	0	0
Pass	0	0	0	0

Aircraft Information----

Make/Model - ROBINSON R22
Landing Gear - SKID
Max Gross Wt - 1370
No of Seats - 2

Eng Make/Model - LYCOMING O-320-B2C
Number Engines - 1
Engine Type - RECIPROCATING-CARBURETOR
Rated Power - 160 HP

ELT Installed/Activated - NO -N/A
Stall Warning System - NO

Environment/Operations Information----

Weather Data
Wx Briefing - NO RECORD OF BRIEFING
Method - N/A
Completeness - N/A
Basic Weather - VMC
Wind Dir/Speed- 180/011 KTS
Visibility - 15.0 SM
Lowest Sky/Clouds - 1800 FT SCATTERED
Lowest Ceiling - 12000 FT BROKEN
Obstructions to Vision- NONE
Precipitation - RAIN
Condition of Light - DAYLIGHT

Itinerary
Last Departure Point
OAKLAND, CA
Destination
LOCAL

ATC/Airspace
Type of Flight Plan - NONE
Type of Clearance - NONE
Type Apch/Lndg - NONE

Airport Proximity
OFF AIRPORT/STRIP

Airport Data
Runway Ident - N/A
Runway Lth/Wid - N/A
Runway Surface - N/A
Runway Status - N/A

Personnel Information----

Pilot-In-Command
Certificate(s)/Rating(s)
COMMERCIAL, CFI
SE LAND
HELICOPTER

Age - 36
Biennial Flight Review
Current - YES
Months Since - UNK/NR
Aircraft Type - R22

Medical Certificate - VALID MEDICAL-WAIVERS/LIMIT
Flight Time (Hours)
Total - 2200
Make/Model- 2000
Instrument- UNK/NR
Multi-Eng - UNK/NR
Last 24 Hrs - 0
Last 30 Days- 14
Last 90 Days- 70
Rotorcraft - 2000

Instrument Rating(s) - NONE

Narrative----

STUDENT HAD RECORDED HER PRIMARY FLIGHT LESSON ON A TAPE RECORDER. AFTER REACHING THE PRACTICE AREA, THE CFI [illegible]RUCTED THE STUDENT TO TURN 180 DEG LEFT. THE STUDENT COMPLIED AND PERFORMED A SHALLOW BANK TURN. SECONDS LATER, [illegible]E CRUISING AT 2,200 FT, THE CFI BEGAN TALKING. IN MIDSENTENCE AN UNDETERMINED EVENT OCCURRED WHICH INTERRUPTED HIS [illegible]CH. A WIND-LIKE BACKGROUND NOISE STARTED, AND THE STUDENT EXCLAIMED "HELP." RADAR DATA CONFIRMED WITNESS REPORTS [illegible] THE TAIL BOOM AND M/R HAD SEPARATED IN LEVEL FLT. EXAM OF THE WRECKAGE INDICATED MAST BUMPING HAD OCCURRED, A M/R [illegible]E CRUSHED THE LEFT SIDE OF THE INBOARD TAIL CONE, AND THE ENTIRE MAST WITH ATTACHED M/R BLADES BROKE OUT OF THE TOP [illegible]HE TRANSMISSION. THE OUTBOARD TAIL BOOM AND ROTOR ASSEMBLY HAVE NOT BEEN FOUND. EVIDENCE OF A MAIN ROTOR BLADE [illegible]RGENCE WAS FOUND. SPECTRUM ANALYSIS OF THE TAPE REVEALED NO ANOMALIES UNTIL THE CFI'S VOICE WAS TERMINATED. WITHIN [illegible]CONDS THE ROTOR SPEED APPEARED TO SIGNIFICANTLY OSCILLATE AND ABRUPTLY END.

Brief of Accident (Continued)

File No. - 1003 6/29/92 RICHMOND,CA A/C Reg. No. N83858 Time (Lcl - 1242 PDT

:ence #1 AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
of Operation CRUISE

:g(s)
:OTOR SYSTEM - UNDETERMINED

rence #2 IN FLIGHT COLLISION WITH TERRAIN/WATER
of Operation DESCENT - UNCONTROLLED

robable Cause----

.ational Transportation Safety Board determines that the Probable Cause(s) of this accident was:
:RGENCE OF THE MAIN ROTOR FROM ITS NORMAL PLANE OF ROTATION FOR AN UNDETERMINED REASON(S) WHICH RESULTED IN ROTOR
.:T TO THE TAILBOOM.

88

National Transportation Safety Board

Washing-ton, D.C. 20594

Safety Recommendation

Date: January 6, 1995

Inreply refer to: A-95-1 through-8

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On December 8, 1994, about 1405 local time, a Robinson R44 helicopter, registered in Germany as D-HPHS and operated by Luftfahrt-Geseltschaft-Mannheim, broke apart during an instructional flight about 2,000 feet above ground level, near Speyer, Germany. The flight was intended to be a continuation of the second pilot's R44 type-rating training.[1] Witnesses near the accident site reported that they heard a Ioud noise and observed the helicopter falling to the ground with parts of the helicopter separating from the structure as it fell. The instructor pilot and student were fatally injured, and the helicopter was destroyed. The instructor had accumulated 2,885 pilot flight hours in helicopters, 123 hours of which were in the R44. The R44 student held a commercial pilot certificate (airplane and helicopter) with flight time in the smaller, but similar, Robinson R22 and several hours in the R44. The National Transportation Safety Board and the Federal Aviation Administration (FAA) are participating in the German Flugenfalluntersuchungsstelle (FUS) Accidents Investigation Board's continuing investigation of the accident.

Radar data and the history of flight indicate that the helicopter was cruising about 80 knots (nautical miles per hour) before the accident. The main wreckage (cockpit, skid assembly, and engine) came to rest inverted on level ground. The tailboom had separated from the fuselage, and pieces were located 1,400 feet north of the main wreckage. The main rotor mast and rotor assembly remained attached to the transmission assembly. One main rotor blade had broken chordwise, approximately 2 feet from the root, and the outer portion of the blade was located about 1,200 feet south of the main wreckage.

Examination of the wreckage revealed that a main rotor blade had struck the front cockpit structure of the helicopter and that the other main rotor blade had struck the second tailboom bay causing the tailboom in the fourth tailboom bay aft of the fuselage to separate. One of the

[1] German regulations require that pilots obtain a minimum of 5 hours of flight time in the specific model before acting as pilot-in-command.

main rotor blades exhibited scoring that matched the windshield attachment screws of the center support in the nose of the fuselage. The other main rotor Made exhibited scoring that matched a row of similarly scored rivets on the left side of the tailboom. One main rotor blade was fractured about 2 feet from the blade horn and was found 1,400 feet from where the fuselage came to rest. The other main rotor blade exhibited severe bending and twisting, and was fractured in several places. Examination of the tail rotor drive assembly showed no indications of preimpact failure.

The main rotor gear box (transmission), main rotor mast, and main rotor assembly were examined. The main rotor shaft exhibited evidence of mast bumping but no evidence of an initiating material failure was found. The evidence indicates that the mast bumping occurred secondary to the main rotor blades traveling beyond their normal flapping range. The transmission upper cap and entire mast assembly were integral to the transmission and helicopter structure. Both sides of the upper swashplate were fractured at the outer arms, and the corresponding pitch change links were also fractured. Examination of the recovered pieces of pitch change links indicated overload failures. The structural damage of the plexiglass and cockpit structure indicated low blade momentum during the in-flight strike. An instability of the main rotor, rocking of the mast, and extreme pitch divergence of at least one of the main rotor blades appeared to precede all of the fractures of the main rotor flight control system. The reason for the main rotor pitch divergence has not been determined.

On April 2, 1994, about 1345 local time, another Robinson R44 helicopter, registered in Germany as D-HTOP, crashed about 8 miles east of Hanover, Germany, during an intended pleasure flight. The private pilot and his wife received fatal injuries. The pilot was qualified in fixed-wing airplanes and helicopters. His total flight experience was not known, but he had logged 110 hours of R22 flight time. This was the pilot’s first unsupervised flight after receiving more than 5 hours of R44 instruction and his R44 type-rating checkout. The Safety Board and the FAA are participating in the continuing FUS investigation of the accident.

The investigation has revealed that the main rotor blades struck the cockpit area of the fuselage. The evidence indicates that the helicopter yawed sharply due to the blade strike, and the structure of the tailboom wrinkled and then failed, resulting in separation of the tailboom. The main rotor mast shows evidence of being bumped by the main rotor blades, and the main rotor system separated from the helicopter. No precipitating mechanical failure of the helicopter has been found. The investigation has not determined the reason for the main rotor blade divergence that resulted in the rotor striking the body of the helicopter during powered flight.[2]

On December 27, 1994, about 1440 local time, a Robinson R22 helicopter, registered in Switzerland as HB-XZW and operated by BB Helicopter AG, crashed onto the roof of an apartment house near Zurich, Switzerland, after a loss of control in flight. The flight’s purpose was not reported, and the pilot’s flight experience is not yet known. The weather was reported

---

[2] For more detailed information, refer to the German FUS Accident File 3x047-94.

to be good with gusting wind conditions.Witnesses saw the helicopter in cruise flight about 1,000 feet above the ground and heard the engine running normally before the accident. The witnesses then heard a loud bang and saw parts of the tailboom separate from the helicopter before the helicopter crashed onto the apartment house. Parts of the tailboom and tail rotor assembly were found about a quarter of a mile from the accident site, and there was evidence of paint transfer from the tailboom to one of the main rotor blades. The pilot and passenger received fatal injuries. The Swiss Aircraft Accident Investigation Bureau (AAIB) has requested the assistance of the Safety Board and the FAA in the continuing investigation. The cause of the main rotor divergence that led to the contact with the tailboom has not been determined.

On September 28, 1994, about 0947 local time, a Robinson R22 helicopter, registered in the United States as N83112, crashed near Knightdale, North Carolina, after an in-flight separation of the tailboom. The pilot was operating the helicopter for business purposes. The pilot had accumulated 790 total flight hours, with 373 of those hours in helicopters and 305 in the R22. A witness observed the helicopter about 200 feet above the ground when it appeared to fishtail and began to lose parts. He additionally said he heard a sputtering sound, which has not been identified. Radar data indicated that the helicopter was maneuvering at a moderate speed before the accident. The pilot was fatally injured, and the helicopter was destroyed.

Following the on-site investigation, pieces from the main rotor blades, transmission, tailboom, and main rotor head were sent to the Safety Board's materials laboratory for examination; however, no evidence was found to indicate a precipitating mechanical or material failure of any helicopter system. The engine did not exhibit any evidence that would indicate a loss of power before the tailboom separation and loss of control. The investigation is continuing and no determination has been made as to the cause of the accident.

In the four recent R44 and R22 accidents described above, the in-flight breakups are believed to have occurred while the helicopters were being operated at speeds well within the aircraft's defined operating envelope. In these cases, the pilots-in-command were experienced, and the investigations indicate that they had been adequately trained in the R44 and R22. The pilots assumed to be manipulating the flight controls of the R44s had low R44 experience; however, the investigations found no evidence that the pilots were improperly operating the helicopters. In addition to these accidents, the Safety Board is investigating other Robinson helicopter accidents involving over 20 in-flight breakups of the R22 helicopter. In all of these accidents, the breakups occurred when the main rotor blades diverged from their normal plane of rotation and struck the airframe in flight. The known circumstances of the above R44 accidents are very similar to the R22 accidents that have concerned the Safety Board since 1982.[3]

On September 30, 1982, a Robinson R22 was involved in an in-flight breakup accident near Paige, Texas, The investigation determined that the tailboom of the helicopter was struck in flight after the pilot maneuvered near power lines, possibly in an evasive maneuver.

---

[3]For more information refer to the Safety Board's safety recommendation letters to the FAA dated October 27, 1982, and July 21, 1994.

Following this accident, the Safety Board issued Safety Recommendations A-82-143 and -144 to the FAA on October 27, 1982, which stated:

> Suspend the Airworthiness Certificate of the Robinson R22 model helicopter until (1) The main rotor system stability/stall characteristics and the main rotor rpm [revolutions per minute] decay rates are determined to provide adequate margins of safety and to be compatible with normal pilot reaction times, and (2) the R22 main rotor system is determined to be in compliance with 14 CFR [Code of Federal Regulations] 27.661.[4] (A-82-143)
>
> Conduct a study to verify that adequate engine torque is available to the Robinson R22 model helicopter main rotor system to recover rpm should a rapid decay of rpm occur during flight. (A-82-144)

On December 29, 1982, the FAA responded that it had completed a supplementary flight test program and a critical design review of the R22 main rotor system in conjunction with the Robinson Helicopter Company. The results reportedly indicated that the main rotor system complied with 14 CFR Part 27 and that no unusual flight characteristics existed when the R22 helicopter was operated within its Flight Manual Limitations. The FAA also stated that the rpm decay rates and helicopter recovery characteristics were evaluated during supplementary flight tests. The tests indicated that adequate engine power is available to recover rpm should a rapid decay occur. In addition, the FAA issued a telegraphic airworthiness directive (AD) T82-23-51 on October 29, 1982, which required that the low rotor warning indication be increased from 91% +1% to 95%+1% rpm. The AD required installation of a low rotor speed warning light adjacent to the rpm indicator.

The FAA also prepared an operations bulletin to emphasize R22 flight instructor responsibilities in student training. Also, additional analytical and simulation studies considered relevant to the evaluation of the R22 rotor system were conducted by the National Aeronautics and Space Administration (NASA) Ames facility, at the FAA's request. The NASA studies reportedly did not disclose any adverse or divergent characteristics associated with the lightweight, low inertia rotor system of the R22. There was no NASA report of the study. On April 7, 1983, the Safety Board classified Safety Recommendations A-82-143 and -144 "Closed--Acceptable Action" and "Closed--Acceptable Alternate Action" respectively.

The Safety Board is aware of 339 R22 accidents that have occurred in the United States. According to the FAA, there are 855 currently registered R22s in the United States.[5] The Safety

---

[4] 14 CFR Part 27.661 provides for the minimum acceptable standards for certification of helicopters by speci fying the minimum clearance between the main rotor blades and the structure of the helicopter during any operation.

[5] According to the FAA there are three currently registered R44 helicopters in the United States. There are approximately 142 R44s operating worldwide.

Board has found that R22 mechanical reliability problems have not contributed significantly to the accident rate compared to other light utility helicopters, but the R22 has had an unusually high number of accidents attributed to pilot performance or undetermined causes (including in-flight rotor instability and breakup accidents) compared to other helicopters. The R22 is the smallest helicopter of those compared. Its small size and relatively low operating cost result in its use as a training and light utility aircraft and operation by a significant population of relatively inexperienced helicopter pilots.

The R44 main rotor system has design features that are very similar to the R22. The two-bladed, semi-rigid R44 and R22 main rotor systems include rotor blades that are connected to the main rotor hub through coning (flapping) hinges.[6] The main rotor hub is connected to the main rotor shaft (mast) through an additional hinge so that the hub teeters with influence from main rotor blade movement. In other two-bladed, semi-rigid systems, the advancing blade flaps up, causing the retreating blade to flap down; however, each R44 and R22 main rotor blade flaps independently of the other blade's vertical movement. The flapping blade causes a change in the main rotor hub (teeter), which causes an appropriate change in the opposite blade. In each of the R44 and R22 in-flight breakup accidents described above, the evidence relative to the sequence of breakup was similar to that found by the Safety Board in other R22 accident investigations.

The main rotor rpm of both the R44 and the R22 is much higher, and the rotor inertia is very low by comparison to other light utility two-bladed main rotor systems manufactured in the United States. Such systems are affected to a much greater extent by abrupt control inputs, external perturbations, and other factors causing rpm to droop. The Safety Board believes that changes in rpm occur at a significantly higher rate in the R44 and R22 than in other helicopter rotor systems.

The Robinson Helicopter Company has theorized that low main rotor rpm is contributing to the stall and divergence of the main rotor blades in some of the R22 in-flight breakup accidents in the United States, including those involving experienced instructor pilots. However, none of the participants in the Safety Board's investigations have adequately defined a sequence of events leading to a critically low rotor rpm (and follow-on instabilities of the main rotor system) or the factors that prevented experienced pilots from being able to apply corrective action to recover when main rotor rpm is lost.

The Safety Board is concerned that in the above accidents and in other accidents investigated by the Safety Board, 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 R22 and R44 rpm indicator and the low rpm warning light are smaller and less conspicuous, unlike those found in many other helicopters, and may not provide pilots adequate cues when immediate response is necessary.

---

[6] Coning is the upward bending of the blades caused by the resultant forces of lift and centrifugal force. Flapping is the vertical movement of the blade as a result of aerodynamic forces.

The Safety Board has found that in at least one relevant accident, sound spectrum analysis of background rotor noise on a tape recording of the flight showed that loss of main rotor occurred in the normal main rotor rpm operating range and within the normal operating envelope of the R22.[7] Other aerodynamic characteristics (Mach tuck, drag divergence, dynamic pitch moment changes, and negative blade damping) could also have devastating effects on a low-inertia, high rpm rotor system. Data from FAA certification test reports and Robinson Helicopter engineering reports indicate that no math modeling, computer simulation, or wind tunnel testing was conducted before, during, or after the R22 helicopter was issued its certificate of airworthiness by the FAA. The required flight tests were accomplished in prototype helicopters, but rotor systems were not tested in anomalous conditions such as to-failure or in areas beyond the prescribed normal flight envelope. The data from the flight tests do not indicate whether external disturbances to the rotor system such as turbulence, wind gusts, or other phenomena that could upset a low inertia rotor system were conducted. According to the FAA, the R44 flight test program was conducted similarly to the R22 flight test program. Therefore, the Safety Board is concerned that adequate testing may not have been accomplished during certification to resolve possible adverse aerodynamic characteristics of the rotor and flight control systems of both the R22 and the R44.

Because of its concerns regarding the R22 main rotor system, on July 21, 1994, the Safety Board made two urgent recommendations and one priority recommendation to the FAA:

> Issue an immediate airworthiness directive to reduce the Robinson R22 helicopter "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. (A-94-143)

> In conjunction with the National Aeronautics and Space Administration and Robinson Helicopter Company, conduct wind tunnel and modeling tests to examine flight parameters of the R22 helicopter to determine the helicopter's design characteristics that are related to main rotor divergent behavior; and if any abnormal rotor system performance characteristics are found, take the necessary actions to assure proper dissemination of the information and to modify the R22 design. (A-94-144)

> Examine the appropriateness of the Designated Engineering Representative (DER) assignment at the Robinson Helicopter Company and at other small manufacturers where senior executives are assigned DER responsibilities, and take necessary actions to eliminate any conflict of interest with DER responsibilities. (A-94-145)

---

[7] For more detailed information, see Brief of Accident File #1003 (attached).

The FAA responded to the recommendations on October 7, 1994, stating that it had convened a panel to research the R22 in-flight breakup accidents, to recommend a course of action for the FAA to follow concerning testing, and to evaluate the causes of the breakups. The FAA also resolved to change the DER at the Robinson factory when conditions were appropriate. However, the FAA slected not to restrict R22 flight operations pending completion of the work of the special research panel. On December 13, 1994, the Safety Board classified the first two recommendations "Open--Unacceptable Response" and the third recommendation, "Open--Acceptable Response. " The Safety Board stated that it was disappointed that the FAA did not respond to the urgency of the recommendations, which were intended to prompt appropriate interim action to reduce the potential for continuing loss of main rotor control accidents while the cause(s) of main rotor instability were further researched.

The Safety Board is aware that the R44 complies with the FAA's certification requirements and that, following the July 31, 1993, accident, a certification review related to the unique cyclic control system was conducted and evidence of noncompliance with certification standards or of a deficiency that would explain accidents such as those discussed above was not uncovered. However, because of the catastrophic nature of the continuing accidents and the evidence of possible main rotor involvement, the Safety Board believes that the FAA should, in conjunction with the National Aeronautics and Space Administration (NASA) and Robinson Helicopter Company, conduct further testing to evaluate the R44 main rotor **and** control system. The testing should include flight testing as well as wind tunnel and computer modeling to evaluate the main rotor design, including rotor stability, control responsiveness, main rotor performance in cruise flight, and other possible areas in which main rotor divergence or instabilities may have occurred on accident flights. The Safety Board is specifically concerned that the unique design of the R22 and R44 rotor system may result in flight characteristics that are not adequately addressed by 14 CFR Part 27 certification standards; In addition, the Safety Board is concerned that the R44 main rotor control system, which includes the teetering cyclic control[8] in the cockpit, may have undesirable dynamic characteristics that are not adequately addressed in the flight and ground testing under 14 CFR Part 27 standards. Of special concern to the Safety Board, are the effects that turbulence may have on the main rotor control system and ergonomic factors relative to the interaction between the pilots through the unique teetering cyclic control systems in R44 and R22 helicopters. Anomalies in the main rotor system or cyclic control in the cockpit may have gone undetected during the original certification process.

Because the recent German R44 accidents occurred abruptly and with no apparent warning to the flightcrew, they are of particular concern to the Safety Board. Those accidents and the other similar R22 in-flight breakup accidents examined by the Safety Board indicate that undesirable aerodynamic characteristics of R44 and R22 main rotor blades can result in one or both blades diverging from their normal plane of rotation during normal operation in the approved flight envelope. The Safety Board is concerned that the stability of the R44 and R22 main rotor blades may be compromised by an inherent rotor system design deficiency that may

---

[8]The Robinson R44, like the R22, has a cyclic flight control that teeters to allow a dual control system for two pilots.

allow loss of control of the rotor system when operating the helicopter within the currently defined flight envelope and in a manner that would seem normal in other light helicopters. The Safety Board is aware of the importance of the R44 and R22 as training and light utility helicopters. However, until the causes of the accidents cited above are determined, and appropriate flight envelope restrictions and operating limitations are defined, the FAA should prohibit further flight.

The Safety Board has paid particular attention to the R22 main rotor blades and the rotor head during an ongoing special investigation because the in-flight breakup accidents under investigation were found to be more likely caused by blade divergence that initiated failures at the main rotor, rather than initiating failures in the transmission, its mounts, or the main rotor control system. As a result of its scrutiny of the main rotor, the Safety Board requested Material Review Records (MRRs) for the main rotor blades involved in those accidents. The Safety Board's review of several MRRs of rotor blades not involved in an accident caused the Board to become concerned with the disposition and subsequent approval of blades containing defects or not passing quality assurance testing. The Safety Board is concerned about the reported use of main rotor blades on new R22 or R44 helicopters when those blades did not pass design inspection requirements. The proper design, manufacture, testing, and approval of main rotor blades are crucial to the airworthiness of a helicopter. Main rotor blades should be carefully examined for defects, and any blade not meeting the original design inspection requirements should be rejected unless modification of the design inspection requirements are specifically approved by the FAA. The Safety Board believes that additional FAA oversight of the R44 and R22 main rotor blade manufacturing quality assurance program is necessary to ensure that these blades are properly inspected and approved; and if inadequacies in the approval process are found, the FAA should modify and correct the approval process as necessary.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Prohibit further flight of the Robinson Helicopter Company R44 helicopter until (1) adequate research and testing are accomplished to determine the cause of in-flight main rotor blade divergent behavior, and (2) modifications are made to the helicopter or appropriate limitations are placed in the flight manual to preclude divergent main rotor behavior and in-flight breakup accidents where pilots are unable to prevent loss of main rotor control in the approved operating envelope. (Class 1, Urgent Action)(A-95-1)

> Prohibit further flight of the Robinson Helicopter Company R22 helicopter until (1) adequate research and testing are accomplished to determine the cause of in-flight main rotor blade divergent behavior, and (2) modifications are made to the helicopter or appropriate limitations are placed in the flight manual to preclude divergent main rotor behavior and in-flight breakup accidents where pilots are unable to prevent loss of main rotor control in the approved operating envelope. (Class I, Urgent Action) (A-95-2)

Conduct flight, ground, simulation,and modeling tests to determine the responsiveness of the Robinson Helicopter Company R44 and R22 rotor systems in all flight conditions to ensure that any qualified pilot, including students approved for solo flight and low experienced but rated helicopter pilots, may be expected to receive adequate warning of rotor system anomalous conditions and be capable of recovering from rotor system revolutions per minute decay or rotor system divergence safely when warned of anomalous conditions. (Class I, Urgent Action)(A-95-3)

Determine if the Robinson Helicopter Company rotor system low revolutions per minute (rpm) warning and indication systems in the R22 and R44 helicopters adequately alert the pilot in time to initiate prompt control inputs to correct a low rotor rpm condition, and require modifications to those systems if deficiencies are found. (Class II, Priority Action) (A-95-4)

Examine the appropriateness of the teetering cyclic flight control used in the Robinson R22 and R44 helicopters and make any design and modification changes to the cyclic and collective control systems as necessary to ensure that pilots-in-command and flight instructors can respond in time to prevent loss of control of the main rotor following in-flight main rotor anomalies initiated by low main rotor revolutions per minute or turbulence encounters in flight. (Class H, Priority Action) (A-95-5)

Conduct special studies and reviews of the Robinson R44 certification similar to that being conducted now for the R22, to determine that the ‘flight control and main rotor system may be safely operated in all modes of flight and throughout the approved flight envelope by all pilots qualified to operate the helicopter. (Class II, Priority Action) (A-95-6)

Conduct Robinson R44 main rotor blade design and manufacturing process reviews and testing to determine if there are any main rotor blade construction deficiencies, either in design or in the manufacturing process, that may be contributing to main rotor divergence incidents or accidents, and modify the design and structure of the blade as necessary. (Class II, Priority Action) (A-95-7)

Conduct special reviews of the Robinson R44 and R22 main rotor blade inspection criteria and practices to determine if blades not meeting quality assurance inspections are inappropriately being approved by company personnel, and if inadequacies in the approval processes are found, modify and correct the approval process as necessary. (Class II, Priority Action) (A-95-8)

Chairman HALL, and Members HAMMERSCHMIDT and FRANCIS concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

File No. - 1003 6/29/92 RICHMOND,CA A/C Reg. No. N83858 Time (Lcl) - 1242 PDT

--Basic Information----

Type Operating Certificate-NONE (GENERAL AVIATION)
Type of Operation -INSTRUCTIONAL
Flight Conducted Under -14 CFR 91
Accident Occurred During -CRUISE

Aircraft Damage
DESTROYED
Fire
NONE

Injuries	Fatal	Serious	Minor	None
Crew	2	0	0	0
Pass	0	0	0	0

--Aircraft Information----

Make/Model - ROBINSON R22
Landing Gear - SKID
Max Gross Wt - 1370
No. of Seats - 2

Eng Make/Model - LYCOMING O-320-B2C
Number Engines - 1
Engine Type - RECIPROCATING-CARBURETOR
Rated Power - 160 HP

ELT Installed/Activated - NO -N/A
Stall Warning System - NO

---Environment/Operations Information----

Weather Data
Wx Briefing - NO RECORD OF BRIEFING
Method - N/A
Completeness - N/A
Basic Weather - VMC
Wind Dir/Speed- 180/011 KTS
Visibility - 15.0 SM
Lowest Sky/Clouds - 1800 FT SCATTERED
Lowest Ceiling - 12000 FT BROKEN
Obstructions to Vision- NONE
Precipitation - RAIN
Condition of Light - DAYLIGHT

Itinerary
Last Departure Point
OAKLAND,CA
Destination
LOCAL

ATC/Airspace
Type of Flight Plan - NONE
Type of Clearance - NONE
Type Apch/Lndg - NONE

Airport Proximity
OFF AIRPORT/STRIP

Airport Data
Runway Ident - N/A
Runway Lth/Wid - N/A
Runway Surface - N/A
Runway Status - N/A

--Personnel Information----

Pilot-In-Command
Certificate(s)/Rating(s)
COMMERCIAL,CFI
SE LAND
HELICOPTER

Instrument Rating(s) - NONE

Age - 36
Biennial Flight Review
Current - YES
Months Since - UNK/NR
Aircraft Type - R22

Medical Certificate - VALID MEDICAL-WAIVERS/LIMIT

Flight Time (Hours)
Total - 2200
Make/Model- 2000
Instrument- UNK/NR
Multi-Eng - UNK/NR
Last 24 Hrs - 0
Last 30 Days- 14
Last 90 Days- 70
Rotorcraft - 2000

----Narrative----

THE STUDENT HAD RECORDED HER PRIMARY FLIGHT LESSON ON A TAPE RECORDER. AFTER REACHING THE PRACTICE AREA, THE CFI INSTRUCTED THE STUDENT TO TURN 180 DEG LEFT. THE STUDENT COMPLIED AND PERFORMED A SHALLOW BANK TURN. SECONDS LATER, WHILE CRUISING AT 2,200 FT, THE CFI BEGAN TALKING. IN MIDSENTENCE AN UNDETERMINED EVENT OCCURRED WHICH INTERRUPTED HIS SPEECH. A WIND-LIKE BACKGROUND NOISE STARTED, AND THE STUDENT EXCLAIMED "HELP." RADAR DATA CONFIRMED WITNESS REPORTS THAT THE TAIL BOOM AND M/R HAD SEPARATED IN LEVEL FLT. EXAM OF THE WRECKAGE INDICATED MAST BUMPING HAD OCCURRED, A M/R BLADE CRUSHED THE LEFT SIDE OF THE INBOARD TAIL CONE, AND THE ENTIRE MAST WITH ATTACHED M/R BLADES BROKE OUT OF THE TOP OF THE TRANSMISSION. THE OUTBOARD TAIL BOOM AND ROTOR ASSEMBLY HAVE NOT BEEN FOUND. EVIDENCE OF A MAIN ROTOR BLADE DIVERGENCE WAS FOUND. SPECTRUM ANALYSIS OF THE TAPE REVEALED NO ANOMALIES UNTIL THE CFI'S VOICE WAS TERMINATED. WITHIN [illegible] SECONDS THE ROTOR SPEED APPEARED TO SIGNIFICANTLY OSCILLATE AND ABRUPTLY END.

Brief of Accident (Continued)

File No. - 1003 6/29/92 RICHMOND,CA A/C Reg. No. N83858 Time (Lcl) - 1242 PDT

urrence #1 AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
ise of Operation CRUISE

nding(s)
1. ROTOR SYSTEM - UNDETERMINED

urrence #2 IN FLIGHT COLLISION WITH TERRAIN/WATER
ase of Operation DESCENT - UNCONTROLLED

--Probable Cause----

e National Transportation Safety Board determines that the Probable Cause(s) of this accident was:
DIVERGENCE OF THE MAIN ROTOR FROM ITS NORMAL PLANE OF ROTATION FOR AN UNDETERMINED REASON(S) WHICH RESULTED IN ROTOR
NTACT TO THE TAILBOOM.

100

FEB 2 2 1996

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

Dear Mr. Hinson:

Thank you for the Federal Aviation Administrationts (FAA) responses of March 27, 1995, and November 20, 1995, to the National Transportation Safety Board's Safety Recommendations A-94-145, and A-95-1 through -8. The recommendations addressed issues raised during the Safety Board's investigation of a series of Robinson Helicopter Company (RHC) helicopter accidents in which the main rotors struck the helicopter airframe in flight.

Safety Recommendation A-94-145 asked the FAA to examine the appropriateness of the Designated Engineering Representative (DER) assignment at the RHC and at other small manufacturers where senior executives are assigned DER responsibilities, and take necessary actions to eliminate any conflict of interest with DER responsibilities.

The Safety Board notes that the FAA examined the appropriateness of the DER assignment at the RHC and at other small manufacturers. The FAA found that the DER approvals at Robinson were proper; however, the President of the RHC no longer serves as a DER. Also, although the FAA found no conflict of interest when it evaluated 30 senior executives who hold DER positions elsewhere, the FAA will issue guidance to transition these DERs out of the program or to provide for increased oversight of their performance as DERs. The Safety Board finds the FAA action to be fully responsive to the intent of the recommendation and classifies Safety Recommendation A-94-145 'Closed--Acceptable Action."

Safety Recommendations A-95-1 and-2 asked the FAA to prohibit further flight of R44 and R22 helicopters until (1) adequate research and testing are accomplished to determine the cause of in-flight main rotor blade divergent behavior, and (2) modifications are made to the helicopter or appropriate limitations are placed in the flight manual to preclude divergent main rotor behavior and in-flight breakup accidents where pilots are unable to prevent loss of main rotor control in the approved operating envelope.

The Safety Board notes that while the FAA did not prohibit or promptly restrict further flight of the R22 or R44 in response to these recommendations, it did place limitations on operations in certain wind conditions, require enhanced pilot training, and establish operational limitations to prevent pilots from performing certain low-G in-flight maneuvers in the R22 and R44.

A technical panel created by the FAA in response to earlier Safety Board recommendations completed its research in March 1995 and recommended further research and design enhancements. Also, the FAA and the RHC conducted flight testing of the R44 in July 1995 to evaluate its performance in the approved flight envelope, and the FAA contracted with the Georgia Institute of Technology (Georgia Tech) to perform computer simulation modeling of the R22 main rotor. The Georgia Tech research was concluded with a report to the FAA in December 1995. In response to RHC initiatives and technical panel recommendations, the FAA issued a notice of proposed rulemaking in December 1995, which asked for comments on a proposal to require modification to R22s to include installation of a new rotor speed governor.

The actions taken by the FAA have been responsive to Safety Board concerns generated from the 34 known R22 and R44 loss of main rotor control accidents. Also, the RHC has introduced optional modifications to the R22 that, combined with pilot awareness and proficiency training, also reduce the potential for loss of main rotor control accidents. The positive actions undertaken to inform R22 and R44 pilots of how to avoid such accidents are commendable, and the Safety Board is pleased with the responsiveness and efforts of the FAA and RHC to address the issues raised by the Safety Board. Although the Board is disappointed that the FAA did not promptly restrict operations of these helicopters when the reasons for the accidents were totally unknown, it acknowledges the significant alternate steps taken by the FAA to resolve the safety issues associated with the accidents. Therefore, the Safety Board classifies Safety Recommendations A-95-1 and -2 "Closed--Acceptable Alternate Action."

Safety Recommendations A-95-3 through -8 asked the FAA to conduct flight, ground, simulation, and modeling tests to determine the responsiveness of the R44 and R22 rotor systems in all flight conditions; to consider the abilities of students and low experienced but rated helicopter pilots who might fly these helicopters; to determine if the RHC rotor system low revolutions per minute (rpm) warning and indication systems in the R22 and R44 helicopters adequately alert the pilot in time to correct a low rotor rpm condition; to examine the appropriateness of the teetering cyclic flight control used in the R22 and R44 helicopters; to conduct special studies and reviews of the R44 certification to determine if the flight control and main rotor system may be safely operated throughout the approved flight envelope; to conduct RHC R44 main rotor blade design and manufacturing process reviews and testing to determine if there are any main rotor blade construction deficiencies; and to conduct special reviews of the RHC main rotor blade inspection criteria and practices.

The FAA has conducted or sponsored research on many of the issues addressed by these recommendations, some of which is ongoing. A detailed assessment of the FAA response to Safety Recommendations A-95-3 through -8 will be included in the Safety Board's report on its special investigation of R-22 accidents involving the loss of main rotor control.

Sincerely,

ORIGINAL SIGNED BY
JIM HALL

Jim Hall
Chairman

cc: Dr. Donald R. Trilling, Director
Office of Environment, Energy and Safety

APR - 2 1996

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

Dear Mr. Hinson:

Thank you for the Federal Aviation Administration's (FAA) response of March 11, 1996, to the National Transportation Safety Board's Safety Recommendations A-94-143 through -145 and A-95-1 through -8. The recommendations addressed issues raised during the Safety Board's investigation of a series of Robinson Helicopter Company (RHC) helicopter accidents in which the main rotors struck the helicopter airframe in flight.

Safety Recommendations A-94-145, A-95-1, and A-95-2 were closed previously by the Safety Board in a letter dated February 22, 1996. Safety Recommendation A-94-145 was classified "Closed--Acceptable Action" and Safety Recommendations A-95-1 and -2 were classified "Closed--Acceptable Alternate Action."

Safety Recommendation A-94-143 asked the FAA to issue an immediate airworthiness directive (AD) to reduce the RHC R22 helicopter "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 FAA has issued ADs that imposed airspeed and operational restrictions on the R22 in high wind and turbulent conditions and an AD prohibiting intentional low-G maneuvers in R22 helicopters. The FAA had previously issued art airworthiness alert warning pilots to avoid operation of the R22 in high speed cruise flight. The Safety Board believes that these specific changes are in line with the intent of this recommendation and therefore classifies Safety Recommendation A-94-143 "Closed--Acceptable Action."

Safety Recommendation A-94-144 asked the FAA, in conjunction with the National Aeronautics and Space Administration and RHC, to conduct wind tunnel and modeling tests to examine flight parameters of the R22 helicopter to determine the helicopter's design characteristics that are related to main rotor divergent behavior; and if arty abnormal rotor system performance characteristics are found, take the necessary actions to assure proper dissemination of the information and to modify the R22 design.

Safety Recommendation A-95-3 asked the FAA to conduct flight, ground, simulation, and modeling tests to determine the responsiveness of the RHC R44 and R22 rotor systems in all flight conditions to ensure that any qualified pilot, including students approved for solo flight and low experienced but rated helicopter pilots, may be expected to receive adequate warning of rotor system anomalous conditions and be capable of recovering from rotor system rpm decay or rotor system divergence safely when warned of anomalous conditions.

The FAA commissioned the Georgia Institute of Technology (Georgia Tech) to conduct a simulation study of the R22 helicopter and provided the results of the study to the Safety Board staff in March 1996. The Board is aware that the research was concluded before the mathematical model was thoroughly validated by comparison to flight test data. However, the Safety Board's review of the data produced by the simulation revealed main rotor-to-static stop contact in several of the simulations. The Safety Board also recognizes the complexity and potential hazards associated with flight tests and full-scale wind tunnel testing. Nevertheless, the Safety Board believes that the information obtained from further development of the simulation of lightweight, low rotor inertia helicopters could be extremely valuable to the FAA and to manufacturers seeking certification of similar designs in the future. Therefore, the Safety Board has issued a new recommendation on this subject in its final report of its special investigation of R22 helicopter accidents, and Safety Recommendations A-94-144 and A-95-3 are classified "Closed--Acceptable Action/Superseded."

Safety Recommendation A-95-4 asked the FAA to determine if the RHC rotor system low rpm warning and indication systems in the R22 and R44 helicopters adequately alert the pilot in time to initiate prompt control inputs to correct a low rotor rpm condition, and require modifications to those systems if deficiencies are found.

The FAA has conducted tests of the low rpm warning systems of the R22 and R44 and has required changes to these systems. The Safety Board is also aware that a new R22 rotor speed governor has been introduced by the RHC, and that the FAA plans to issue an AD to mandate its use. The proposed AD would increase the low rotor warning rpm threshold and mandate the use of the governor except under certain situations. The FAA determined that the volume of the R22 low rotor rpm warning horn was adequate. The Safety Board believes that the FAA has met the intent of this recommendation and therefore classifies Safety Recommendation A-95-4 "Closed--Acceptable Action."

Safety Recommendation A-95-5 asked the FAA to examine the appropriateness of the teetering cyclic flight control used in the RHC R22 and R44 helicopters and make any design and modification changes to the cyclic and collective control systems as necessary to ensure that pilots-in-command and flight instructors can respond in time to prevent loss of control of the main rotor following in-flight main rotor anomalies initiated by low main rotor rpm or turbulence encounters in flight.

The FAA has participated in two human factors evaluations of the R22 and R44 teetering cyclic controls to determine their adequacy for flight instruction. The FAA has also evaluated an alternative STC-approved cyclic control and reports that both cyclic control designs were found to be satisfactory. Based on this action, the Safety Board classifies Safety Recommendation A-95-5 "Closed--Acceptable Action."

Safety Recommendation A-95-6 asked the FAA to conduct special studies and reviews of the RHC R44 certification similar to what was being conducted for the R22, to determine that the flight control and main rotor system may be safely operated in all modes of flight and throughout the approved flight envelope by all pilots qualified to operate the helicopter.

The FAA has accomplished flight tests of the R44 to assess rotor stability and control within the approved flight envelope and believes that its flight testing of the R44 has demonstrated that the R44 meets the requirements of 14 CFR Part 27. Because the FAA has met the intent of this recommendation, the Safety Board classifies Safety Recommendation A-95-6 "Closed--Acceptable Action."

Safety Recommendation A-95-7 asked the FAA to conduct RHC R44 main rotor blade design and manufacturing process reviews and testing to determine if there are any main rotor blade construction deficiencies, either in design or in the manufacturing process, that may be contributing to main rotor divergence incidents or accidents, and modify the design and structure of the blade as necessary.

The FAA's review of the R44 main rotor blade design, manufacturing process, and quality assurance system found no deficiencies or non-conformities. The Safety Board has received a copy of the FAA's main rotor blade design and manufacturing process review. Based on the FAA's action, the Safety Board classifies Safety Recommendation A-95-7 "Closed--Acceptable Action."

Safety Recommendation A-95-8 asked the FAA to conduct special reviews of the RHC R44 and R22 main rotor blade inspection criteria and practices to determine if blades not meeting quality assurance inspections are inappropriately being approved by company personnel, and if inadequacies in the approval processes are found, modify and correct the approval process as necessary.

The FAA conducted a review of the Material Review Board processes and Material Review Records on March 2, 1995, and found no discrepancies. The review concluded that there were no inappropriate approvals by RHC personnel or inadequacies in the approval process. The

Safety Board believes that the FAA has met the intent of this recommendation and therefore classifies Safety Recommendation A-95-8 “Closed--Acceptable Action. ”

Sincerely,

ORIGINAL SIGNED BY
JIM HALL

Jim Hall
Chairman

cc: Dr. Donald R. Trilling, Director
Office of Environment, Energy and Safety