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U.S. Civil Rotorcraft Accidents, 1963 Through 1997

Franklin D. Harris, Eugene F. Kasper, and Laura E. Iseler

December 2000

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U.S. Civil Rotorcraft Accidents, 1963 Through 1997

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U.S. Civil Rotorcraft Accidents, 1963 Through 1997

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SUMMARY

The narrative summary data produced by the U.S. National Transportation Safety Board (NTSB) were obtained and analyzed for all 8,436 rotorcraft accidents that occurred from mid-1963 through 1997. This analysis was based on the NTSB's assignment of each accident into one of 21 "first event" categories. The number of U.S. civil registered rotorcraft as recorded by the Federal Aviation Administration (FAA) for the same period were obtained as well. Taken together, these data indicate the civil rotorcraft accident rate (on a per 1,000 registered rotorcraft basis) decreased by almost a factor of 10 over the 34-year study period (i.e., from 118 accidents per 1,000 rotorcraft in 1964 to 13.6 per 1,000 in 1997).

Analysis of the accident data indicated that the first event in over 70% of the 8,436 rotorcraft accidents fell into four categories:

2,408 loss of engine power (28.5%)
1,322 in flight collision with objects (15.7%)
1,114 loss of control (13.2%)
1,083 airframe/component/system failure or malfunction (12.8%).

Because the vast majority of rotorcraft registered over the study period had a single engine (piston or turbine), these aircraft dominated the accident statistics. Over 985 loss of engine power accidents were caused by improper fuel/air mixture. Fuel exhaustion was a major, common event in both piston and turbine helicopter accidents. In-flight collisions with wires and poles accounted for over 700 accidents. Pilots of the commercial fleet lost control of their helicopters regardless of their certified skill level. Airframe related failures left the commercial helicopter pilot without antitorque and directional control in 470 accidents. Without significantly increased safety efforts in the immediate future, the authors project that in the year 2010 there will be about 6 accidents per 1,000 registered rotorcraft. If the fleet doubles in size by 2010, then this accident rate corresponds to 150 accidents per year—about 3 accidents per week.

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1. EXECUTIVE OVERVIEW

The U.S. civil rotorcraft fleet grew from fewer than 10 in 1946 to 2,196 at the end of 1964 and to 12,911 at the end of December 1997. Throughout this period, the commercially manufactured, single-engine helicopter dominated the registered fleet. Although the single-piston engine configuration still sold in quantity, the rotorcraft industry introduced the single-turbine engine configuration in the mid-1960s. In 1997, nearly equal numbers of single-piston and single-turbine helicopters were registered (about 5,000 each). The commercially manufactured, twin-turbine helicopter began selling in quantity in the late 1970s—slightly over 1,200 were registered at the end of 1997. A growing fleet of registered amateur-built rotorcraft included close to 1,000 helicopters and 2,000 autogyros in 1997.

During the 34-year period from mid-1963 through the end of 1997, the National Transportation Safety Board (NTSB) recorded a total of 8,436 rotorcraft accidents. However, because of continuing emphasis on safety, the rotorcraft industry was able to reduce accidents per year, even though the registered fleet grew in size. Specifically, annual U.S. civil rotorcraft accidents decreased from 260 in 1964 to 175 in 1997. In broad terms then, the industry succeeded in reducing annual accidents per 1,000 registered rotorcraft by nearly a factor of 10 over the 34-year period (i.e., from 118 accidents per 1,000 registered rotorcraft in 1964 to 13.6 per 1,000 in 1997). Nevertheless, accidents over this 34-year period took a heavy toll. The 8,436 accidents directly affected 16,825 people: 2,135 were killed and 1,760 were seriously injured, but 12,930 survived with minor or no injury. Rotorcraft damage during this period was significant. Of the 8,436 rotorcraft involved, 2,363 (i.e., nearly 20% of today's registered fleet) were listed as destroyed by the NTSB. Another 5,909 rotorcraft were substantially damaged; 164 received little or no damage.

Analysis of each accident (table 1) showed that accident similarities far outnumbered dissimilarities, despite obvious differences in the helicopter classes. The major observations are as follows:

1. Single-engine, commercially manufactured helicopters, whether piston- or turbine-powered, experienced the most accidents because of a partial or total loss of engine power. The primary reason for loss of engine power was directly traced by the NTSB to fuel/air mixture problems, which accounted for no less than 985 accidents. Fuel exhaustion, fuel starvation, fuel contamination, and, for the piston engine, carburetor heat were key words repeatedly used by the NTSB accident investigators. Apparently, many pilots disregarded the need by both engine types for clean fuel and air in proper proportions—to say nothing about the FAA regulations for fuel reserves. Engine structural failure accounted for 452 accidents. The power-loss cause was not established in 578 single-engine helicopter accidents. Power-off landing proficiency is not required by the FAA in order to obtain a helicopter pilot's certification. This standard appears inconsistent with the number of accidents caused by loss of engine power. However, it also appears that helicopters—currently in the civil fleet—provide marginal to inadequate autorotational capability for the average pilot to successfully complete the final flare and touchdown to a generally unsuitable landing site.

TABLE 1. SUMMARY ACCIDENT COUNT AND DISTRIBUTION, 1963–1997

	Commercially manufactured			
	Single piston	Single turbine	Twin turbine	Amateur types
NTSB first event accident category	**Count (%)**	**Count (%)**	**Count (%)**	**Count (%)**
Loss of engine power	1,554 (28.9)	704 (31.3)	39 (12.9)	111 (21.5)
In flight collision with object	953 (17.7)	298 (13.2)	43 (14.2)	28 (5.43)
Loss of control	625 (11.6)	284 (12.6)	40 (13.2)	165 (32.0)
Airframe/component/system failure/ malfunction	639 (11.9)	282 (12.5)	89 (29.5)	73 (14.1)
Hard landing	483 (8.99)	140 (6.23)	8 (2.65)	25 (4.89)
In flight collision with terrain/water	443 (8.25)	143 (6.36)	16 (5.23)	40 (7.75)
Rollover/nose over	290 (5.40)	119 (5.29)	4 (1.32)	20 (3.88)
Weather	57 (1.06)	85 (3.78)	12 (3.97)	5 (0.97)
Other	327 (6.09)	192 (8.54)	51 (16.9)	49 (9.49)
Total	**5,371**	**2,247**	**302**	**516**

2. Twin-turbine helicopters significantly reduced loss of engine power accidents (on a percentage basis). However, 23 of the 39 accidents began with a total loss of power in both engines. Most discouragingly, 17 of the 39 accidents were caused by fuel/air mixture problems, a finding similar to that for single-engine helicopter accidents.

3. Introducing twin-turbine helicopters reduced loss of engine power accidents, but a very disturbing trend began with the larger helicopters capable of carrying more people. In the single-piston helicopter fleet, there were 5,371 accidents, and 683 people were killed. Because of the 2,247 accidents involving single-turbine helicopters, 951 people died. Now, in just 302 twin-turbine helicopter accidents, there were 321 fatalities.

4. The commercially manufactured helicopter fleet collectively had 1,294 accidents because of in-flight collisions with objects. Collisions with wires and poles accounted for 720 accidents. Collisions with trees added another 205 accidents. The major contributor to these in flight collisions was the single-piston helicopter fleet, most frequently during crop dusting. This helicopter type had about equal numbers of main- and tail-rotor strikes. The single-turbine helicopter class, which does relatively little crop dusting, experienced four tail rotor strikes for every three main rotor strikes. Twin-turbine helicopters had more than twice as many tail rotor strikes than main-rotor strikes.

5. Pilots of commercially manufactured helicopters lost control regardless of their certified skill level, and this precipitated 12% of the commercial fleets' 7,920 accidents. Pilots of amateur built rotorcraft lost control nearly three times as often. The requirement to adequately control

antitorque in all flight phases appears as a root problem with the single main rotor helicopter configuration. Single-piston helicopters (and turbine-powered helicopters to a somewhat lesser extent) appear to be inordinately difficult to fly; particularly when the average pilot must devote some attention to any other task or is experiencing a real or imagined emergency. Cross-coupling between the vertical, power/RPM, and yaw axes is excessive. The handling qualities design standards applicable to the current helicopter fleet date back to the 1950s. Although generally tolerated, the resulting helicopter stability and control characteristics now appear quite unsatisfactory. Equipping some single-turbine and virtually all twin-turbine helicopters with an electro-hydraulic, automatic stability and control system improved the overall loss of control situation.

6. Airframe system, subsystem, and component failures or malfunctions were one of the leading causes of helicopter accidents over the 34-year study period. Pilots of commercially manufactured helicopters were left without antitorque and directional control in 470 accidents, virtually 50% of the 1,010 accidents NTSB charged to the airframe category. The tail rotor driveshaft, which includes the shaft couplings and bearings, failed in 122 accidents. Failure of the tail rotor control system led to 56 accidents, and blade/hub failures accounted for 186 accidents. The corresponding main rotor system dynamic components also failed or malfunctioned, which led to 404 additional accidents. Specifically, engine to main rotor gearbox failures caused 137 accidents, control system failures caused 103, and blade/hub failures caused 112. The commercial helicopter airframe failure rate strongly suggests that past design standards are inadequate relative to the many new and varied activities in which this aircraft class is engaged. Pilots did exceed design limits, required and timely maintenance was skipped, and less than thorough inspections were performed, but still the current fleet appears, broadly speaking, to be underdesigned in view of today's commercial usage.

7. The favorable, downward trend in rotorcraft accidents per year enumerated above was not linear. During a 15-year period, beginning in 1972 and ending in 1987, the industry experienced a rash of accidents that drove the annual rate to 327 accidents in 1980 before dropping to 196 accidents in 1987. We believe that the increased accidents per year during this period was initiated by the 10-year period during which commercial helicopter yearly sales increased by over 50%. The relatively abrupt increase of new helicopters in the U.S. civil fleet was accompanied by a jump in accidents caused by loss of engine power and failure of airframe systems and components.

8. Single-turbine helicopter accidents per year increased slightly over the last decade of the period studied. There were 62 accidents in 1987, 65 accidents in 1993 and 73 accidents in 1997, during which time the registered fleet increased only modestly in size. Most recently, new, single-turbine helicopters were being registered at a rate comparable to that of the 1970s. There is concern, therefore, that a rapid fleet expansion will prompt an increase in accidents just as it did two decades ago. We recommend that more intensive safety improvement efforts be quickly initiated by the industry.

9. The amateur-built helicopter and autogyro fleet experienced approximately the same accident distribution, based on percentage, as the commercially manufactured helicopter fleet. The primary exceptions were that loss of control was nearly three times as prevalent and loss of engine power occurred with two-thirds the frequency. Because the amateur fleet is growing so fast, we

believe that major manufacturers, operators, and trade associations must provide considerably more help to this segment of their industry to lower the risks being taken.

10. There is little doubt that single- or twin-turbine-engine-powered helicopters are safer than the single-piston-engine helicopter. How much safer can not, in our opinion, be quantified. The rotorcraft industry is being misguided by accident rate trends that use FAA data for active fleet size, hours flown, takeoffs made, etc. In fact, we believe it quite likely that the rotorcraft industry will miss significant safety trends if the currently used methods of computing accident rates remain as the measure of progress. Unquestionably, the true aviation goal is no fatalities or injuries, in which case safety rates become meaningless.

This report provides detailed analysis, specific conclusions, and challenging recommendations relative to each helicopter class. Section 9 provides a concise group of final remarks, conclusions, and detailed recommendations. Without significantly increased safety efforts in the immediate future, including implementing the submitted recommendations, it is projected that in the year 2010 there will be about 6 accidents per 1,000 registered rotorcraft. If the fleet doubles in size by 2010, then this accident rate corresponds to 150 accidents per year—about 3 accidents per week. It is doubtful that the public will perceive this projection as an indication that pilots and their rotorcraft are, in fact, becoming safer.

2. INTRODUCTION

The gathering, analyzing, and reporting of aviation accident data has played an important part in making air transportation safer. One of the earliest examples of this safety improvement activity took place in November 1921, at the Premier Congrés International de la Navigation Aérienne, held in Paris. During this conference, Albert Tete presented a review of the status of aerial transportation in France (ref. 1). Additionally, Mayo presented a paper entitled “Aviation and Insurance,” (ref. 2), in which he discussed the “causes of the many accidents which account for the high insurance rates.” Specifically, he stated:

> The frequent accidents to airplanes employed on air routes have been due to widely divergent causes. Probably 90% of them were due to carelessness and could have been avoided, had the necessary precautions been taken. The principal causes of accidents may be enumerated as follows:
>
> 1. Poor piloting;
> 2. Engine trouble;
> 3. Lack of system [organization of personnel];
> 4. Poorly adapted airplanes;
> 5. Poor airdromes;
> 6. Unfavorable meteorological conditions.

With only minor changes, Mayo’s paper could be presented at any “aerial transportation” safety conference today.

2.1 Early History

In the United States, following World War I, the National Advisory Committee on Aeronautics (NACA), by request of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, established a special commission “to prepare a basis for the classification and comparison of aircraft accidents, both civil and military.” In NACA Technical Report TR-308 (ref. 3), 13 classes of accidents, 4 classes of injuries, and 6 classes of damage to material were defined. Categories of immediate and underlying accident causes were established and an accident form was adopted (fig. 1). This approach was used to analyze 1,432 military and 1,400 civilian accidents that occurred before January 1929 (ref. 4). In June 1936, a further refinement to definitions and methods of analysis was established in NACA TR-576 (ref. 5). That report, entitled “Aircraft Accidents, Method of Analysis,” became the standard United States reference on the subject and formed the foundation for current NTSB aviation accident reporting.

There was an immediate payoff for the efforts of the NACA-led committee. Analysis of the data revealed major shortcomings in aircraft design and pilot training (e.g., deficiencies in aircraft stability and control and spin recognition and recovery) for which corrective actions were developed and implemented. It should be noted that solving these problems did not require computing accidents per flight hour or other ratios that are considered important measures of transportation safety today. The priority then, as now, was to put an end to accidents.

In October 1944, the U.S. Civil Aeronautics Administration (CAA), the predecessor to the Federal Aviation Administration (FAA), published the first "Statistical Handbook of Civil Aviation" (ref. 6). This first of many CAA handbooks pointed out that reported accident statistics were based on definitions and classifications established by NACA TR-576 (although the Statistical Handbook incorrectly referenced the NACA TR as "TR-567"). This document summarized aviation statistics dating back to 1926, including air carrier and private flying accident statistics compiled by the U.S. Civil Aeronautics Board (CAB), the predecessor to the NTSB. In the introduction, the CAA acknowledged that, "There are some gaps in the early statistics because fact-gathering machinery had not been fully organized and it also was extremely difficult to obtain reliable figures from an industry still inchoate." With respect to private flying, the CAA noted that, "Because of the dislocation caused by the War, statistics on the amount of private flying during the war years are incomplete." Despite these reservations, the 1944 CAA handbook provided early examples of detailed tables regarding such aircraft operating statistics as the number of hours flown, miles covered, and passengers carried. Many of the safety measures using these statistics are still used today.

2.2 Recent Developments

Today, the NTSB investigates civil aviation accidents and has amassed a database of coded, as well as narrative, information. Over 32,000 aviation accidents that have occurred since 1982 are summarized at the NTSB web site (www.ntsb.gov) and at the FAA Office of System Safety (http://nasdac.faa.gov./asp/asy_ntsb.asp). The FAA Statistics and Forecast Branch publishes a yearly "Census Of U.S. Civil Aircraft." The census provides details about the number and types of aircraft currently operating in the U.S. civil aviation fleet, along with other relevant data. Fleet-size data are obtained by extrapolating data from a survey questionnaire mailed to a sample of registered owners. The validity of this extrapolation has been questioned occasionally. Today, there are approximately 350,000 U.S. civil registered aircraft, which makes updating and correcting the census and registration records a daunting task. Nevertheless, by combining data from the FAA and NTSB, such statistics as accidents per 100,000 operating hours for each civil aircraft grouping are prepared and given wide distribution.

2.3 Present Study

The objective of this report is to present and analyze rotorcraft accident trends with the expectation that areas requiring improvement in rotorcraft design and operation will be identified, and that long- and short-term actions will be developed and implemented to reduce the number of accidents. In contrast to many studies (e.g., ref. 7) that provide snapshots of safety trends over short periods of time, this study covers a 34-year span from mid-1963 to the end of 1997. This includes the period of widespread use of matured single-piston-engine helicopters, as well as the introduction and maturation of single- and twin-turbine powered helicopters. This report also includes a review of accident trends within the growing amateur rotorcraft (i.e., autogyros and helicopters) fleet. We have chosen not to include extensive statistics on accidents per flight hour, preferring a more in-depth study of the accidents themselves.

The basic data gathered for this report were compiled from NTSB and FAA records. Although the CAA/FAA census separated rotorcraft fleet size from fixed wing aviation as early as 1951, CAB/NTSB accident reports for rotorcraft were only obtained from mid-1963 on.

Regarding the structure of this report, please note the following:

> There are 109 figures accompanying this report. A list of these figures begins on page 99 and figure 1 is placed on page 103. The page number for any subsequent figure is simply the figure number plus 102.
>
> Tables 1–45 appear at or near the points in the text at which they are cited. There are 31 supplemental tables enclosed in Appendix D. A supplemental table is identified by D- as a prefix.

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3. ACCIDENT CATEGORIZATION

The NTSB defines and categorizes the terms they use in investigating and reporting on accidents. The key definitions are set down in Part 830 of the Federal Aviation Regulations (FAR). The NTSB defines an *aircraft accident* as

> An occurrence incident to flight in which "as a result of the operation of an aircraft, any person (occupant or non-occupant) receives *fatal or serious injury* or any aircraft receives *substantial damage*."

Fatal, serious, and minor injuries are defined as follows:

> "A *fatal injury* is one that results in death within 30 days of the accident."
>
> "A *serious injury* is one that
>
> 1. Requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received,
> 2. Results in a fracture of any bone (except simple fractures of the fingers, toes, or nose),
> 3. Involves lacerations that cause severe hemorrhages, nerve, muscle, or tendon damage,
> 4. Involves injury to any internal organ; or
> 5. Involves second- or third-degree burns, or any burns affecting more than 5% of body surface."
>
> "A *minor injury* is one that does not qualify as fatal or serious."

Aircraft damage ranges from destroyed to minor; "*destroyed* means that an aircraft was demolished beyond economical repair, that is, substantially damaged to the extent that it would be impractical to rebuild it and return it to an airworthy condition."

The NTSB notes that this definition of destroyed "may not coincide with the definition of total loss for insurance purposes. Because of the variability of insurance limits carried and such additional factors as time on engines and propellers and aircraft condition before the accident, an aircraft may be totaled even though it is not considered destroyed for accident investigation purposes."

With respect to *substantial* damage, the FAR Part 830 states:

> 1. Except as provided below, substantial damage means damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected part.
> 2. Engine failure, damage limited to an engine, bent fairings or cowling, dented skin, small puncture holes in the skin or fabric, ground damage to rotor or propeller blades, damage to landing gear,

wheels, tires, flaps, engine accessories, brakes, or wing tips are not considered "substantial damage."

The NTSB carefully points out that "As with destroyed above, the definition of substantial for accident investigation purposes does not necessarily correlate with substantial in terms of financial loss. Contrary to popular misconception, there is no dollar value that defines substantial damage. Because of the high cost of many repairs, large sums may be spent to repair damage resulting from incidents that do not meet the FAR Part 830 definition of substantial damage." Finally, the NTSB states that "minor damage is damage that does not qualify as substantial, such as that under substantial damage above."

Today, the NTSB uses a number of other definitions, categories, and computer code numbers to provide a detailed accident report. A sample of this information from the NTSB manual is provided in appendix A.

In contrast to current NTSB investigation reports, the early NACA aircraft accident analysis form (fig. 1) categorized accidents in one of four groups: personal, material, miscellaneous, and undetermined. As time went on, the CAB or NTSB added detail so that today a "mini-brief" of each complete accident report is available which summarizes the sequence of events leading to the accident outcome. For purposes of this report, the accidents were categorized based on the first event in the sequence of events that led to the accident (i.e., the first physical event that adversely affected the rotorcraft or unusual occurrence the aircrew became aware of). The NTSB has established the following 21 categories (here presented in order of number of accidents across the entire rotorcraft fleet):

Loss of engine power
In-flight collision with object
Loss of control
Airframe/component/system failure/malfunction
Hard landing
In-flight collision with terrain/water
Rollover/nose over
Weather
Miscellaneous/other
Propeller/rotor contact to person
Stall/settling with power
Mid-air collision
On ground/water collision with object
Fire/explosion
Abrupt maneuver
Gear collapsed
Undershoot/overshoot
Dragged wing, rotor, pod, float, or tail/skid
Undetermined
On ground/water encounter with terrain/water
Missing aircraft.

It is clear from the names of these categories, and by review of accident narrative summaries, that there is significant overlap among them. This gives the accident investigator leeway for personal judgment at the cost of possible inconsistency in the assignment of accidents to specific categories. We noted that different accidents with very similar narratives were assigned to different categories. Examples include some engine failures being categorized as airframe failures, some in-flight collisions with terrain being counted as dragged rotors, and other similar cases. It should be noted, however, that the analysis in this report is based only on the accident narratives provided by the NTSB and not on the full accident report when it exists.

The amount and character of information contained in the NTSB mini-briefs changed substantially over the period covered by this report. Four distinct mini-brief forms were used from 1963 to 1971, 1972 to 1981, 1982, and 1983 to 1997. Despite the format differences, the basic data given in table 2 were generally available for each accident studied by the authors.

TABLE 2. DATA ELEMENTS IN NTSB MINI-BRIEFS, 1963–1997

Data element
FAA report reference number
Date and local time of accident
Location of accident
Aircraft make, model, and FAA registration number
Fatalities, serious injuries, minor/no injuries (CX-crew, PX-passengers, OT-others)
Mission type
Pilot-in-command qualification and experience
Aircraft damage
Accident category (i.e., NTSB first event)
Phase of operation during which first event occurred
Probable cause (legal)
Contributing factor(s)
Special weather factors (not included when accident was not weather-related)
Special agricultural operational data (not included when accident was not during agricultural operations)
Remarks

The depth of data in the mini-briefs improved across the 34-year period. As an example of data available during the period 1963 to 1971, figure 2 shows a mini-brief for an accident in agricultural operations that involved weather. From 1972 through 1981, the mini-briefs contained essentially the same information as for 1963 through 1971. The most significant change in 1972 was the addition of information on the departure point, intended destination, and last en route stop. Figure 3 provides a mini-brief example for this period.

A major change in the format and data content of the mini-brief took place in 1982. In addition to more detailed information about the aircraft, engine, environment, and pilot qualification, this format specifically included a brief narrative of the accident sequence, findings, and the declaration of which findings constituted the probable cause. This summary format probably contained the most information of any of the formats encountered during this study. Figure 4 provides a mini-brief example for this period.

For accidents that occurred after 1982, mini-briefs in two formats are now available through online resources. At the NTSB web site (www.ntsb.gov/aviation/aviation.htm), the mini-brief format was changed to emphasize the narrative. This change eliminated information about pilot experience, weather, and special agricultural data (see fig. 5). The second form of mini-briefs, which can be obtained through the FAA Office of System Safety web site, has essentially the same information as the NTSB mini-briefs of 1982 shown in figure 4.

As a final example of available data, figure 6 presents a typical entry as presented on the NTSB web site. In this format, only identification information and a narrative are included; the user is referred to the NTSB off-line imaging system for the more complete report. The purpose of these entries appears to be the rapid dissemination of factual accident information. As accident investigation progresses from the preliminary through the factual to the final, the entry is modified with additional data. The example above is for a factual report that does not present formal findings or causes. Because of the time necessary to investigate an accident and file the final report, we relied on the information contained in these summaries for many accidents that took place from late 1996 through 1997.

Using these mini-briefs, it was found that the 21 categories paralleled the expanded groupings listed on the 1936 NACA form (fig. 1) under “Immediate Causes of Accident” and were reasonably consistent over the 34 years under study. Thus, today’s NTSB first event categories, *not to be confused with the ultimate accident cause,* allowed a distribution of the 8,436 accidents within the 21 first event categories. In fact, the bulk of rotorcraft accidents fell into 7 of the 21 NTSB categories, with 70% in just 4 categories.

4. OVERVIEW OF RESULTS

Annual U.S. civil rotorcraft accidents decreased from 260 in 1964 to 175 in 1997 (fig. 7). During this period, the U.S. registered rotorcraft fleet expanded from 2,196 to 12,911 aircraft (fig. 8). In broad terms, the industry succeeded in reducing accidents per rotorcraft by nearly a factor of 10 over this period (i.e., from 118 accidents per 1,000 rotorcraft in 1964 to 13.6 per 1,000 in 1997). The 8,436 accidents that occurred during this 34-year period took a large toll (fig. 9), directly affecting 16,825 people: 2,135 killed, 1,760 seriously injured, and 12,930 with minor or no injuries. Rotorcraft damage during this period was significant (table D-3). Of the 8,436 rotorcraft involved, 2,363 (i.e., nearly 20% of today's registered fleet) were listed as destroyed by the NTSB. Another 5,909 rotorcraft were substantially damaged, and only 164 received little or no damage. Of course, as is well known, helicopter crews and their aircraft have saved more than a million lives. However, without major safety improvements, the potential exists for an increasing number of rotorcraft accidents with more people being affected. This could be especially true, as new rotorcraft types (e.g., civil tilt rotor) become operational.

The distribution of the 8,436 accidents by rotorcraft type for the 34-year period was as shown in table 3 (which is excerpted from table D-1).

TABLE 3. ACCIDENT DISTRIBUTION BY ROTORCRAFT TYPE, 1963–1997

Commercially manufactured helicopters	**7,920**
Single piston	5,371
Single turbine	2,247
Twin turbine	302
Other rotorcraft types	**516**
Commercially built autogyros	50
Amateur built helicopters	137
Amateur built autogyros	261
Unknown/others	68

There was improvement in the safety records of each of these rotorcraft types during the period under study. However, the improvements were not always uniform. As shown in figure 7, the period from 1972 to 1987 showed an unfavorable "bubble" relative to the reference trend. There were "above normal" accidents per year for both matured single-piston helicopters and relatively newer single-turbine models during this 15-year period. Single-piston helicopters had overly large numbers of accidents from 1971 to 1983 (fig. 10), whereas single-turbine helicopters showed a similar increase from 1978 to 1987. Twin-turbine helicopter accidents were relatively rare and did not markedly influence the broad trend or the 15-year "bubble." The other rotorcraft types listed above contributed relatively few accidents per year during the study period (table D-1). Since the single-engine helicopter, piston or turbine, dominates the U.S. civil helicopter fleet, it was not surprising that it was involved in more accidents per year.

4.1 Major Trends

The 21 first event categories used by the NTSB, *which should not be confused with the ultimate accident cause,* establishes a reasonably consistent way to group accidents over the period under study. The distribution of the 8,436 accidents within the 21 first event categories is summarized in figure 11. The bulk of rotorcraft accidents fell into 7 of the 21 NTSB categories, with 70% associated with 4 categories (table 4).

TABLE 4. ACCIDENT COUNT AND DISTRIBUTION, 1963–1997

Loss of engine power	2,408 (28.5%)
In-flight collision with object	1,322 (15.7%)
Loss of control	1,114 (13.2%)
Airframe/component/system failure or malfunction	1,083 (12.8%)
Other first event categories	2,509 (29.7%)
Total	**8,436**

The trend over the 34-year period for these four accident categories is illustrated in figures 12 and 13 using data from table D-4. Figure 12 shows that the first events, loss of engine power and airframe/components/system failure or malfunction, were major contributors to the 15-year "bubble" shown in figure 7. In-flight collision with object accidents decreased over the period studied (fig. 13). However, the number of accidents in the loss of control category virtually doubled in the last 15 years of the study period relative to the first 15 years.

Single-engine rotorcraft dominated the accident history because they constituted most of the fleet over the study period; for these aircraft, loss of engine power was the most prevalent first event. The causes of loss of engine power are shown in figure 14. More than one-half of the loss of engine power accidents were related to fuel/air mixture. *In fact, fuel exhaustion, followed by an inadequate or otherwise unsuccessful autorotative landing, was the major factor in single-engine rotorcraft accidents, regardless of whether the rotorcraft was piston or turbine powered.* Note that figure 14 shows that there was no confirmed reason for loss of engine power in one-fourth of the 2,408 accidents.

4.2 Accident Statistics

Before detailing accident trends for each rotorcraft type, the applicability of accident statistics needs to be discussed. Frequently, these statistics are presented as accidents per 100,000 flying hours, passenger miles, etc. These statistics are relatively accurate for air-carrier operations where there are statutory requirements for the accurate recording and reporting of such data. The situation is different for general aviation, which includes most rotorcraft operations. Appendix B and detailed rotorcraft-type discussions presented below describe the method the FAA uses to obtain data on the size and composition of the civil aircraft fleet. The FAA yearly aircraft registration data are an estimate, based on voluntary returns by aircraft owners to an FAA mailing to a sample of recorded owners. In turn, fleet flight hours are a further estimate based on voluntary reporting by the respondents to the FAA mailing. As a result, we believe that the FAA reported registered fleet size, despite its shortcomings, is a more reliable measure of annual aircraft use than reported flight hours. Therefore, we have elected to normalize yearly accident counts by reported registered fleet size and present accident rates per 1,000 registered aircraft (fig. 15). The accident trend data so normalized do not highlight the accident “bubble” of figure 7.

Extrapolating the annual accident rate data, it appears that without a substantial effort to improve rotorcraft safety, the overall trend projects to 6 accidents per 1,000 registered rotorcraft in the year 2010. If the rotorcraft fleet doubles over the next 15 years (i.e., to 25,000 aircraft), the industry will experience 150 accidents a year—about 3 per week. In short, although the accident rate might remain constant at 6 per 1,000 registered rotorcraft, the public would likely find the projected frequency of accidents unacceptable. It is doubtful that the public in the year 2010 would consider this to be much of an improvement over today’s situation.

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5. COMMERCIAL SINGLE-PISTON ENGINE HELICOPTERS

5.1 Fleet History and Growth

The modern era of U.S. civil rotorcraft operations officially began on 8 March 1946 with the CAA certification of the Bell Model 47. In that year, Bell began a first lot production run of 10 rotorcraft. The two-place Model 47 was followed by the four-place Sikorsky S-51, certificated 17 April 1947. The S-51 was developed from Sikorsky's R-5 military helicopter and benefited from experience gained with the smaller R-4 and R-6 military models. On 14 October 1948, the CAA certificated the Hiller Model 360, the beginning of the UH-12 series. By the end of 1957, the CAA census reported 540 registered helicopters in the civil fleet (table 5).

TABLE 5. CAA HELICOPTER CENSUS AT END OF 1957[a]

Manufacturer	Model	Active[b]	Inactive	Total
Bell Aircraft Corp.	47	246	49	**295**
Hiller Helicopters	UH-12	29	20	**49**
Sikorsky	R-4, R-6, S-51, S-52	14	25	**39**
	S-55	27	12	**39**
	S-58	21	0	**21**
All others	Various	33	64	**97**
Total		**370**	**170**	**540**

[a]The CAA "Statistical Study of U.S. Civil Aircraft" as of January 1, 1958 (i.e., the end of 1957) was the earliest the authors found that contained a breakdown by rotorcraft model.

[b]The CAA segregated aircraft by "active" and "inactive" based on the following definitions, which are from the Preface to the January 1964 census: "Active" aircraft, as defined by the FAA, are those which hold a valid certificate of airworthiness and which have had an approved inspection during the last 12 months and are eligible to fly. Aircraft classified as "inactive" need not necessarily be in unairworthy condition and may hold a valid airworthiness certificate, but they have not met the periodic inspection requirement. In later years, "active" became "eligible" and "inactive" was replaced with "ineligible." In 1970, the FAA returned to using "active" and "inactive" descriptions; however, the definitions changed (see text). Regardless of the words or definitions used, no consistent count of the number of aircraft actually flying appears available.

The size of the single-piston helicopter fleet grew substantially after the type was first introduced (fig. 16). This growth continued until the early 1980s when the market for new rotorcraft virtually collapsed.

To obtain the fleet size, FAA census data (ref. 12) were edited by the principal author to correct such obvious errors as incorrect coding of engine types. Many models were (and still are today) listed as turbine-powered but are well known in the industry to be piston-powered (refs. 13 and 14). These coding errors, which originated at the FAA's Mike Monroney Aeronautical Center in Oklahoma City, illustrate the daunting task of maintaining an accurate, up-to-date database of 350,000 aircraft.

Figure 16 shows a drop of about 350 in the number of single-piston helicopters from 1969 to 1970. This drop "resulted from changes introduced by a new and improved aircraft data system which will produce more reliable data pertaining to the nation's civil aircraft fleet," according to the Census of U.S. Civil Aircraft for calendar years 1971/1970 (ref. 12). Approximately 24,000 aircraft in the civil aircraft fleet of 190,000 were "deregistered" as reported in this 1971/1970 census. Additionally, this census stated the following:

"Beginning in 1970, the aircraft universe was divided into two major categories:

1. Active—All legally registered civil aircraft for which flight hours were reported or imputed. (Refer to "Method of Imputation.")

2. Inactive—All legally registered civil aircraft that do not meet the above-mentioned criteria."

This 1971/1970 census report established the FAA's statistical method for estimating the number of active and inactive aircraft and the hours flown by the active aircraft. The method was required because "so many owners failed to furnish aircraft activity on their revalidation forms." This statistical process (i.e., the "Method of Imputation" established in 1970) is still used today. Unfortunately for data collectors and analyzers, the FAA survey questionnaires are mailed to only about one-tenth of all aircraft owners of record and only about one-half of those respond.

Figure 16 shows that the single-piston helicopter fleet had four distinct growth periods since 1955. Between 1955 and 1970, the fleet grew, on average, by 127 rotorcraft per year. From 1970 to 1980, the growth rate increased to 193 per year, a 52% increase. During the 1980's, the boom collapsed and the fleet size declined from 1980 to 1989. The fourth period, 1989 through 1997, showed only modest growth.

Figure 16 also shows single-piston fleet size data published in Air Track's Rotor Roster (ref. 15), a recognized source for information about the world's helicopter fleet. Their records differ from FAA records because Air Track follows transactions and other detailed data, and "uses multiple sources to arrive at a conclusion of who and where." The 1997 listings from the FAA and Air Track were compared and it was found that about 90% of the data they contained were in agreement. However, neither the FAA nor Air Track knew how many rotorcraft were actually flying (i.e., active) in any given year.

5.2 Accident Analysis

The number of reported accidents investigated by the NTSB is not in doubt, however. Despite the growing number of aircraft in the fleet (fig. 16), the number of single-piston rotorcraft accidents per year dropped over the 34 years, as figure 10 shows. The accident rate, in accidents per 1,000 registered rotorcraft, generally decreased from 1964 to 1985 (fig. 17). However, a period of no improvement in the rate occurred between 1985 and 1990. This was followed by a return to a favorable trend from 1990 through 1997.

These accident trends (figs. 10 and 17) for commercially manufactured, single-piston helicopters raise two questions. First, what caused the increased number of accidents between 1971 and 1983? Second, what caused the 5-year period of no improvement in accident rates between 1985 and 1990? To answer these two questions requires more details about how the number of accidents in each first event category varied with time.

To reiterate, approximately 90% of the 5,371 single-piston helicopter accidents fell into 7 of the 21 NTSB first event categories, as shown in table 6 (see also fig. 18).

TABLE 6. SINGLE-PISTON ACCIDENT COUNT AND DISTRIBUTION, 1963–1997

29%	Loss of engine power (1,554 accidents)
18%	In-flight collision with object (953)
11%	Loss of control (625)
12%	Airframe/component/system failure or malfunction (639)
9%	Hard landing (483)
8%	In flight collision with terrain/water (443)
5%	Rollover/nose over (290)
7%	Other (384)
100%	**Total (5,371)**

The trends in the number of accidents per year for the top four first event categories are shown in figures 19 and 20. The "bubble" in total accidents between 1971 and 1983 began with an increase in loss of engine power and airframe failure accidents (fig. 19). During this period, in-flight collisions with objects and loss of control accidents remained essentially constant (fig. 20). As a result, the total number of accidents each year was higher than the long-term trend line. The "bubble" ended when the trends in loss of engine power, airframe failure, and in-flight collision with object accidents turned downward. The drop in accidents at the end of the "bubble" would have been greater had there not been an increase in loss of control accidents starting in 1982 (fig. 20).

Another interpretation of both the "bubble" and the no-improvement periods can be made. Consider first the "bubble" period. Looking back at the single-piston helicopter fleet growth, shown in figure 16, the "bubble" between 1971 and 1983 nearly coincides with a boom period in helicopter fleet size. We suggest that the 52% increase in new helicopters sold to a new and expanding group of users was the principal cause of the increase in accidents during this period. This interpretation gains some validity by reexamining the accident rate per 1,000 registered aircraft trend (fig. 21). The overall trend is reexamined in three periods using exponential regression curve fitting. Using the first 6 years of accident rate data, the regression analysis predicts, when extrapolated 16 years, the most likely accident rate during the "bubble" period. This extrapolation is shown in figure 21 as the light, solid line. The regression analysis applied to just the “bubble” period is shown as a dashed line in figure 21. Comparing these first two trends suggests that had the industry continued its pre-1970 trend, the 1985 accident rate of 30 per 1,000 aircraft could have been nearly halved. The conclusion to be drawn offers the following cautionary note for the future: *When the next rapid expansion of the fleet occurs, the industry must increase its efforts to improve safety to an extent that is more than proportional to the fleet growth rate.*

Now consider the plateau or “no improvement period” from 1985 to 1990 shown in figures 10, 17, and 21. During this period the fleet size remained virtually constant (fig. 16). This apparent plateau was caused by increased numbers of loss of control accidents coupled with no further reduction in in-flight collision with object accidents.

From 1990 through 1997, the most commonly occurring first events were again showing a collective decline in accident rate per 1,000 registered aircraft, as the heavy solid line in figure 21 suggests. However, over this period, the relative frequencies of first events changed. The distribution of the top seven accident categories from the past 8 years, in contrast to the past 34-year history, is shown in table 7.

The positive aspect when comparing the 1990–1997 distribution to the data over the entire 34 years is that in-flight collision with object accidents dropped substantially (i.e., from 18% to 12%). The alarming aspect is that the loss of control category doubled (i.e., 11% to 22%). Furthermore, little improvement was made in the airframe/component/ system failure or malfunction category and loss of engine power remained the number one first event.

TABLE 7. SINGLE-PISTON ACCIDENT DISTRIBUTION, LAST 8 YEARS VS. 1963–1997

	Last 8 years		Last 34 years	
First event category	**Percent**	**Number**	**Percent**	**Number**
Loss of engine power	27	(207)	29	(1,554)
In-flight collision with object	12	(91)	18	(953)
Loss of control	22	(166)	11	(625)
Airframe/component/system failure or malfunction	10	(80)	12	(639)
Hard Landing	7	(56)	9	(483)
In flight collision with terrain/water	8	(63)	8	(443)
Rollover/nose over	4	(340)	5	(290)
Other	9	(69)	7	(384)
Total	**100**	**(766)**	**100**	**(5,371)**

Most discouraging is the fact that fuel exhaustion (i.e., simply running out of gas) was still the number one factor in losing engine power. The FARs are quite clear about fuel reserves. For example, FAR Parts 91.151 and 91.167 state the following:

Sec. 91.151 Fuel requirements for flight in VFR conditions.

(a) No person may begin a flight in an airplane under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed

(1) During the day, to fly after that for at least 30 minutes; or

(2) At night, to fly after that for at least 45 minutes.

(b) No person may begin a flight in a rotorcraft under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed, to fly after that for at least 20 minutes.

Sec. 91.167 Fuel requirements for flight in IFR conditions.

(a) Except as provided in paragraph (b) of this section, no person may operate a civil aircraft in IFR conditions unless it carries enough fuel (considering weather reports and forecasts and weather conditions) to—

(1) Complete the flight to the first airport of intended landing;

(2) Fly from that airport to the alternate airport; and

(3) Fly after that for 45 minutes at normal cruising speed or, for helicopters, fly after that for 30 minutes at normal cruising speed.

(b) Paragraph (a)(2) of this section does not apply if—

(1) Part 97 of this chapter prescribes a standard instrument approach procedure for the first airport of intended landing; and

(2) For at least 1 hour before and 1 hour after the estimated time of arrival at the airport, the weather reports or forecasts or any combination of them indicate—

(i) The ceiling will be at least 2,000 feet above the airport elevation; and

(ii) Visibility will be at least 3 statute miles.

On this issue of loss of engine power due to fuel exhaustion, Mayo's November 1921 statement that "probably 90% of them [i.e., accidents] were due to carelessness and could have been avoided, had the necessary precautions been taken" is quite applicable today (ref. 2).

Based on the data from 1990 through 1997 and on analysis that shows that the rotorcraft accident number and rate histories are examples of statistically stable systems, it is projected that by the year 2010, the annual accident rate for commercially manufactured, single-piston helicopters may still be above 5 accidents per 1,000 registered aircraft. This projection (fig. 22) assumes "a business-as-usual" approach by the rotorcraft industry and no major changes in the system (e.g., major new aircraft categories such as tilt rotor or missions). It appears that without the "bubble" and the "no-improvement" periods, the industry would already be at this rate.

5.3 Detailed Analysis by Accident Category

Of the 8,436 rotorcraft accidents, single-piston helicopters that were commercially manufactured had 5,371 accidents. Of these, 3,771 (about 70%) were associated with just four first event categories. Therefore, an in-depth analysis of these four top categories provides considerable insight into nearly one-half of all rotorcraft accidents during the 34-year period under study. The next several paragraphs and associated figures and tables provide detailed analyses gleaned from the mini-briefs of the four categories (loss of engine power, in-flight collision with objects, loss of control, and airframe failures).

5.3.1 Loss of Engine Power (1,554 Accidents)

The pilot of any type of single-engine, heavier-than-air aircraft experiences a true emergency following loss of engine power. However, helicopters provide some safety margin over their fixed-wing counterparts because of their inherent ability to glide with a turning rotor (i.e., their autorotation capability) and their generally slower power-off landing speed. These relative safety advantages are often negated, however, because helicopter pilots routinely operate their rotorcraft much closer to the ground where time to react is minimal.

5.3.1.1 Overall Accident Trends. From 1963 through 1997, loss of engine power was implicated by the NTSB in 1,554 accidents involving commercially manufactured, single-piston helicopters. Accidents that occurred during this 34-year period took a large toll (table D-24). The 1,554 accidents directly affected 2,621 people: 106 were killed and 234 were seriously injured; 2,281 survived with minor or no injuries. Of the 1,554 helicopters involved, 265 were listed as destroyed by the NTSB. Another 1,286 helicopters were substantially damaged, and only 3 received little or no damage. Figure 19 shows that the overall trend in accidents per year for this first event category decreased over the last 17 years. As a rate of accidents per 1,000 registered single-piston helicopters, accidents initiated by the loss of engine power showed steady improvement, as seen in figure 23. However, loss of engine power constantly accounted for approximately 30% of the accidents over the 34-year period (fig. 23).

5.3.1.2 Loss of Engine Power by Category. The NTSB cited the reason for loss of engine power in 1,157 of the 1,554 accidents they investigated. Table D-12 shows that 18 primary reasons lay behind the 1,157 accidents. When the 18 reasons are grouped by major subsystems, fuel/air mixture problems caused 686 of the 1,157 accidents (fig. 24). A closer inspection of figure 24 and the associated mini-briefs reveals that fuel exhaustion, fuel starvation, fuel contamination, etc., were repetitive examples of the “poor piloting” discussed by Mayo (ref. 2). In fact, simply running out of gas was the number one reason for loss of engine power throughout the 34-year period under study.

Both figure 24 and table D-12 indicate that over 100 accidents were incorrectly charged to loss of engine power. For example, when the final determination was made, 53 accidents attributed to loss of engine power were actually rotor drive system component failures, more correctly charged to the airframe/component/system failure or malfunction first event category. Other subcategories, which accounted for 54 accidents, were more generally found in the loss of control first event category. On the other hand, several accidents attributed to airframe failure, for example, were actually engine failures.

5.3.1.3 Loss of Engine Power by Activity. The commercially manufactured helicopter, powered by a single-piston engine, has been the breadwinner in the rotorcraft industry, as recounted in reference 16. The most intensive activity as a “breadwinner” has been aerial application (i.e., agricultural operations). This activity has always been high-risk and led to the most accidents in the loss of engine power first event category, as figure 25 shows.

Aerial application operations are conducted at extremely low heights above the ground (on the order of 100 feet or less). This frequently requires flight in the "avoid" regions of the helicopters' height/velocity diagram and offers little time and height for the pilot to perform a successful autorotation. Other activities in which single-piston helicopters engage are generally conducted between 500 and 1,500 feet above ground level (AGL). Loss of engine power in this height range should allow the practiced pilot time to enter autorotation and perform a safe power-off landing. Unfortunately, as will be discussed shortly, the average pilot proficiency in accomplishing this task appears insufficient in view of the number of destroyed and substantially damaged helicopters.

5.3.1.4 Loss of Engine Power by Phase of Operation. Loss of engine power was experienced in every phase of operation in which the single-piston helicopter operated, as figure 26 shows. Not unexpectedly, the overwhelming loss of engine power situations occurred in cruise flight, which reflects the general aviation character of helicopter use. The high power required in takeoff and climb evidently accounted for this subcategory being the second most common phase of flight in which accidents occurred. The helicopter inherently allows low-speed, low-altitude maneuvering, which generally requires operation at high power. Therefore, it is reasonable that the 328 accidents in this flight phase could be combined with the 280 accidents in takeoff and the 53 accidents in hover. This suggests a total of 661 accidents during high-power operations vs. 607 accidents during cruise. Since the helicopter has been designed and marketed for hovering and for slow, low-altitude flight, the ratio of 661 to 607 or 108% does not appear unreasonably high for this type of aircraft.

5.3.1.5 Power-Off Landing. Apparently, the power-off landing that follows a loss of engine power is considered “successful” by the industry today if (1) there is no serious injury and (2) the main rotor blades are destroyed while severing the tailboom or when the helicopter rolls over. In other words, “If you can walk away from it, it’s successful.” This conclusion was arrived at after several informal conversations with members of the insurance industry, instructional and high-time pilots (both civil and military), and operations personnel from one firm primarily engaged in helicopter pilot training. Today’s initial or recurring training of helicopter pilots rarely includes completion of the simulated power-off landing to touchdown. Rather, the average pilot is well schooled in the transition from powered to unpowered autorotational flight, proper gliding techniques, and the flare maneuver required just prior to touchdown. At this point, the pilot under instruction (perhaps with instructor assistance) generally increases power to end up in a hover. The industry premise appears to be that if the average pilot can successfully accomplish the maneuver to the flare point, the odds are that the final outcome in a real emergency will be "successful," albeit with the possible level of damage listed above.

This standard for power-off landing training was initially adopted by U.S. Army Aviation during the Vietnam War. That war's requirement for many new helicopter pilots led to a high accident rate when training military students to complete the power-off autorotational landing to touchdown. The cost of these training accidents was deemed greater than the benefit during emergency experiences in the field and the training syllabus was changed accordingly. Today, the FAA Practical Test Standards* (pp. 2–13, par. 4 C, Task—Power Plant Failure, Single engine helicopter) also reflect this proficiency standard associated with a pilot's certification.

The NTSB's mini-briefs provide any number of narratives describing the recurring events following loss of engine power. For example, the narrative for a loss of engine power accident that occurred 3 February 1982 (NTSB File No. 0059) states:

> "THE ENGINE LOST POWER DURING A NIGHT FLIGHT WHILE ENROUTE TO OBTAIN FUEL. THE LOW RPM AUDIO AND WARNING LIGHT WERE NOTED WHEN THE LOSS OF POWER OCCURRED. THE PILOT ENTERED AN AUTOROTATIVE DESCENT AND TURNED TO LAND ON AN INTERSTATE HIGHWAY. AS HE STARTED TO DECELERATE FOR LANDING, POWER LINES BECAME VISIBLE IN HIS FLIGHT PATH. HE DUMPED THE NOSE AND DOVE UNDER THE POWER LINES, THEN FLARED AND TOUCHED DOWN AT ABOUT 25 TO 30 MPH. DURING THE LAST PART OF A GROUND SLIDE, THE MAIN ROTOR STRUCK A POLE FOR AN OVERHEAD SIGN AND A SPEED LIMIT SIGN. NO PRE-ACCIDENT ENGINE FAILURES WERE FOUND." [Note: The pilot was not injured and the damage to the helicopter was substantial.]

The recurring theme from the 1,554 loss of engine power narratives was that if the engine quit, the pilot was most probably over the most unsatisfactory terrain for an emergency landing. The mini-brief narratives continually suggested that even near-perfect pilot technique would most likely only minimize damage. The subsequent autorotative landing by the average pilot was almost invariably a hard one. The rate of decent and/or forward speed were rarely zeroed out prior to touchdown. The helicopter frequently was flared too high above the ground, causing the tail skid to hit the ground first. This caused the helicopter to rock forward as the main skids touched down and the main rotor tip path plane to tilt aft, severing the tailboom. In many other cases, if the emergency landing area was soft, the helicopter slid, dug a skid into soft ground, and rolled over. In other cases, the pilot caused the main rotor to tilt aft and sever the tailboom in attempting to brake the slide with full aft cyclic stick. The preceding sequences reflect our analyses of the 1,554 mini-brief narratives that were read in the course of this work.

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*This document can be found at www.mmac.jccbi.gov/afs/afs600/akt.html#pts.

Taken in total, it appears that helicopters in the current civil fleet have insufficient stored energy for the average pilot to successfully complete the final autorotational flare and touchdown, in most cases. To be sure, skilled pilots frequently demonstrate the helicopter's inherent autorotation capability following loss of engine power by softly landing on a paved surface with near zero forward motion. However, this is not a good measure of what the average pilot, under emergency conditions, can do in day-to-day operations in the field.

Appendix C provides additional discussion concerning accidents involving autorotations.

5.3.1.6 Conclusions About Loss of Engine Power Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 5,371 accidents involved commercially manufactured, single-piston helicopters. Of these, 1,554, or roughly 30%, were attributed to loss of engine power. No fewer than 686 accidents were directly traced to fuel/air mixture problems. Virtually every one of the 686 accidents was caused by human error. Fuel exhaustion, fuel starvation, and fuel contamination accounted for over 400 of the 686 accidents. Apparently, many pilots disregarded the engine's need for clean fuel and air in proper proportions—to say nothing about the FAA regulations for fuel reserves.

Structural failure of the single-piston engine caused 263 accidents, and the reason for the loss of engine power was not established in 397 accidents.

Virtually every one of the 1,554 loss of engine power accidents resulted in a substantially damaged or destroyed helicopter. Therefore, the fact that power-off landing proficiency is not required by the FAA to obtain a helicopter pilot's certification appears inconsistent with the number of accidents. It also appears that helicopters currently in the civil fleet provide marginal to inadequate autorotational capability for the average pilot to successfully complete the final flare and touchdown to a generally unsuitable landing site. Clearly, training in full autorotation landings—even to a prepared landing site—is avoided because of both real and perceived risks.

5.3.2 In Flight Collision with Object (953 Accidents)

One of the most widely known advantages that helicopters have over fixed-wing aircraft is their capability to hover, fly slow and low, and operate in confined areas. Thus, they are routinely used in just this manner and therefore encounter a more hostile environment that is full of objects such as wires and towers that are hard to see. Hence, it is not unexpected that accidents involving in-flight collision with objects constitute a large portion of rotorcraft accidents. Depending on the severity of the collision, a pilot may or may not be able to recover. If the helicopter's main rotor control is lost from a blade strike, or if the altitude is insufficient for autorotation, recovery, and safe landing may not be possible. If directional control is lost following a tail rotor strike, any recovery at all becomes extremely difficult.

5.3.2.1 Overall Accident Trends. The NTSB cited in-flight collision with object as the first event in 953 single-piston helicopter accidents from mid-1963 through 1997. These collision with object accidents affected 1,416 people: 166 were killed and 205 suffered serious injuries; 1,045 survived with minor injuries or no injuries at all. Of the 953 helicopters involved, 327 were listed as destroyed by the NTSB. Another 620 helicopters were substantially damaged; only 6 received little or no damage. Figure 20 shows that the overall trend in accidents per year for this first event category decreased substantially during the first 17 years of the 34-year study period. However, as figure 27 shows, in-flight collision with object accidents leveled off at about 12% of the annual single-piston helicopter accidents. In terms of annual accidents per 1,000 registered single-engine helicopters, the trend in the later years shows no substantial reduction (fig. 27).

5.3.2.2 Collision with Object by Object Hit. Figure 28 lists the type of objects that were hit in the first event category, referred to as in-flight collision with object. Unquestionably, wires and the combination of wire/pole were the most prevalent objects hit. Together, these two objects account for 507 (53%) of the 953 accidents. With respect to collisions with trees, the mini-briefs frequently were unclear whether the pilot descended into a forest of trees (and would have hit whatever was between the aircraft and the ground) or clipped a branch of one tree from the side. The latter might have been a result of misjudging distance or not correcting for drift. Most of the other objects were man-made. Of the 32 accidents associated with the airport/helipad facility objects, most of these facilities were oil rigs. Conventional heliport design, therefore, did not appear to be an issue.

5.3.2.3 Collision with Object by Cause. The accidents were further subdivided by the condition that resulted in an object strike. We chose the 12 categories shown in figure 29. It is evident that an improper decision, which includes poor planning, inadequate training and misjudging clearances, was the most common cause, followed by the two least descriptive categories; Failure to see and avoid and undetermined. Failure to see and avoid was used as a "catchall" category for accidents in which more specific detail was not available in the mini-brief. For the agricultural application or crop dusting activity, failure to see and avoid was the most frequently reported cause. Since most accidents in agricultural operations do not result in fatalities, reports were often sketchy. Quite often, however, "crop dusters" appeared to know where the obstacles were relative to a field, but for some reason (e.g., fatigue, sun glare, misjudging distance, etc.) still collided with them.

Degraded visibility encompassed fog, instrument meteorological conditions, snow, rotorwash brownout and whiteout darkness, and sun glare; most of these accidents involved sun glare, however.

Not surprisingly, the most frequent condition found for external load and proximity to obstacle work was precisely the nature of the task: proximity to obstacles. This was followed by improper decision and performance or RPM issues. For emergency operations, the most frequent cause of collision with objects was inadequate RPM, followed by wind drift and diverted attention.

5.3.2.4 Collision with Object by Phase of Operation. The phase of operation during which collision with object accidents occurred is shown in figure 30. As might be expected, collisions occurred most frequently during maneuvering, a typical phase of flight for aerial application operations. Aerial application involves extensive maneuvering to ensure complete coverage of the field being treated. Takeoff, cruise, and landing (taken to together) accounted for 335 of the 953 collision with object accidents. Cruise in a helicopter generally occurs at low altitude and at relatively high speed, which makes it more difficult to avoid wires that are difficult to see in the first place.

5.3.2.5 Collision with Object by Activity. The mini-briefs were analyzed to determine the activity in which a pilot was engaged when a collision with object accident occurred. The activities were extracted from the narratives based on FAR paragraph numbers and the verbal description of the activity. The accidents were placed into 10 activity groups, 7 of which accounted for over 95% of the total. The distribution by activity is shown in figure 31.

This activity analysis overlapped the phase of operation analysis in revealing that accidents occurred most frequently during aerial application and general utility operations, which includes, for example, aerial surveying, herding, and hunting. The activities involving passenger service, personal, and business use accounted for 237 of the 953 collision with object accidents. The frequency of accidents that occurred during instruction clearly showed that student pilots, by necessity, focused their attention more on learning to operate the aircraft than on avoiding obstacles. Student pilots were also relatively inexperienced in judging distances, maintaining RPM and avoiding drift. The pilots flying personal flights may have also been inexperienced in these areas and may have suffered from lack of regular practice.

5.3.2.6 Collision with Object by Part Hit. The part of the helicopter involved in a collision was rarely mentioned in NTSB summary reports. The statistics available on this subject are shown in figure 32. For the 228 (23.9%) of the 953 single-piston helicopter collision with object accidents in which such data were reported, the most frequent rotorcraft components involved in collisions were the tail and main rotor blades. The main rotor collisions differed from tail rotor collisions: the rotorcraft were, more often, in forward flight when a main rotor strike occurred. In contrast, tail rotor strikes occurred, most often, when the pilot “dragged the tail” or was backing up. These components together accounted for 170 (75%) of the 228 accidents in which the part hit was reported, but it is not clear whether this statistic can be extrapolated to the total of 953 accidents.

5.3.2.7 Conclusions About In-Flight Collision with Object Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 5,371 involved commercially manufactured, single-piston helicopters. Of these, 953, or roughly 18%, were attributed to in-flight collisions with objects. Nearly one-half (471) of the 953 accidents occurred during aerial application (i.e., crop spraying) activities. Wire, wire/pole and trees accounted for 655 of the accidents. Wire strikes, agricultural operations, and main and tail rotor strikes were the dominant characteristics of collision with object accidents. The unique characteristics of rotorcraft and the missions flown (e.g., proximity to obstacles, frequent low-altitude flight) were reflected in the types of objects with which helicopters collided.

To adequately address and reduce the number of collision with object accidents, systematic changes must be implemented in the human (e.g., improved training and ongoing pilot development), the aircraft (e.g., less sensitivity to environmental conditions, more robust controllability), and associated equipment (e.g., proximity sensors, enhanced visibility devices).

5.3.3 Loss of Control (625 Accidents)

Helicopters (particularly the small, single main rotor with antitorque tail rotor configuration) are generally perceived to be difficult to fly. Unlike pilots of their fixed-wing counterparts, the helicopter pilot must constantly maintain control of four primary axes that are frequently tightly coupled. The control of vertical position requires a collective pitch control stick. Roll and pitch are controlled with a cyclic stick, which is comparable to the fixed-wing stick or yoke. Left and right pedals control antitorque and directional heading. Finally, constant control of engine RPM with a motorcycle-like twist-grip throttle attached to the end of the collective stick is required. A pilot must, therefore, use both feet and both hands, as well as a left-wrist twist motion to fly most piston-powered helicopters successfully.

In and near hover, the helicopter is inherently unstable in both roll and pitch. Constant movement of the cyclic stick in all directions is required to maintain an upright attitude above a desired point. Early helicopters, such as those manufactured by Hiller and Bell, incorporated mechanical devices to reduce roll and pitch instability. Those devices became known as the “Hiller servo paddle” and the “Bell bar.” The primary control coupling that increases pilot workload involves balancing antitorque so the aircraft generally maintains the desired heading. The antitorque balance is altered whenever collective pitch or engine RPM is altered.

At typical cruise speeds, the helicopter’s positive stability is quite similar to that of a fixed-wing aircraft. Little attention to the collective stick and the twist-grip throttle is required. The pilot is required to coordinate only cyclic stick and pedals to maintain trim and comfortable control of the aircraft.

To date, no commercially manufactured helicopter, powered by a single-piston engine, is available with stability augmentation or an autopilot, either of which could reduce pilot workload and enhance safety.

5.3.3.1 Overall Accident Trends. From 1963 through 1997, the NTSB cited loss of control in 625 accidents involving commercially manufactured, single-piston helicopters. Accidents that occurred during this 34-year period took a large toll (table D-24). The 625 accidents directly affected 1,048 people: 92 were killed, 105 were seriously injured, and 851 survived with minor or no injuries. Of the 625 helicopters involved, 194 were listed as destroyed by the NTSB. Another 428 helicopters were substantially damaged; only 3 received little or no damage. Figure 20 shows that loss of control accidents per year decreased over the first 17 years of the study period. However, this type of accident showed a rapid increase in 1982, remained at a relatively high level until 1991, and then dropped. Figure 33 shows that loss of control accounted for a growing percentage of single-piston helicopter accidents from 1980 through 1997. When expressed as the number of accidents per 1,000 registered single-piston helicopters, accidents initiated by loss of control showed little improvement during the last 17 years (fig. 33).

5.3.3.2 Loss of Control by Phase of Operation. Considering the phase of operation in which loss of control occurred, the accidents fell into the 11 categories shown in figure 34. As might be expected, loss of control occurred most frequently during the hover and takeoff phases of a flight. The control input precision required for hovering, combined with a lack of time and altitude to react to abnormal conditions and aircraft sensitivity to environmental inputs (e.g., winds, density altitude) combined to put the greatest demands on a pilot. Most rotorcraft powered by a piston engine require considerable throttle manipulation, which adds additional workload, particularly during maneuvering.

5.3.3.3 Loss of Control by Activity. The accident records were analyzed to determine the frequency distribution of loss of control accidents by flight activity. The activity was extracted from the narrative based on FAR paragraph numbers and verbal description in the NTSB mini-brief. Eleven activities dominated, as shown in figure 35. Single-piston helicopters had the most loss of control accidents during instructional, agricultural, and personal-use operations. It appears that the lower cost of purchasing and operating single-piston helicopters made them more attractive for the individual and agricultural operator. Furthermore, most basic civilian rotorcraft pilot training takes place in single-piston helicopters.

Instructional flights were the most prevalent activity in which loss of control occurred. Considering instructional flights that resulted in accidents, approximately 43% occurred during dual flights and about 28% during solo flights. The remainder occurred during general instruction (17%), practice (11%), or check rides. These statistics illustrate the difficulty of piloting rotorcraft and the extreme demands placed on both student and instructor during training activity. This, in turn, emphasizes the importance of proper training, evaluation, and professional development of the rotorcraft instructor corps. Not only does the quality of instruction and instructor directly affect the quality of the newly trained helicopter pilot, but also the demands of instruction itself require the highest professional standards.

The second largest number of loss of control accidents occurred during agricultural flying. These operations require constant low-altitude maneuvering in close proximity to obstacles, frequent low-speed and downwind flight, service from unprepared areas (e.g., fields, landing trailers), flight at night (especially in hot climate areas), and extensive travel from job site to job site. These factors, among many others, resulted in a higher risk of control problems occurring in flight with little or no time for the pilot to recover.

Personal-use flights were the third most frequent type of activity when vehicle loss of control occurred. However, the specific flying tasks ranged from point-to-point transportation to high-risk maneuver practice. The range of aircraft and maintenance characteristics varied from owner-maintained to rentals from a commercial aircraft enterprise.

5.3.3.4 Loss of Control by Cause. The accident mini-briefs were further analyzed in an effort to understand the conditions that were associated with the control loss. We consolidated reasons that appeared to precipitate the control loss into 12 categories, as shown in figure 36.

Improper operation of the flight controls was the single factor most frequently implicated in loss of control accidents. Although it is tempting to assert that “pilot error” must, therefore, be the biggest single problem, this conclusion is not fully supported. Since aircraft control is the result of both pilot capability and aircraft design, any effort to address the “improper operation of controls” problem must address both factors. Human-centered actions (e.g., improved training, stricter currency/proficiency requirements) will be relatively ineffective if airframes are designed and certificated with known adverse flying characteristics (e.g., an unusual tendency toward loss of tail rotor effectiveness or extreme control sensitivity in one or more axes). Conversely, even inherently safe designs may fail if pilots are inadequately trained or lack safety consciousness.

5.3.3.5 Loss of Control by Axis. In an attempt to determine which control axis might be the most difficult for the pilot, it was noted that only 338 of the 625 single-piston helicopter accidents were described in sufficient detail to permit such a distinction. The distribution that did emerge is shown by figure 37. In many cases, loss of control appeared to begin with a loss of rotor RPM, which occurred for a variety of reasons. Therefore, figure 37 provides the noted problems in each axis (pitch, roll, yaw, and vertical) where low rotor RPM was not involved. Many mini-briefs stated the axis and also noted that low rotor RPM was a factor. Thus, to interpret figure 37’s total loss of yaw control count, one adds the 21 accidents with low rotor RPM to the 95 accidents without low rotor RPM for a total of 116 yaw axis-related accidents.

Figure 37 indicates that pilots experienced the most loss of control accidents in the yaw axis and vertical axes, most frequently during the hover and takeoff phases of a flight. Of the 338 accidents, 235 involved loss of yaw and/or vertical control. Because the yaw and vertical axes are quite coupled in today's single-piston helicopter fleet, this is not an unexpected result. There were 103 main rotor cyclic-related (i.e., pitch and roll) loss of control accidents. Thus, loss of directional control and vertical position accounted for nearly 70% of the loss of control accidents in single-piston helicopters.

5.3.3.6 Loss of Control by Pilot-in-Command Certification Level. The last characteristic of loss of control accidents analyzed in detail was the reported certification level of the pilot in command (PIC). The authors examined only mini-briefs from 1963 through 1982 in detail for the PIC data. Cross-checking was made against data from 1993, 1994, and 1995 that was available at the NTSB web site.* Therefore, only 461 of the 625 single-piston helicopter mini-briefs were examined. The data reviewed yielded the distribution provided in figure 38. The most striking finding was that the PIC held at least a commercial rating in well over 60% of loss of control accidents. It should also be noted that loss of control accidents involved student pilots (55), private pilots (77), and pilots with no certificates (12). Since we do not know how many pilots there were at each certification level, we cannot draw any conclusions about the relationship between certification and accidents. However, it is clear that loss of control accidents involved pilots of all certification and experience levels.

5.3.3.7 Conclusions About Loss of Control Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 5,371 accidents involved commercially manufactured, single-piston helicopters. Of these, 625, or roughly 12%, were attributed to loss of control. In the 338 accidents for which the control axis loss was specified, 235 involved loss of yaw and/or vertical control. Current single-piston helicopters appear to have a highly coupled vertical/yaw/power/RPM flight characteristics that, potentially, led to as many as two-thirds of the loss of control accidents.

Loss of control accidents occurred most frequently during instructional and training activities (152). However, aerial application, general utility, and personal-use activities together accounted for 347 accidents. This suggests that no activity was immune to a loss of control accident. Loss of control accidents occurred with pilots of all certification and experience levels at the controls.

The overall impression from the large number of loss of control accidents is that the single-piston helicopters currently in the registered fleet are inordinately difficult to fly, particularly when the pilot must devote some attention to any other task. Clearly, given today's technology, the handling qualities of this helicopter type could be substantially improved.

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*The information can be found on the web at http://nasbac.faa.gov/asp/asy_ntsb.asp. Access to this site allows a search by each specific NTSB accident document number.

5.3.4 Airframe/Component/System Failure or Malfunction (639 Accidents)

In the United States, the single main rotor with antitorque tail rotor configuration has dominated the civil fleet. Since 1946, this configuration's field experience has been the basis for the industry's engineering and manufacturing experience. The many lessons learned have allowed the industry to slowly improve its product.

The helicopter requires a number of airframe systems and components not found on fixed-wing aircraft. For example, comparably sized airplanes connect the propeller directly to the engine. In helicopters, a much more complicated drive train is required to transmit power to the main rotor. This drive train includes a coupling from the engine to a speed-reducing gearbox that outputs power to a main rotor mast to which the main rotor is attached. The helicopter's main rotor has two or more blades that are quite flexible compared to an airplane propeller and continually flex as they turn. In fact, many helicopter systems and components are subjected to continuous vibration and flexing, which has forced the industry to become a leader in understanding failure of materials in fatigue. Put simply, many airframe failures deal with this kind of question: How many times can you bend and unbend a paper clip before it breaks?

The helicopter's overall complexity, the different materials used, and the several different ways in which these materials can fail (i.e., failure modes) are important factors in accidents related to the NTSB first event category of Airframe/component/system Failure or Malfunction.

5.3.4.1 Overall Accident Trends. The NTSB cited airframe/component/system failure or malfunction (referred to from here on as simply airframe failure) as the first event in 639 accidents experienced by the single-piston helicopter fleet during the study period. Accidents that occurred during this 34-year period took a large toll (table D-24). The 639 accidents directly affected 1,051 people: 153 were killed, 109 were seriously injured, and 789 survived with minor injuries or no injuries at all. Of the 639 helicopters involved, 212 were listed as destroyed by the NTSB, and 422 helicopters were substantially damaged; only 5 received little or no damage. Figure 19 shows that the overall trend in accidents per year for this first event category remained relatively constant for the first 17 years of the study period. However, airframe failure accidents showed a rapid decrease in 1982 and remained at a relatively low level through 1997. Figure 39 shows that airframe failure from 1980 through 1997 accounted for a nearly constant percentage of single-piston helicopter accidents. As a rate of annual accidents per 1,000 registered single-piston helicopters, accidents initiated by airframe failures showed further reduction during the last 10 years of the study period (fig. 39).

5.3.4.2 Airframe Failures by Phase of Operation. Considering the phase of operation during which airframe failures occurred, the accidents fell into 11 categories, as figure 40 shows. Airframe failures occurred most frequently during the cruise phase of a flight. The large number of airframe failure accidents associated with maneuvering occurred primarily during aerial application activity.

5.3.4.3 Airframe Failures by Activity. The accident records were analyzed to determine the frequency distribution of airframe failure accidents by flight activity. The activity was extracted from the narrative based on FAR paragraph numbers and verbal description in the NTSB mini-brief. Ten activities dominated, as figure 41 shows.

Figure 41 shows that single-piston helicopters had the most airframe failure accidents during agricultural operations and general utility use. These activities require (1) constant low-altitude maneuvering in proximity to obstacles, (2) frequent low-speed and downwind flight, (3) service from unprepared areas (e.g., fields, landing trailers), (4) flight at night (especially in hot climate areas), and (5) extensive travel from job site to job site. These five factors alone suggest that maintenance may suffer.

5.3.4.4 Airframe Failures by System/Component. For the 639 accidents involving commercially manufactured, single-piston helicopters, failures in over 70 systems/components resulted in accidents. These 70 specific failures are combined into the 10 major categories shown in figure 42.

It is evident from figure 42 that the rotor drive system (both main and tail rotors combined) was the most significant airframe failure for this aircraft class. Over 38% of the 639 accidents caused by airframe failures involved problems in transmissions, drive shafts, couplings, clutches, and other components of the rotor drive trains. Since drive train failure usually required an autorotative landing (frequently with degraded control when the failure occurred in the tail rotor drive), the consequences were often very serious. When the tail rotor (i.e., blades and hub), its drive train, and its control system are considered as one category, then over 40% of the 639 airframe failure accidents led to loss of directional control.

The accident count is matrixed by major airframe system and failure mode terminology in table 8. The failure mode terminology used by NTSB accident investigators may lack a certain precise engineering statement from which redesign might be initiated; however, the meaning implied by each mode becomes clearer when related to a specific system that failed. For example, failures of rotor system components owing to fatigue loads are hardly unexpected in the rotorcraft world. Slippage, when associated with drive systems, suggests a belt, clutch or freewheeling unit malfunction. Material failure and failed are, of course, less informative and could be taken as the same. On the other hand, overload could imply under-designed components or improper flight techniques that exceeded aircraft limits flown. Foreign object damage (FOD) and rotor system are clear enough. Lack of lubrication and drive system suggest gearbox problems.

Figure 42 offers a convenient outline from which more detail about each system, subsystem, component or part failure or malfunction can be examined.

5.3.4.4.1 Drive train failures by subsystem: Figure 42 shows that the drive train from the engine to the main and tail rotors was implicated in a total of 246 (i.e., 38% of the 639) accidents involving single-piston helicopters during the study period. These accidents, caused by drive-train failures, are distributed to a lower subsystem level, as shown in table 9.

Failure to transmit power from the engine to the main rotor gearbox accounted for 96 of the 127 main rotor drive train accidents (table 9). Failure to transmit power along the tail rotor drive shaft caused 73 of the 119 tail rotor drive train-related accidents. Taken together, component failures in these two subsystems caused 169 accidents.

TABLE 8. NTSB FAILURE MODE/SYSTEM MATRIX—SINGLE-PISTON HELICOPTERS

Failure mode	Drive system	Rotor system	Control system	Airframe LG	All other	Total
Fatigue	28	74	21	23	0	**146**
Improper assembly, installation, maintenance	50	20	33	26	0	**129**
Material failure	60	19	12	9	0	**100**
Undetermined/not reported	16	7	5	7	15	**50**
Failed	26	1	9	10	1	**47**
Separated	6	13	8	5	0	**32**
Foreign object damage	4	18	1	0	0	**23**
Overload	8	6	5	2	1	**22**
Pilot action/operational issue	2	4	0	5	6	**17**
Lack of lubrication	16	0	0	0	0	**16**
Slippage	16	0	0	0	0	**16**
Disconnected	8	1	5	0	0	**14**
Blade-airframe strike	0	9	1	0	0	**10**
Delaminated/debonded	0	7	0	0	0	**7**
Bearing failure	5	2	0	0	0	**7**
Bent/binding/jammed	1	0	1	1	0	**3**
Hydraulic leak/lock	0	0	0	0	0	**0**
Total	**246**	**181**	**101**	**88**	**23**	**639**

TABLE 9. DRIVE TRAIN FAILURES BY COMPONENTS—
SINGLE-PISTON HELICOPTERS

Drive train—main	**127**
Engine to transmission drive	96
Main rotor gearbox	20
Main rotor mast	11
Drive train—tail	**119**
Tail rotor drive shaft	73
Tail rotor gearbox	46

The main rotor gearbox was cited in 20 accidents (table 9). Of these 20 accidents, gear failures dominated. Four of the 11 main rotor mast failures were traced to the thrust bearing. In all, material failure was cited in 10 cases, and fatigue was implicated in 5 others; one case of a "bogus"— rather than manufacture approved part—was identified. Failure within the 46 tail rotor gearboxes was traced to bearings and gears in about equal numbers.

Table 10 lists the number of accidents caused by components that failed to transmit power between the engine and the main rotor gearbox or to transmit power from the main rotor gearbox to the tail rotor gearbox. The clutch assembly accounted for a large number of accidents. In many cases, the specific part within the assembly that failed was listed by the investigator. Furthermore, the investigators characterized the failure as "slippage" or "disconnect." They frequently pointed to material failure, wear, and fatigue as the cause of clutch failure. Clearly, the point of power transfer between the engine and the rotor drive system—the clutch—is a critical component. Possibly, health and usage monitoring systems (HUMS) and better aircraft inspection techniques/tools could spot and prevent a potential failure in these component failures.

TABLE 10. DRIVE TRAIN MAJOR COMPONENT FAILURES— SINGLE-PISTON HELICOPTERS

Engine to transmission drive	**96**
Clutch assembly	59
Freewheeling unit	16
Torsion coupling	8
Belt	6
Bearing	5
Shaft	2
Tail rotor drive shaft	**73**
Drive shaft	37
Coupling	28
Hangar bearing	8

Tail rotor drive shaft failures accounted for 73 of the 119 single-piston helicopter accidents (table 9). Table 10 shows that one or more shaft segments failed in 37 cases, couplings failed in 28 cases, and the investigator specifically identified hanger bearings in 8 accidents. Material factors accounted for 46 of the tail rotor drive shaft failures (all parts and subsystems). Fourteen were related to maintenance or manufacture, 8 to operations, and the rest miscellaneous or unreported. Bogus parts were implicated in two failures. It appears that efforts to reduce tail rotor drive shaft system problems should concentrate on the design of and materials used for the components of this system, along with HUMS to detect fatigue, wear, and deterioration.

5.3.4.4.2 Rotor failures by subsystem: Figure 42 shows that the main and tail rotor systems were implicated in a total of 181 of the 639 accidents (i.e., 28%) in single-piston helicopters during the study period. Table 11 provides the distribution of rotor system failures by accident count to a lower subsystem and component level. Note that in both the main and tail rotor systems, blade failures accounted for about 50% of the accidents. Fatigue fractures were the most prevalent failure mode for both the main and tail rotor systems (table 12).

TABLE 11. ROTOR SYSTEM FAILURES BY COMPONENTS—SINGLE-PISTON HELICOPTERS

Main rotor	**57**
Main rotor blade	28
Main rotor hub	16
Main rotor system	12
Other	1
Tail rotor	**124**
Tail rotor blades	56
Tail rotor hub	32
Tail rotor system	36

TABLE 12. ROTOR SYSTEM COMPONENTS FAILURE MODE—SINGLE-PISTON HELICOPTERS

Component failure mode	Main rotor blade	Main rotor hub	Main rotor system	Other	Tail rotor blade(s)	Tail rotor hub	Tail rotor system	Total
Fatigue fracture	9	8	0	0	34	25	1	**77**
Material failure	2	2	0	0	8	5	4	**21**
Separated	4	0	0	0	6	0	9	**19**
Foreign object damage	0	0	3	0	0	0	15	**18**
Overload	3	3	0	1	4	1	1	**13**
Improper assembly	4	2	0	0	2	1	0	**9**
Not reported	1	1	0	0	1	0	6	**9**
Blade–airframe strike	0	0	9	0	0	0	0	**9**
Delamination	5	0	0	0	1	0	0	**6**
Total	**28**	**16**	**12**	**1**	**56**	**32**	**36**	**181**

5.3.4.4.3 Control system failures by subsystem: Failure or malfunction of flight control systems precipitated 101 accidents (fig. 42). Failures in the lower controls (i.e., the nonrotating components) far outnumbered those in the upper controls (i.e., primarily rotating components) as shown in table 13. Of the 12 stabilizer bar/paddle failures, 9 were the "Bell bar" and 3 were the "Hiller servo paddle."

The failure mode in the lower controls of the main rotor was characterized by the accident investigators in terms such as disconnected/separated, loose or missing bolt, improper assembly, material failure, overload, and worn. Only eight examples of fatigue failure were noted. The 21 accidents attributed to the tail rotor control cables described the cables as chafed, worn, frayed, loose, disengaged from pulley, separated, improperly assembled, and crossed.

5.3.4.4.4 Airframe failures by components: Figure 42 shows that failures of the fuselage structure, landing gear, and other airframe-associated components accounted for 88 of the 639 accidents (i.e., 14%). Table 14 presents the accidents caused by failures at the lower subsystem and component level. The failure modes of these airframe components is summarized by accident count in table 15. Ground resonance was the key factor in at least 20 of the 24 landing gear-related accidents. Lack of maintenance of the landing gear struts was identified as the primary cause of these accidents. In fact, as table 15 shows, improper assembly, installation, or maintenance specifically accounted for 16 of the 26 total accidents counted in this grouping. Tailboom failure caused 26 accidents; one-half of these came about because of a fatigue fracture. NTSB investigators noted corrosion as a factor in very few fuselage component failures. The six fatigue failures associated with support assembly led to separation of the main rotor gearbox and rotor system.

TABLE 13. CONTROL SYSTEM FAILURES BY COMPONENTS—SINGLE-PISTON HELICOPTERS

Main rotor controls	**63**
Lower controls—cyclic	27
Lower controls—collective	10
Upper controls—swashplate assembly	9
Upper controls—pitch link	3
Upper controls—other	2
Upper controls—stabilizer bar/paddle	12
Tail rotor controls	**38**
Lower controls—cable	21
Lower controls—other	3
Upper controls—swashplate assembly	2
Upper controls—pitch link	4
Upper controls—other	3
Controls—other	5

TABLE 14. AIRFRAME FAILURES BY COMPONENTS—SINGLE-PISTON HELICOPTERS

Airframe and landing gear	**88**
Landing gear	24
Tailboom	26
Other systems	8
Support assembly	10
Other systems (engine)	3
Stabilizer—horizontal	9
Miscellaneous equipment	7
Stabilizer—vertical	1

TABLE 15. AIRFRAME COMPONENTS FAILURE MODE—SINGLE-PISTON HELICOPTERS

Component failure mode	Landing gear	Tail boom	Other systems	Support assy	Other systems (engine)	Stabilizer (horizontal)	Misc equip	Stabilizer (vertical)	Total
Fatigue	0	13	0	6	0	4	0	0	**23**
Improper assembly, installation, maintenance	16	0	4	0	1	2	2	1	**26**
Failed	0	4	2	1	1	0	2	0	**10**
Undetermined/not reported	3	0	1	1	1	0	1	0	**7**
Material failure	0	3	0	2	0	2	2	0	**9**
Pilot action and operational issues	4	0	1	0	0	0	0	0	**5**
Disconnected/separated	0	4	0	0	0	1	0	0	**5**
Overload	1	1	0	0	0	0	0	0	**2**
Bent/binding/jammed	0	1	0	0	0	0	0	0	**1**
Total	**24**	**26**	**8**	**10**	**3**	**9**	**7**	**1**	**88**

5.3.4.5 Conclusions About Airframe Failure or Malfunction Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 5,371 accidents involved commercially manufactured, single-piston helicopters. Of the 5,371 accidents, 639, or roughly 12% of these accidents, were attributed to failure or malfunction of the airframe or of some system or component associated with the airframe. Drive and rotor system failures, primarily in the cruise and maneuvering flight phases, accounted for 427 of the 639 accidents. The clutch from the engine to the main rotor gearbox and the tail rotor drive shaft dominated drive train component failures. Together, these two components accounted for 96 of the 639 accidents. Main and tail rotor blade fatigue failures led to an additional 94 accidents. The pilot was left without antitorque and directional control in over 300 of the 639 accidents because of failures or malfunctions of a tail rotor drive train, a tail rotor system, a tail rotor control, or a tailboom.

Fatigue resulted in more airframe failure accidents in commercially manufactured, single-piston helicopters than any other cause. Following fatigue failures, material failures, failures without specific mode stated, and improper assembly, installation, and maintenance contributed the largest numbers to the accident record. The manufacture and maintenance problem manifested itself by a wide range of errors: improper servicing, unapproved modifications, missing parts, or installation of incorrect or unapproved parts, to name several. As discussed above in the context of flight control problems, improving the quality of design, manufacturing, and maintenance processes is an important area on which to concentrate industry efforts.

In 60% of the accidents in which there was contact of the rotor blades with other parts of the aircraft structure, the aircraft was destroyed. This is not surprising because blade-aircraft contact almost always resulted in loss of part of the main rotor and control systems components. Conversely, component fatigue, material failure, and improper assembly/installation/maintenance tended to result in less severe aircraft damage, although it caused more accidents.

In summary, this analysis of airframe failure accidents indicates the following:

1. Airframe failure accidents for commercially manufactured, single-piston-engine-powered helicopters showed a decreasing trend in accidents per year and in accidents per 1,000 registered aircraft.

2. Material and assembly/installation/maintenance factors dominated the identified causes of airframe failure accidents. The large number of system or components identified to have failed and the large number of failure modes indicate many opportunities for improvement. However, no small set of problem areas appeared such that, if corrected, accident rates would decrease adequately to meet national goals.

3. The clutch from the engine to the main rotor gearbox and the tail rotor drive shaft dominated drive train component failures and led to approximately one-sixth of the airframe-related accidents.

4. The pilot was left without antitorque and directional control in over 300 of the 639 airframe-related accidents.

5.4 Summary Remarks, Conclusions, and Recommended Actions

The number of registered commercially manufactured, single-piston helicopters grew from about 540 at the end of 1957 to over 4,200 at the end of 1997. During the period from mid-1963 through 1997, this growing fleet accounted for 5,371 accidents. The NTSB grouped these accidents into 21 categories; however, as figure 43 shows, 93% of the accidents fell into 7 categories and, in fact, 4 categories accounted for 70% of the accidents.

The summary of accidents by activity and phase of operation, table 16, shows that the overwhelming number of single-piston helicopter accidents occurred during aerial application. Since crop dusting requires considerable maneuvering, it is almost a corollary that the most accidents occurred during some maneuvering operation.

Within the four top accident categories, the following are noted.

1. Loss of engine power because of improper fuel/air mixture caused 686 accidents, of which 400 were caused by fuel exhaustion, fuel starvation, or fuel contamination.

2. Loss of engine power because of engine structural failure caused 263 accidents.

3. Loss of engine power for undetermined reasons was recorded in 397 accidents.

4. In flight collision with man-made objects accounted for 696 of 953 accidents.

TABLE 16. ACCIDENTS BY ACTIVITY AND PHASE OF OPERATION—SINGLE-PISTON HELICOPTERS

Activity		Phase of operation	
Aerial application	1,494	Maneuvering	1,149
Instructional/training	976	Cruise	1,047
General utility	875	Landing	949
Personal use	787	Takeoff	889
Passenger service	421	Hover	450
Business use	338	Approach	241
Ferry/reposition	205	Descent	168
Flight/maintenance test	113	Taxi	164
Public/military use	78	Standing/static	126
Executive/corporate	75	Unknown/other	124
Unknown/not reported	9	Climb	64
Total	**5,371**	**Total**	**5,371**

5. In flight collisions with wires and wire/poles accounted for 507 accidents; only 148 accidents involved collisions with trees.

6. Loss-of-control in the vertical/yaw axes contributed to at least 235 accidents and perhaps to as many as 400 accidents.

7. Loss of control was experienced, regardless of the certification level of the PIC.

8. Drive-train failures caused 246 accidents, of which engine to transmission and tail rotor drive shaft failures contributed 169 airframe-related accidents.

9. Rotor system failures caused 181 accidents, of which the tail rotor system accounted for 124 accidents.

10. Control system failures caused 101 airframe-related accidents.

11. The pilot was left without antitorque and directional control in 307 of the 639 airframe-related accidents.

12. An autorotation took place in approximately 2,000 of the 5,371 accidents.

The top four—or seven—most common accident categories were not the accident types that caused the highest fatality rates (i.e., fatalities per 100 accidents). The worst accident severity using that measure in the single-piston helicopter fleet was midair collisions, of which there were 17 that killed 22 people. Following midair collisions, figure 44 shows, in descending order, fatalities per 100 accidents by other NTSB first event categories. Within this grouping, airframe failure, in flight collision with object, and loss of control clearly led to a high fatality rate. Note that loss of engine power, the greatest cause of accidents, had a relatively low fatality rate. Twelve of the 5,371 accidents fell in the undetermined category in which 18 people lost their lives. When ordered in terms of total fatalities as tabulated in figure 44, in flight collision with object and airframe failure accidents were the leading causes of fatalities with the single-piston helicopter fleet.

Before discussing single-turbine helicopter accidents, some observations and recommendations are in order relative to the single-piston helicopter fleet. To begin with, this class of helicopter is sold on the basis of its unique capability to hover and fly low and slow. This helicopter class has, historically, provided a cost-effective way to spray crops, to instruct students, and to generally attract first-time helicopter buyers who have found any number of new personal and utility uses for the aircraft. In the vast majority of uses, helicopter pilots operate their aircraft in a comparatively hostile environment when viewed by fixed-wing pilot standards. This environment includes many man-made obstacles.

Helicopters appear to provide some safety margin over fixed-wing aircraft because of their inherent autorotation capability (i.e., the ability to glide with turning rotor) and their generally slower power-off landing speed. These relative safety advantages are often negated, however, because helicopter pilots routinely operate their rotorcraft much closer to the ground where reaction times are minimal and emergency landing sites are generally unsuitable.

In 1997, the commercially manufactured, single-piston helicopter fleet experienced 17 accidents per 1,000 registered rotorcraft. It is projected that, by the year 2010, the annual accident rate for single-piston helicopters may still be above 5 accidents per 1,000 registered type (fig. 22). This projection assumes "a business-as-usual" approach by the rotorcraft industry. However, several steps can be taken now and in the short-term to significantly reduce this projected rate of single-piston engine helicopter accidents:

1. There is an apparent disregard by many pilots of an engine's need for clean fuel and air in proper proportions—to say nothing about the FAA regulations for fuel reserves. The fact that power-off landing proficiency is not required by the FAA in order to obtain helicopter pilot certification appears inconsistent with the number of accidents caused by loss of engine power. However, it also appears that helicopters—currently in the civil fleet—provide marginal to inadequate autorotational capability to permit the average pilot to successfully complete the final flare and touchdown to a generally unsuitable landing site. We specifically recommend the following:

    a. Reinforcement of fuel management and mission planning according to current FAA regulations be immediately initiated.

    b. Currently installed fuel quantity measurement and display systems be reexamined for accuracy and applicability to helicopter applications.

    c. Student and recurrent pilot training in full power-off autorotation to touchdown be reinstated as a pilot certification requirement.

    d. Commercial helicopter manufacturers reexamine their current and future product's autorotational capabilities with the objective of reducing height-velocity restrictions to a level consistent with average piloting skills and more representative emergency landing sites.

    e. A detailed examination of the 263 accidents caused by piston-engine structural failure be made with the intent of initiating an engine improvement program.

2. The average pilot's situational awareness of man-made objects that must be avoided is significantly impaired because most of the objects are not readily visible. Wires, in particular, are the best known threat to low flying rotorcraft. It is specifically recommend that:

    a. Flying below 750 feet (above ground level) be discouraged by the industry and regulatory agencies.

    b. All man-made objects higher than 500 feet be prominently marked and mapped, to include electronic databases such as used in Global Positioning System equipment.

    c. A low-price proximity spherical sensor be developed and certified. A sensor sphere of some large radius should, in effect, cocoon the helicopter and provide the pilot with sufficient warning to avoid obstacles.

3. Single-piston helicopters now in the registered fleet appear inordinately difficult to fly, particularly when the average pilot has to devote some attention to other tasks or is experiencing an imagined or real emergency. Cross-coupling between the vertical/power/RPM and yaw axes is excessive. The handling qualities design standards applicable to the current-helicopter fleet date back to the 1950s. Although generally tolerated, the resulting stability and control characteristics appear unsatisfactory. Therefore, it is recommended that:

a. Engine RPM management be more fully automated; preferably to the level offered with turbine engines.

b. A low-price stability augmentation system (in the yaw axis as a minimum) having at least 10% authority be developed and certified.

c. Handling quality standards for all future helicopters be raised to levels consistent with what modern technology can provide.

4. The single-piston helicopter fleet has shown that the design standards of the 1950s do not adequately address the many new and varied activities in which this aircraft class is engaged. This is particularly true because pilots do exceed design limits, required maintenance is skipped, and less than thorough inspections are performed. The current fleet appears to be under-designed relative to today's use. It is recommended that the industry:

a. Reevaluate design and certification criteria of all components involved in transmitting power from the engine to the main rotor gearbox with particular attention to clutch and freewheeling units.

b. Reevaluate design and certification criteria of all components that transmit power to the tail rotor, with particular attention to the drive shaft and couplings typical of current configurations.

c. Adopt more conservative fatigue design criteria, particularly for tail rotor blades.

On a final note about the single-piston helicopter fleet, the number of accidents per year decreased in nearly a linear manner. A representative approximation of this decrease would be from 221 accidents in 1967 to 73 in 1997. However, a significant departure from this favorable trend occurred between 1971 and 1983 when a rash of accidents created a "bubble" above the generally linear trend. It is suspected that this bubble was caused by the increase from 127 per year to 193 per year in newly registered, single-piston helicopters. The conclusion drawn offers the following cautionary note for the future: *When the next rapid expansion of the fleet occurs, the industry must increase all aspects of its safety improvement efforts, and this increase must be more than proportional to the fleet growth rate.*

6. COMMERCIAL SINGLE-TURBINE ENGINE HELICOPTERS

6.1 Fleet History and Growth

The single-turbine helicopter civil fleet began serious growth as the war in Vietnam was coming to an end. The U.S. military services were the first to demand that gas turbine technology be applied to their helicopters. With this development support, manufacturers were soon able to offer the turbine-powered helicopter to the civil marketplace. Following the single-piston helicopter trend, the single-turbine helicopter market also experienced a very real collapse in the mid-1980s. A decade later, growth in the market began again. Today the number of registered single-turbine helicopters is approximately equal to that of the single-piston fleet (fig. 45 and table D-2). Note that the FAA census (as edited by the principal author) and the count Air Track, Inc. published in their "Rotor Roster" are in reasonable agreement.

6.2 Single-Turbine vs. Single-Piston

Contrasts between single-piston and single-turbine helicopters are frequently made, with improved performance from turbine power being particularly noteworthy. With respect to accident trends, however, there are more similarities than differences between the two helicopter types. Figure 46 shows that the single-turbine helicopter reduced the single-engine helicopter accident rate per 1,000 registered aircraft relative to the single-piston helicopter. However, the trend shown in figure 46 understates the very real safety improvement obtained with single-turbine helicopters, because it is based on fleet size as the ratio's denominator. The relative safety improvement can be examined in more detail using data from the Rotorcraft Activity Survey of 1989 (ref. 17), which included the following summary taken from table 2.1 of that survey:

TABLE 17. FAA ROTORCRAFT ACTIVITY SURVEY OF 1989 (From Ref. 17)

Rotorcraft Type	Population Size	Estimate of Number Active	Estimate of Total Hours Flown [in 1989 by Active Aircraft]	Estimate of Avg. Hrs. Flown [per Yr. by Active Aircraft]
Manufacturer Built				
Piston Total (1)	3,994	2,684	728,125	277.8
Single Turbine	3,616	3,248	1,532,270	480.5
Twin Turbine	1,069	984	546,471	551.8
Turbine Total	4,685	4,232	2,078,741	496.5
Manufacturer Total	8,679	6,916	2,806,866	417.3
Amateur Built Total	1,790	572	21,830	38.2
Total – All Rotorcraft	**10,469**	**7,488**	**2,828,697**	**390.2**

The FAA concluded from these published data that the registered fleets of single-piston and single-turbine rotorcraft were comparable in size. However, the active fleet size of single-turbine helicopters outnumbered single-piston helicopters by over 20%. The survey estimated that the single-turbine helicopter fleet flew twice as many hours as the single-piston helicopter fleet (i.e., 1,532,270 vs. 728,125 hours). These differences are very important when accident rates are computed as ratios of accidents to fleet size, active fleet size, 100,000 hours flown, or departures, etc. In contrast, the number of reported accidents recorded by the NTSB is reliable for use in the numerator of any proposed ratio. It is the ratio's denominator that can be quite misleading or unreliable. This leads to considerable misgivings about accident statistics in general by the authors; this issue is discussed in appendix B.

The improved safety of single-turbine relative to single-piston is not exactly clear. The NTSB recorded during 1989 (tables D-5 and D-6) that the single-piston registered fleet of 3,920 helicopters experienced 106 accidents and the single-turbine fleet of 3,574 helicopters experienced 72 accidents.* An immediate conclusion might be that the relative safety for the two rotorcraft types in 1989 was as follows:

Single piston = 106 accidents per 3,920 registered aircraft = 27 per 1,000 aircraft

Single-turbine = 72 accidents per 3,574 registered aircraft = 20 per 1,000 aircraft.

These ratios suggest that the single-turbine helicopter was 1.34 times as safe as the single-piston helicopter in 1989. When the comparison is made using active aircraft, as estimated by the FAA in table 17 above, the comparison changes as follows:

Active single piston = 106 accidents per 2,684 active aircraft = 39.5 per 1,000 aircraft

Active single-turbine = 72 accidents per 3,248 active aircraft = 22.2 per 1,000 aircraft.

The relative safety margin of the single-turbine helicopter, in 1989, now becomes 1.78. A last comparison based on the FAA estimated hours flown in 1989 by the active rotorcraft shows the following:

Active single piston = 106 per 728,125 hours = 14.5 accidents per 100,000 hours flown

Active single turbine = 72 per 1,532,270 hours = 4.7 accidents per 100,000 hours flown.

Based on accidents per estimated 100,000 hours flown, perhaps the most common safety statistic, single-turbine helicopters appeared to be about three times safer than single-piston helicopters. At least this was the case in 1989, if the FAA data can be considered adequately reliable.

We do not suggest extrapolating this conclusion to any other year, because reliable FAA data used in the denominator do not appear to exist, as explained in appendix B.

6.3 Accident Analysis

That rotorcraft safety improved when the single-turbine-powered helicopter was introduced is hardly disputable. However, loss of engine power was still the leading NTSB first event category of the 2,247 accidents involving single-turbine helicopters recorded over 34 years, as figure 47 shows. In

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*The FAA count in their reference 17, table 2.1 is 3,994 and 3,616 respectively; but it was found that many piston-powered helicopters were listed as turbine-powered and vice versa.

fact, as the comparison in table 18 summarizes, the percentage distribution of single-turbine helicopter accidents virtually parallels that for single-piston helicopters. Reduction of in flight collision with object accidents from 18% to 13% appears as the one difference that stands out in table 18.

TABLE 18. SINGLE-TURBINE VS. SINGLE-PISTON ACCIDENT COMPARISON, 1963–1997

NTSB category	Single turbine		Single piston	
	Count	**%**	**Count**	**%**
Loss of engine power	704	31	1,554	29
In flight collision with object	298	13	953	18
Loss of control	284	12	625	11
Airframe/component/system failure or malfunction	282	12	639	12
Hard landing	140	6	483	9
In flight collision with terrain/water	143	6	443	8
Rollover/nose over	119	5	290	5
Other	227	10	384	7
Total	**2,247**	**100**	**5,371**	**100**

The trend of single-turbine helicopter accidents per year for the most frequent first event categories is shown in figures 48 and 49. This rotorcraft type experienced a severe rash of loss of engine power accidents beginning in 1978 (fig. 48). Apparently, it took 10 years to find and correct a number of problems. The *sum* of in flight collision with object *and* loss of control accidents began to rise in the same period as engine related accidents, which is shown by the heavy, solid line in figure 49. The overall picture suggests that it was not until the late 1980s that the single-turbine helicopter fleet matured, nearly 20 years after this rotorcraft type was introduced into the fleet.

The number of accidents per 1,000 registered single-turbine helicopters decreased until 1986 and then remained virtually unchanged after 1986 (fig. 46). We suspect that a plateau occurred with the single-turbine helicopter fleet. Figure 50 projects that, by the year 2010, accidents with single-turbine helicopters may only decrease to about 15 per 1,000 aircraft. The single-turbine helicopter fleet began to expand after 1993 (fig. 45). This expansion, clearly evident over the last 4 years of the study period, reflects an abrupt fleet growth of the type experienced by the single-piston helicopter fleet, as discussed earlier. Therefore, it may be that insufficient emphasis—relative to increased sales, use, and new missions—is being placed on single-turbine helicopter safety. Without a renewed emphasis on safety, the projection shown in figure 50 is quite likely to come true.

Over the last 11 years of the study, the distribution of the 841 accidents changed when compared with the distribution of the 2,247 accidents that occurred over the 34-year period. The comparative distributions are summarized in table 19. Loss of control and airframe/component/system failure or malfunction first event categories increased slightly, while loss of engine power and in flight collision with objects decreased. Although the distributions are similar, certain changes occurred which will be discussed in the detailed analyses below.

TABLE 19. SINGLE-TURBINE ACCIDENT DISTRIBUTION, LAST 11 YEARS VS. 1963–1997

First event category	1987–1997		1963–1997	
Loss of engine power	29%	(244)	31%	(704)
In flight collision with object	11%	(94)	13%	(298)
Loss of control	16%	(132)	12%	(284)
Airframe/component/system failure or malfunction	15%	(124)	12%	(282)
Hard landing	5%	(43)	6%	(140)
In flight collision with terrain/water	6%	(47)	6%	(143)
Rollover/nose over	3%	(26)	5%	(119)
Other	9%	(131)	12%	(277)
Total	**100%**	**(841)**	**100%**	**(2,247)**

6.4 Detailed Analysis by Accident Category

Of the 8,436 rotorcraft accidents, 2,247 accidents were incurred by single-turbine helicopters that were commercially manufactured. Of these, 1,568 (about 70%) fell into the top four first event categories. Therefore, a more in-depth analysis of the four top categories provides considerable insight into most of the single-turbine helicopter accidents during the 34-year period under study. The following several paragraphs and associated figures and tables provide further analysis of these top four categories.

6.4.1 Loss of Engine Power (704 Accidents)

As table 18 shows, the single-turbine helicopter and the single-piston helicopter incurred virtually the same percentage of accidents in the loss of engine power first event category during the 34-year period studied. The explanation for this (perhaps surprising) fact is that *both engine types need clean fuel and air in the correct proportions to operate and that fuel problems, especially fuel exhaustion and starvation, is as prevalent in the single-turbine as in the single-piston helicopter*. It appears many of the poor practices of pilots flying single-piston-engine-powered helicopters appears to have carried over to the operation of turbine-powered helicopters that cost over five times as much. Single-turbine helicopters have, in general, more seats than single-piston helicopters. Thus, as table D-19 enumerates, somewhat fewer numbers of people (1,846 in single-turbine vs. 2,621 in single-piston) were affected by considerably fewer accidents (704 in single-turbine vs. 1,554 in single-piston) following loss of engine power.

6.4.1.1 Overall Accident Trends. From mid-1963 through 31 December 1997, the NTSB cited loss of engine power in 704 accidents involving commercially manufactured, single-turbine helicopters. The 704 accidents directly affected 1,846 people: 129 were killed, 237 were seriously injured, and 1,480 survived with minor or no injuries (table D-25). Of the 704 helicopters involved, 139 were listed as destroyed by the NTSB, 546 were substantially damaged, and 9 received little or no damage. Figure 48 shows that the trend in loss of engine power accidents per year improved over the last 10 years of the study period. Furthermore, as an accident rate in terms of 1,000 registered aircraft, figure 51 shows that accidents initiated by the loss of engine power steadily decreased. However, as figure 51 shows, loss of engine power accidents also grew as the fleet grew, resulting in nearly a constant 30% of the accidents in the 1970s and 1980s. Since 1990, it appears that a concerted effort was made to correct poor-piloting-related accidents in this first event category.

6.4.1.2 Loss of Engine Power by Category. The NTSB cited the reason for loss of engine power in 523 of the 704 accident reports. Table D-12 shows that 18 primary reasons lay behind the 704 accidents. Figure 52 shows that when the 18 reasons are grouped by major subsystems, fuel/air mixture problems caused 299 of the 523 accidents. A closer inspection of figure 52 and the associated mini-briefs reveals that fuel exhaustion, fuel starvation, fuel contamination, etc., repeated single-piston helicopter experiences. Again, simply running out of gas was the primary reason for loss of engine power throughout the 34-year period under study.

Figure 52 and table D-12 indicate that relatively few accidents were incorrectly charged to loss of engine power by NTSB investigators.

6.4.1.3 Loss of Engine Power by Activity. The commercially manufactured helicopter, powered by a single-turbine engine, has become the backbone of the helicopter industry (ref. 16). As figure 53 shows, the greatest number of loss of engine power accidents took place during passenger service (e.g., air taxi) flights.* Agricultural operations contributed proportionally fewer loss of engine power accidents than single-piston helicopters (see fig. 25). This may reflect the fact that modern, single-turbine helicopters cost so much more than the smaller, single-piston helicopter (ref. 18).

Power-off landings in single-turbine helicopters—currently in the civil fleet—generally were no more successful than in single-piston helicopters. As table D-19 shows, there were 1,554 loss of power accidents with the single-piston helicopter; 265 (17%) were destroyed and 1,286 (83%) were substantially damaged. The corresponding statistics for the single-turbine helicopter were 704 accidents, 139 (20%) destroyed, and 546 (78%) were substantially damaged. Thus, of 2,258 single-engine (piston and turbine) loss of power accidents, all but 22 of the helicopters involved were either destroyed or substantially damaged. It appears, therefore, that (1) the average pilot proficiency in accomplishing a full power-off landing in a single-engine helicopter was quite inadequate and (2) the helicopters themselves offered marginal autorotation capability.

6.4.1.4 Loss of Engine Power by Phase of Operation. Loss of engine power occurred in every phase of operation in which the single-turbine helicopter operated, as figure 54 shows. Paralleling single-piston helicopter experience, most losses of power occurred in cruise flight, which reflects the passenger service, general aviation character of turbine helicopter use. The high power required in takeoff and hover accounted for this sub-category being the second riskiest operational phase. When the 104 accidents in takeoff are added to the 84 accidents in maneuvering and the 58 accidents in hover, 246 accidents occurred during high-power use (vs. 314 accidents during cruise). The ratio of

*This activity is still serving to expand the helicopter industry in much the same way that the public was introduced to airline transportation following World War I.

accidents that occurred during high-power flight phases to those in cruise (246/314 or 78%) is lower (78% vs. 108%), but quite comparable to that of single-piston helicopters discussed earlier.

6.4.1.5 Conclusions About Loss of Engine Power Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB from mid-1963 through the end of 1997, 2,247 were incurred by single-turbine-engine-powered helicopters that were commercially manufactured. Loss of engine power was the first event in 704, or roughly 30% of these accidents. No fewer than 299 accidents were directly traced to fuel/air mixture problems as a consequence of human error. Fuel exhaustion, fuel starvation, and fuel contamination accounted for over 151 of the 299 accidents. Apparently, despite the higher cost of single-turbine helicopters, many pilots continued to ignore the engine's need for clean fuel and air in proper proportion. Since the single-turbine helicopter is used primarily for passenger service, running out of fuel will provide the public with reasons to suspect rotorcraft safety.

The need for training and practice in full touchdown autorotations is as great for pilots of single-turbine helicopters as for pilots of single-piston helicopters. It also appears that the single-turbine helicopters that are currently in the civil fleet lack sufficient autorotational capability to permit the average pilot to successfully complete the final flare and touchdown to what is generally unsatisfactory terrain.

6.4.2 In Flight Collision with Object (298 Accidents)

Single-turbine helicopters demonstrated a 5% reduction in in flight collision with objects accidents when compared with the single-piston helicopter fleet (table 18). However, many of the trends observed about single-piston helicopters were also found in the more expensive, single-turbine helicopter fleet.

6.4.2.1 Overall Accident Trends. The NTSB implicated in flight collision with object in 298 single-turbine helicopter accidents from 1963 through 1997. These accidents affected 688 people: 140 were killed, 106 suffered serious injuries, and the remaining 442 survived with minor or no injuries. Of the 298 helicopters involved, 114 were listed as destroyed by the NTSB, 182 were substantially damaged, and 2 received little or no damage. The number of accidents per year for this first event category decreased over the last 17 years of the study period (fig. 49). However, as figure 55 shows, in flight collision with object accidents appeared to level off at a mean level of 12% of the total single-turbine helicopter accidents. In terms of annual accidents per 1,000 of the registered single-turbine helicopter fleet, little reduction occurred in the later years (fig. 55).

6.4.2.2 Collision with Object by Object Hit. The objects hit by single-turbine helicopters while in flight are listed in figure 56, which shows that wires and objects categorized as wire/pole accounted for 108 plus 24 (i.e., 132) or 45% of the 298 accidents. Pilots of single-turbine helicopters appeared more successful in avoiding objects when compared to a 55% rate for single-piston helicopters (as derived from fig. 28).

6.4.2.3 Collision with Object by Cause. The NTSB summary narratives were studied to establish each accident's major causes or conditions. This study was somewhat subjective in that frequently two or more factors were involved. This required that we proportion the cause of some accidents into several parts; the results are provided in figure 57. Single-turbine helicopter pilots caused the overwhelming number of collisions because of improper decisions, just as for single-piston helicopters (fig. 29). Improper decisions include poor planning, inadequate training, and misjudging clearances. Thus, for passenger transport operations (when helicopter safety is most visible to the public), improper pilot decisions were the most frequent NTSB-reported cause, followed by degraded visibility and winds.

6.4.2.4 Collision with Object by Phase of Operation. The single-turbine helicopter fleet experienced nearly an equal number of collisions over all flight phases (fig. 58). This contrasts with the single-piston helicopter fleet, which experienced an overwhelming number of collisions with objects while maneuvering (fig. 30). The difference appears related to the different activities in which these two helicopter classes were engaged.

6.4.2.5 Collision with Object by Activity. The NTSB mini-briefs' summary narratives were analyzed to identify the activities that resulted in accidents. The results are summarized in figure 59. Unlike single-piston helicopters (fig. 31), single-turbine helicopters were engaged in general utility and passenger service when most of the objects were struck. Single-turbine helicopters did not appear to engage in significant aerial application activities or, if they did, agricultural operations were conducted with much greater regard to safety.

6.4.2.6 Collision with Object by Part Hit. Another question regarding collision with object accidents concerns what part of the helicopter was involved in the collision. The statistics available on this subject are shown in figure 60. Tail rotor strikes occurred in 43 of the 104 single-turbine helicopter accidents in which the part hit was reported. Whether this dominates the statistics because it is noteworthy or because it is truly reflective of all of the collision with object accidents is unknown.

6.4.2.7 Conclusions About In Flight Collision with Object Accidents. Of the 8,436 rotorcraft accidents that occurred between mid-1963 and the end of 1997, 2,247 accidents involved single-turbine helicopters that were commercially manufactured. Of these, 298 (or roughly 13%) were attributed to in flight collision with objects. Even though agricultural activities constituted only a small percentage of single-turbine helicopter use (compared to single-piston helicopters), three object struck categories—wire, wire/pole, and trees—accounted for 182 accidents. Main and tail rotor strikes dominated helicopter components in the collision with object accidents. The data strongly suggest that pilots lack situational awareness of the tail rotor.

6.4.3 Loss of Control (284 Accidents)

The number of single-turbine helicopter loss of control accidents fluctuated year to year. There was an improvement relative to the single-piston helicopter fleet, but many of the same problems were just as evident.

6.4.3.1 Overall Accident Trends. Loss of control was cited by the NTSB in 284 accidents involving commercially manufactured, single-turbine helicopters. These 284 accidents directly affected 754 people: 155 lost their lives, 123 were seriously injured, and 476 survived with minor or no injuries. Of the 284 helicopters involved, 125 were listed as destroyed by the NTSB and 159 were substantially damaged, while none went undamaged. Figure 49 shows that the trend in accidents per year for this first event category steadily increased for the first 15 years of the study period. Then, beginning in 1981, loss of control accidents showed a rapid increase, reaching a peak of 20 accidents in 1984. After 1984, loss of control accidents per year dropped for nearly a decade. However, in 1997, there were again 20 accidents per year attributed to loss of control.

Loss of control accidents accounted for an erratic percentage of single-turbine helicopter accidents during the 1981 through 1997 period (fig. 61). As a rate of accidents per 1,000 registered single-turbine helicopters, accidents initiated by loss of control showed little improvement over the latter 17 years. The yearly variability in the number of accidents in this category makes statistical analysis difficult.

The long-term rate of single-turbine helicopter loss of control accidents was 3.83 per 1,000 aircraft. The rate peaked sharply in the late 1960s, and exceeded its statistical upper control limit of 12.66 in 1969. This implies some systematic change took place, perhaps related to the large-scale introduction of the single-turbine helicopter into the civil fleet which occurred during that period (see fig. 45). In addition, since the actual number of registered single-turbine helicopters was still relatively low during that time, a small change in the number of accidents resulted in a large change in the rate. However, after 1969, overall accidents per 1,000 aircraft generally decreased, with some spikes noted (fig. 61).

6.4.3.2 Loss of Control by Axis. Only 145 of the 284 mini-briefs for loss of control accidents provided information about which axis of control was lost. However, two aspects became clear when the remaining accidents were evaluated in descending order, as shown in figure 62. Two striking differences between single-turbine helicopters (fig. 62) and single-piston helicopters (figure 37) were observed. Low rotor RPM was not a serious problem with the single-turbine helicopter, at least as a contributing factor to loss of control accidents. This difference can be attributed to the better engine speed governing provided by turbine engine fuel controls. On the other hand, the single-turbine helicopter fleet suffered more loss of yaw control accidents (i.e., 75 of the 145 for which the loss of control axis was reported, or 52%). In contrast, loss of yaw control accounted for only 95 of 338 accidents (i.e., 28%) in the single-piston helicopter fleet (fig. 37). Thus, loss of yaw control was nearly twice as prevalent with single-turbine helicopters as with single-piston helicopters.

This increased percentage may be attributable to the generally higher installed power and associated higher antitorque corrections required. Alternatively, the higher percentage may be related to "loss of tail rotor effectiveness" (LTE). Although LTE was directly cited in the accident mini-briefs in only a few cases, a review of the narratives indicates that LTE was probably involved in many loss of yaw control accidents. It appears that pilots were not fully aware of the conditions conducive to LTE or had difficulty interpreting in flight information to determine whether LTE might occur.

Single-turbine helicopters experienced proportionally fewer loss of control accidents in the vertical axis than did single-piston helicopters. This may be a result of the better engine speed governing provided by turbine engine fuel controls or the higher, power-to-weight ratios in turbine helicopters, which minimizes the potential for low rotor RPM and loss of altitude control.

6.4.3.3 Loss of Control by Cause. Loss of control accidents were subdivided into which of the 24 categories brought on the control loss; figure 63 lists the top 12 categories (this information may be contrasted with single-piston helicopter experience given in fig. 36). As for piston rotorcraft, improper operation of controls again was the most prevalent factor cited by the NTSB in loss of control accidents. However, the percentage of accidents attributed to this rather vague term was somewhat lower for single-turbine helicopters (29%) than for single-piston helicopters (33%). This reduction may be attributed to the generally higher experience level of single-turbine helicopter pilots, especially since little high-risk civilian initial training was conducted in single-turbine helicopters. Loss of control accidents involving low rotor RPM were considerably reduced in single-turbine helicopters, primarily for the same reasons given for axis of control lost.

Finally, accidents involving spatial disorientation or loss of visual reference were significantly higher for single-turbine (13%) than for single-piston (3%) helicopters. This may be a result of the more frequent operations in unprepared areas that are conducted in single-turbine helicopters and the consequent higher risk for operations in degraded visual environments.

6.4.3.4 Loss of Control by Phase of Operation. Considering the phase of operation during which loss of control occurred, the accidents were first subdivided into 18 categories and then condensed into 11 key groups. As was noted for single-piston helicopters (fig. 34), loss of control occurred more frequently in single-turbine helicopters during the takeoff and hover phases than during any other single flight phase (fig. 64).

6.4.3.5 Loss of Control by Activity. The mini-briefs were reviewed to associate loss of control accidents with the activity in which single-turbine helicopters were engaged. The results are provided in figure 65. Single-turbine helicopters showed a substantially different activity distribution than did the single-piston helicopter (fig. 35). First, single-turbine helicopter accidents during passenger operations were two-and-a-half times those of single-piston helicopters. Conversely, accidents during personal use operations occurred less than half as frequently. This may be explained by the relative costs (purchase and ownership) of turbine engine-powered helicopters compared with the average purchase and ownership costs of piston-engine-powered helicopters; single-turbine helicopters being more frequently used in commercial operations than for personal pleasure or convenience. Second, figure 65 shows the far lower percentage of loss of control accidents during agricultural operations. This can be attributed to the fact that agricultural flying was a more important role for single-piston helicopters than for single-turbine helicopters.

Finally, note that no accidents related to instructional flights appear in figure 65. Little civilian initial rotorcraft flight training was conducted in single-turbine helicopters. Thus, even pilots transitioning into turbine types for the first time were, presumably, experienced in the principles and practices of helicopter flight.

6.4.3.6 Loss of Control by PIC Certification Level. The last characteristic of loss of control accidents analyzed was the reported certification level of the PIC. The results are shown in figure 66. For loss of control accidents involving single-turbine helicopters, an overwhelming majority of accidents involved PICs with commercial or higher certified ratings at the controls. This statistic supports the analysis by activities, which concluded that the difference in mission-type distribution was due to the greater use of single-turbine helicopters for commercial purposes than single-piston helicopters.

6.4.3.7 Conclusions About Loss of Control Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB from mid-1963 through the end of 1997, 2,247 involved single-turbine-engine-powered helicopters that were commercially manufactured. Of these, 284 (or roughly 13%) were attributed to loss of control.

There is little evidence that low rotor RPM was a serious problem with the single-turbine helicopter, at least as a contributing factor to loss of control accidents. This improvement, relative to the single-piston helicopter, is attributed to the better engine speed governing provided by turbine-engine fuel controls. However, loss of yaw control was nearly twice as prevalent with the single-turbine helicopter fleet as it was with the single-piston helicopter fleet. On the positive side, single-turbine helicopters experienced proportionally fewer loss of control accidents in the vertical axis than the single-piston helicopters.

There were significant differences in loss of control accidents involving single-turbine helicopters and piston-engine helicopters. Single-turbines experienced proportionally more loss of control accidents during commercial operations and fewer in training or personal use operations.

The accident rate per 1,000 registered aircraft showed an extremely high peak during the time this helicopter type was coming into wide civil aviation use. Since then, the rate shows an irregularly decreasing trend. The raw numbers of loss of control accidents jumped in the early 1980s and remained high through 1997.

6.4.4 Airframe/Component/System Failure or Malfunction (282 Accidents)

The introduction of helicopters powered by a single-turbine engine required the rotorcraft industry to engineer and manufacture an aircraft with a much higher power-to-weight ratio. Virtually every component found on the lower power, piston-engine helicopter required strengthening. Adequately designing for fatigue loads became even more important. Increased system complexity, such as adding hydraulic boosted controls, became more prevalent.

The single-turbine helicopter allowed an expanded flight envelope in speed, altitude, and maneuvering capability. Frequently, within this expanded flight envelope, operational experience showed the new aircraft to be under-designed, which required the industry to retrofit various components and parts. In addition, the industry saw that the user community had found new applications for its helicopters, and many of these new applications had not been considered in the design of first-generation, single-turbine helicopters.

6.4.4.1 Overall Accident Trends. The NTSB cited airframe/component/system failure or malfunction (again referred to from here on as airframe failure) in 282 accidents involving the single-turbine helicopter fleet during the 34-year study period. These accidents directly affected 705 people: 157 were killed, 110 were seriously injured, and 438 survived with minor or no injuries. Of the 282 helicopters involved, 111 were listed as destroyed by the NTSB, 163 were substantially damaged, and 8 received little or no damage. Figure 48 shows that the number of airframe failure accidents per year grew in a nearly linear manner during the first 17 years of the study period. This trend is a partial measure of the industry's problems as the first-generation single-turbine helicopters grew to maturity. After a peak in 1982, airframe failure accidents began to drop and than leveled off.

Following the widespread introduction of single-turbine helicopters in the early 1970s, airframe failure accidents (as a percentage of all single-turbine helicopter accidents) grew from about 10% in

1971 to over 15% in 1997 (fig. 67). Accidents per 1,000 registered single-turbine helicopters showed continuous improvement from 1972 until 1991. After 1991, however, airframe failures remained constant at about 2.5 per year per 1,000 registered single-turbine helicopters (fig. 67). This is believed to be a reflection of the increased maturity of single-turbine engine helicopter designs and the increasing familiarity of designers, manufacturers, and maintainers with this aircraft class.

6.4.4.2 Airframe Failures by Phase of Operation. The single-turbine helicopter fleet experienced the most airframe failures while in cruise (fig. 68). These 107 accidents accounted for 38% of the 282 accidents, slightly more than the single-piston helicopter fleet's 33% (fig. 40). Accidents during the maneuvering flight phase were relatively infrequent for the single-turbine helicopter. This contrasts with single-piston helicopters, which are used more extensively in aerial application activities. There were 83 accidents in the hovering and takeoff flight phases of passenger service and general utility activities (fig. 68).

6.4.4.3 Airframe Failures by Activity. Figure 69 shows that the single-turbine helicopter fleet had the most airframe failure accidents while engaged in general utility and passenger service activities. This was in sharp contrast to the single-piston helicopter fleet experience (fig. 41). As noted earlier, aerial application did not appear to be an activity for which modern single-turbine helicopters were extensively used.

6.4.4.4 Airframe Failures by System/Component. For the 282 airframe failure accidents involving commercially manufactured, single-turbine helicopters, the many detailed categories were combined into the 10 major categories shown in figure 70. These 10 categories compare directly to those for the single-piston helicopter fleet (fig. 42). When compared on a percentage basis, as presented in table 20, it becomes clear that both single-engine helicopter types experienced virtually the same airframe failure problems. If anything, single-turbine helicopters had more main rotor, fuselage, and other subsystem failures than single-piston helicopters.

It is evident from figure 70 and table 20 that the drive system—to both main and tail rotors combined—and the two rotor systems were the most significant problem areas in airframe failure accidents with the single-turbine helicopter fleet. Over 67% of the 282 airframe failure accidents were caused by transmissions, drive shafts, blades, and hub failures. As discussed earlier, the change from piston to turbine engine improved helicopter safety. It is not evident from table 20, however, that corresponding improvements to the remaining major airframe systems were achieved.

The failure mode terminology used by NTSB accident investigators is matrixed with the major rotorcraft systems in table 21 to summarize the airframe accident count. (A comparable summary for the single-piston helicopter was provided in table 8.)

TABLE 20. SINGLE-ENGINE-HELICOPTER AIRFRAME FAILURE COMPARISON, 1963–1997

Airframe major systems	Single piston		Single turbine	
	Count	%	Count	%
Drive train—main	127	19.9	49	17.3
Drive train—tail	119	18.6	54	19.1
Main rotor	57	8.9	36	12.8
Tail rotor	124	19.4	52	18.4
Control system—main	63	9.9	29	10.3
Control system—tail	38	5.9	11	3.9
Airframe (fuselage, other subsystems)	64	10.0	41	14.5
Landing gear	24	3.8	2	0.7
Engine	7	1.1	3	1.1
Undetermined/other	16	2.5	5	1.8
Total	**639**	**100**	**282**	**100**

Following the earlier discussion format used to examine the single-piston helicopter airframe failures, figure 70 offers a convenient outline from which more detail about each system/subsystem/component/part failure or malfunction can be examined. Consider first the number of accidents caused by failures in the main and tail drive trains.

6.4.4.4.1 Drive train failures by subsystem: Figure 70 shows that the drive train from the engine to the main and tail rotors was implicated in a total of 103 (i.e., 36%) of the 282 accidents involving single-turbine helicopters during the study period. Table 22 gives the number of accidents caused by lower-level-subsystem failures within the drive train.

Failure to transmit power from the engine to the main rotor gearbox accounted for 35 of the 49 main rotor drive train accidents (table 22). Failure to transmit power along the tail rotor drive shaft caused 32 of the 54 tail rotor drive train accidents charged to this subsystem. Taken together, component failures in these two subsystems caused 67 accidents. This approximately parallels single-piston helicopter experience shown in table 9.

The components most frequently failing to (1) transmit power between the engine and the main rotor gearbox and (2) transmit power from the main rotor gearbox to the tail rotor gearbox caused the number of accidents shown in table 23.

It should be noted that the clutch assembly accounted for the largest number of single-piston helicopter accidents, as enumerated in table 10. Clearly, improvement in this component's design and operation was achieved, as table 23 shows. In contrast, relatively little improvement (on a percentage basis) was achieved in the tail rotor drive shaft components.

TABLE 21. NTSB FAILURE MODE/SYSTEM MATRIX—SINGLE-TURBINE HELICOPTERS

Failure mode	Drive system	Rotor system	Control system	Airframe LG	All other	Total
Fatigue	26	21	5	17	1	**70**
Improper assembly, installation, maintenance	15	5	14	4	1	**39**
Material failure	0	30	0	0	0	**30**
Undetermined/not reported	6	6	5	7	2	**26**
Failed	15	3	1	5	0	**24**
Separated	13	3	4	1	1	**22**
Foreign object damage	8	11	0	2	0	**21**
Overload	9	0	2	0	0	**11**
Pilot action/operational issue	2	0	1	5	3	**11**
Lack of lubrication	0	6	0	0	0	**6**
Slippage	1	0	5	0	0	**6**
Disconnected	4	0	0	1	0	**5**
Blade-airframe strike	1	0	2	1	0	**4**
Delaminated/debonded	1	3	0	0	0	**4**
Bearing failure	2	0	0	0	0	**2**
Bent/binding/jammed	0	0	1	0	0	**1**
Hydraulic leak/lock	0	0	0	0	0	**0**
Total	**103**	**88**	**40**	**43**	**8**	**282**

TABLE 22. DRIVE TRAIN FAILURES BY COMPONENTS—SINGLE-TURBINE HELICOPTERS

Drive train—main	**49**
Engine to transmission drive	35
Main rotor gearbox	8
Main rotor mast	6
Drive train—tail	**54**
Tail rotor driveshaft	32
Tail rotor gearbox	22

**TABLE 23. DRIVE TRAIN MAJOR COMPONENT FAILURES—
SINGLE-TURBINE HELICOPTERS**

Engine to transmission drive	**35**
Clutch assembly	8
Freewheeling unit	9
Torsion coupling	13
Shaft	5
Tail rotor drive shaft	**32**
Driveshaft	16
Coupling	13
Hang bearing	3

The tail rotor gearbox was the second largest contributor to tail rotor drive train failures for single-turbine helicopters (table 22). Failures occurred within the gear train and its rotating components. Failures in the gearbox case and aircraft mounting points were frequently noted. The primary failure mode of drive train components was fatigue.

The basic similarity in failure modes for the single-turbine and single-piston helicopter fleets implies that general improvements in materials and component design will be applicable to and benefit both of these major rotorcraft types.

6.4.4.4.2 Rotor failures by subsystem: Figure 70 shows that the main and tail rotor systems were implicated in a total of 88 single-turbine helicopter accidents (i.e., 31% of the 282) during the period studied. The accident count of rotor system failures at a lower subsystem/component level is provided in table 24. Table 25 summarizes the accidents in relation to the prevalent failure mode for both main and tail rotors.

**TABLE 24. ROTOR SYSTEM FAILURES BY COMPONENTS—
SINGLE-TURBINE HELICOPTERS**

Main rotor	**36**
Main rotor blade	12
Main rotor hub	14
Main rotor system	10
Tail rotor	**52**
Tail rotor blades	12
Tail rotor hub	5
Tail rotor system	35

TABLE 25. ROTOR SYSTEM COMPONENTS FAILURE MODE—SINGLE-TURBINE HELICOPTERS

Subsystem/component failure mode	Main rotor blade	Main rotor hub	Main rotor system	Tail rotor blades	Tail rotor hub	Tail rotor system	Total
Foreign object damage	0	0	4	0	0	26	30
Fatigue fracture	3	9	0	6	3	0	21
Separated	3	1	0	3	0	4	11
Not reported	1	1	0	1	0	4	7
Material failure	3	1	0	0	2	0	6
Blade-airframe strike	0	0	6	0	0	0	6
Delamination	2	1	0	2	0	0	5
Improper assembly	0	1	0	0	0	1	2
Overload	0	0	0	0	0	0	0
Total	**12**	**14**	**10**	**12**	**5**	**35**	**88**

The contrast between this single-turbine helicopter experience (tables 24 and 25) and single-piston helicopter experience is provided in tables 11 and 12. For example, where main rotor blades accounted for 49% of the 57 single-piston helicopter main rotor failures, only 33% of the 36 single-turbine accidents were attributable to this component. In fact, main rotor hub failures accounted for most of this subsystem's failures for single-turbine helicopters.

Foreign object damage (FOD) to the tail rotor was a significant problem in the operation of single-turbine helicopters (table 25). In the 26 accidents, 6 involved external loads or associated equipment, 6 involved unsecured items from the aircraft cabin, 1 involved the loss of an aircraft exit hatch, 1 was caused by flight through the debris cloud of a planned motion picture production explosion, and 12 were unspecified. Approximately the same number of accidents involved the main rotor head as the main rotor blades. Fatigue, material failures, and delamination were the major blade problems that resulted in accidents, especially for the main rotor hub. This distribution is similar to that of the single-piston helicopters (table 12). However, improper assembly was a less significant problem for single-turbine helicopters. This may be the result of more stringent maintenance procedures and oversight for the more complex (and expensive) turbine fleet as opposed to that of the relatively simpler piston aircraft. As was discussed for single-piston helicopter accidents, main rotor system failures associated with blade-to-airframe strikes tended to be very severe and generally resulted in fatalities.

Finally, just as for single-piston helicopters, improvements in the design, construction, and maintenance of main rotor system components represent an important opportunity for reduction of serious helicopter accidents.

6.4.4.4.3 Control system failures by subsystem: Forty single-turbine helicopter accidents were attributed to failures or malfunctions in the main and tail rotor flight control systems (fig. 70). A breakdown to lower level subsystems/components is provided by accident count in table 26.

TABLE 26. CONTROL SYSTEM FAILURES BY COMPONENTS—SINGLE-TURBINE HELICOPTERS

Main rotor controls	**29**
Lower controls—cyclic	9
Lower controls—collective	1
Upper controls—swashplate assembly	4
Upper controls—pitch link	2
Upper controls—other	3
Hydraulic	10
Tail rotor controls	**11**
Lower controls—cable	5
Lower controls—other	1
Upper controls—swashplate assembly	2
Upper controls—pitch link	3
Upper controls—other	0
Controls—other	0

No modern single-turbine helicopter was found that uses stabilizer bar/paddle such as the "Bell bar" or the "Hiller servo-paddle." Instead, the rotorcraft industry moved to hydraulically boosted control systems. As table 13 summarizes, 12 stabilizer bar/paddle failures occurred out of 63 main rotor flight control accidents with the single-piston helicopter fleet. In a sense then, the 10 of 29 main rotor flight control accidents with the single-turbine helicopter fleet represents a substantial step backward. Nevertheless, the lower pilot workload offered by boosted controls is considered by the industry as a plus.

As was the case with single-piston helicopters, improper assembly or installation—primarily in the lower controls—was the most frequent factor identified for single-turbine helicopter flight control system failure accidents. This issue was discussed in some detail for single-piston helicopter flight control failures, and the conclusions and recommendations are equally applicable to single-turbine helicopters.

6.4.4.4.4 Airframe failures by components: Figure 70 shows that failures of the fuselage structure, landing gear, and other airframe-associated components accounted for 43 (i.e., 15%) of the 282 single-turbine helicopter accidents during the 34-year study period. Table 27 shows that tailboom failures and subsystems that support operation of other major systems (i.e., engine, etc.) were major contributors to this category. Evidently, the increase in complexity of single-turbine helicopters was accompanied by an increase in accidents. Although the percentage of airframe failures was comparable to that of single-piston helicopters' experience (table 14), decreased numbers of landing-gear-related accidents (from 24 to 2) was substantial; earlier ground resonance accidents (caused primarily by inadequate maintenance) were virtually eliminated.

TABLE 27. AIRFRAME-SPECIFIC FAILURES BY COMPONENTS—SINGLE-TURBINE HELICOPTERS

Airframe and landing gear	**43**
Landing gear	2
Tailboom	10
Other systems	6
Support assembly	6
Other systems (engine)	11
Stabilizer-horizontal	0
Miscellaneous equipment	3
Stabilizer-vertical	5

Tailboom failure caused 10 accidents, one-half of which were caused by fatigue fractures. NTSB investigators noted corrosion as a factor in very few of the fuselage component failures. The six fatigue failures associated with main gearbox support assemblies led to complete separation of main rotor gearbox and rotor system from the helicopter.

A substantial reduction in failures caused by improper assembly, installation, and maintenance was achieved with the single-turbine-helicopter fleet, as the accident count shows (table 28). This can be seen when compared with similar failures in single-piston helicopters (table 15). With that exception, fatigue failures were, on a percentage basis, quite comparable for the two helicopter types.

6.4.4.4.5. Conclusions about airframe failure or malfunction accidents: Of the 8,436 rotorcraft accidents recorded by the NTSB from mid-1963 through the end of 1997, 2,247 accidents involved commercially manufactured, single-turbine-engine-powered helicopters. Of these, 282, or 12%, were attributed to failure or malfunction of the airframe, or some system or component associated with the airframe. Drive and rotor system failures, primarily in the hover, takeoff, and cruise flight phases, accounted for 191 of the 282 accidents.

Single-turbine and single-piston helicopters show quite comparable airframe failures on a percentage basis. The engine to transmission and the tail rotor drive systems (i.e., shaft and gearbox) accounted for 89 of the 103 drive system related accidents. Main and tail rotor system failures, primarily caused by fatigue, led to an additional 88 accidents. The pilot was left without antitorque and directional control in over 125 of the 282 accidents, because a tail rotor drive train, rotor system, rotor control, or a tailboom failed or malfunctioned.

TABLE 28. AIRFRAME COMPONENTS FAILURE MODE—
SINGLE-TURBINE HELICOPTERS

Subsystem/component failure mode	Landing gear	Tail boom	Other systems	Support assy	Other systems (engine)	Stabilizer (horizontal)	Misc equip	Stabilizer (vertical)	Total
Fatigue	2	4	2	3	1	0	0	5	**17**
Improper assembly, install, maintenance	0	1	0	0	3	0	0	0	**4**
Failed	0	1	0	1	1	0	2	0	**5**
Undetermined/not reported	0	0	1	0	5	0	1	0	**7**
Material failure	0	0	0	1	0	0	0	0	**1**
Pilot action and operational issues	0	3	1	0	1	0	0	0	**5**
Disconnected/separated	0	0	2	1	0	0	0	0	**3**
Overload	0	1	0	0	0	0	0	0	**1**
Bent/binding/jammed	0	0	0	0	0	0	0	0	**0**
Total	**2**	**10**	**6**	**6**	**11**	**0**	**3**	**5**	**43**

Taking an overall look at the single-turbine helicopter accident history resulting from airframe/component/system failure or malfunction, the conclusion appears to be that fatigue caused more airframe failure accidents in single-turbine helicopters than any other single factor. Following fatigue failures, several other factors contributed in more or less equal proportions to the overall airframe failure problem.

Lubrication failures in the rotor drive systems were, on a fatal accident percentage basis, the most severe. Loss of lubrication to the gearboxes, shafts, bearings, and control systems normally resulted in, at best, a marginally controllable situation and an immediate forced landing. However, these failures were fairly rare—only 10 over the study period. Again, component fatigue was a serious problem area. There is evidence that failures caused by operational errors (e.g., intentional repeated operation of the aircraft beyond its limits) tended to result in severe accidents, both from the aircraft damage and fatality perspective. As in the case of lubrication failure, operational error accidents tended to be infrequent, but the toll was high.

6.5 Summary Remarks, Conclusions, and Recommended Actions

The registered fleet of commercially manufactured, single-turbine helicopters grew from fewer than 100 at the end of 1963 to approximately 5,000 by the end of 1997. During this period, this growing fleet had 2,247 accidents. The NTSB grouped these accidents into 21 different categories. However, as figure 71 shows, 92% of the accidents fell into eight categories and, in fact, four categories accounted for 70% of all the accidents.

A summary of these accidents by activity and phase of operation, table 29, shows that most single-turbine helicopter accidents occurred during passenger service and general utility activities. Takeoff, cruise, and landing constituted the primary operations of these activities, and that was when most accidents occurred.

TABLE 29. ACCIDENTS BY ACTIVITY AND PHASE OF OPERATION—SINGLE-TURBINE HELICOPTERS

Activity		Phase of Operation	
Passenger service	642	Cruise	633
General utility	520	Takeoff	353
Business use	209	Landing	301
Personal use	200	Maneuvering	270
Aerial application	150	Hover	247
Ferry/reposition	135	Approach	146
Instructional/training	127	Standing/static	97
Executive/corporate	97	Descent	73
Public/military use	93	Unknown/other	47
Flight/maintenance test	67	Taxi	40
Unknown/not reported	7	Climb	40
Total	**2,247**	**Total**	**2,247**

The following study findings are for the four top accident categories:

1. Loss of engine power because of improper fuel/air mixture caused 299 accidents of which 151 were caused by fuel exhaustion, fuel starvation, or fuel contamination.

2. Loss of engine power because of engine structural failure caused 189 accidents.

3. Loss of engine power for undetermined reasons was recorded in 181 accidents.

4. In flight collision with man-made objects accounted for 213 of 298 accidents.

5. In flight collisions with wires and wire/poles accounted for 151 accidents; there were only 50 collisions with trees.

6. Loss of control in yaw contributed no fewer than 75 accidents and, on a percentage basis, as many as 140 accidents.

7. Loss of directional control was nearly twice as prevalent with single-turbine helicopters as with single-piston helicopters, on a percentage basis.

8. Loss of control was experienced regardless of the PIC certification.

9. Drive train failures caused 103 accidents, of which engine to transmission and tail rotor drive shaft failures contributed 67 airframe failure accidents.

10. Rotor system failures caused 88 accidents, of which the tail rotor system accounted for 52 accidents.

11. Control system failures caused 40 airframe failure accidents.

12. The pilot was left without antitorque and directional control in 127 of the 282 airframe failure accidents.

13. An autorotation took place in about 800 of the 2,247 accidents.

The most frequently occurring accident types were not the accident types that caused the highest fatality rate (i.e., fatalities per 100 accident). The greatest risk of fatality was in midair collisions, of which 37 occurred killing 66 people. Figure 72 shows the number of fatalities per 100 accidents by NTSB first event category. Airframe failure, in flight collision with object, and loss of control accidents clearly had the highest fatality rate. Note that loss of engine power, the greatest cause of accidents, had a relatively low fatality rate. When ordered in terms of total fatalities, as tabulated in figure 72, airframe failures were the leading cause of fatalities with the single-turbine helicopter fleet.

Before discussing twin-turbine helicopter fleet accidents, several observations and recommended actions relative to the single-turbine helicopter fleet can be set forth. Unquestionably, single-turbine helicopters have an improved safety record over that of single-piston helicopters. The most reliable evidence, gathered in 1989, suggests that the improvement amounts to a reduction by a factor of 3 in accidents per 100,000 fleet flight hours (i.e., 14.5 single-piston helicopter accidents per 100,000 flight hours vs. 4.7 single-turbine helicopter accidents per 100,000 flight hours).

This safety improvement is impressive, but there is little evidence suggesting that single-turbine and single-piston helicopters differ in the distribution of first event accident cause. For example, loss of engine power was the first event in approximately 30% of the accidents for both types of helicopters. Fuel exhaustion, fuel starvation, or fuel contamination were just as prevalent with each helicopter type, on a percentage of total accidents basis. The apparent disregard by many pilots of the engine's need for clean fuel and air in proper proportions (to say nothing about the FAA regulations for fuel reserves) was just as characteristic of the single-turbine helicopter fleet as it was of the single-piston helicopter fleet. Despite the different types of activities in which the two single engine helicopter types engaged, loss of control in yaw was equally likely, on a percentage of total accidents basis. However, there were considerably fewer in flight collisions with man-made objects with the single-turbine helicopter, probably because single-turbine helicopters were less frequently used in agricultural operations.

In 1997, there were 15 accidents per 1,000 registered commercially manufactured, single-turbine helicopters, a rate similar to that of the average of 18 accidents per 1,000 aircraft from 1986 through 1996. However, the single-turbine helicopter experience virtually paralleled that of the single-piston helicopter (on a percentage of total fleet basis). Therefore, it is projected that little improvement will occur by the year 2010 if no more than “a-business-as-usual” effort is made by the rotorcraft industry. Therefore, it is recommended that all but one of the several specific corrective actions for single-piston helicopters (sec. 5.4) be directly applied to the single-turbine helicopter fleet. The one exception is automated RPM control already incorporated in turbine engine fuel control systems.

On a final note, single-turbine helicopter accidents per year increased slightly over the last decade of the period studied: there were 62 accidents in 1987, 65 in 1993, and 73 in 1997, during which time the registered single-turbine helicopter fleet increased only modestly in size. Most recently, new single-turbine helicopters were being registered at a rate comparable to that of the 1970s. There is concern, therefore, that a rapid fleet expansion will prompt an increase in accidents just as it did with the single-piston helicopter fleet. For this reason, it is recommended that more intensive safety improvement efforts be quickly initiated by the industry.

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7. COMMERCIAL TWIN-TURBINE ENGINE HELICOPTERS

7.1 Fleet History and Growth

Helicopters powered by two turbine engines were introduced into the civil fleet in 1961. At that time, several helicopter airlines operated scheduled mail and passenger service. Each hoped that Sikorsky S-61s, S-62s, or Vertol 107s would dramatically lower their operating costs from the level experienced using the piston-powered Bell 47s, Sikorsky S-51s, S-55s, S-58s, and Vertol V-44Bs.* In fact, the introduction of twin-turbine helicopters was not immediately followed by great demand and the civil fleet grew relatively slowly (fig. 73). In the early 1970s, following a number of widely publicized, high-fatality accidents, and the termination of government mail subsidies, the Part 121 helicopter airlines ceased operations. In 1972, Bell began delivering its 212 series (based on the military UH-1N), followed shortly by Aerospatiale's SA-330J Puma series and MBB's BO-105 series. Sikorsky's S-76 series became available in 1977 and by 1980 Boeing Vertol offered its 40–45 passenger Model 234, based on the U.S. Army's CH-47 Chinook. This significant growth in the twin-turbine helicopter fleet during the 1980s was fueled by primarily corporate and offshore oil customers. However, after almost 40 years and substantially improved twin-turbine-powered helicopters, a flourishing scheduled helicopter airline industry in the U.S. has yet to be established.

7.2 Twin turbine vs. Single turbine

Twin-turbine-engine helicopters were developed for two reasons. First, in many cases, no single-turbine engine of sufficient power was available to meet the payload requirements of larger helicopters. Second, there was an industry-wide perception that two engines would improve safety. This perception is potentially misleading, if not even false, whenever the twin-engine helicopter is unable to continue flight with one engine inoperative. Fortunately, modern twin-engine helicopters offer adequate one-engine-inoperative performance.

Twin-turbine helicopters demonstrated further improvement in annual accidents per 1,000 registered aircraft when compared with single-turbine helicopters (fig. 74). Although this statement may not apply to the first 15 years of its civil use, experience since 1990 seems indisputable. Twin-turbine accidents plateaued during the 1990s suggesting that 10 accidents per 1,000 registered aircraft might be a minimum, given current technology and operations. This might, however, be an unfortunate conclusion based on figure 74.

The distribution, over the NTSB's 21 first event categories, of the 302 twin-turbine accidents over the 34-year period of this study is provided in figure 75. Loss of engine power ceased to be the leading accident factor for helicopters powered by two turbine engines. Rather, the 302 accidents in this rotorcraft class were dominated by airframe and system failures. Twin-turbine helicopters also experienced a significantly different accident first event category distribution than did the single engine (piston or turbine) helicopter fleet. This point is illustrated in table 30.

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*Reference 19 notes that this early experience with piston-powered helicopters operating in a mail, freight, and passenger carrying mode was anything but profitable for Chicago Helicopter Airways, Los Angeles Airways, and New York Airways, and later San Francisco and Oakland Helicopter Airlines.

TABLE 30. SINGLE-TURBINE VS. TWIN-TURBINE ACCIDENT DISTRIBUTION COMPARISON, 1963–1997

NTSB category	Single turbine		Twin Turbine	
	Count	%	Count	%
Loss of engine power	704	31	39	13
In flight collision with object	298	13	43	14
Loss of control	284	12	40	13
Airframe/component/system failure or malfunction	282	12	89	29
Hard landing	140	6	8	9
In flight collision with terrain/water	143	6	16	5
Rollover/nose over	119	5	4	1
Other	277	12	63	21
Total	**2,247**	**100**	**302**	**100**

The top four first event accident categories remained the same for the two helicopter classes, as table 30 shows; but a different order appeared. Engine malfunctions and airframe failures reversed themselves on a percentage basis. The top four categories accounted for 70% of the accidents for each helicopter type, but the remaining categories were quite different. For example, "other" increased from 10% to 21% (with more detail provided by comparing figure 75 to figure 47). A more meaningful comparison on a percentage basis (fig. 76) shows that in 17 first event categories, twin-turbine helicopter accidents exceeded single-turbine helicopter accidents. Although gear collapsed might easily be reclassified as an airframe failure, the differences in on ground/water collision with object, propeller/rotor contact to person, and fire/explosion are of concern.

7.3 Accident Analysis

Twin-turbine helicopter accident trends are shown in figure 77. Since 1992, a favorable trend occurred in the top four categories as a group. Accidents in the other 17 categories were randomly distributed, averaging 3 to 4 a year. Table 31 contrasts twin-turbine accident counts from 1992 through 1997 with the entire 34-year study period. On a percentage basis, only minor changes appear evident.

The overall picture suggests that the twin-turbine helicopter demonstrated its maturity in civil operations by the very early 1990s, approximately 15 years after second-generation models, such as Bell 212s, Aerospatiale's SA-330J Puma, and MBB's BO-105 became operational. Based on the 12 years from 1985 through 1997, it appears that yearly twin-turbine helicopter accidents per 1,000 registered aircraft will drop below 5 per year by 2010 (fig. 78). The implication is that the 1991–1997 rates do not represent a minimum, as figure 74 might suggest, but rather a broad point in the 12-year experience.

TABLE 31. TWIN-TURBINE ACCIDENT DISTRIBUTION, LAST 5 YEARS VS. 1963–1997

NTSB category	1992–1997		Last 34 years	
	Count	**%**	**Count**	**%**
Loss of engine power	14	10	39	13
In flight collision with object	19	13	43	14
Loss of control	21	15	40	13
Airframe/component/system failure or malfunction	39	27	89	29
Hard landing	3	2	8	3
In flight collision with terrain/water	11	8	16	5
Rollover/nose over	1	1	4	1
Other	35	25	63	21
Total	**143**	**100**	**302**	**100**

7.4. Detailed Analysis by Accident Type

Commercially manufactured, twin-turbine helicopters accounted for 302 of the 8,436 rotorcraft accidents. Approximately 70% were associated with four first event categories, paralleling single-engine helicopter experience. Therefore, a more in-depth analysis of the four top categories provides considerable insight into the differences between single and twin configurations from 1963 through 1997. The next several paragraphs analyze these top four categories in some depth, even though 302 accidents is a relatively small sample of experience from which to infer trends.

7.4.1 Loss of Engine Power (39 Accidents)

As table 30 shows, introduction of twin-turbine helicopters to the civil fleet dramatically reduced the percent of loss of engine power accidents from 31% to 13%. However, table 32 suggests that a very disturbing trend began when larger helicopters capable of carrying more people were introduced: any serious accident affects more people and likely receives greater attention by the public. This trend exactly parallels the situation faced by the fixed-wing industry as they moved from the 1920s Ford Tri-motor to modern day, large jet airliners, such as the Boeing 747.

TABLE 32. FATALITIES PER 100 ACCIDENTS BY TYPE OF ENGINE, 1963–1997

Engine type	Loss of engine power accidents	Fatalities	Fatalities per 100 accidents
Single piston	1,554	106	7
Single turbine	704	129	18
Twin turbine	39	16	41

7.4.1.1 Overall Accident Trends. From 1963 through 1997, loss of engine power was the first event in 39 of the 302 accidents involving twin-turbine helicopters. The 39 accidents directly affected 140 people; 16 were killed, 26 were seriously injured, and 98 survived with minor or no injuries. Of the 39 helicopters involved, 13 were listed by the NTSB as destroyed, 21 were substantially damaged, and 5 received little or no damage. Twin-turbine helicopter yearly accidents per 1,000 registered aircraft remained relatively constant from 1990 through 1997 (fig. 74). A contributing factor to this apparent plateau was the increase in loss of engine power accidents, as shown in figure 79.

7.4.1.2 Loss of Engine Power by Category. The NTSB cited the reason for loss of engine power in 33 of the 39 accidents. Table D-12 lists 18 primary reasons for the 39 accidents, and figure 80 groups them by major subsystems. Fuel/air mixture problems caused 17 of the 33 accidents. A closer inspection of figure 80 and the associated mini-briefs reveals that fuel exhaustion, fuel starvation, fuel contamination, etc. were, on a percentage basis, just as prevalent with twin-turbine helicopters as with single-piston and single-turbine helicopters.

Total or partial loss of engine power is a key issue for twin-engine-powered helicopters. Pilots of twin-turbine helicopters, faced with performing a total power-off landing, appeared no more successful at the task than pilots of single-engine helicopters. From 1963 through 1997, 23 of the 39 accidents (i.e., nearly 60%) began with a total loss of power from both engines. In fact, even with partial loss of power in 16 of the 39 accidents, 5 helicopters were destroyed, 10 received substantial damage, and only 1 was landed with minor damage.

Pilot proficiency in accomplishing total or partial power-off landings appears insufficient. A possible explanation is that the chances of a dual-engine failure are perceived to be very low and, in many cases, the approved aircraft flight manual does not permit touchdown autorotations. If power-off landings are practiced at all, they are practiced in simulators of questionable fidelity.

7.4.1.3 Loss of Engine Power by Activity. Most twin-turbine helicopter loss of power accidents occurred during passenger service and general utility activities (fig. 81). The twin-turbine configuration allowed the rotorcraft industry to expand passenger service beyond the capability provided by single-turbine helicopters (ref. 16). This, in many ways, is how the public was introduced to airline transportation when single- and multi-engine airplanes from World War I were converted from military to civilian use.

7.4.1.4 Loss of Engine Power by Phase of Operation. Loss of engine power was experienced during every flight phase (fig. 82). Although most (13) occurred in cruise flight, high-power operations (low-speed/low-altitude maneuvering, takeoff, and hover), taken together, accounted for 18 loss of engine power accidents. Neither single-piston (see fig. 26) nor single-turbine helicopters (see fig. 54) had the same pattern of loss of engine power accidents in high-power situations vs. cruise.

7.4.1.5 Conclusions About Loss of Engine Power Accidents. Of the 8,436 rotorcraft accidents recorded between mid-1963 and the end of 1997, 302 involved commercially manufactured, twin-turbine helicopters. Of the 302 accidents, 39, or roughly 13%, of these accidents were attributed to partial (16) or total (23) loss of engine power. No fewer than 17 accidents, roughly 44%, were directly traced to fuel/air mixture problems paralleling experiences of both single-piston and single-turbine helicopters. However, there have been relatively few loss of engine power accidents with twin-turbine helicopters. Therefore, statistically meaningful trends remain open to question.

7.4.2 In Flight Collision with Object (43 Accidents)

The twin-turbine helicopter fleet demonstrated no reduction (on a percentage basis) of in flight collision with objects accidents when compared with the single-turbine helicopter fleet (table 30). Furthermore, many of the trends observed about single-turbine helicopters were also found with the more expensive twin-turbine helicopters.

7.4.2.1 Overall Accident Trends. The NTSB implicated in flight collision with object in 43 twin-turbine helicopter accidents from 1963 through 1997. These accidents affected 175 people: 35 received fatal injuries, 29 suffered serious injuries, and the remaining 111 survived with minor or no injuries. Of the 43 helicopters involved, 16 were listed by the NTSB as destroyed, 25 were substantially damaged, and 2 received little or no damage. As figure 83 shows, in flight collision with object accidents leveled off at about 12% of twin-turbine helicopter accidents, but with significant year-to-year variability. From 1987 through 1997, the trend was one to two accidents per year per 1,000 registered aircraft.

7.4.2.2 Collision with Object by Object Hit. Figure 84 shows that pilots of twin-turbine helicopters were—on a percentage basis—nearly as prone to hitting wires and trees as pilots of single-engine helicopters (see figs. 28 and 56). What stands out in figure 84 are the 12 collisions associated with airport/helipad facilities. Upon reviewing the 12 mini-briefs listing these collision with object accidents, nine objects were protuberances around the heliport (six on offshore oil rig platforms, one stairwell at a hospital, one crane at a building site, one jetway gate). A tail rotor was swung into a hanger, a barge rising and falling was an inadequate heliport, and the object was unspecified in the last mini-brief reviewed.

7.4.2.3 Collision with Object by Cause. Figure 85 shows that improper pilot decision-making was the cause of most collision with object accidents, although more than one factor was often involved. This required proportioning one accident into part causes. The corresponding interpretation of the results for single-engine helicopters is provided in figures 57 and 29. Improper decision includes poor planning, inadequate training, and misjudging clearances.

7.4.2.4 Collision with Object by Activity. The twin-turbine helicopter fleet rapidly became the helicopter of choice for passenger transport operations. Thus, it is not surprising that 44% of 43 accidents occurred during passenger service activity (fig. 86). Note that ferry and repositioning accounted for another 16% of the 43 accidents.

7.4.2.5 Collision with Object by Phase of Operation. Figure 87 shows that operation during takeoff and landing accounted for a total of 21 of the 43 accidents. Preparations prior to takeoff, such as taxi and hover, accounted for another 11 accidents. Actual cruise flight was a relatively low-risk phase of operation.

7.4.2.6 Collision with Object by Part Hit. The NTSB mini-briefs provided information about the part of the helicopter that struck the object in only 14 cases. For those 14 examples, 75% were tail rotor strikes (fig. 88). Only four cases of main rotor strikes were noted.

7.4.2.7 Conclusions About In flight Collision with Object Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 302 accidents involved commercially manufactured, twin-turbine helicopters. Of the 302 accidents, 43, or roughly 14%, were attributed to in flight collision with object. This experience directly parallels single-turbine helicopter experience when compared as a percentage of total accidents.

Most collisions occurred while the twin-turbine helicopter was engaged in passenger service to and from offshore oil rigs. There were 13 wire-strike accidents and 12 objects attached to the airport/helipad landing site were struck. Limited data suggest that twin-turbine helicopters were at least twice as prone to tail rotor strikes as main rotor strikes.

7.4.3 Loss of Control (40 Accidents)

Twin-turbine helicopters constituted only about 10% of the total rotorcraft fleet in 1997. Thus, as might be expected, the number of loss of control accidents involving twin-turbine helicopters was a small fraction of the total number of loss of control accidents—a little over one per year. The number of twin-turbine helicopter accidents in this first event category grew slowly and irregularly as the twin-turbine fleet increased.

7.4.3.1 Overall Accident Trends. The NTSB cited loss of control as the first event in 40 twin-turbine helicopter accidents of the 302 total (13%) from 1963 through 1997. The number of accidents by year (fig. 89) appears nearly random, both as a percentage of total annual accidents and in annual accidents per 1,000 registered twin-turbine helicopters. Long term, there were 3.93 accidents per 1,000 aircraft, quite similar to the single-turbine helicopter rate of 3.83 per 1,000 aircraft. Although the twin-turbine helicopter rate showed considerable variation about its mean since the mid-1970s, the rate remained generally below the rate of the total rotorcraft fleet. This highlights the importance of increased safety efforts as new aircraft types are introduced.

7.4.3.2 Loss of Control by Axis Lost. Figure 90 shows that the axis about which control was lost was not identified in 20 of the 40 accidents. The available data indicate that loss of control was nearly equally distributed about all axes. Unlike single engine helicopters, yaw coupled with vertical was not an obvious problem.

Because of the small number of twin-turbine helicopter loss of control accidents, the differences between twin-turbine and single-turbine helicopters (see fig. 62) may not be significant. The proportionally lower number of unknown/not reported accidents for the twin-turbine helicopter fleet may be related to the more thorough accident investigations required for high-cost aircraft and the higher proportion of fatalities in twins. Otherwise, it remains evident that loss of control accidents involved all aircraft axes.

7.4.3.3 Loss of Control by Cause. As was done for single-piston and single-turbine helicopters (figs. 36 and 62, respectively), the loss of control accidents for twin-turbine helicopters were subdivided by cause. The results are shown in figure 91.

Again, because of the small number of twin-turbine helicopter loss of control accidents, statistical comparison with overall rates or with the accident history of any other rotorcraft type is premature. However, some qualitative observations can be made. First, improper operation of controls was not the clearly leading precipitating event in loss of control for twin-turbine helicopters as it was for single-piston or single-turbine helicopters. This may be a result of the higher experience level of the pilots involved, the preference for multi-pilot operations, or the more general use of stability augmentation systems. The relatively increased importance of flight control failure may reflect the increased dependence on control augmentation; if the control system malfunctions, the chance for an accident increases. The proportionally greater incidence of accidents attributed to loss of visual references and/or spatial disorientation may be a result of more planned operations into instrument meteorological conditions or in other degraded visual conditions.

7.4.3.4 Loss of Control by Phase of Operation. The 40 accidents fell into 11 phase of operation categories (fig. 92). The distribution of loss of control accidents for twin-turbine helicopters appeared distinctively different from the distributions for single-engine helicopters (see figs. 34 and 64). However, the small number of twin-turbine helicopter accidents makes direct statistical comparison problematical. The two most obvious differences were (1) the relatively low percentage of accidents that occurred in hover, 12.5% for twin-turbine helicopters and 23% for the single-engine helicopter fleet; and (2) the relatively higher percentage of accidents that occurred in the traffic pattern or approach phases of flight, 24% for twins and 12% for singles. Improved hover controllability may be credited to the wider use of stability augmentation systems in the twin-turbine helicopter class or, perhaps, better inherent stability with the generally greater size of these aircraft. With respect to the increased percentage of approach accidents, there was a broad range of contributory factors. For the seven traffic-pattern/approach accidents, two were attributed to FOD, two to downwind approaches, and one each to pilot impairment because of alcohol, a cyclic flight control failure, and spatial disorientation.

7.4.3.5 Loss of Control by Activity. The frequency distribution of activities that resulted in loss of control accidents is shown in figure 93. For the twin-turbine helicopter, it was found that the general utility activity was primarily emergency medical service (EMS) missions. Air passenger operations, along with ferry and reposition activities, showed accidents in similar proportions to single-turbine helicopter experience (see fig. 65). These data point out the preferential use of turbine helicopters for commercial passenger transportation. The discussion presented regarding the relative use of single-turbine and piston-powered helicopters for personal and instructional missions applies to twins as well.

7.4.3.6 Loss of Control by PIC Certification Level. All loss of control accidents involving twin-turbine helicopters, for which a PIC certification level was stated, involved pilots with commercial or higher ratings. Therefore, a figure comparable to that for the single engine helicopters (figs. 38 and 66) is not included.

7.4.3.7 Conclusions About Loss of Control Accidents. Of the 8,436 rotorcraft accidents recorded by the NTSB during the 34-year period from mid-1963 through the end of 1997, 302 accidents involved commercially manufactured twin-turbine helicopters. Of these, 40 (or roughly 13%) were attributed to loss of control. This directly parallels single-turbine helicopter statistics as a percentage of total accidents.

Loss of control was relatively evenly distributed about all axes. Where pilots of single-engine helicopters clearly experienced loss of yaw control, the electronic stability and control augmentation offered with twin-turbine helicopters appears to have considerable benefit.

No single problem (nor small set of problems) can be identified, which, if solved, would immediately reduce the accident rates in this first event category. However, the "spikes" in the annual accident numbers and rates (which occurred when second-generation, twin-turbine helicopters were introduced into the civil fleet) reinforce the observations made for the single-turbine helicopter: it is absolutely necessary to understand the possible consequences of introducing new aircraft types (e.g., civil tilt rotor) and ensure that the entire aviation system (design, manufacture, training, professional development, use, etc.) is prepared to address the resulting systematic changes.

7.4.4 Airframe/Component/System Failure or Malfunction (89 Accidents)

With few exceptions, modern, twin-turbine helicopters evolved from successful, single-turbine designs. Manufacturers "simply" added an engine, redesigned associated components/systems and incorporated other product improvements derived from single-engine helicopter field experience. No major configuration changes in drive train or rotor systems appear to have been made, although more advanced materials were substituted in many cases. With a comparatively small fleet having accumulated relatively few flight hours, it is probably premature to assess the effects of all of the changes made in progressing from the single- to the twin-turbine helicopter. Furthermore, 89 airframe failure accidents is a small number from which to draw major conclusions.

7.4.4.1 Overall Accident Trends. The NTSB cited airframe/component/system failure or malfunction (again referred to from here on as airframe failure) in 89 twin-turbine helicopter accidents from 1965 through 1997. These relatively few accidents took a large toll however (table D-26). The accidents directly affected 452 people: 148 were killed in 27 accidents, 37 were seriously injured, and 267 survived with minor or no injuries. Of the 89 helicopters involved 34 were listed by the NTSB as destroyed, 40 were substantially damaged, and 15 received little or no damage.

Airframe failures accounted for a higher proportion of twin-turbine helicopter accidents (29.5% of 302) than for accidents involving single-piston (12.8% of 2,247) or single-turbine (11.7% of 5,371) helicopters. This is primarily because of a lower proportion of loss of engine power accidents with the twin-turbine helicopter fleet. Figure 94 suggests that accident rates in this first event category decreased, both as a percentage of total accidents and per 1,000 registered aircraft. It is believed that many airframe failure accidents reflect the twin-turbine helicopter fleet's relative immaturity.

7.4.4.2 Airframe Failures by Phase of Operation. Fifty-two percent of the airframe failures experienced by twin-turbine helicopters occurred in cruise (fig. 95). The accident distribution by phase appears consistent with twin-turbine helicopter passenger carrying service. However, takeoff and climb-out (when taken together) accounted for 24 accidents.

7.4.4.3 Airframe Failures by Activity. Figure 96 shows that most airframe failure accidents involving twin-turbine helicopters occurred while those aircraft were engaged in passenger service activities. Note that ferry and repositioning accident experience with the twin-turbine helicopter was, percentage wise, similar to that of the single-engine helicopter fleet (see figs. 41 and 69). Twin-turbine helicopters do not appear to be engaged in significant aerial application operations a sharp contrast to the single-engine helicopter fleet experience examined in figure 41.

7.4.4.4 Airframe Failures by System/Component. The 89 airframe failure accidents were grouped into 10 major categories (fig. 97). These 10 categories compare directly with those used for the single-piston and single-turbine helicopter fleets (see figs. 42 and 70, respectively). When compared on a percentage basis (table 33), it is clear that single-engine helicopter types and twin-turbine helicopters experienced virtually the same airframe failure problems. The significant reduction in tail rotor blade and hub failures was promising. It should be remembered that these comparative data are based on experience with a relatively small fleet of twin-turbine helicopters.

TABLE 33. HELICOPTER AIRFRAME FAILURE COMPARISON, 1963–1997

Airframe major systems	Single piston		Single turbine		Twin turbine	
	Count	**%**	**Count**	**%**	**Count**	**%**
Drive train—main	127	19.9	49	17.3	13	14.6
Drive train—tail	119	18.6	54	19.1	19	21.3
Main rotor	57	8.9	36	12.8	19	21.3
Tail rotor	124	19.4	52	18.4	10	11.2
Control system—main	63	9.9	29	10.3	11	12.3
Control system—tail	38	5.9	11	3.9	7	7.9
Airframe (fuselage, other subsystems)	64	10.0	41	14.5	8	9.0
Landing gear	24	3.8	2	0.7	2	2.2
Engine	7	1.1	3	1.1	0	0
Undetermined/other	16	2.5	5	1.8	0	0
Total	**639**	**100**	**282**	**100**	**89**	**100**

It is evident from figure 97 and table 33 that failures in the drive system (to both main and tail rotors combined) and in the two rotor systems caused most of the airframe failure accidents with the twin-turbine helicopter fleet. Over 68% of these 89 airframe failure accidents were caused by problems in transmissions, driveshafts, rotor blades, and hubs. This percentage virtually duplicates that of the single-turbine helicopter fleet. As discussed earlier, the change from single- to twin-turbine engines apparently improved helicopter safety (for example, see fig. 74). It is not evident from table 33, however, that corresponding improvements in the remaining major airframe systems were achieved.

Accident counts by failure mode matrixed with the major rotorcraft systems are provided in table 34. (Comparable summaries for single-engine helicopters are shown in tables 8 and 21). Fatigue failures in both drive and rotor systems were just as prevalent in the twin-turbine helicopter fleet as in the single-turbine fleet. Note also that accidents caused by damage inflicted by foreign objects were nearly as prevalent.

Figure 97 will be used as the outline from which more detail about each system/subsystem/component/part failure or malfunction is examined. This duplicates the summary data presentation for single-piston (fig. 42) and single-turbine helicopter (fig. 70) airframe failures. Consider first the main and tail drive train failures.

TABLE 34. NTSB FAILURE MODE/SYSTEM MATRIX—TWIN-TURBINE HELICOPTERS

Failure mode	Drive system	Rotor system	Control system	Airframe LG	Total
Fatigue	13	13	4	3	**33**
Improper assembly, installation, maintenance	3	1	7	3	**14**
Material failure	3	2	2	0	**7**
Undetermined/not reported	1	4	1	1	**7**
Failed	1	3	2	0	**6**
Separated	5	0	0	0	**5**
Foreign object damage	1	4	0	0	**5**
Overload	2	0	0	2	**4**
Pilot action/operational issue	1	1	0	1	**3**
Lack of lubrication	1	0	1	0	**2**
Slippage	0	1	0	0	**1**
Disconnected	0	0	1	0	**1**
Blade–airframe strike	1	0	0	0	**1**
Total	**32**	**29**	**18**	**10**	**89**

7.4.4.4.1 Drive train failures by subsystem: The drive train from the engine to the main and tail rotors was implicated in 32 (i.e., 36% of the 89) twin-turbine helicopter accidents during the study period (fig. 97). The distribution of accident count to a lower drive train subsystem level is provided in table 35. Failure to transmit power from the engine to the main rotor gearbox accounted for 6 of the 13 main rotor drive train accidents. Failure to transmit power along the tail rotor drive shaft caused 17 of the 19 tail rotor drive-train accidents. Taken together, the components in these two subsystems caused 23 of the 32 drive-train-related accidents. The number of tail rotor drive shaft failures was excessive when compared with that of the single-turbine helicopter fleet (refer to table 23).

Table 36 shows accidents caused by components that most frequently failed to (1) transmit power between the engine and the main rotor gearbox, and (2) transmit power from the main rotor gearbox to the tail rotor gearbox. Apparently, clutch assembly and freewheeling unit design and operation improvements were made. It also appears that, tail rotor drive shaft and associated components remain relatively unimproved. It should be noted, however, that many of the fleet's twin-turbine helicopters were, in fact, derived by simply "twinning" an earlier single-turbine model, an evolutionary process that attempted to modify the basic design as little as possible.

TABLE 35. DRIVE-TRAIN FAILURES BY COMPONENTS—TWIN-TURBINE HELICOPTERS

Drive train—main	**13**
Engine to transmission drive	6
Main rotor gearbox	4
Main rotor mast	3
Drive train—tail	**19**
Tail rotor drive shaft	17
Tail rotor gearbox	2

TABLE 36. DRIVE-TRAIN MAJOR COMPONENT FAILURES—TWIN-TURBINE HELICOPTERS

Engine to transmission drive	**6**
Clutch assembly	0
Freewheeling unit	0
Torsion coupling/input shaft	6
Tail rotor drive shaft	**17**
Drive shaft	8
Coupling	5
Hangar bearing	4

7.4.4.4.2 Rotor failures by subsystem. Figure 97 shows that the main and tail rotor systems were implicated in 29 (or 33%) of the 89 twin-turbine helicopter accidents during the study period. Accidents caused by rotor system failures distributed to a lower subsystem/component level is provided in table 37. Fatigue was the prevalent failure mode for both main and tail rotors (table 38). Foreign object damage to the tail rotor (a significant problem in the operation of single-turbine helicopters, as table 25 shows) was not a major factor in twin-turbine helicopter accidents.

TABLE 37. ROTOR SYSTEM FAILURES BY COMPONENTS—TWIN-TURBINE HELICOPTERS

Main rotor	**19**
Main rotor blade	7
Main rotor hub	7
Main rotor system	5
Tail rotor	**10**
Tail rotor blades	7
Tail rotor hub	0
Tail rotor system	3

TABLE 38. ROTOR SYSTEM COMPONENTS FAILURE MODE—TWIN-TURBINE HELICOPTERS

Component failure mode	Main rotor blade	Main rotor hub	Main rotor system	Tail rotor blade(s)	Tail rotor hub	Tail rotor system	Total
Fatigue fracture	4	4	0	4	0	0	**12**
Separated	1	0	1	2	0	0	**4**
Foreign object damage	0	0	3	0	0	1	**4**
Undetermined/not reported	0	1	0	0	0	2	**3**
Improper assembly	0	2	0	0	0	0	**2**
Material failure	1	0	0	1	0	0	**2**
Overload	1	0	0	0	0	0	**1**
Blade–airframe strike	0	0	1	0	0	0	**1**
Delamination	0	0	0	0	0	0	**0**
Total	**7**	**7**	**5**	**7**	**0**	**3**	**29**

7.4.4.4.3 Control system failures by subsystem: Eighteen twin-turbine helicopter accidents were attributed to failures or malfunctions in the main and tail rotor flight control systems (fig. 97). A breakdown of the accident count to lower-level subsystems/components is provided in table 39.

As with single-engine helicopters, improper assembly or installation—primarily in the lower controls—was the most frequently identified factor in twin-turbine flight control system failure accidents. This issue was discussed in some detail for single-piston helicopter flight control failures (refer to table 13) and the conclusions and recommendations are equally applicable to twin-turbine helicopters.

7.4.4.4.4 Airframe specific failures by components: Figure 97 shows that failures of the fuselage structure, landing gear, and other airframe-associated components accounted for 10 of the 89 twin-turbine helicopter accidents during the study period. Subsystems that support operation of other major systems (e.g., engine), and the other systems themselves accounted for 6 of the 10 accidents. The failure mode of the major subsystems listed in table 40 was improper assembly and fatigue in 6 of the 10 accidents.

7.4.4.4.5 Conclusions about airframe failure or malfunction accidents: Twin-turbine engine powered helicopters accounted for 302 of the 8,436 rotorcraft accidents recorded by the NTSB from mid-1963 through 1997. Of these, 89, or roughly 29%, involved airframe/component/system failure or malfunction. This was nearly twice the accident rate of single-engine helicopters when compared as a percentage of total accidents.

TABLE 39. CONTROL SYSTEM FAILURES BY COMPONENTS—TWIN-TURBINE HELICOPTERS

Main rotor controls	**11**
Lower controls—cyclic	3
Lower controls—collective	0
Upper controls—swashplate assembly	2
Upper controls—pitch link	1
Upper controls—other	2
Hydraulic	3
Tail rotor controls	**7**
Lower controls—cable	2
Lower controls—other	3
Upper controls—swashplate assembly	0
Upper controls—pitch link	1
Upper controls—other	1
Controls—other	0

TABLE 40. AIRFRAME SPECIFIC FAILURES BY COMPONENTS—TWIN-TURBINE HELICOPTERS

Airframe and landing gear	**10**
Landing gear	2
Tailboom	0
Other systems	4
Support assembly	1
Other systems (engine)	2
Stabilizer—horizontal	1
Miscellaneous equipment	0
Stabilizer—vertical	0

Drive and rotor system failures, primarily in cruise flight, accounted for 61 of the 89 accidents. The tail rotor drive system dominated drive train component failures and accounted for 19 of the 61 accidents. Failure, primarily in fatigue, of 29 main and tail rotor systems (i.e., blades and hubs) occurred.

The pilot was left without antitorque and directional control in 36 of the 89 accidents because a tail rotor drive train, a tail rotor system, or a tail rotor control failed or malfunctioned. On a percentage basis of total accidents, this experience directly parallels that of single-engine helicopters.

Taking an overall look at the history of twin-turbine helicopter accidents resulting from airframe/component/system failure or malfunction, the conclusion appears to be that fatigue failures cause more airframe failure accidents in twin-turbine helicopters than any other single problem.

7.5 Summary Remarks, Conclusions and Recommended Actions

The registered fleet of commercially manufactured, twin-turbine helicopters grew from fewer than 50 at the end of 1963 to approximately 1,200 by the end 1997. During this period, the fleet had 302 accidents, 91% of which fell into the 10 categories shown in figure 98.

The summary of accidents by activity and phase of operation in table 41 shows that the overwhelming number of twin-turbine helicopter accidents occurred during a passenger carrying or similar activity. Since point-to-point activities involve relatively long duration, high-speed flight, it is understandable that most twin-turbine helicopter accidents occurred during a cruise operation.

**TABLE 41. ACCIDENTS BY ACTIVITY AND PHASE OF OPERATION—
TWIN-TURBINE HELICOPTERS**

Activity		Phase of Operation	
Passenger service	97	Cruise	84
General utility	49	Takeoff	36
Ferry/reposition	46	Landing	35
Executive/corporate	31	Hover	32
Business use	23	Maneuvering	30
Flight/maintenance test	16	Approach	26
Instructional/training	13	Standing/static	22
Public/military use	12	Taxi	15
Personal use	6	Climb	14
Unknown/not reported	5	Descent	6
Aerial application	4	Unknown/other	2
Total	**302**	**Total**	**302**

The following study findings relate to the four top accident categories.

1. Total loss of engine power occurred in 23 of the 39 (60%) loss of engine power accidents experienced by the twin-turbine helicopter fleet. The cause of 17 of these 23 accidents was attributed to improper fuel/air mixture. Fuel exhaustion, fuel starvation, or fuel contamination occurred in the twin-turbine helicopter fleet, just as they did in single-engine helicopters.

2. Loss of engine power because of engine structural failure caused 15 accidents.

3. Loss of engine power for undetermined reasons was recorded in six accidents.

4. In flight collision with man-made objects accounted for 34 of 43 accidents.

5. In flight collisions with 13 wires occurred and 12 objects attached to the airport/helipad landing site were struck.

6. Loss of control was relatively evenly distributed about all axes.

7. Airframe failures caused nearly 30% (89) of the 302 total twin-turbine helicopter accidents.

8. Drive train failures caused 32 accidents, of which 19 were tail rotor drive shaft failures.

9. Rotor system failures caused 29 accidents, of which the tail rotor system accounted for 10 accidents.

10. Control system failures caused 18 airframe failure accidents.

11. The pilot was left without antitorque and directional control in over 36 of the 89 airframe failure accidents.

12. An autorotation took place in approximately 50 of the 302 accidents.

The top 4—or 10—most common accident categories were not the accident types that caused the highest fatality rate (i.e., fatalities per 100 accidents). The greatest risk of fatality in twin-turbine helicopter accidents occurred in midair collisions; there were six midair collisions in which 13 people were killed. Figure 99 shows, in descending order, fatalities per 100 accidents by NTSB first event category. On ground/water collision with object, airframe failure, weather, and in flight collision with terrain/water led to the highest fatality rates. When ordered in terms of total fatalities, as tabulated on figure 99, airframe failures were the leading cause of fatalities with the twin-turbine helicopter fleet.

Before discussing accidents that all other rotorcraft types had, several observations and recommendations relative to the twin-turbine helicopter fleet are offered. From 1990 through 1997, the twin-turbine helicopter fleet demonstrated an improved safety record over that of the single-turbine helicopter fleet by nearly a factor of 2. Single-turbine helicopters had 17.2 accidents per 1,000 registered aircraft and twin-turbine helicopters had 9.5. However, the improvements due to fewer loss of engine power accidents were offset by an increase in airframe failure accidents. There is little evidence to suggest that the twin-turbine helicopter significantly improved in any of the other first event accident categories.

In 1997, the commercially manufactured, twin-turbine helicopter fleet experienced 8.2 accidents per 1,000 registered rotorcraft. It is projected here that this accident rate will drop below 4 accidents per 1,000 registered rotorcraft by the year 2010 (fig. 78). To ensure that this projection is achieved, it is recommended that design and certification criteria and standards applicable to the airframe be raised. The tail rotor drive train and tail rotor system should receive immediate attention.

Most of the recommendations applicable to the single-engine helicopter fleet are also applicable to twin-turbine helicopters. However, these further suggestions are offered:

1. Begin a detailed review of the basic causes of loss of aircraft control for twin-turbine helicopters. Review transition and refresher training, currency requirements, and evaluation criteria for pilots of twin-turbine helicopters. In particular, address issues of aircraft handling, especially in marginal weather conditions.

2. Incorporate into the fleet an alert system that effectively warns the pilot that aircraft operational limits are being approached (e.g., maximum power available, conditions conducive to loss of tail rotor effectiveness, avoid areas of the aircraft height-velocity diagram). Control force cueing or cockpit displays should be considered as a means of alerting the pilot.

3. Examine the information and flying task requirements for EMS and commercial passenger transportation operations to improve crew selection and training. Ensure that required operational information is provided clearly to the crew and properly acted upon.

4. Examine aircraft certification criteria to ensure that time/cycle part-change requirements provide adequate safety margins and are based on sound materials science and operational experience.

5. Develop requirements and standards for health and usage monitoring systems. Continue and intensify research and development efforts leading to widespread fielding of prototype HUMS and analysis of data obtained.

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8. ALL OTHER ROTORCRAFT TYPES

8.1 Fleet History and Growth

A large and growing number of registered rotorcraft are classified by the FAA as amateur built (i.e., principally homebuilt from kits). This group began with small, single-place autogyros modeled after larger autogyros manufactured by de la Cierva, Pitcairn, and Kellett before World War II. Igor Bensen pioneered the early amateur autogyros in the mid-1950s. Ten years later, Air & Space America developed and began selling its M-18A series. Amateur single-place helicopters became available from Rotorway in the early 1970s. In 1997, a large number of kit rotorcraft were offered to the homebuilt market, as reference 20 notes. This fleet of amateur built rotorcraft grew at a steady pace (fig. 100). (Note, however, the substantial drop in fleet count from 1969 to 1970 when the FAA introduced its revised aircraft data system.) Amateur built helicopters accounted for approximately one-third of the homebuilt rotorcraft fleet by the end of 1997. The amateur rotorcraft fleet, whether autogyro or helicopter, is dominated by single-piston engine power plants. Although virtually all of these rotorcraft are single-seat, some kit manufacturers have recently begun to offer multi-place versions.

8.2 Accident Analysis

The annual accidents per 1,000 registered amateur rotorcraft dropped steadily from 1963 through 1997, as shown in figure 101. It might be argued that the amateur fleet was the safest group of all rotorcraft based solely on this figure. However, the Rotorcraft Activity Survey of 1989 (ref. 17), suggests that this would be an incorrect presumption. Out of a fleet of 1,790, only 572 were active and this small group flew only 21,830 hours (table 17). The estimated average annual hours flown during 1989 by active amateur rotorcraft was only 38.2. This was about 14% of the activity of the single-piston helicopters sold by manufacturers. Table D-1 indicates that the NTSB recorded 17 "All Other Types" accidents in 1989. Therefore, a more realistic accident rate comparison between commercially built and amateur homebuilt single-piston rotorcraft for 1989 would be as follows:

Active commercially built = 106 per 728,125 hours = 14.5 accidents per 100,000 hours flown

Active amateur built = 17 per 21,830 hours = 77.9 accidents per 100,000 hours flown.

This sobering statistic suggests that amateur homebuilt rotorcraft were over five times as accident prone as commercially built rotorcraft. The NTSB investigated 516 All Other Types accidents over the study period (table 42).

TABLE 42. ACCIDENT DISTRIBUTION BY ALL OTHER ROTORCRAFT TYPES, 1963–1997

All other types	Count	Reference
Manufacturer—autogyro	50	Table D-8
Amateur helicopter	137	Table D-9
Amateur autogyro	261	Table D-10
Unknown configuration	68	Table D-11
Total	**516**	

8.3 Detailed Analysis by Accident Category

The 516 accidents are charted by first event category in figure 102. Approximately 90% of the accidents fell into 7 of the 21 NTSB categories; a comparison summary to single-piston rotorcraft sold by manufacturers is provided in table 43. Loss of control was the leading cause of accidents in the homebuilt fleet. Although this might be expected, given the "amateur" character assigned to the group, the homebuilt fleet was notably safer in almost all other first event accident categories. In particular, the loss of engine power category shows that the amateur fleet had a much better safety record.

TABLE 43. AMATEUR VS. COMMERCIAL ACCIDENT DISTRIBUTION, 1963–1997

	Single piston amateur		Single piston manufacturer	
NTSB category	Count	%	Count	%
Loss of engine power	111	21	1,554	29
In flight collision with object	28	5	953	18
Loss of control	165	32	625	11
Airframe/component/system failure or malfunction	73	14	639	12
Hard landing	25	5	483	9
In flight collision with terrain/water	40	8	443	8
Rollover/nose over	20	4	290	5
Other	54	10	384	7
Total	**516**	**100**	**5,371**	**100**

Figures 103 through 106 provide a review of the four top first event categories. From figure 103, it is quite evident that the amateur fleet was just as susceptible to fuel/air mixture problems that caused loss of engine power as the rest of the rotorcraft fleet; 40 of the 111 loss of engine power accidents. Pilots of amateur built rotorcraft were as prone to colliding with wires, poles, and trees as pilots of commercially manufactured helicopters (fig. 104). Figure 105 suggests that, after construction, the pilots tried to teach themselves to fly with very little assistance and—too often—without success. Finally, every major subsystem associated with the main rotor was a potential problem for amateurs (fig. 106).

8.4 Summary Remarks, Conclusions, and Recommended Actions

There were approximately 3,000 homebuilt and a few experimental rotorcraft as of 31 December, 1997. Nearly 1,000 of these rotorcraft were single-rotor helicopters, with the rest being autogyros. From mid-1963 through 1997, this fleet accumulated 516 accidents. The NTSB grouped these accidents into 21 different categories. However, 80% of the accidents fell into five categories (fig. 107).

The summary of accidents by activity and phase of operation in table 44 shows that the overwhelming number of accidents occurred during personal use. Takeoff was the most critical phase of flight for builders/pilots of amateur rotorcraft.

Observations from the most common first events:

1. Loss of control was the leading cause of amateur rotorcraft accidents. No fewer than 165 of the 516 accidents were attributed to this cause by the NTSB.

2. Loss of engine power because of improper fuel/air mixture caused 40 of the 111 loss of engine power accidents.

3. Loss of engine power because of engine structural failure caused 28 accidents.

TABLE 44. ACCIDENTS BY ACTIVITY AND PHASE OF OPERATION—ALL OTHER TYPES

Activity		Phase of Operation	
Personnel use	358	Takeoff	127
Instructional/training	82	Cruise	93
Flight/maintenance test	43	Landing	74
General Utility	13	Maneuvering	70
Business use	11	Approach	54
Aerial application	4	Hover	28
Ferry/reposition	3	Unknown/other	24
Passenger service	1	Taxi	19
Unknown/not reported	1	Descent	12
Executive/corporate	0	Climb	10
Public/military use	0	Standing/static	5
Total	**516**	**Total**	**516**

4. Loss of engine power for undetermined reasons was recorded in 25 accidents.

5. In flight collision with object (e.g., wires, wire/poles, and trees) accounted for relatively few accidents (i.e., 28 out of 516).

6. Drive train and rotor system failures caused 33 of the 73 airframe-related accidents. Control system failures caused an additional 11 airframe failure accidents.

As before, the most common first event accident categories were not the accident types that caused the highest fatality rate (i.e., fatalities per 100 accidents). There was one midair collision that killed the pilot. Beyond this one accident, figure 108 shows, in descending order, the high-risk accident categories for amateur rotorcraft.

There is considerable evidence that the amateur built fleet will continue to grow by approximately 80 to 120 rotorcraft per year. The number of amateur built helicopters has been increasing at a rate of approximately 40 per year for the last 5 years, and interest appears very high considering the relatively low selling price. From the projection shown in figure 109, it is estimated that the amateur fleet will have two to three accidents per 1,000 registered aircraft by the year 2010 if concerns about safety are not raised above today's level.

The projection shown in figure 109 could easily be optimistic by a factor of 2, and perhaps even 3. Taking a pessimistic view, there could be as many as 35 amateur rotorcraft accidents per year by 2010 (given the enthusiasm of the members of this segment of aviation, the likely increase in active aircraft count and flying hours per active fleet). Thus, the situation now being experienced in England (ref. 9, Vol. 22, No. 4, pg. 102), could happen in the U.S. in 2010.

9. FINAL REMARKS, CONCLUSIONS, AND RECOMMENDATIONS

The civilian rotorcraft fleet registered in the United States by the FAA includes, principally, helicopters and autogyros. Commercially manufactured helicopters dominate the fleet, followed by amateur built autogyros and helicopters. Periodically, experimental rotorcraft of either type are added to the FAA registry for a short time. The most common helicopter configuration follows the Igor Sikorsky arrangement (i.e., a large main rotor for lift and propulsion and a small, propeller-like rotor at the tail for antitorque and directional control). Since no scheduled airline-type (i.e., Part 121) operations are currently flown with rotorcraft, the FAA includes rotorcraft in its general aviation class.

This civil rotorcraft fleet grew from fewer than 10 in 1946 to 2,196 in 1964 to 12,911 by the end of 1997. Single-engine helicopters dominated the registered fleet throughout this period. While the single-piston-engine configuration still sold in quantity, the rotorcraft industry introduced the single-turbine-engine configuration in the mid-1960s. In 1997, nearly equal numbers of single-piston and single-turbine helicopters were registered (about 5,000 each). The commercially manufactured, twin-turbine helicopter began selling in quantity in the late 1970s and, by the end of 1997, slightly over 1,200 were registered. A growing fleet of registered amateur built autogyros and helicopters numbered close to 3,000 at the end of 1997.

The NTSB recorded 8,436 rotorcraft accidents between mid-1963 and the end of 1997. Because of continuing emphasis on safety, the industry reduced accidents per year from 260 in 1964 to 175 in 1997, even as the registered fleet grew. Per 1,000 registered rotorcraft, accidents were reduced by nearly a factor of 10 over this period (i.e., from 118 in 1964 to 13.6 in 1997). Nevertheless, these accidents took a large toll, directly affecting 16,825 people: 2,135 were killed, 1,760 were seriously injured, while 12,930 survived with minor or no injuries. Of the 8,436 rotorcraft involved, 2,363 (i.e., nearly 20% of the 1997 registered fleet) were listed by the NTSB as destroyed, 5,909 were substantially damaged, and 164 received little or no damage.

The favorable downward trend in rotorcraft accidents per year enumerated above was not linear. During a 15-year period, beginning in 1972 and ending in 1987, the industry experienced a rash of accidents that drove the annual rate to 327 accidents in 1980 before dropping to 196 accidents in 1987. We believe that the increase in accidents per year during this period was initiated by the 10-year period during which commercial helicopter yearly sales increased by over 50%. The relatively abrupt increase of new helicopters in the U.S. civil fleet was accompanied by a jump in accidents caused by (1) loss of engine power and (2) failure of airframe systems and components. It is clear, therefore, that when the next rapid expansion of the fleet occurs, the industry must increase all aspects of its safety improvement efforts. This increase must be more than proportional to the fleet growth rate.

Table 45 summarizes rotorcraft accidents over the study period. Analysis of the 8,436 rotorcraft accidents recorded by the NTSB showed that approximately 90% of the accidents were precipitated by only 7 of the NTSB's 21 first event accident categories.

TABLE 45. SUMMARY OF ROTORCRAFT ACCIDENTS FROM MID-1963 TO THE END OF 1997

NTSB first event accident category	Commercially manufactured			Amateur types
	Single piston	Single turbine	Twin turbine	
	Count (%)	Count (%)	Count (%)	Count (%)
Loss of engine power	1,554 (28.9)	704 (31.3)	39 (12.9)	111 (21.5)
In flight collision with object	953 (17.7)	298 (13.2)	43 (14.2)	28 (5.43)
Loss of control	625 (11.6)	284 (12.6)	40 (13.2)	165 (32.0)
Airframe/component/system failure/ malfunction	639 (11.9)	282 (12.5)	89 (29.5)	73 (14.1)
Hard landing	483 (8.99)	140 (6.23)	8 (2.65)	25 (4.89)
In flight collision with terrain/water	443 (8.25)	143 (6.36)	16 (5.23)	40 (7.75)
Rollover/nose over	290 (5.40)	119 (5.29)	4 (1.32)	20 (3.88)
Weather	57 (1.06)	85 (3.78)	12 (3.97)	5 (0.97)
Miscellaneous/other	74 (1.38)	42 (1.87)	9 (2.98)	9 (1.74)
Stall/settling with power	67 (1.25)	2 (0.09)	1 (0.33)	13 (2.52)
Propeller/rotor contact to person	33 (0.61)	35 (1.56)	8 (2.65)	3 (0.58)
Midair collision	17 (0.32)	37 (1.65)	6 (1.99)	1 (0.19)
On ground/water collision with object	26 (0.49)	18 (0.80)	10 (3.31)	2 (0.39)
Fire/explosion	28 (0.52)	15 (0.67)	5 (1.66)	2 (0.39)
Abrupt maneuver	12 (0.22)	8 (0.36)	2 (0.66)	10 (1.94)
Undetermined	12 (0.22)	13 (0.58)	2 (0.66)	1 (0.19)
Gear collapsed	16 (0.23)	3 (0.13)	6 (1.99)	2 (0.39)
Dragged wing/rotor, pod, float, or tail/skid	20 (0.37)	2 (0.09)	1 (0.33)	1 (0.19)
Undershoot/overshoot	16 (0.23)	4 (0.18)	1 (0.33)	3 (0.58)
On ground/water encounter with terrain/ water	5 (0.09)	12 (0.53)	0 (0)	2 (0.39)
Missing	1 (0.02)	1 (0.05)	0 (0)	0 (0)
Total	**5,371**	**2,247**	**302**	**516**

Detailed analyses of these accidents showed that similarities far outnumbered differences. The three commercially manufactured helicopter types are viewed by the industry as quite different, but they shared many common accident causes. The major similarities observed are discussed below:

1. Thirty percent of single-piston or single-turbine helicopter accidents were caused by a partial or total loss of engine power. The primary reason for the loss of power *was not* engine structural failure, which only accounted for 452 accidents. Rather, the primary cause for the loss of power was directly traced by the NTSB to fuel/air-mixture problems, which accounted for no fewer than 985 accidents. Virtually every one of the 985 accidents was caused by human error. Fuel exhaustion, fuel starvation, fuel contamination, and, for the piston-engine, improper use of carburetor heat were key words repeatedly used in the NTSB accident reports. Apparently, many pilots disregarded the need by both engine types for clean fuel and air in proper proportions—to say nothing about the FAA regulations for fuel reserves.

Power-off landing proficiency is not required by the FAA in order to obtain a helicopter pilot's certificate. This standard appears inconsistent with the number of accidents caused by loss of engine power (also see ref. 21). Virtually all of these accidents resulted in substantially damaged or destroyed helicopters. It therefore appears that helicopters currently in the civil fleet provide marginal to inadequate autorotational capability for the average pilot to successfully complete the final flare and touchdown to what is usually an unsuitable landing site. Lastly, training in full autorotation landings—even to a prepared landing site—is apparently avoided because of both real and perceived risks. Based on these findings, the following are recommended:

- Immediate reinforcement of fuel management and mission planning according to current FAA regulations.
- Reexamination of currently installed fuel quantity measurement and display hardware for accuracy and applicability to rotorcraft operations.
- Reinstatement of full power-off autorotation to touchdown as an industry standard for students and recurrent pilot training as soon as possible.
- Reexamination by commercial helicopter manufacturers of their current and future product's autorotational capabilities with the objective of reducing height-velocity restrictions to a level consistent with average piloting skills, and more representative emergency landing sites.
- Reexamination in detail of the accidents caused by piston-engine structural failure for the purpose of initiating an engine improvement program.

2. Although twin-turbine helicopters appear to have significantly reduced loss of engine power accidents on a percentage basis, 23 of the 39 accidents were caused by a total loss of power in both engines. The other 16 accidents followed a partial loss of power. Most discouragingly, 17 of the 39 accidents were caused by fuel/air-mixture problems similar to those encountered in single-engine helicopters. Clearly, the rotorcraft industry is dealing with a situation where approximately 50% of loss of engine power accidents (regardless of the type of engine) are caused by improper fuel/air mixture. Approximately, 25% to 30% of the loss of engine power accidents are related to engine structural failure.

3. In flight collision with object accidents were common with all types of helicopters. Commercially manufactured helicopters are sold primarily because they perform well flying low and slow. Unfortunately, this flight regime places the helicopter pilot in a very hostile environment, populated by many natural and man-made objects. The commercial helicopter fleet collectively had 1,294 collision with object accidents. There were 720 accidents involving collisions with wires and poles, and 205 involving trees. The major contributor to these in flight collisions was the single-piston helicopter fleet, which was most frequently involved in an agricultural operation (e.g., crop dusting). This helicopter type had about equal numbers of main and tail rotor strikes. The single-turbine helicopter class, used relatively less in aerial applications, experienced four tail rotor strikes for every three main rotor strikes. Twin-turbine helicopters experienced more than twice as many tail rotor strikes as main rotor strikes. The average pilot's situational awareness of objects that must be avoided was significantly impaired because most of the objects were not readily visible. Wires, in particular, are well-known threats to low flying by all aircraft types. Based on these findings, the authors recommend that:

- Flying below 750 feet (above ground level) be discouraged by the industry and regulatory agencies.

- All man-made objects higher than 500 feet be marked, mapped, and included in electronic databases, such as used in Global Positioning System equipment.

- A low-price proximity spherical sensor be developed and certified; a sensor sphere of some large radius should, in effect, cocoon the helicopter and provide the pilot with sufficient warning to avoid obstacles.

4. Pilots of the commercial fleet lost control of their helicopters—regardless of their certification level—causing 12% of the commercial fleet's 7,920 accidents. Pilots of amateur rotorcraft lost control nearly three times as often. The requirement to adequately control antitorque in all flight phases appeared to be the root problem with the single main rotor helicopter configuration. This was particularly true with the single-piston helicopter, where fluctuations in engine RPM occurred because of the reciprocating engine's governing system. The turbine engine RPM governing system virtually removed this cause of accidents. However, on a percentage basis, pilots of single-turbine helicopters lost directional control twice as often as pilots of single-piston helicopters, which suggests a design deficiency. Equipping some single-turbine and virtually all twin-turbine helicopters with an automatic stability and control system generally improved the overall loss of control situation.

Current single-piston helicopters (and turbine-powered helicopters to a somewhat lesser extent) appeared inordinately difficult to fly; particularly when the average pilot had to devote attention to another task, or had a real or imagined emergency. Cross-coupling between the vertical/power/RPM and yaw axes appeared excessive. The handling qualities design standards applicable to the current helicopter fleet date back to the 1950s. Although generally tolerated, the resulting helicopter stability and control characteristics now appear quite unsatisfactory. Therefore, the authors recommend that:

- Piston-engine RPM management be more fully automated, to the level offered with turbine engines, if possible.
- A low-price stability augmentation system (in the yaw axis as a minimum), having at least 10% authority, be developed and certified.
- Handling quality standards for all future helicopters be raised to levels consistent with what modern technology can provide.
- A detailed review of the basic causes of loss of aircraft control for single- and twin-turbine helicopters be initiated.
- Transition and refresher training, currency requirements, and evaluation criteria for pilots of twin-turbine helicopters be reviewed, with particular emphasis on aircraft handling issues, especially in marginal-weather conditions.
- Aircraft certification criteria be reviewed and modified to ensure that undesirable flying characteristics encountered in real-world operational use are included in pre-certification testing and corrected before final certification.
- Current certification and currency requirements for rotorcraft flight instructors be reviewed with the intent of improving selection and training of instructors, thus ensuring ongoing professional development, while providing a higher level of instruction to future pilots.

5. Airframe system, subsystem, and component failures or malfunctions were one of the leading causes of helicopter accidents. With the commercial helicopter fleet, the pilot was left without antitorque and directional control in 470 accidents related to airframe failure or malfunction (nearly 50% of 1,010 accidents). The failure or malfunction occurred in the tail rotor system dynamic components (i.e., drive train, control system, and blades and hub). More specifically, failures in the tail rotor drive train (which includes the shafts, couplings, bearings, and gearboxes) caused 192 accidents. Failure of the tail rotor control system caused 56 accidents, and tail rotor blade/hub failures caused 186 accidents. Tailboom failures accounted for the remaining 36 accidents. The corresponding main rotor system dynamic components also failed or malfunctioned, which led to 404 accidents. Specifically, engine to main rotor gearbox failures caused 137 accidents, control system failures caused 103, and blade/hub failures caused 112. Transmission and mast failures caused 52 accidents.

The accident record of the commercial helicopter fleet shows that past design standards are inadequate relative to the many new and varied activities in which this aircraft class is engaged. Even considering that pilots did exceed design limits, that required and timely maintenance was skipped, and that less than thorough inspections were performed, the current fleet appears, broadly speaking, to be under-designed when faced with its commercial use. Therefore, the authors recommend that the industry:

- Reevaluate design and certification criteria of all components involved in transmitting power from the engine to the main rotor gearbox, with particular attention to clutch and freewheeling units.

- Reevaluate design and certification criteria of all components that transmit power to the tail rotor with particular attention to the drive shaft and couplings typical of current configurations.

- Adopt more conservative fatigue design criteria (both loads and material allowables), particularly for tail rotor blades and hubs.

- Incorporate into the fleet an alert system that effectively tells the pilot when aircraft operational limits (e.g., maximum power available, conditions conducive to loss of tail rotor effectiveness, "avoid" areas of the aircraft height-velocity diagram) are being approached, perhaps by control force cueing or cockpit displays.

- Develop a reliable, low-priced health and use monitoring system with the intent of requiring that such a system be installed on all future turbine-engine-powered helicopters.

- Review certification and currency requirements for helicopter manufacturing, and maintenance workers with the intent of raising standards.

- Raise aircraft design and certification standards to permit reduced maintenance and incorporate additional system fail-safe modes.

- Continue research and development of better structural materials that are more practical, more resistant to fatigue, and more affordable than the materials currently in use.

6. The amateur helicopter and autogyro fleet experienced an accident distribution similar to that of the commercial fleet, based on percentage. The primary exceptions were that loss of control was nearly three times as prevalent and loss of engine power occurred one-third less often. Because the amateur fleet is growing so fast, major manufacturers, operators, and trade associations must provide considerably more help to this segment of their industry in an effort to lower the risks being taken.

7. Single-turbine helicopter accidents per year increased slightly over the last decade of the period studied. A measure of this unfavorable trend is that there were 62 accidents in 1987, 65 in 1993, and 73 in 1997, while the registered fleet increased only modestly in size. Most recently, new,

single-turbine helicopters were being registered at a rate comparable to that of the 1970s. There is concern, therefore, that a rapid fleet expansion will prompt an increase in accidents, just as it did with the single-piston helicopter fleet. We recommend that more intensive safety improvement efforts be quickly initiated by the industry.

8. Introducing twin-turbine helicopters reduced loss of engine-power accidents, but a very disturbing trend began with the larger helicopters capable of carrying more people. In the single-piston helicopter fleet, there were 5,371 accidents and 683 fatalities. In the 2,247 accidents involving single-turbine helicopters, 951 people died. In 302 twin-turbine helicopter accidents, 321 people were killed.

9. There is little doubt that helicopters powered by turbine engines are safer than those powered by a single-piston engine. How much safer *can not*, in the our opinion, be quantified. The rotorcraft industry is being misguided by accident rate trends that use FAA data for active fleet size, hours flown, takeoffs made, etc. In fact, it is quite likely that the rotorcraft industry will miss significant safety trends if the currently used methods of computing accident rates remain as the measure of progress. Unquestionably, the true goal of any aviation safety effort is no fatalities or injuries.

10. Without significantly increased industry-wide safety efforts in the immediate future, including implementing the above recommendations, it is projected that in the year 2010 there will be about 6 accidents per 1,000 registered rotorcraft. Should the rotorcraft fleet size double by 2010, there will be 150 accidents per year—about 3 accidents per week. It is not likely that the public will perceive this projection as an indication that pilots and their rotorcraft are, in fact, becoming safer. Rather, the perceived dangers of rotorcraft operations will make it more likely that rotorcraft will be restricted, if not prohibited, from many areas and, as a result, rotorcraft will not be allowed to perform a significant role in the U.S. air transportation system.

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LIST OF FIGURES

The 109 figures contained in this document are sequenced by the rotorcraft class. That is, after 15 figures that give a picture of the total rotorcraft fleet, 29 figures then deal with the commercially manufactured single-piston engine powered helicopter. Next, 28 figures relate to the single-turbine, commercially manufactured helicopter followed by another 28 figures devoted to the commercially manufactured twin-turbine helicopter. All other rotorcraft types are dealt with by 10 figures. Figure 1 is found on page 103. In like manner, the page number for any figure which follows is simply the figure number + 102.

Total Rotorcraft Fleet

Commercial, Single-Piston Engine Helicopters

Commercial, Single-Turbine Engine Helicopters

Commercial, Twin-Turbine-Engine Helicopters

All Other Rotorcraft Types

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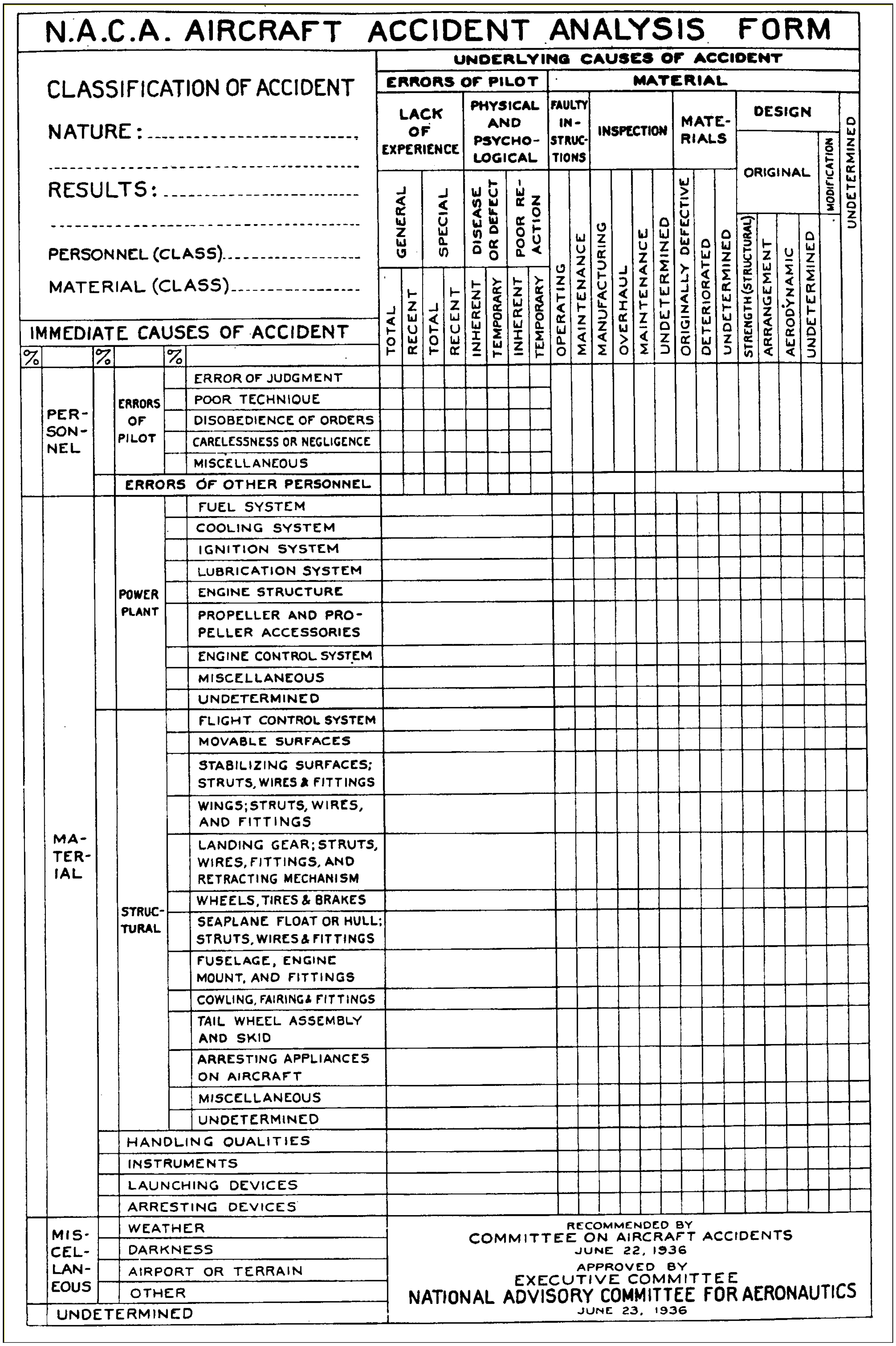


N.A.C.A. AIRCRAFT ACCIDENT ANALYSIS FORM

CLASSIFICATION OF ACCIDENT

NATURE: ....

RESULTS: ....

PERSONNEL (CLASS)..................

MATERIAL (CLASS)..................

UNDERLYING CAUSES OF ACCIDENT

ERRORS OF PILOT								MATERIAL														
LACK OF EXPERIENCE				PHYSICAL AND PSYCHOLOGICAL				FAULTY INSTRUCTIONS		INSPECTION				MATERIALS			DESIGN					UNDETERMINED
GENERAL		SPECIAL		DISEASE OR DEFECT		POOR RE-ACTION											ORIGINAL				MODIFICATION	
TOTAL	RECENT	TOTAL	RECENT	INHERENT	TEMPORARY	INHERENT	TEMPORARY	OPERATING	MAINTENANCE	MANUFACTURING	OVERHAUL	MAINTENANCE	UNDETERMINED	ORIGINALLY DEFECTIVE	DETERIORATED	UNDETERMINED	STRENGTH (STRUCTURAL)	ARRANGEMENT	AERODYNAMIC	UNDETERMINED		

IMMEDIATE CAUSES OF ACCIDENT

%		%		%	
	PERSONNEL		ERRORS OF PILOT		ERROR OF JUDGMENT
					POOR TECHNIQUE
					DISOBEDIENCE OF ORDERS
					CARELESSNESS OR NEGLIGENCE
					MISCELLANEOUS
			ERRORS OF OTHER PERSONNEL		
	MATERIAL		POWER PLANT		FUEL SYSTEM
					COOLING SYSTEM
					IGNITION SYSTEM
					LUBRICATION SYSTEM
					ENGINE STRUCTURE
					PROPELLER AND PROPELLER ACCESSORIES
					ENGINE CONTROL SYSTEM
					MISCELLANEOUS
					UNDETERMINED
			STRUCTURAL		FLIGHT CONTROL SYSTEM
					MOVABLE SURFACES
					STABILIZING SURFACES; STRUTS, WIRES & FITTINGS
					WINGS; STRUTS, WIRES, AND FITTINGS
					LANDING GEAR; STRUTS, WIRES, FITTINGS, AND RETRACTING MECHANISM
					WHEELS, TIRES & BRAKES
					SEAPLANE FLOAT OR HULL; STRUTS, WIRES & FITTINGS
					FUSELAGE, ENGINE MOUNT, AND FITTINGS
					COWLING, FAIRING & FITTINGS
					TAIL WHEEL ASSEMBLY AND SKID
					ARRESTING APPLIANCES ON AIRCRAFT
					MISCELLANEOUS
					UNDETERMINED
			HANDLING QUALITIES		
			INSTRUMENTS		
			LAUNCHING DEVICES		
			ARRESTING DEVICES		
	MISCELLANEOUS		WEATHER		
			DARKNESS		
			AIRPORT OR TERRAIN		
			OTHER		
	UNDETERMINED				

RECOMMENDED BY
COMMITTEE ON AIRCRAFT ACCIDENTS
JUNE 22, 1936
APPROVED BY
EXECUTIVE COMMITTEE
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
JUNE 23, 1936

Figure 1. NACA accident form, ca. 1936.

2-0342 *(1)*
64/5/14 TIME - 1030 *(2*

BRYANT WASH *(3)*

BRANTLY B2 N5900X *(4)*

CR- 0 0 1
PX- 0 0 0, *(5)*
OT- 0 0 0

COMMERCIAL AERIAL APPLICATION *(6)*

COMMERCIAL, AGE 42, 8177 TOTAL HOURS, 52 IN TYPE NOT INSTRUMENT RATED. *(7)*

DAMAGE-SUBSTANTIAL *(8)*

TYPE OF ACCIDENT *(9)*
ENGINE FAILURE OR MALFUNCTION
ROLL OVER

PHASE OF OPERATION *(10)*
IN FLIGHT: STARTING SWATH RUN
LANDING: POWER-OFF AUTOROTATIVE LANDING

PROBABLE CAUSE(S) *(11)*
MISCELLANEOUS ACTS,CONDITIONS - ICE-CARBURETOR
MISCELLANEOUS ACTS,CONDITIONS - ANTI-ICING/DEICING EQUIPMENT-IMPROPER OPERATION OF/OR FAILED TO USE

FACTOR(S) *(12)*
WEATHER - CONDITIONS CONDUCIVE TO CARB./INDUCTION SYSTEM ICING
COMPLETE POWER LOSS - COMPLETE ENGINE FAILURE/FLAMEOUT-1 ENGINE
EMERGENCY CIRCUMSTANCES - FORCED LANDING OFF AIRPORT ON LAND

SKY CONDITION CLEAR *(13)*
CEILING AT ACCIDENT SITE UNLIMITED
VISIBILITY AT ACCIDENT SITE 5 OR OVER(UNLIMITED)
TEMPERATURE-F 60
WIND DIRECTION-DEGREES 270
WIND VELOCITY-KNOTS 5
TYPE OF WEATHER CONDITIONS VFR
TYPE OF FLIGHT PLAN NONE

SPECIAL DATA *(14)*
TOTAL HOURS IN CROP CONTROL - 1750
KIND OF OPERATION - SPRAYING FORESTS
KIND OF CROP - FOREST-TREES
TYPE OF CHEMICAL USED - LIQUID CHEMICAL-NONTOXIC
PILOT' S SEAT BELT -FASTENED-PROPERLY
GLOVES - NOT USED
GOGGLES - NOT USED
CRASH HELMET - NOT AVAILABLE
COCKPIT CRASHPAD - NOT INSTALLED
CRASH BAR - NOT INSTALLED
TANK/HOPPER-LOCATION - BELLY
ELEVATION-AREA BEING TREATED-FEET - 680

REMARKS *(15)*
FORCED LANDING ON UNSUITABLE TERRAIN

Figure 2. Accident mini-brief, 1963–1971.

3-0196
72/1/9 TIME - 1415

HILLSBOROUGH,NC
ENSTROM F-28A N426RD

CR- 0 0 1
PX- 0 0 1
OT- 0 0 0

COMMERCIAL CTR PASSG-D

COMMERCIAL, AGE 38, 5750 TOTAL HOURS, 38 IN TYPE, INSTRUMENT RATED.

DAMAGE-SUBSTANTIAL

DEPARTURE POINT HILLSBOROUGH,NC
INTENDED DESTINATION LOCAL

TYPE OF ACCIDENT
ENGINE FAILURE OR MALFUNCTION
HARD LANDING

PHASE OF OPERATION
TAKEOFF: INITIAL CLIMB
LANDING: POWER-OFF AUTOROTATIVE LANDING

PROBABLE CAUSE(S)
POWERPLANT - MISCELLANEOUS: POWERPLANT FAILURE FOR UNDETERMINED REASONS
PILOT IN COMMAND - MISJUDGED SPEED AND ALTITUDE
PARTIAL POWER LOSS - PARTIAL LOSS OF POWER - 1 ENGINE
EMERGENCY CIRCUMSTANCES - PRECAUTIONARY LANDING OFF AIRPORT
UNUSUAL NOISE

REMARKS
ENG CKD OK.PLT RPRTD LOUD BANG,ENG RPM INCRD TO 3300.ENTERED AUTO FM LOW ALT,T/R BLDS HIT TLCONE.

Figure 3. Accident mini-brief, 1972–1981.

FILE NO. - 0069 2/10/82 URBANA,IL A/C Reg. No. N2256G Time (Lcl) - 1400 CST

----Basic Information----

Type Operating Certificate-NONE (GENERAL AVIATION) Aircraft Damage Injuries
Substantial Fatal Serious Minor None
Type of Operation -OTHER Fire Crew 0 0 0 2
Flight Conducted Under -14 CFR 91 NONE Pass 0 0 0 0
Accident Occurred During -LANDING

----Aircraft Information----

Make/Model - SIKORSKY UH-19B Eng Make/Model - WRIGHT R-1300 ELT Installed/Activated - NO -N/A
Landing Gear - Tailwheel-all fixed Number Engines - 1 Stall Warning System - UNK/NR
Max Gross Wt - 7200 Engine Type - Reciprocating-carburetor Weather Radar - NO
No. of Seats - 4 Rated Power - 600 HP

----Environment/Operations Information----

Weather Data Itinerary Airport Proximity
Wx Briefing - No record of briefing Last Departure Point On airport
Method - N/A HOMER,IL
Completeness - N/A Destination Airport Data
Basic Weather - VMC URBANA,IL RESTRICTED HELIPORT
Wind Dir/Speed- 180/005 KTS Runway Ident - UNK/NR
Visibility - 12.0 SM ATC/Airspace Runway Lth/Wid - UNK/NR
Cloud Conditions(1st) - NONE Type of Flight Plan - None Runway Surface - Concrete
Cloud Conditions(2nd) - NONE Type of Clearance - None Runway Status - Snow - dry
Obstructions to Vision- None Type Apch/Lndg - Visual full circuit
Precipitation - None
Condition of Light - Daylight

----Personnel Information----

Pilot-In-Command Age - 48 Medical Certificate - Valid medical-waivers/limit
Certificate(s)/Rating(s) Biennial Flight Review Flight Time (Hours)
Private,Commercial Current - YES Total - 561 Last 24 Hrs - 0
SE land Months Since - 1 Make/Model- 53 Last 30 Days- UNK/NR
Helicopter Aircraft Type - UNK/NR Instrument- 12 Last 90 Days- 38
Multi-Eng - 64 Rotorcraft - 291
Instrument Rating(s) - None

----Narrative----

THE PILOT AND A MEDICAL ATTENDANT WERE ON A FLIGHT TO URBANA TO MAKE A MEDICAL EVACUATION. THE PILOT STATED THAT JUST PRIOR TO TOUCHDOWN, THE HELICOPTER BEGAN TO ROTATE TO THE LEFT. HE REPORTED THAT HE LANDED IMMEDIATELY, CUT THE POWER, AND STOPPED THE ROTATION OF THE MAIN ROTOR AS QUICKLY AS POSSIBLE AFTER TOUCHDOWN. DURING THE LANDING, A MAIN ROTOR BLADE HIT THE TAIL CONE AND TAIL ROTOR DRIVE SHAFT, AND FLYING PARTS STRUCK THE FUSELAGE.

Occurrence #1 HARD LANDING
Phase of Operation LANDING - FLARE/TOUCHDOWN

Finding(s)
1. ALTITUDE - MISJUDGED - PILOT IN COMMAND
2. DISTANCE - MISJUDGED - PILOT IN COMMAND
3. ROTORCRAFT FLIGHT CONTROLS - IMPROPER USE OF - PILOT IN COMMAND

----Probable Cause---- is/are finding(s) 1,2,3

Figure 4. Accident mini-brief, 1982.

Public 02/25/83 1518 MKC83FA073 COUNCIL BLUFFS ,IA:

HUGHES TH-55A N1040S
IOWA WESTERN COMMUNITY
COLLEGE /
0 0 1 1
ACC / On Airport/ COUNCIL BLUFFS MUNICIPAL (CBF) Substantial
91 Instruction

THE STUDENT, WHO WAS A RATED HELICOPTER PLT, AND A HELICOPTER INSTRUCTOR (CFI) WERE ON A DUAL INSTRUCTIONAL FLT. AFTER TAKEOFF, THE AIRCREW REMAINED IN A RIGHT TRAFFIC PATTERN FOR RWY 13 , INTENDING FOR THE STUDENT TO MAKE A 180 DEG AUTOROTATION TO A PARALLEL TAXIWAY. THE STUDENT OVERSHOT THE AUTOROTATIVE TURN & THE CFI INSTRUCTED HIM TO CONTINUE THE APCH TO A GRASS AREA BETWEEN THE TAXIWAY & RWY. THE CFI REPORTED THAT THE TOUCHDOWN WAS SMOOTH WITH ZERO AIRSPEED. HOWEVER, THE HELICOPTER BEGAN VIBRATING & TURNED TO THE LEFT. REPORTEDLY, THE MAIN ROTOR BLADES HAD SEVERED THE TAIL BOOM.

```
No Occ Phs   Subj  Mod Pers
-- --- ---  ----- ---- ----
 1 200 571   Hard landing   Landing - flare/touchdown
        F 24545 3141 4103  Emergency procedure <> Simulated <> Pilot in command(CFI)
        F 24520 3135 4101  Autorotation <> Performed <> Dual student
        C 24523 3120 4101  Distance <> Misjudged <> Dual student
        C 24518 3120 4101  Altitude <> Misjudged <> Dual studen
        C 24627 3115 4103  Supervision <> Inadequate <> Pilot in command(CFI)
```

Figure 5. Accident mini-brief, 1983–1997.

NTSB Identification: MIA98LA051. The docket is stored in the (offline) NTSB Imaging System.

Accident occurred JAN-03-98 at BUNNELL, FL
Aircraft: Bell 47D1, registration: N59326
Injuries: 1 Uninjured.

The student pilot was on a supervised solo flight in the traffic pattern, practicing landings and takeoffs. At an altitude of about 300 feet above the airport, the helicopter's engine lost power. The student autorotated to an open field, and the helicopter was damaged during a forced landing. The student said when he checked the fuel gauge during preflight, it indicated "5/8" of a tank, which was confirmed by a "dip stick test." When he next checked the fuel gauge after doing some pattern work, it indicated "3/8" tank. According to an FAA Inspector's statement, "...the fuel tank was drained and less than 12 ounces of fuel remained in the undamaged fuel tank...no other maintenance discrepancies were found which may have contributed to the accident." The flight was about 1 hour and 10 minutes in duration.

Probable Cause
the student pilot's improper planning/decision, which resulted in fuel exhaustion, loss of engine power, and a forced landing.

The helicopter was released to the owner's representative**.**

MIA98LA051

On January 3, 1998, about 0840 eastern standard time, a Bell 47D1 helicopter, N59326, registered to a private owner, operating as a 14 CFR Part 91, local instructional flight, crashed during a forced landing near Bunnell, Florida. Visual meteorological conditions prevailed and no flight plan was filed. The helicopter was substantially damaged. The student pilot was not injured. The flight originated about 0730.

The student pilot was on a solo flight in the traffic pattern, practicing landings and takeoffs when the engine lost power. The pilot autorotated to an open field. The pilot said when he checked "the fuel indicator [it] was on 5/8 tank (sic), which was confirmed by the dip stick test." When he next checked the fuel gauge after doing some pattern work, it indicated "3/8 tank (sic)."

According to the FAA Inspector's statement, the student pilot was on a supervised instructional flight, and at an altitude of about 300 feet above the airport the helicopter's "engine stopped." The inspector stated, "...the fuel tank was drained and less then 12 ounces of fuel remained in the undamaged fuel tank...no other maintenance discrepancies were found which may have contributed to the accident."

Figure 6. Accident mini-brief, NTSB web site summary.

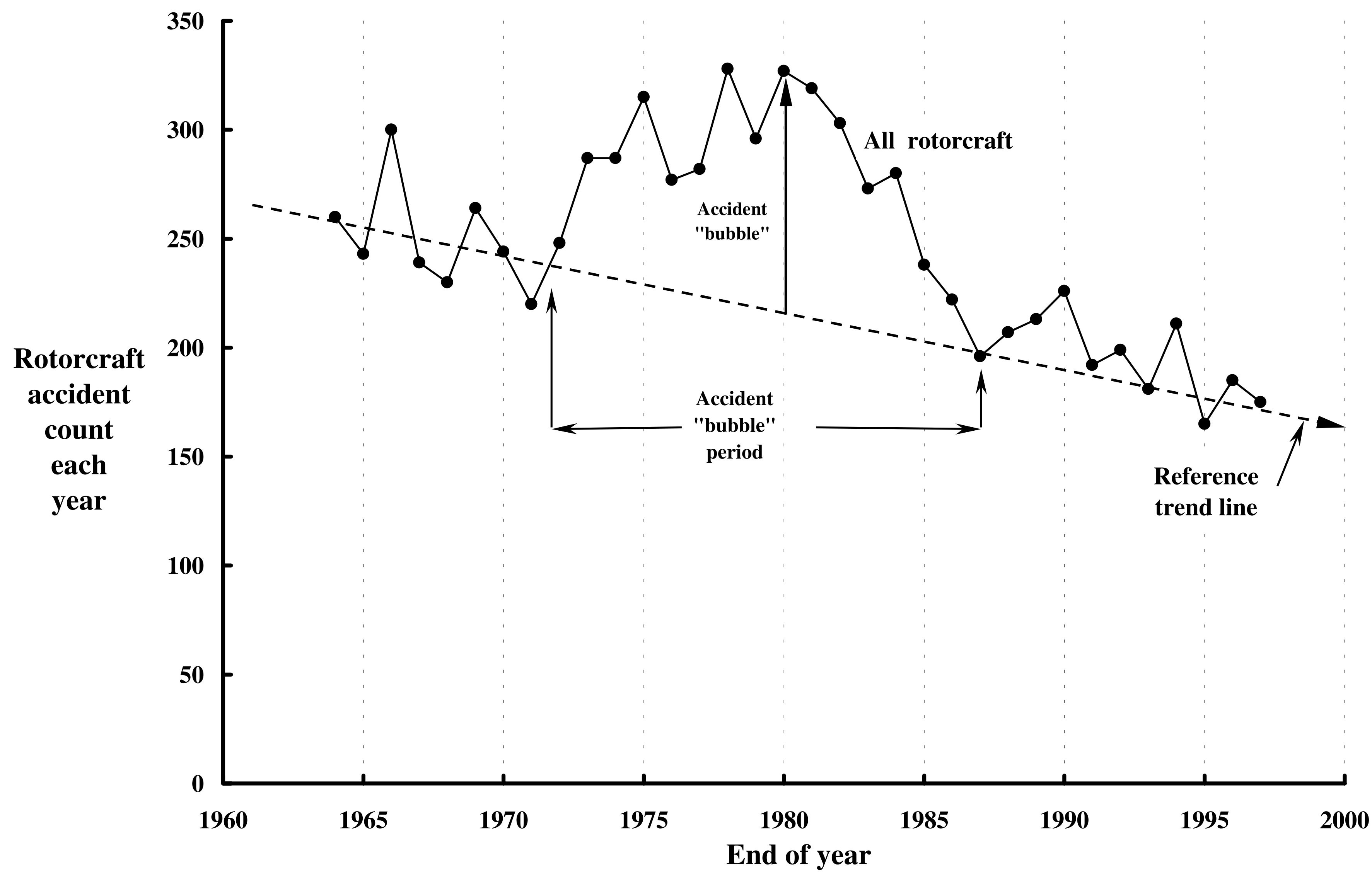


Figure 7. Rotorcraft accidents per year: 1964–1997 (total registered rotorcraft fleet).

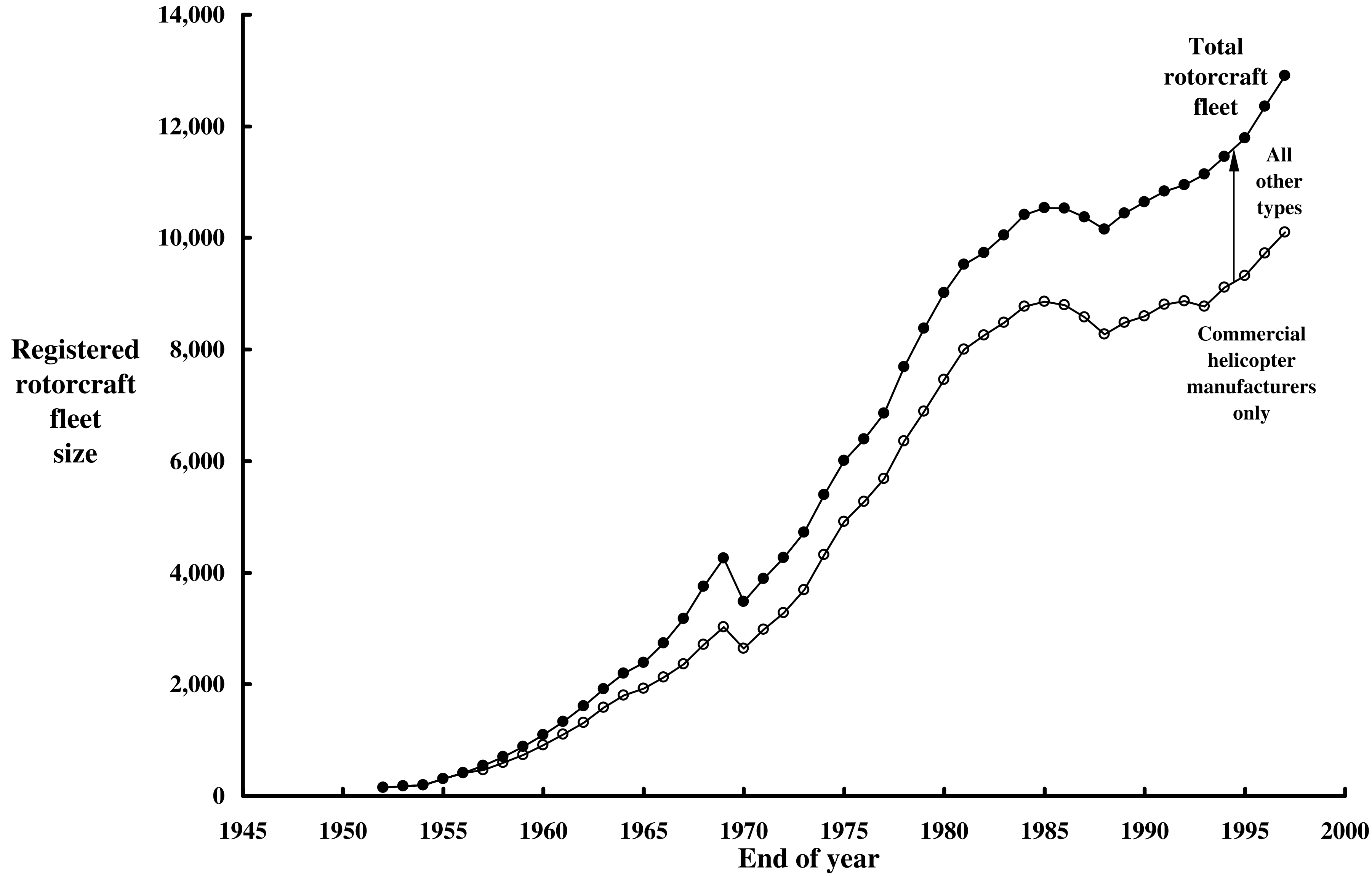


Figure 8. FAA registered rotorcraft count: 1951–1997 (total registered rotorcraft fleet).

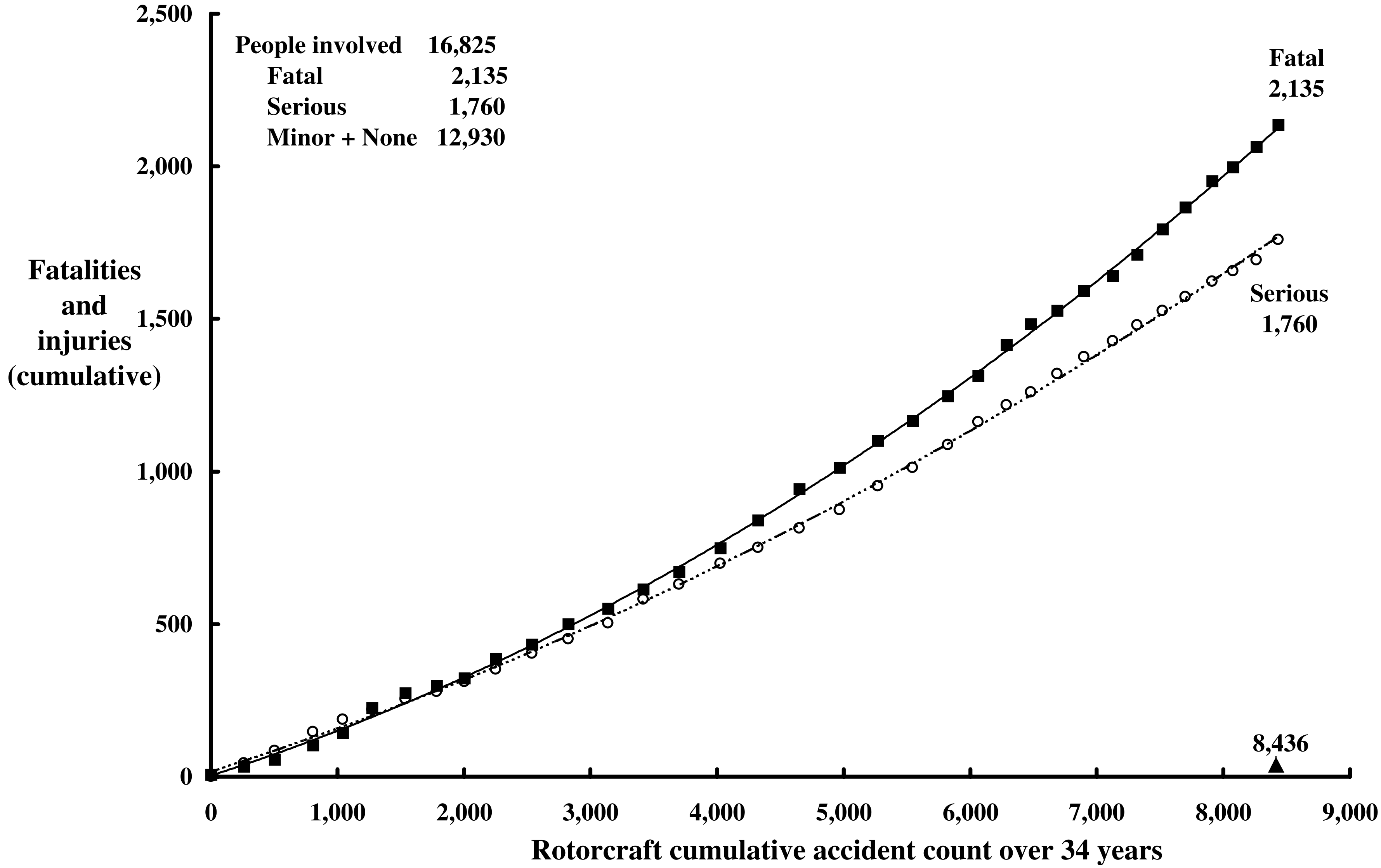


Figure 9. Injuries and fatalities caused by rotorcraft accidents: 1963–1997 (total registered rotorcraft fleet).

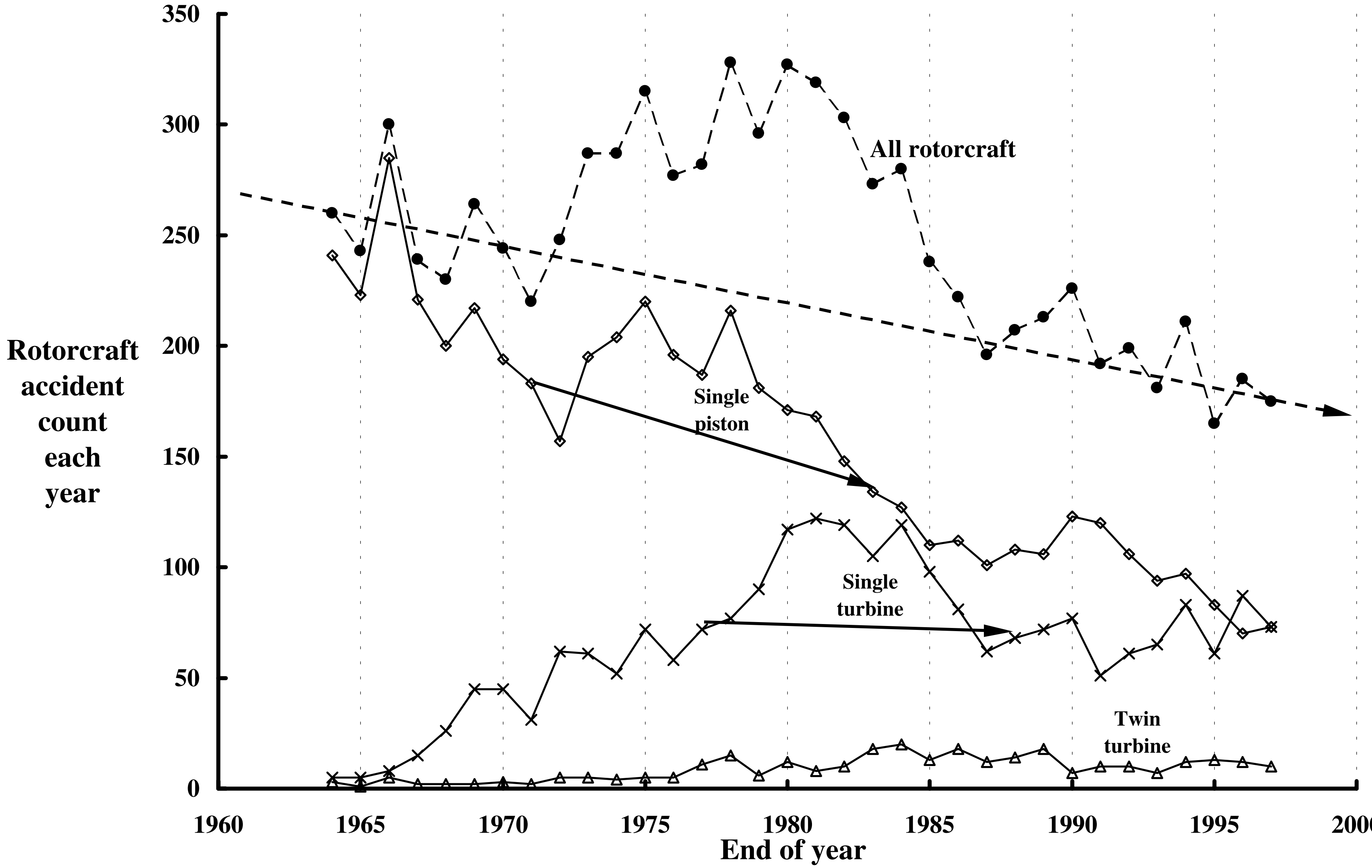


Figure 10. Rotorcraft accidents per year: 1964–1997 (total registered rotorcraft fleet).

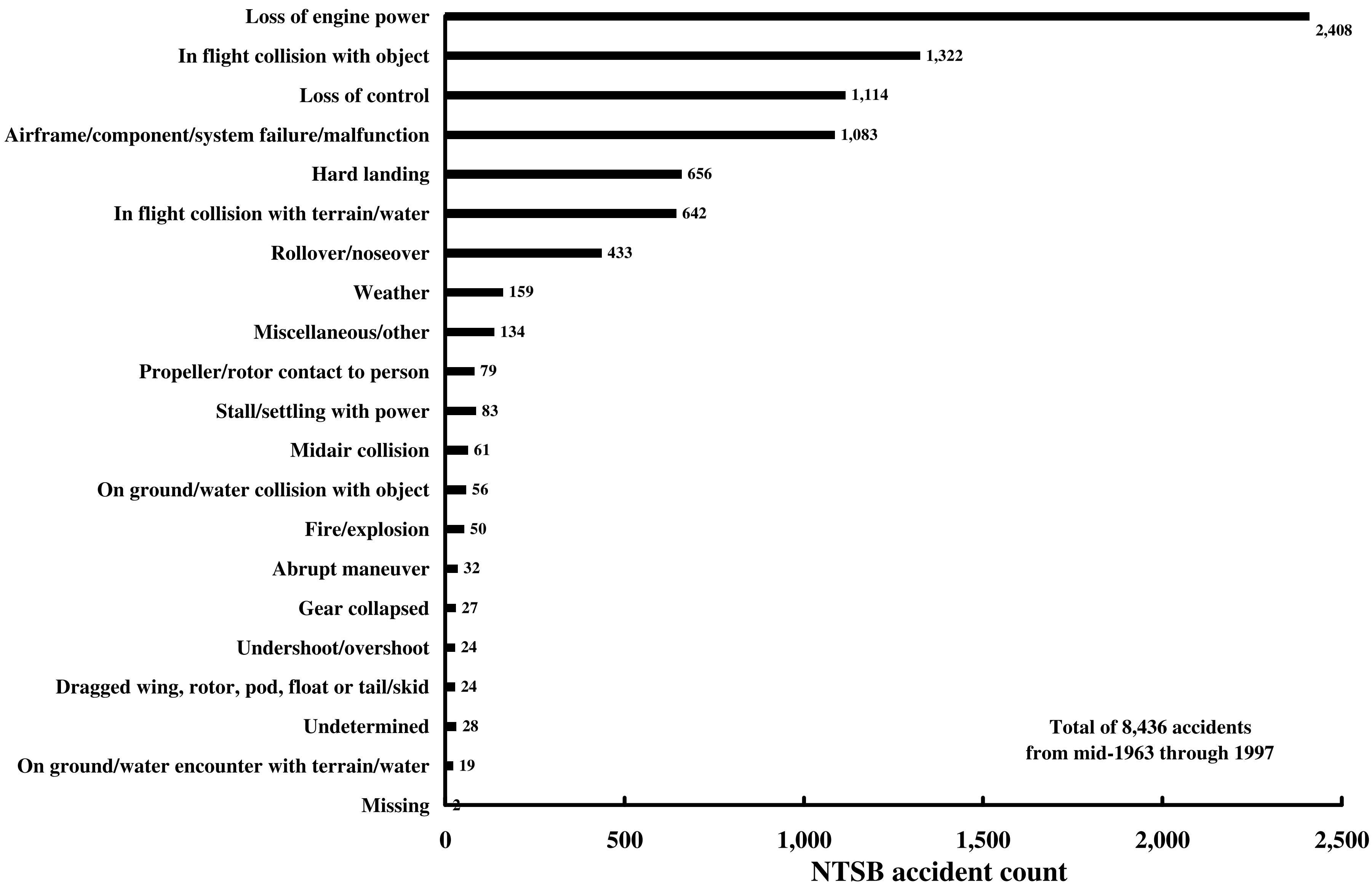


Figure 11. Rotorcraft accident count by first event category (total registered rotorcraft fleet).

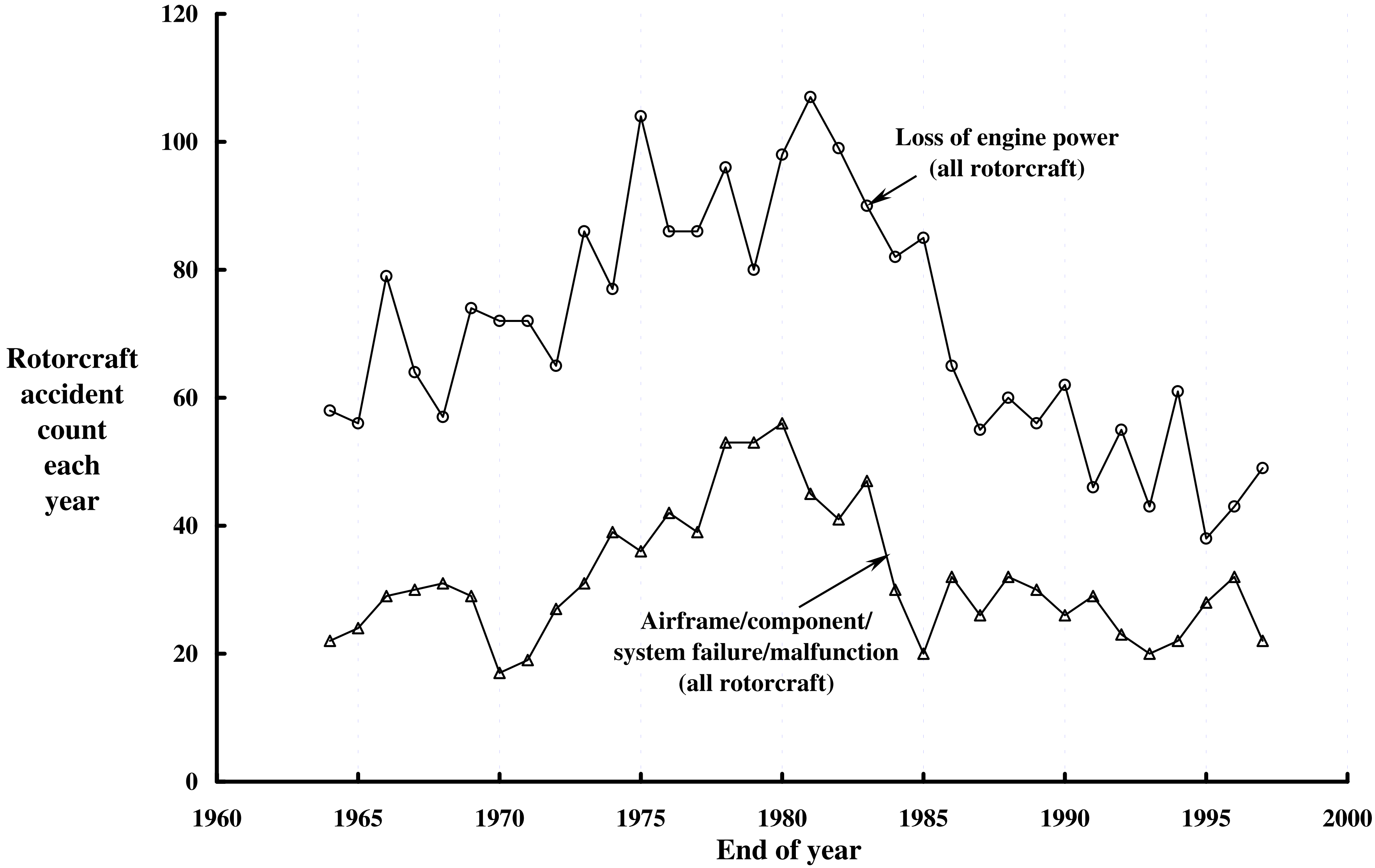


Figure 12. Loss of engine power and airframe/component/system failure or malfunction accidents (total registered rotorcraft fleet).

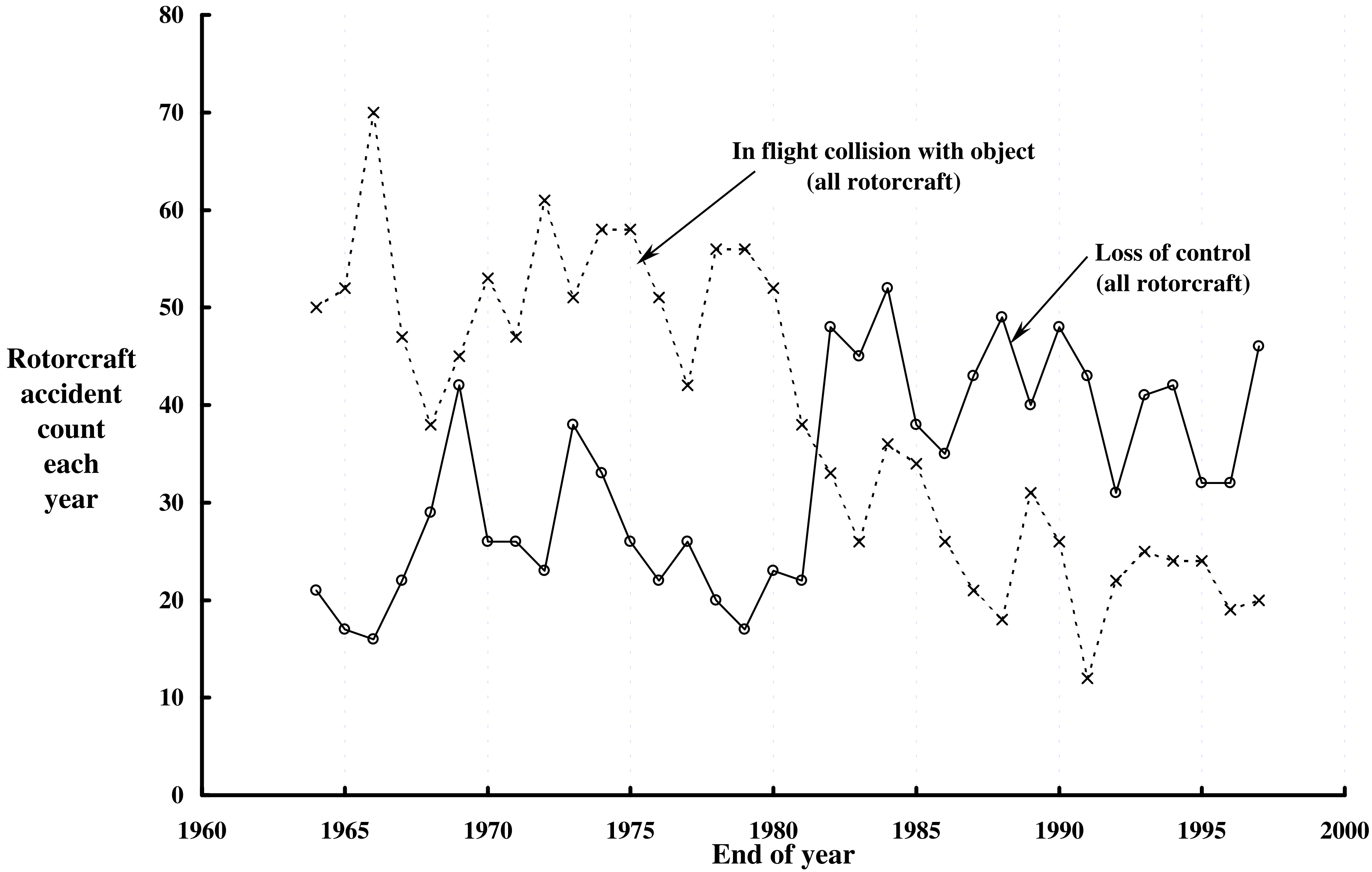


Figure 13. In flight collision with object and loss of control accidents (total registered rotorcraft fleet).

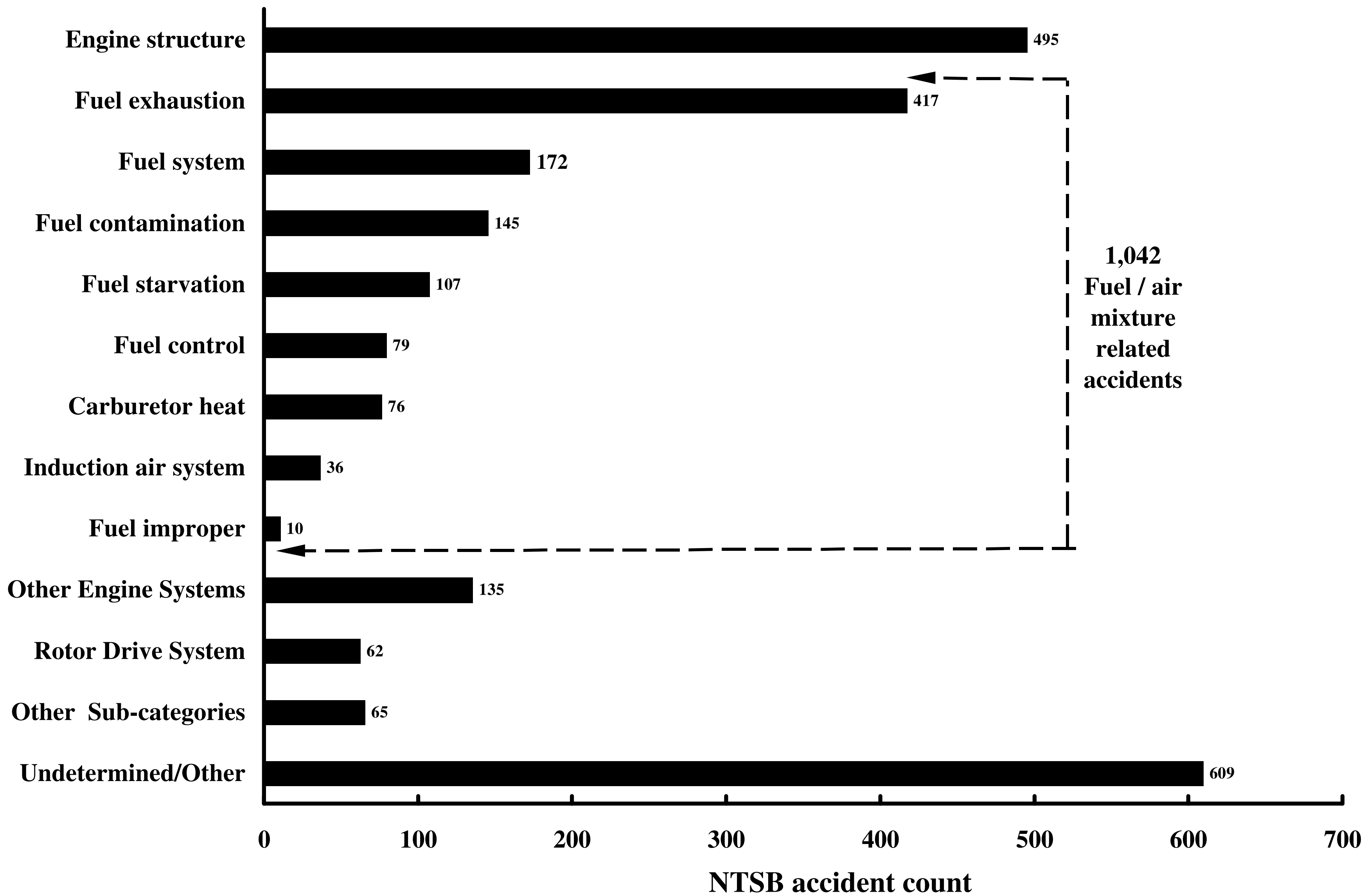


Figure 14. Factors related to loss of engine power accidents (total registered rotorcraft fleet).

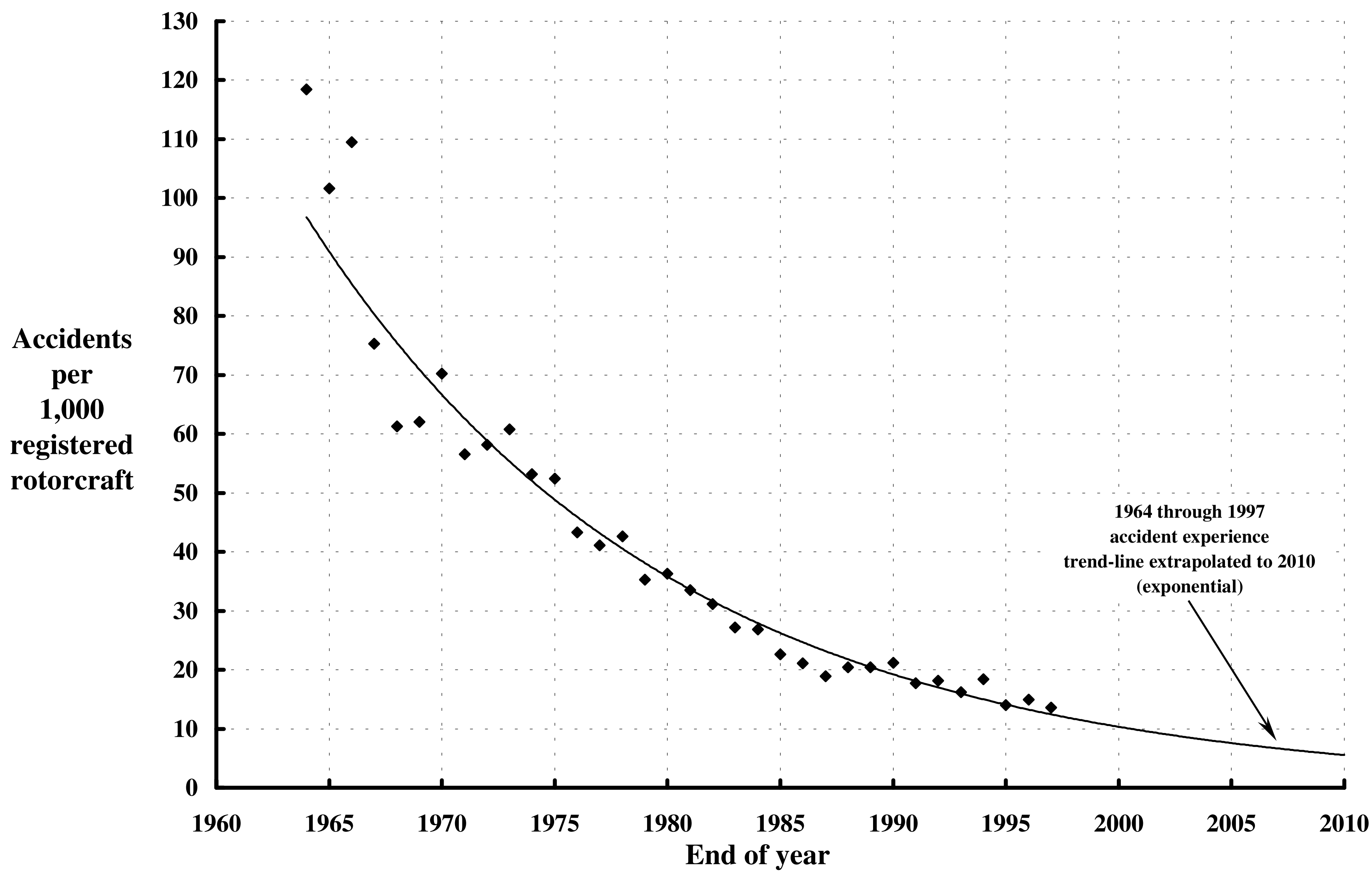


Figure 15. Rotorcraft accidents per 1,000 registered aircraft: (total registered rotorcraft fleet).

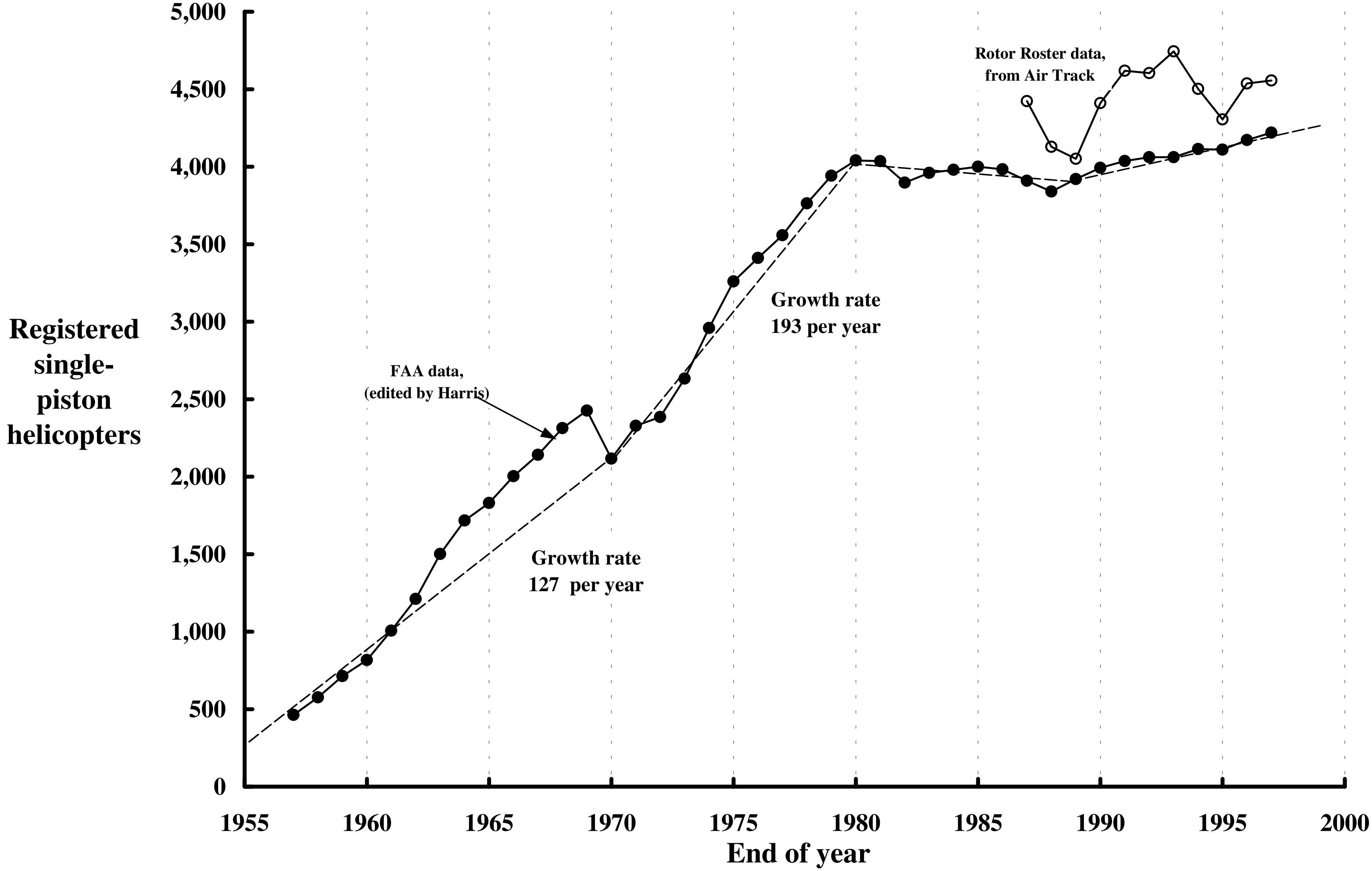


Figure 16. Single-piston helicopter fleet size (commercially manufactured).

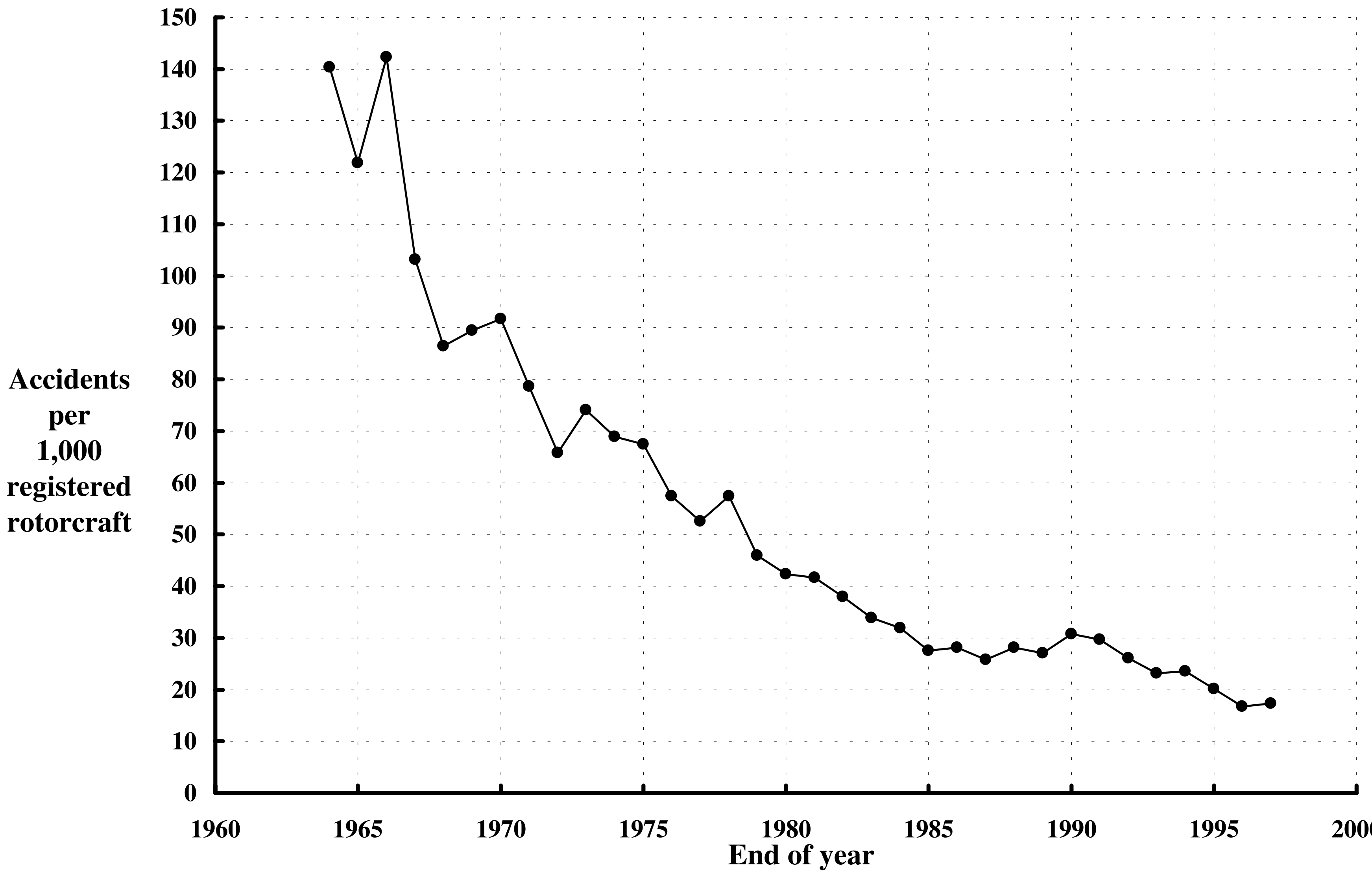


Figure 17. Accidents per 1,000 registered aircraft: single-piston helicopters (commercially manufactured).

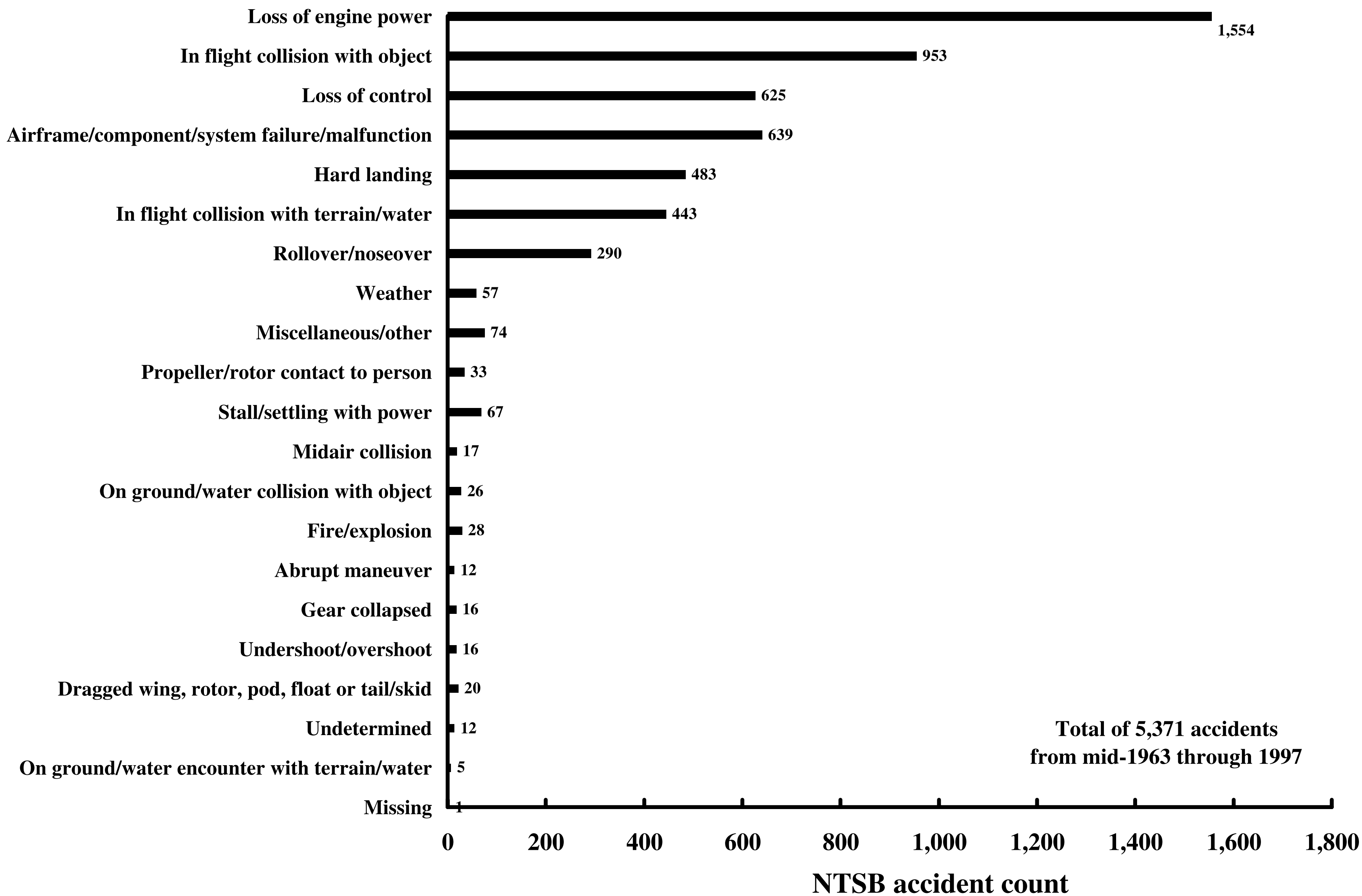


Figure 18. Accident count by first event category: single-piston helicopters (commercially manufactured).

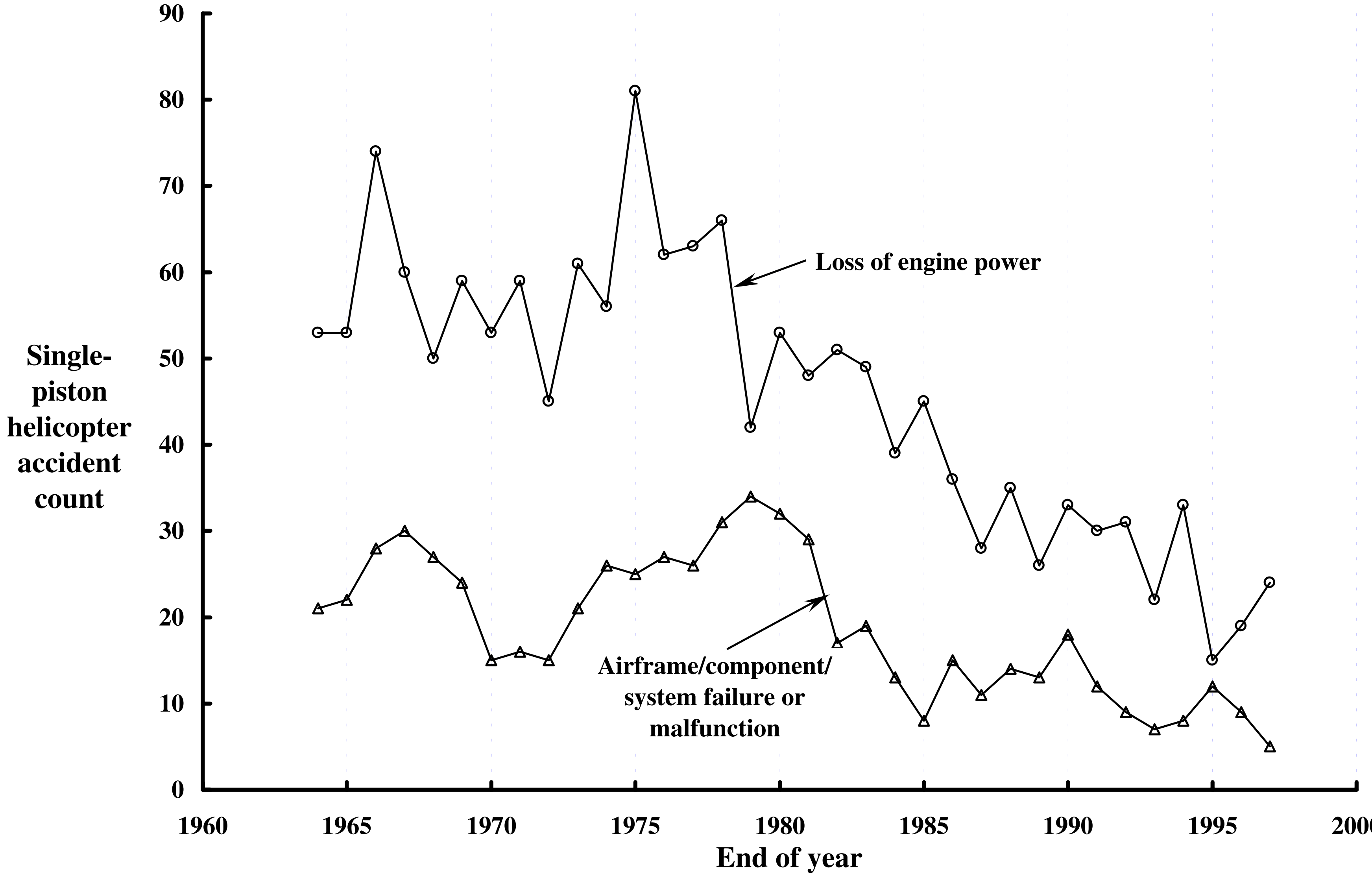


Figure 19. Loss of engine power and airframe failure or malfunction accidents: single-piston helicopters (commercially manufactured).

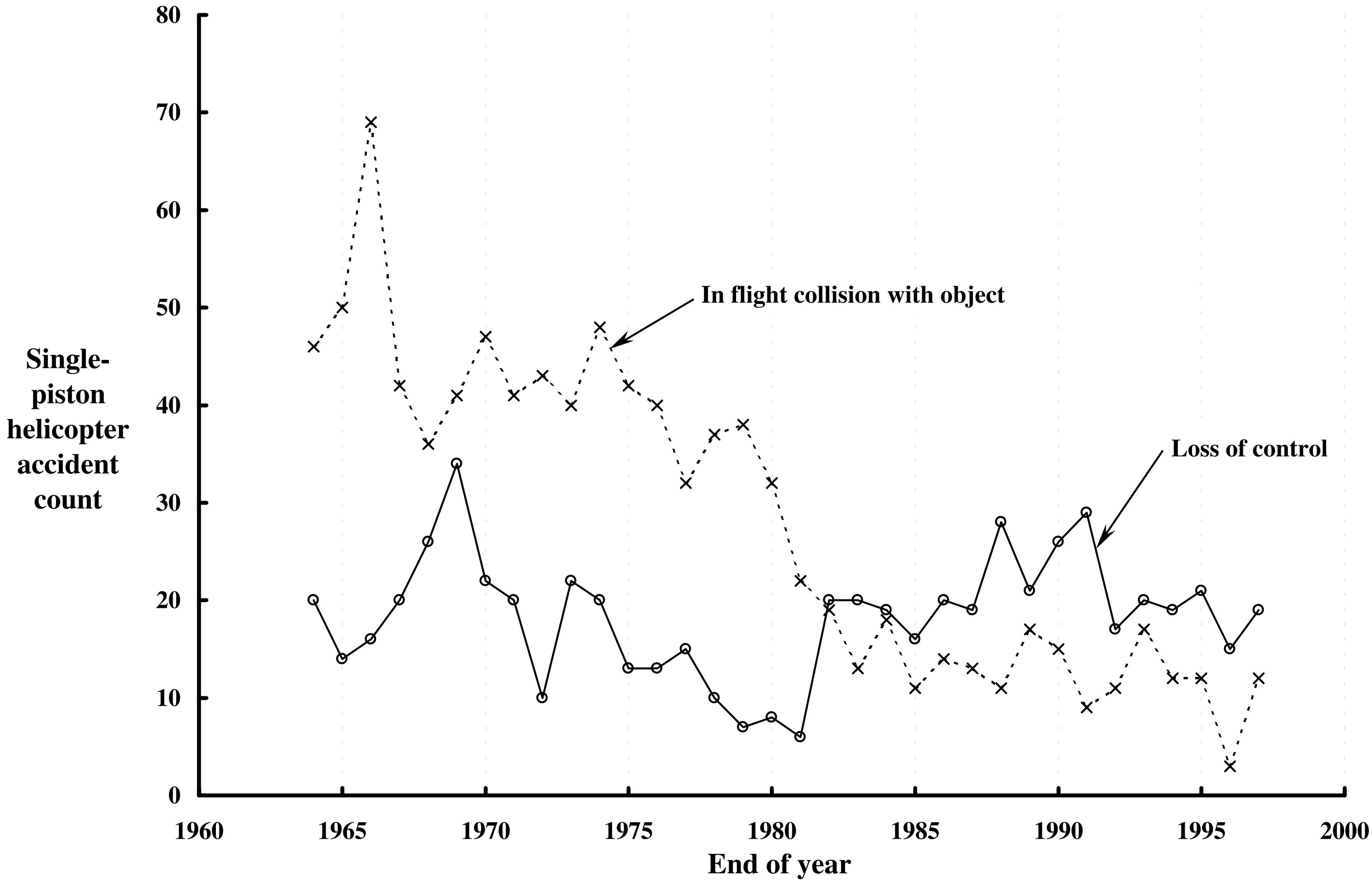


Figure 20. In flight collision with object and loss of control accidents: single-piston helicopters (commercially manufactured).

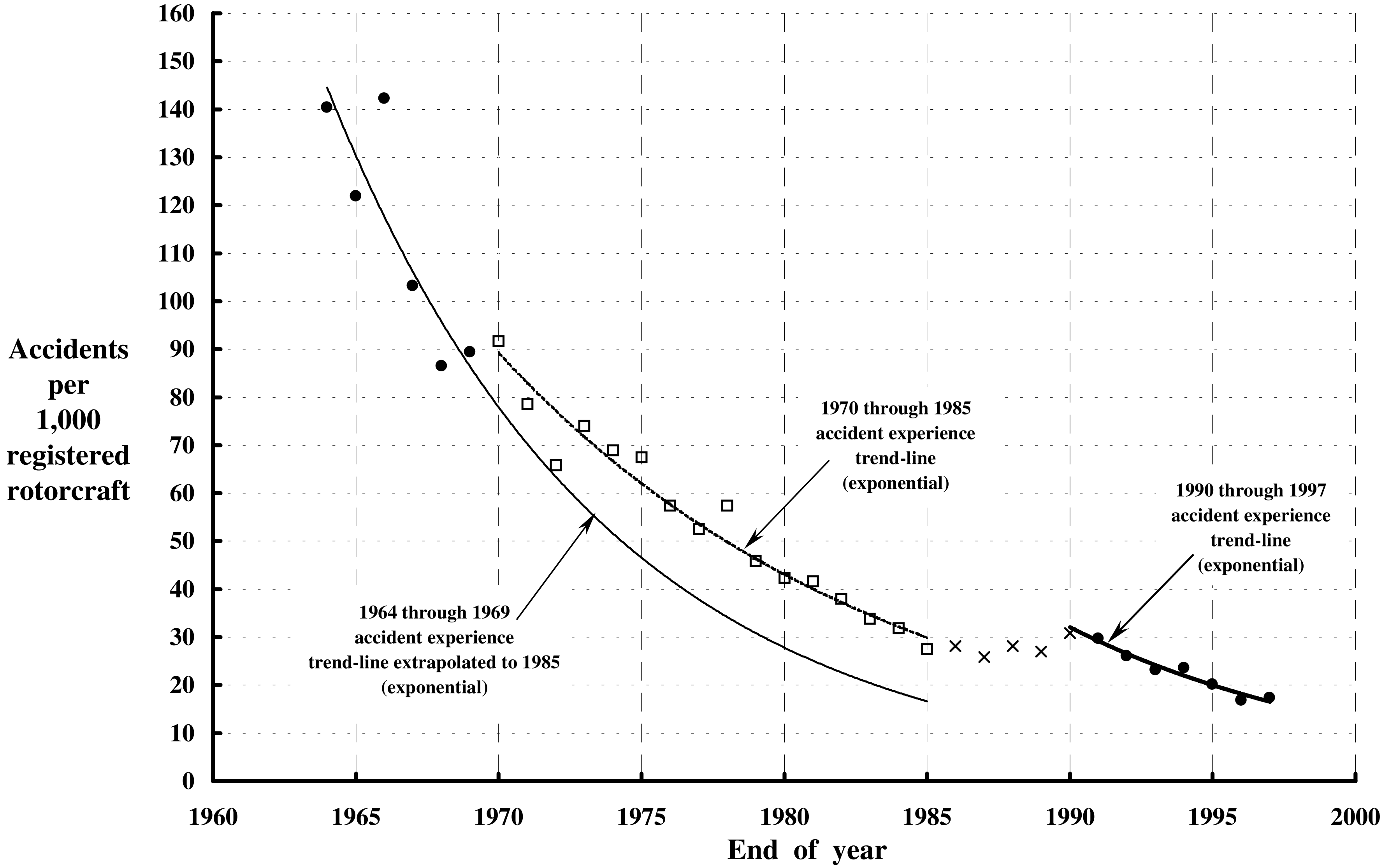


Figure 21. Accidents per 1,000 registered aircraft: 1964–1997: single-piston helicopters (commercially manufactured).

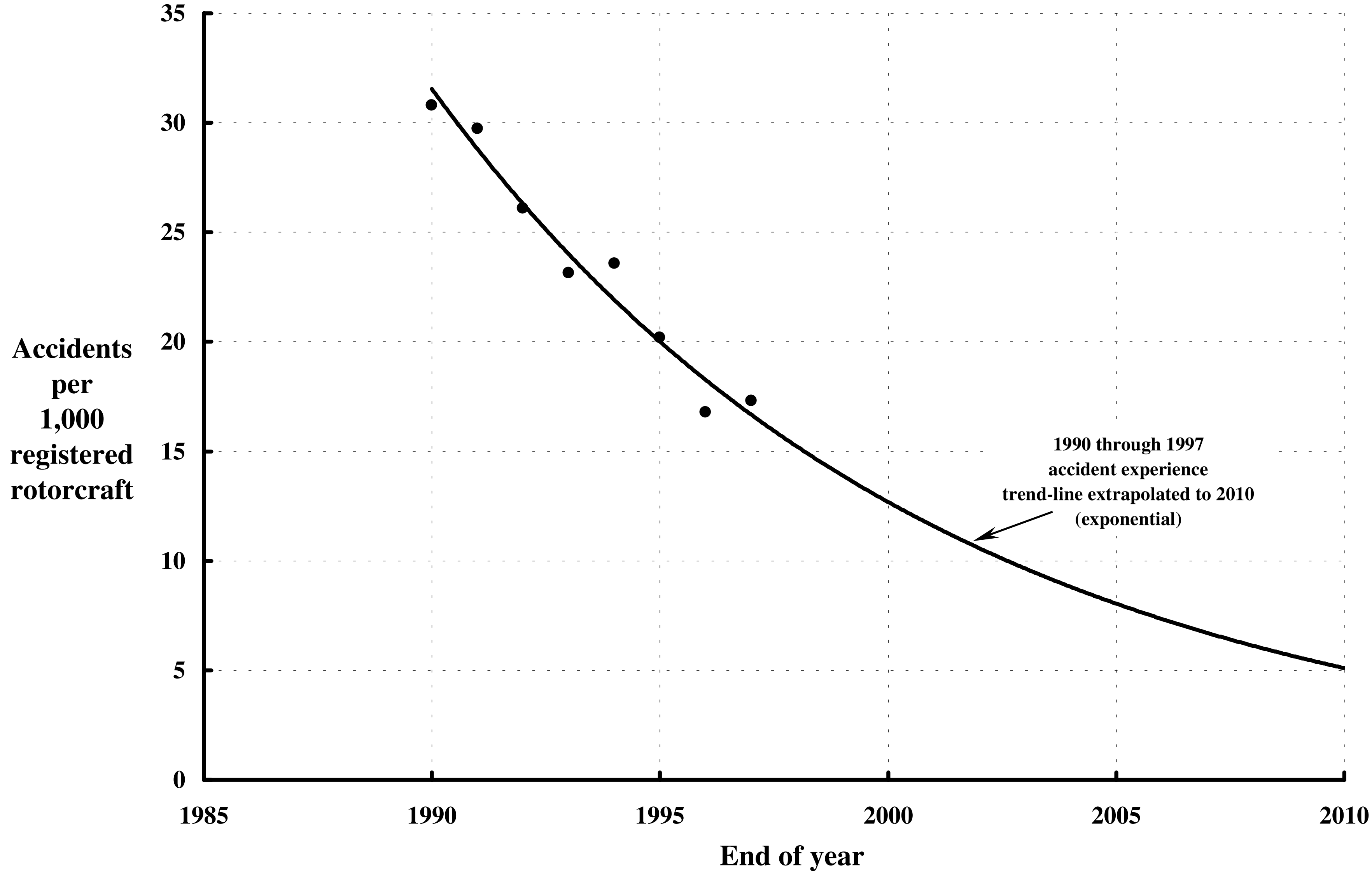


Figure 22. Accidents per 1,000 registered aircraft projected to 2010: single-piston helicopters (commercially manufactured).

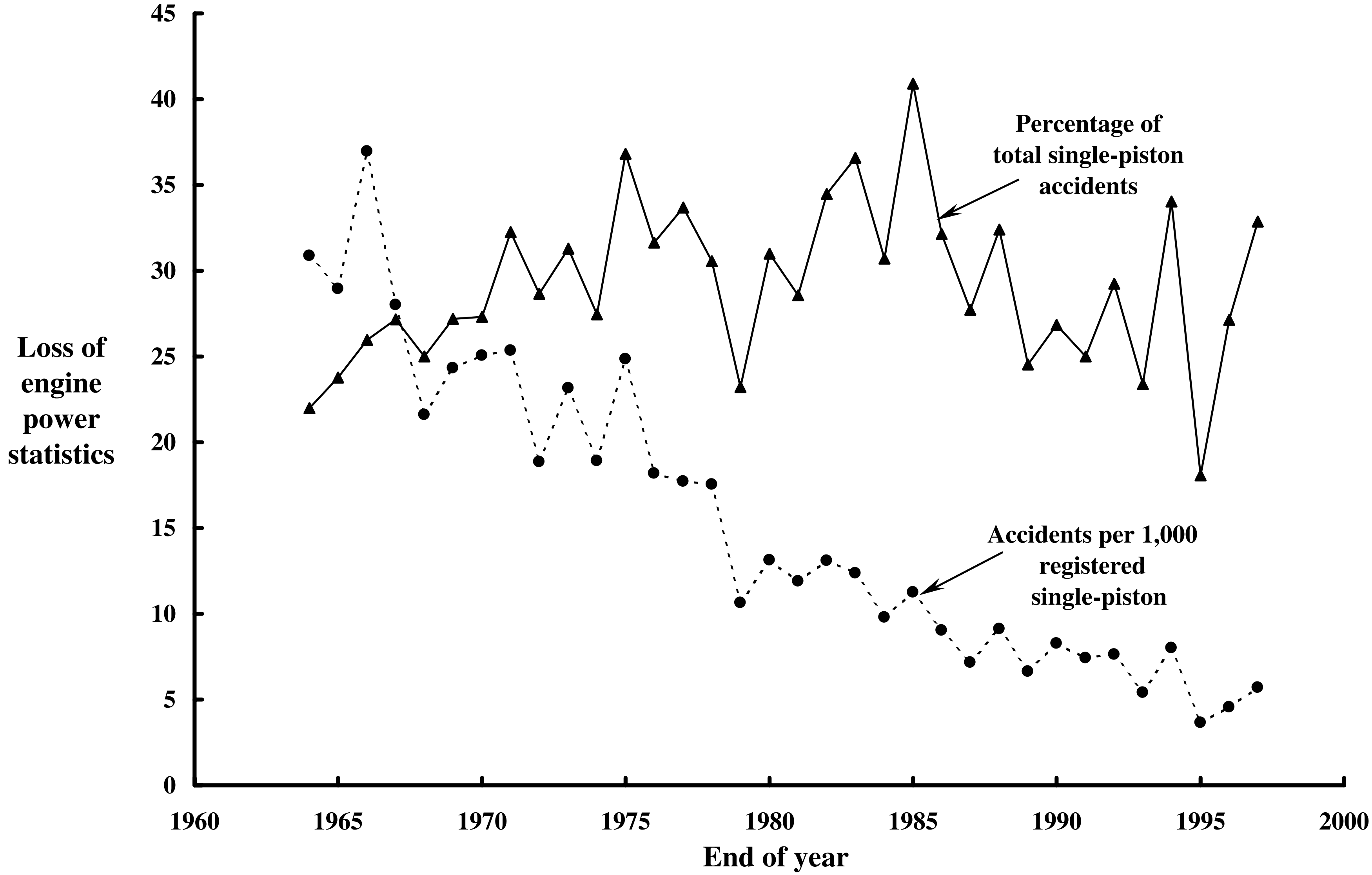


Figure 23. Loss of engine power yearly accident statistics: single-piston helicopters (commercially manufactured).

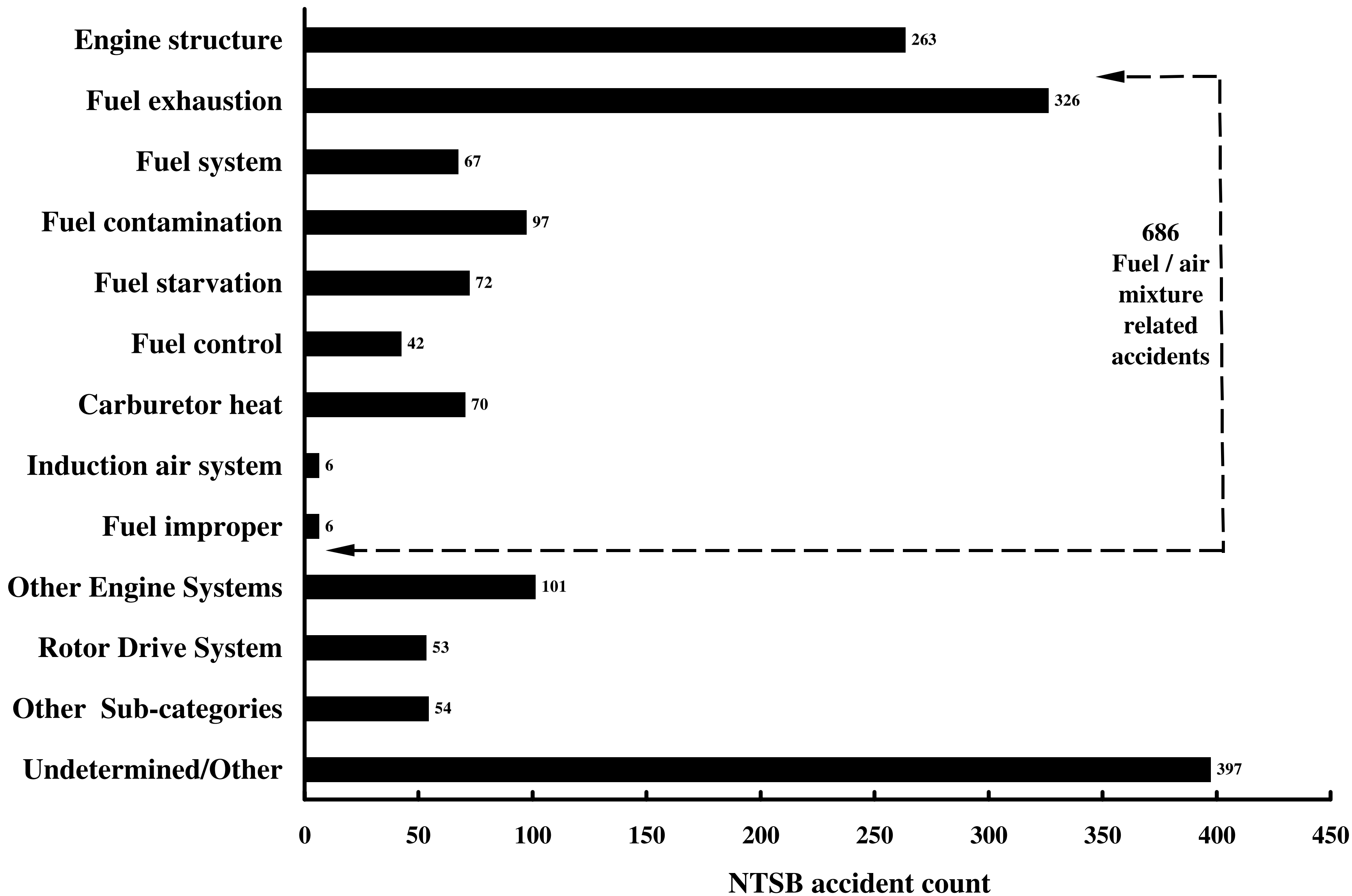


Figure 24. Loss of engine power accidents by category: single-piston helicopter (commercially manufactured).

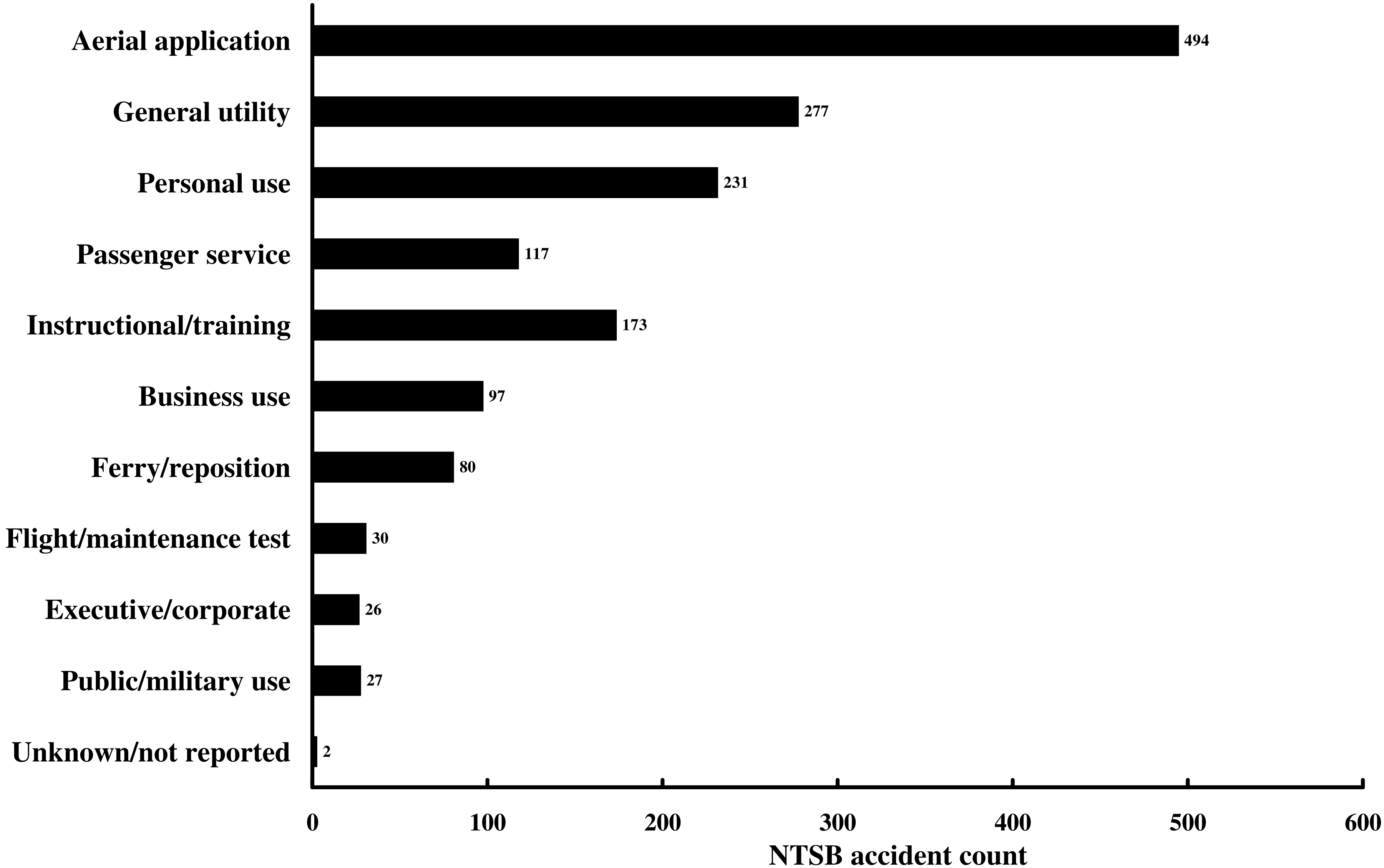


Figure 25. Loss of engine power accidents by activity: single-piston helicopters (commercially manufactured).

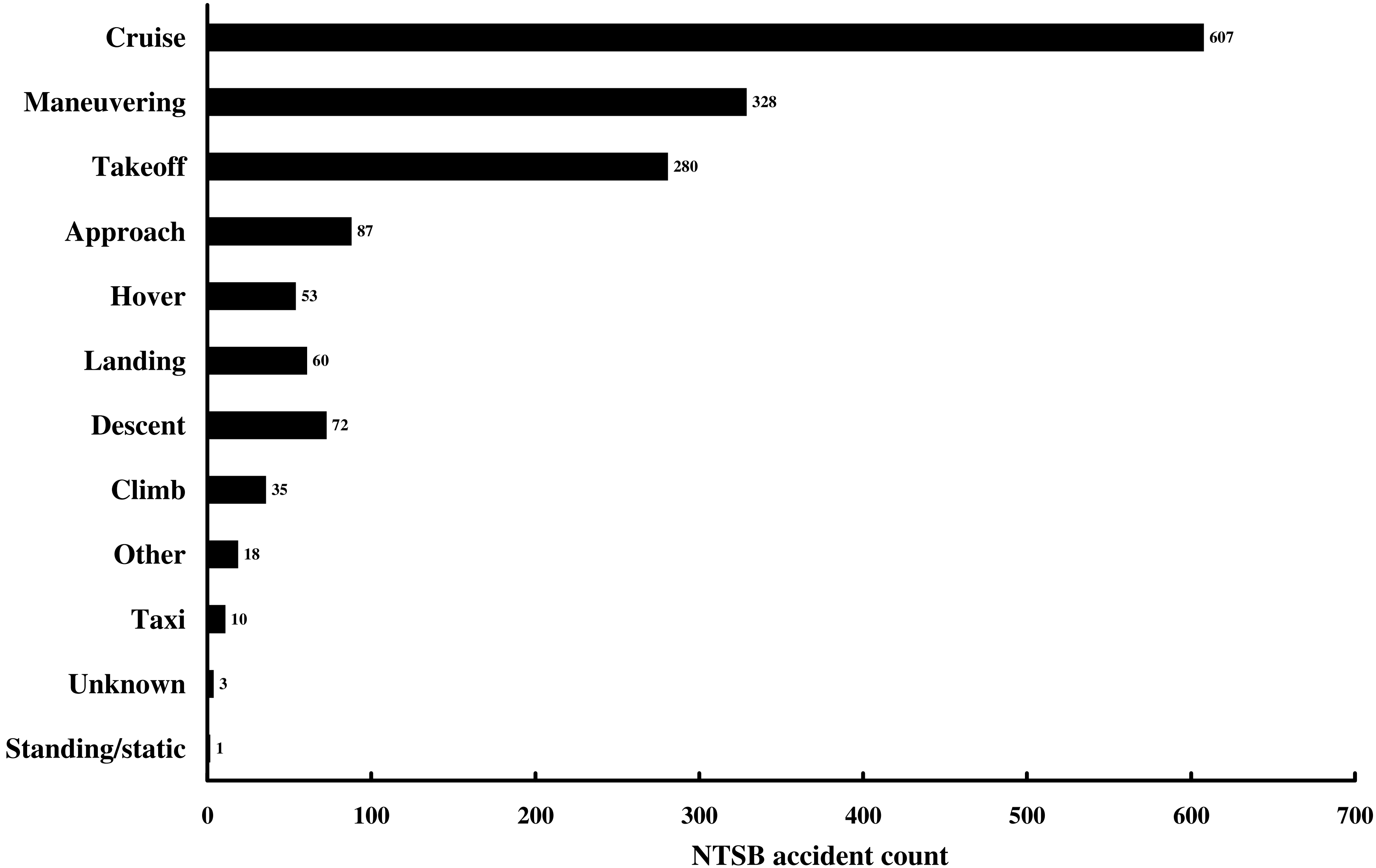


Figure 26. Loss of engine power accidents by phase of operation: single-piston helicopters (commercially manufactured).

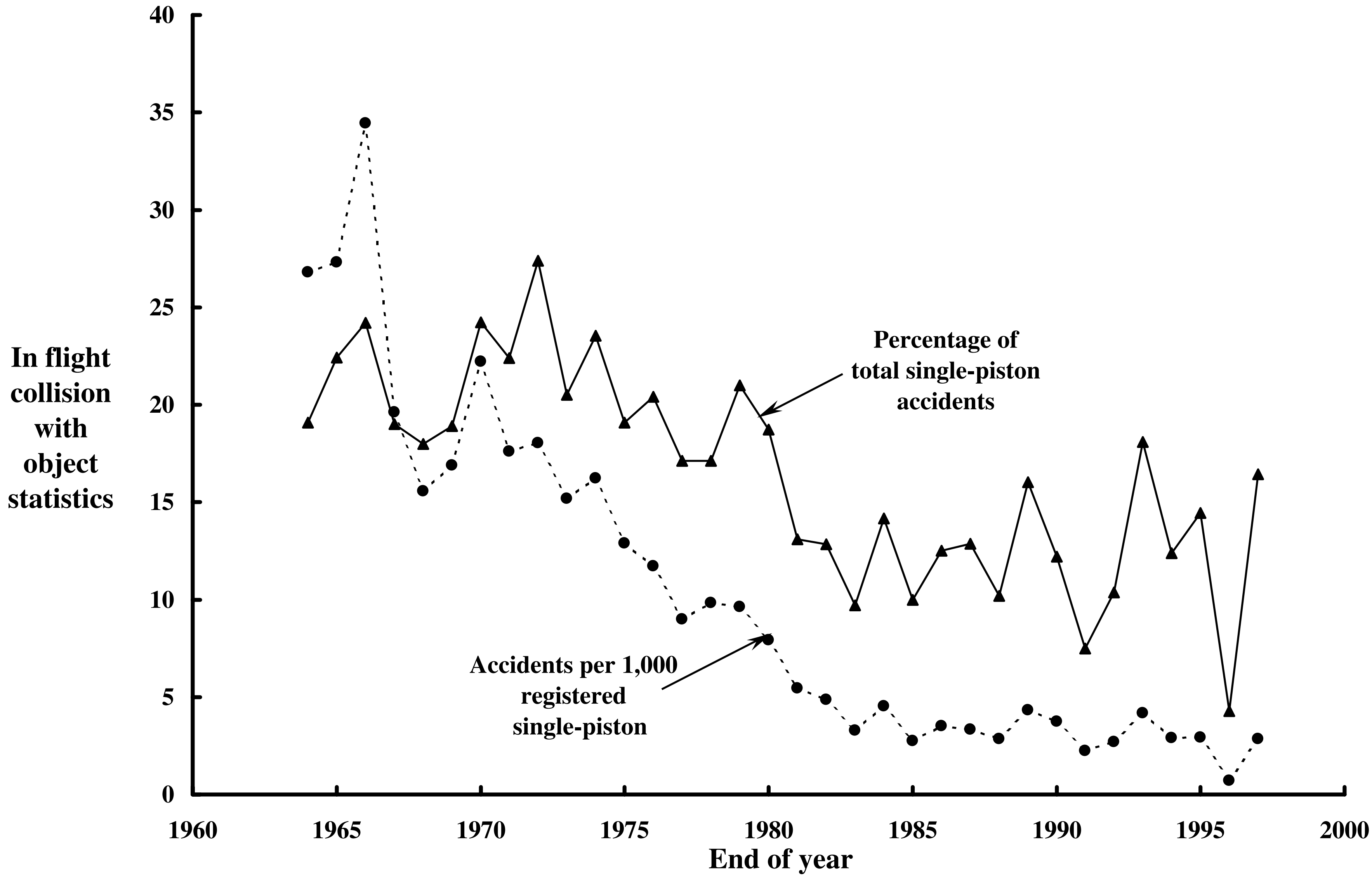


Figure 27. In flight collision with object yearly accident statistics: single-piston helicopters (commercially manufactured).

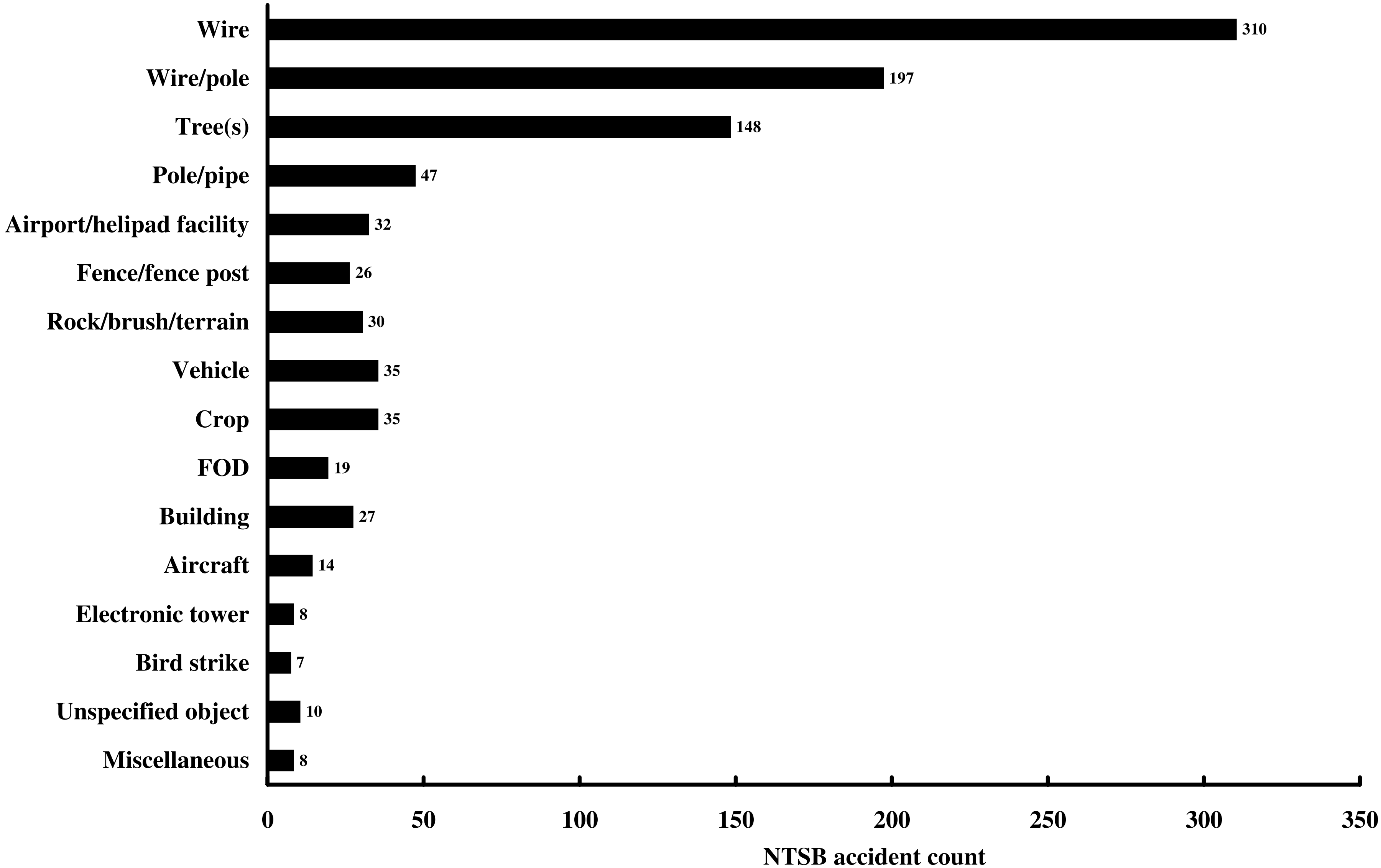


Figure 28. In flight collision with object accidents by object hit: single-piston helicopters (commercially manufactured).

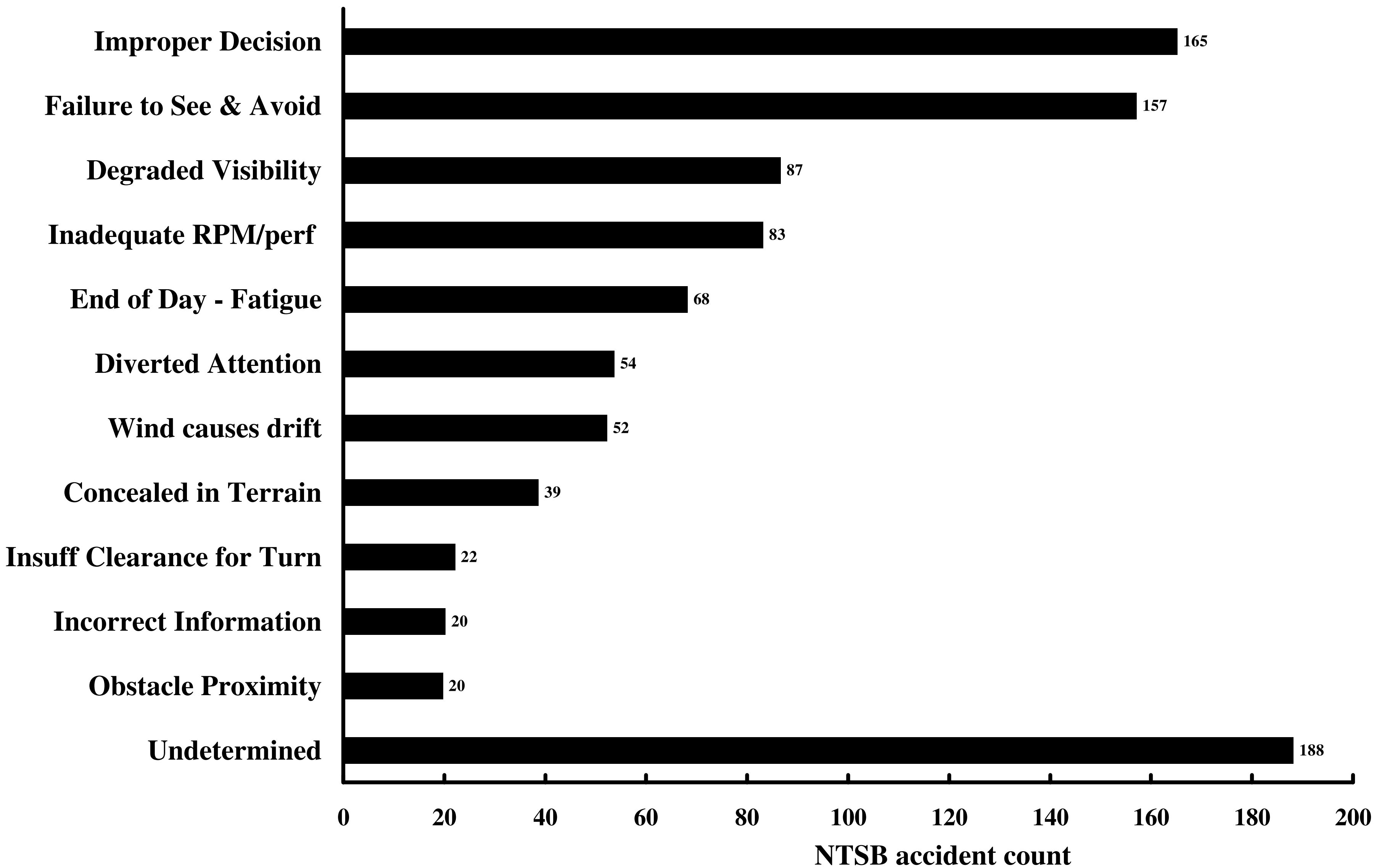


Figure 29. In flight collision with object accidents by cause: single-piston helicopters (commercially manufactured).

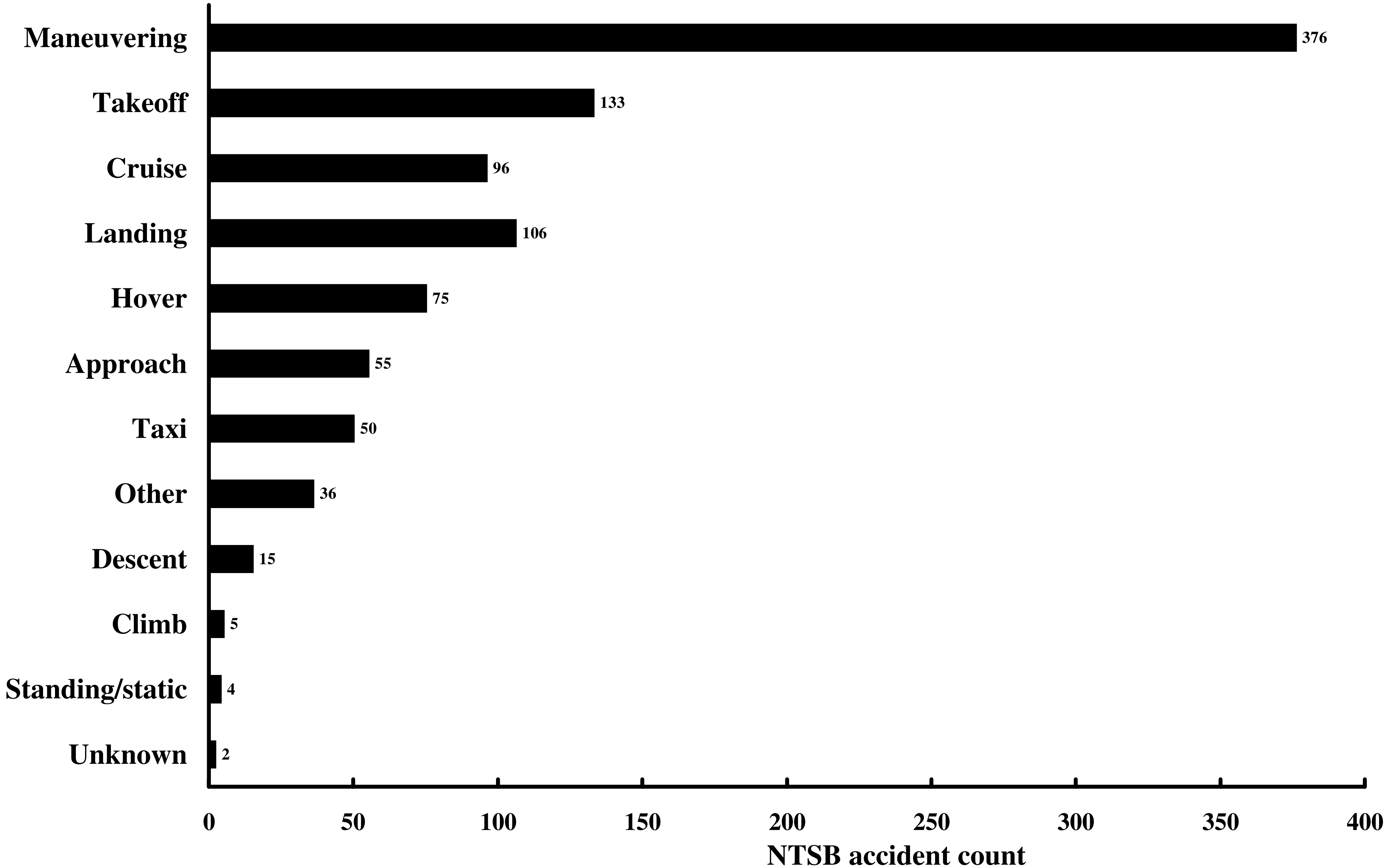


Figure 30. In flight collision with object accidents by phase of operation: single-piston helicopters (commercially manufactured).

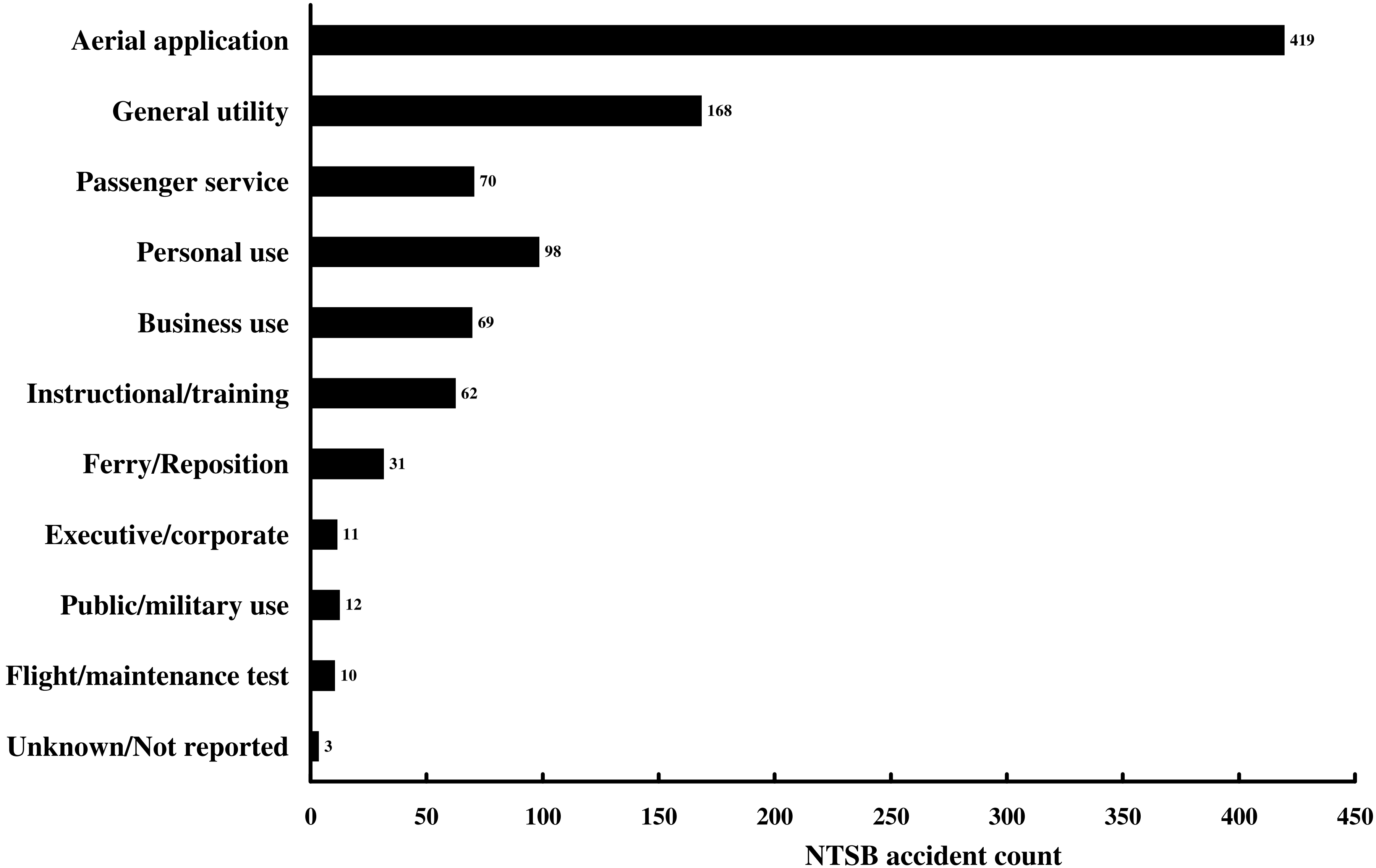


Figure 31. In flight collision with object accidents by activity: single-piston helicopters (commercially manufactured).

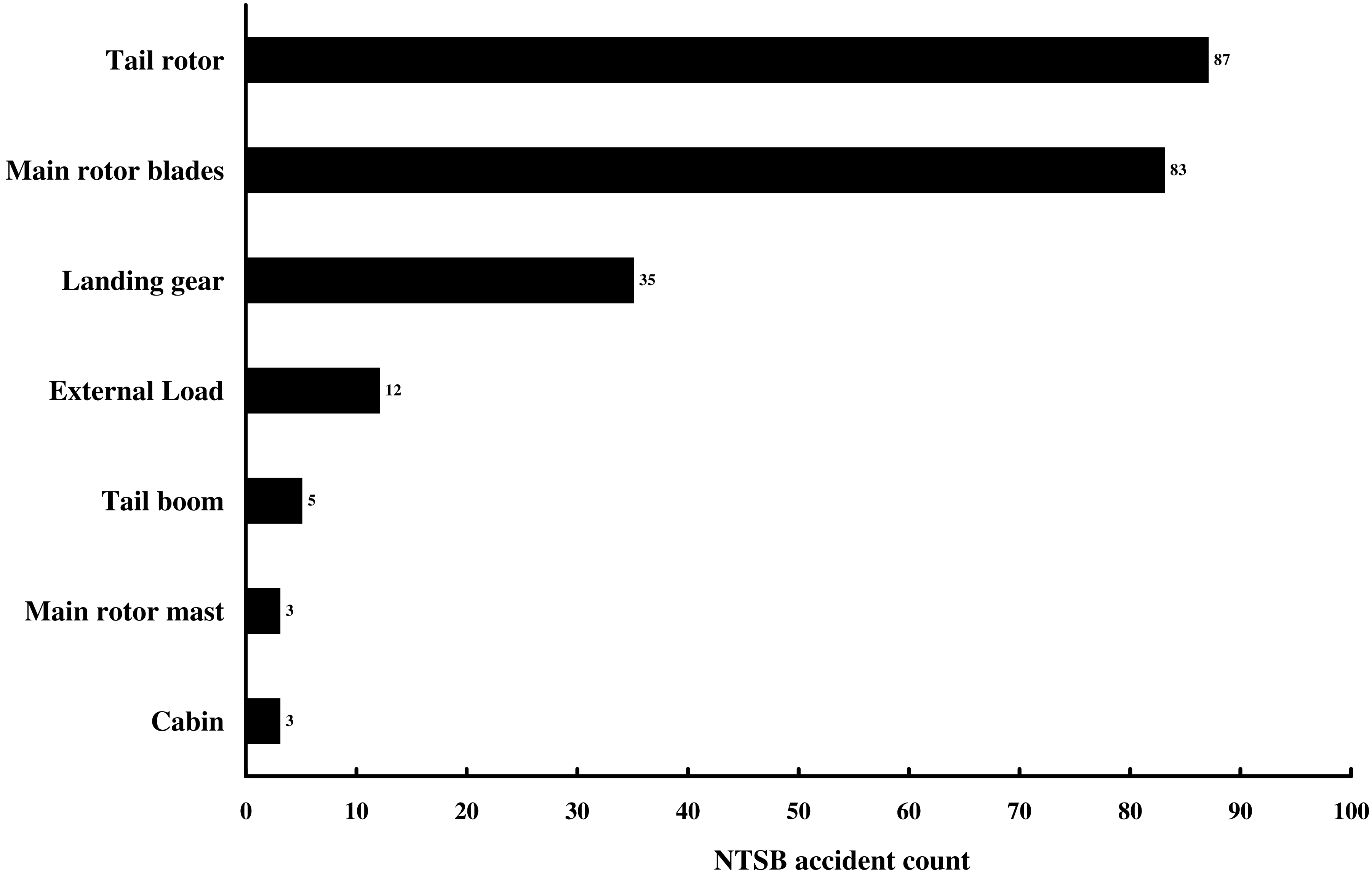


Figure 32. In flight collision with object accidents by part hit: single-piston helicopters (commercially manufactured).

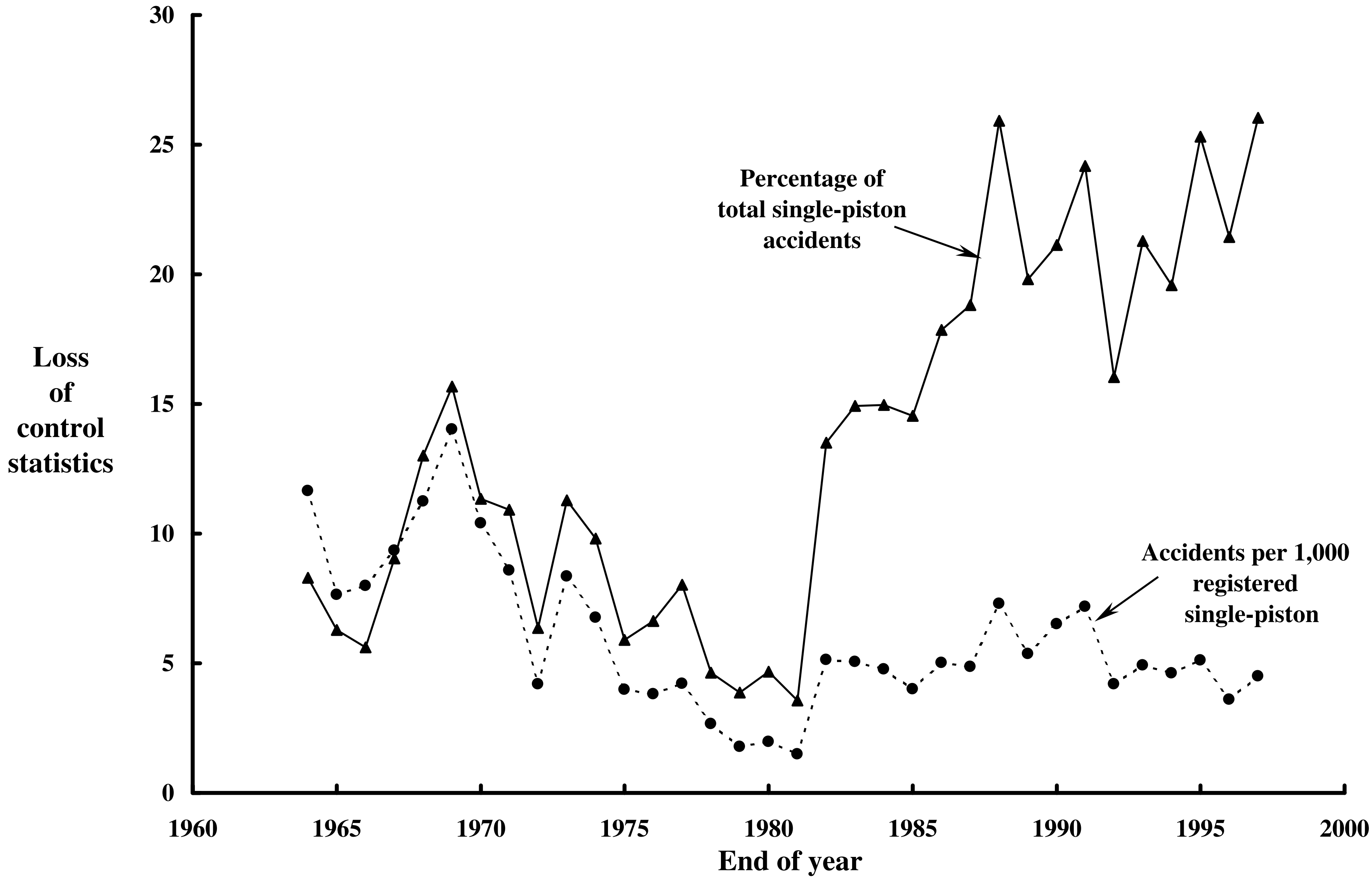


Figure 33. Loss of control early accident statistics: single-piston helicopters (commercially manufactured).

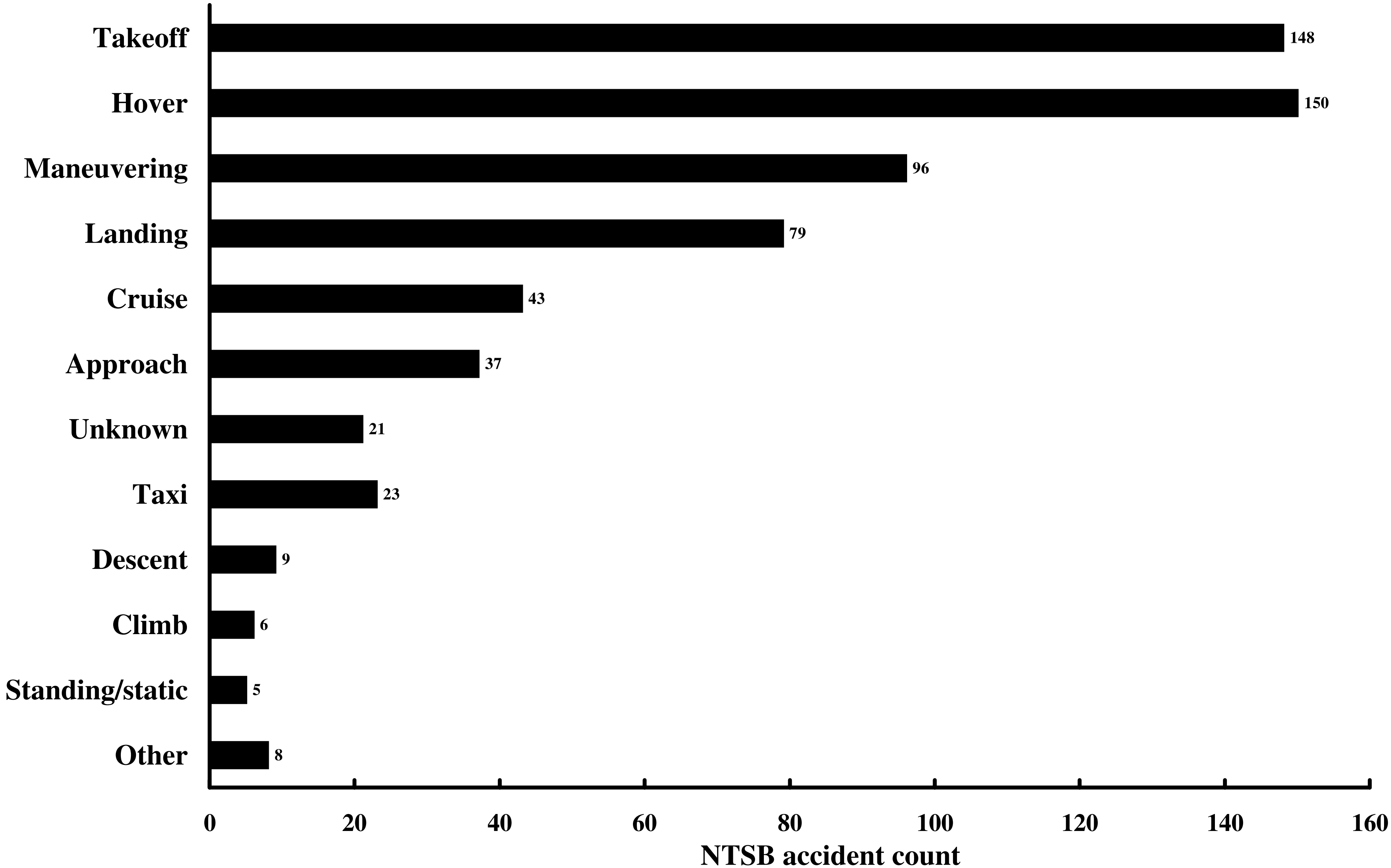


Figure 34. Loss of control accidents by phase of operation: single-piston helicopters (commercially manufactured).

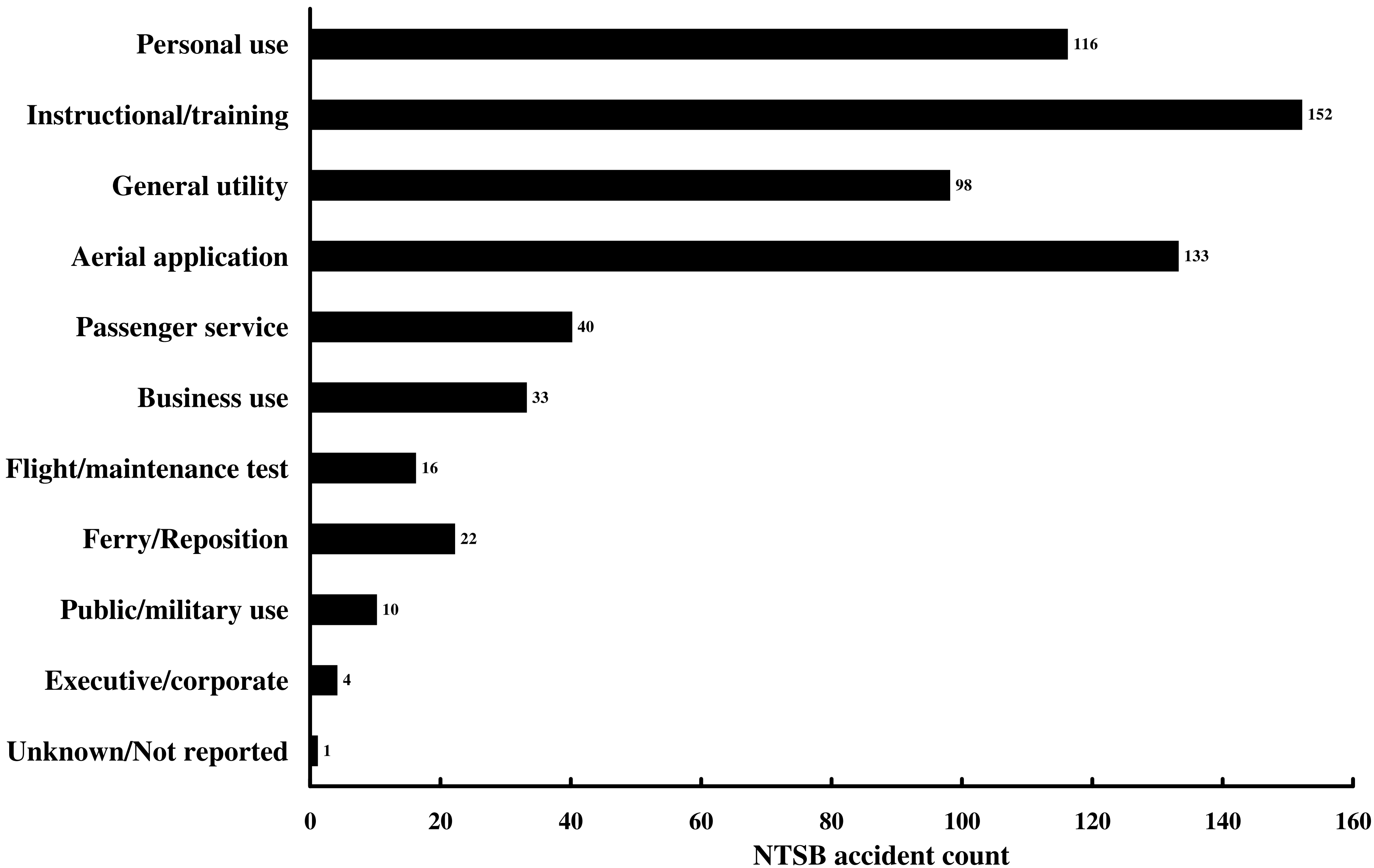


Figure 35. Loss of control accidents by activity: single-piston helicopters (commercially manufactured).

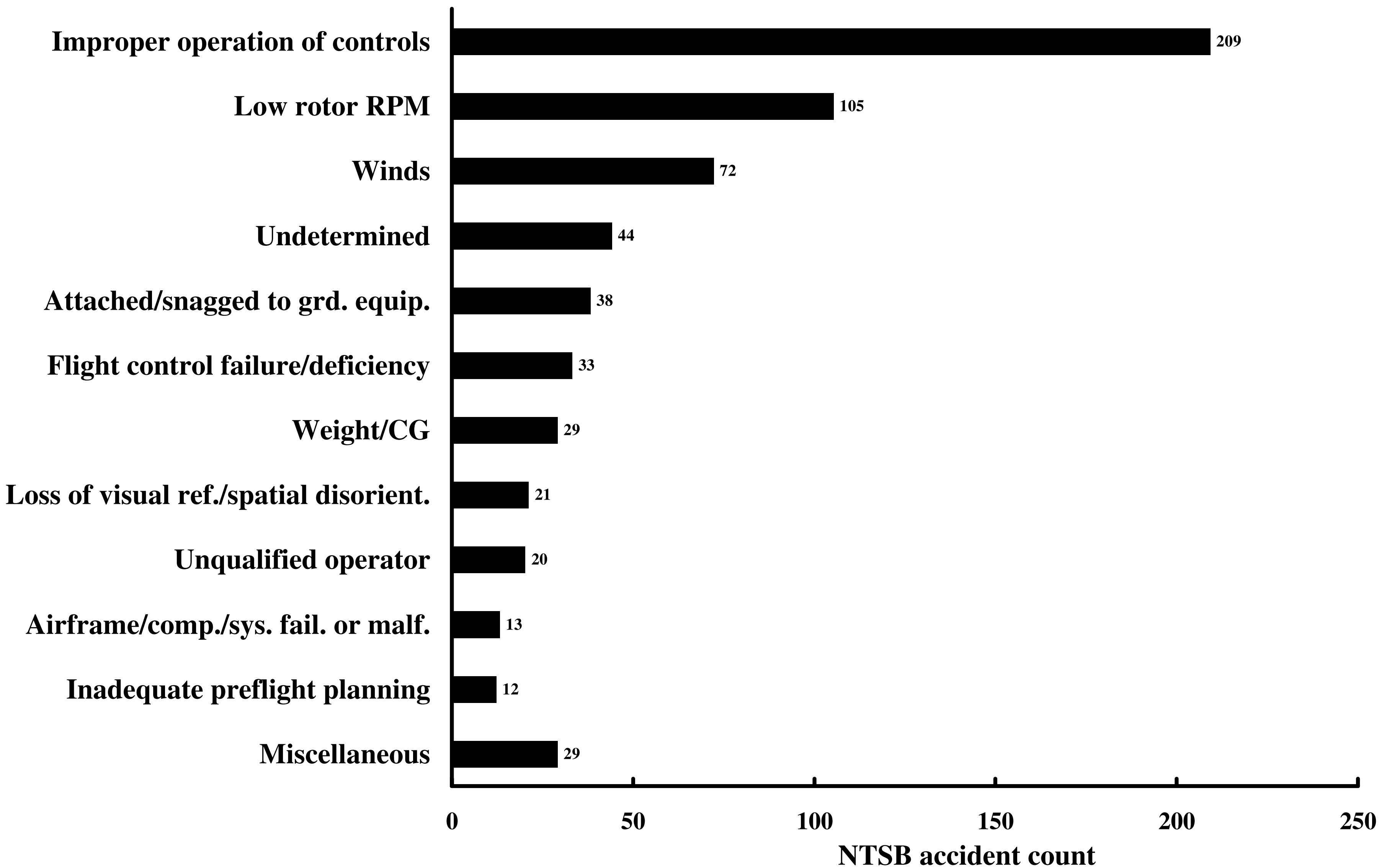


Figure 36. Loss of control accidents by cause: single-piston helicopters (commercially manufactured).

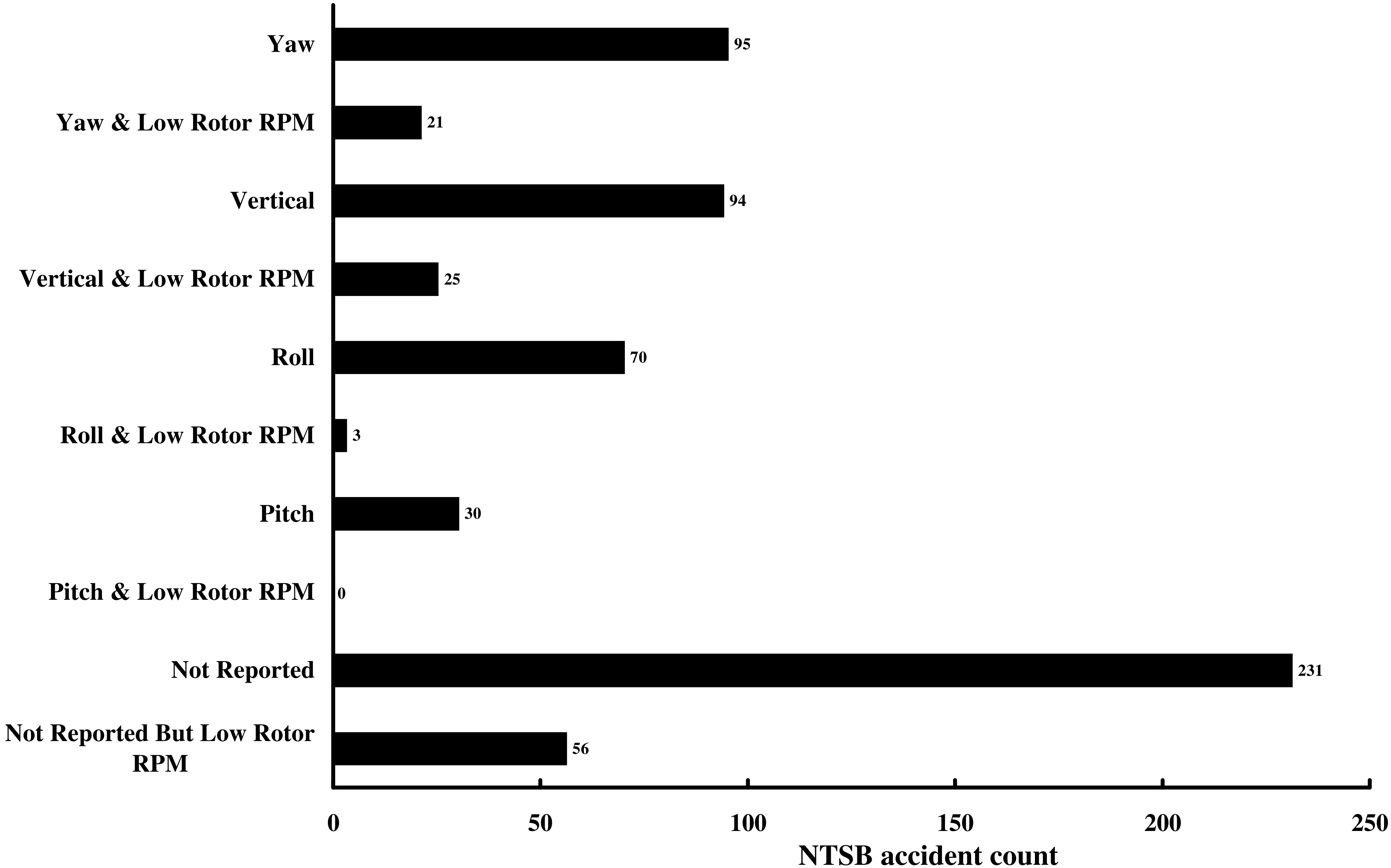


Figure 37. Loss of control accidents by axis lost: single-piston helicopters (commercially manufactured).

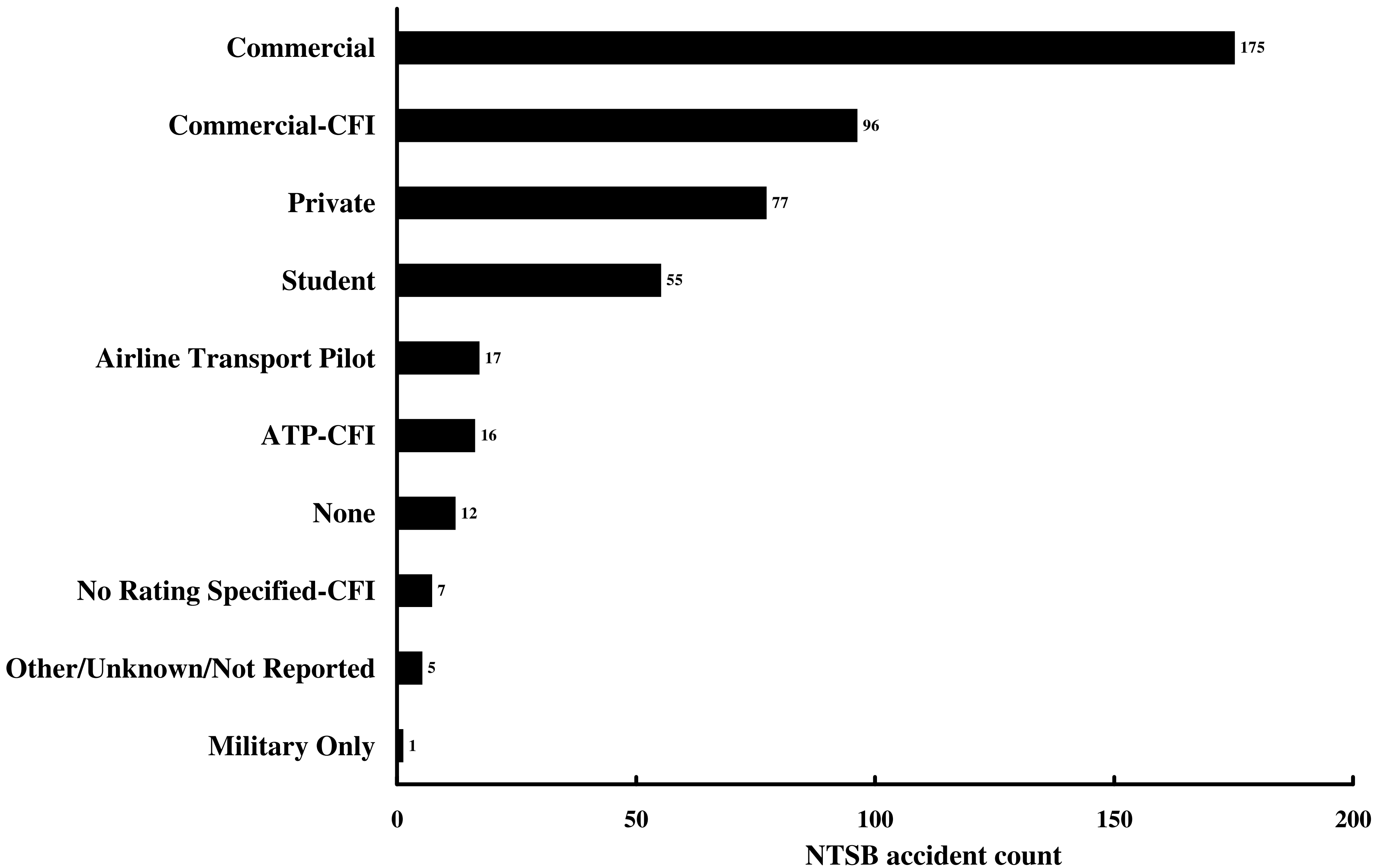


Figure 38. Loss of control accidents by pilot in command certification: single-piston helicopters (commercially manufactured).

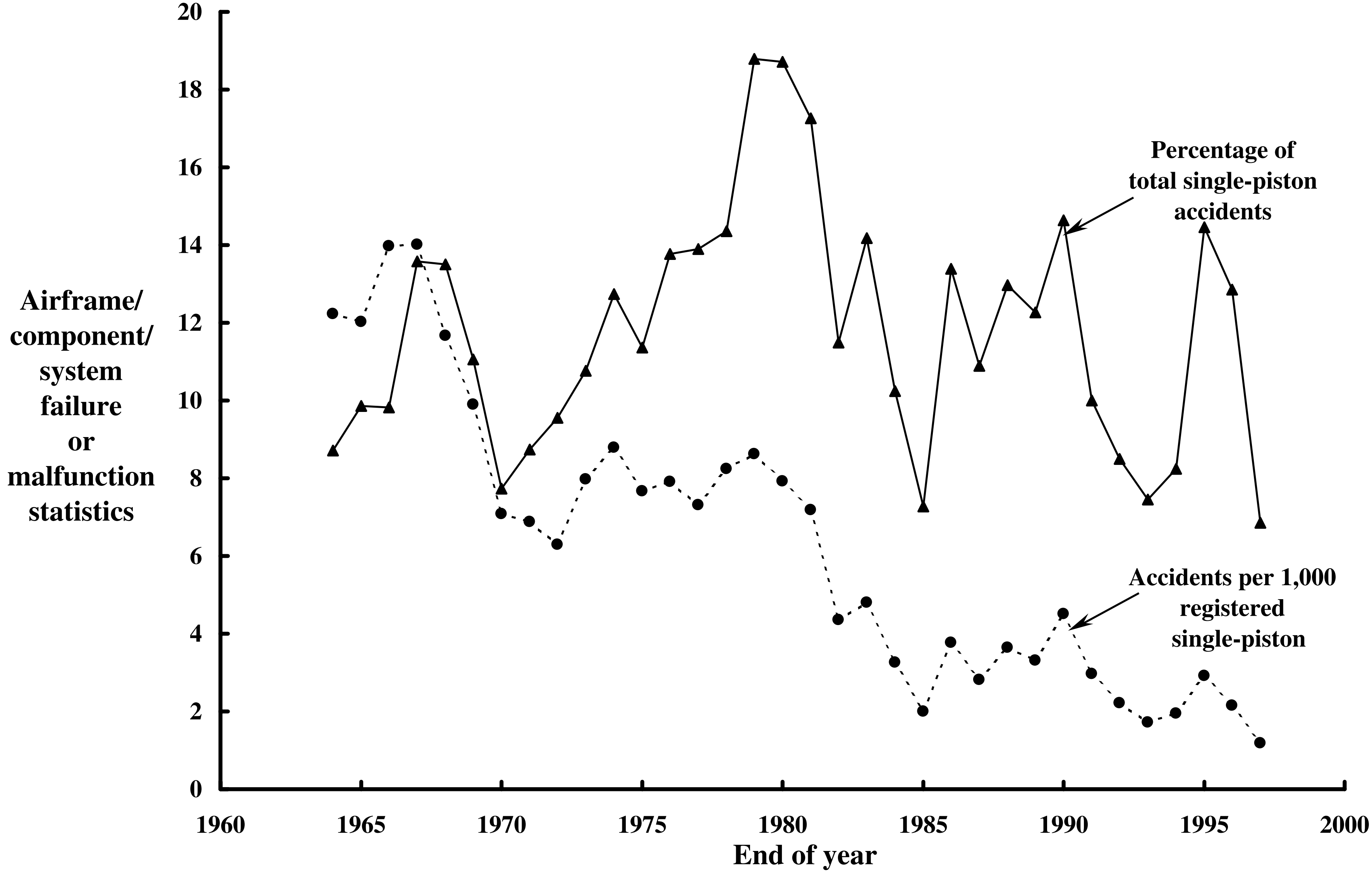


Figure 39. Airframe failure yearly accident statistics: single-piston helicopters (commercially manufactured).

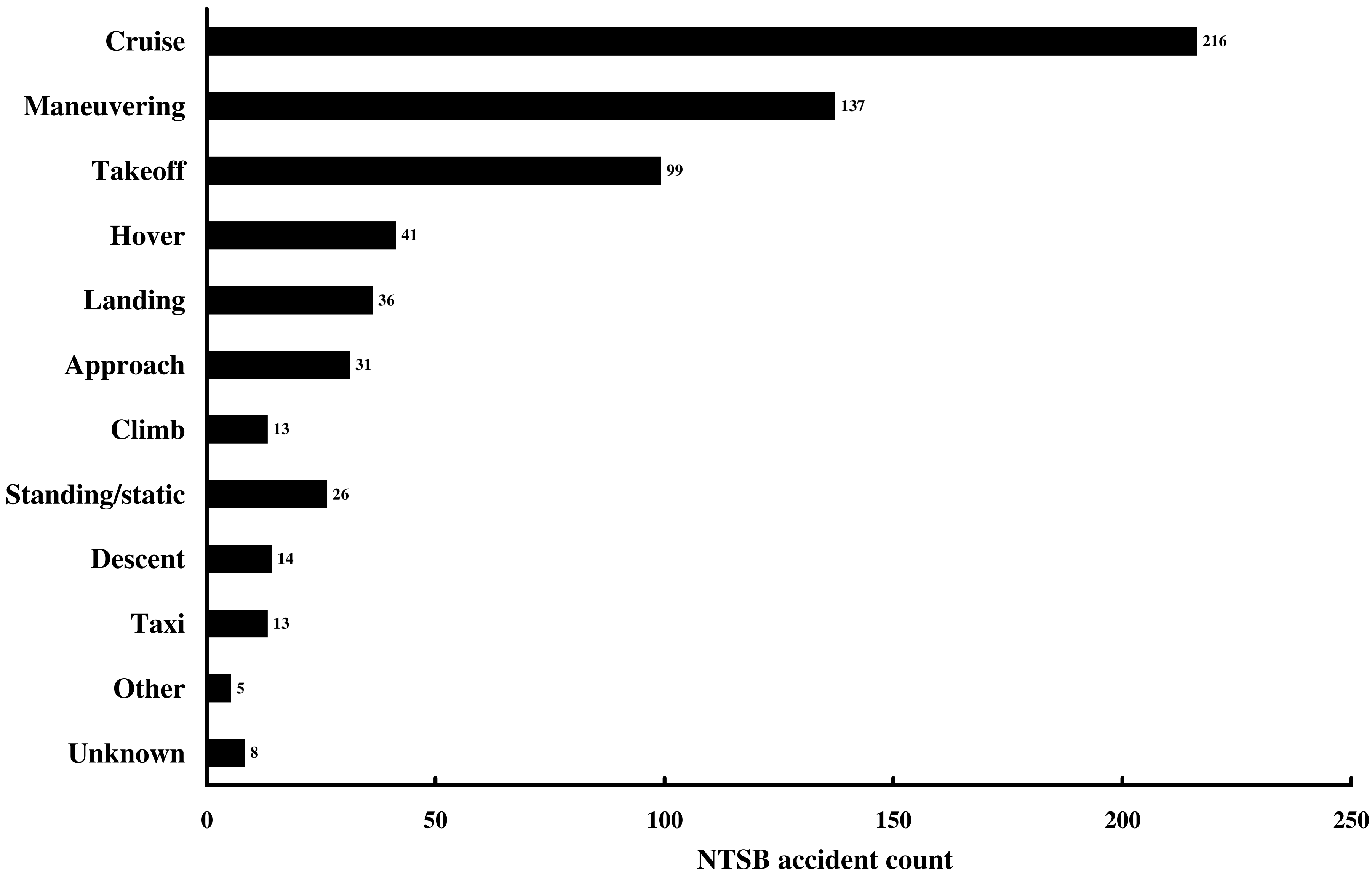


Figure 40. Airframe failure accidents by phase of operation: single-piston helicopters (commercially manufactured).

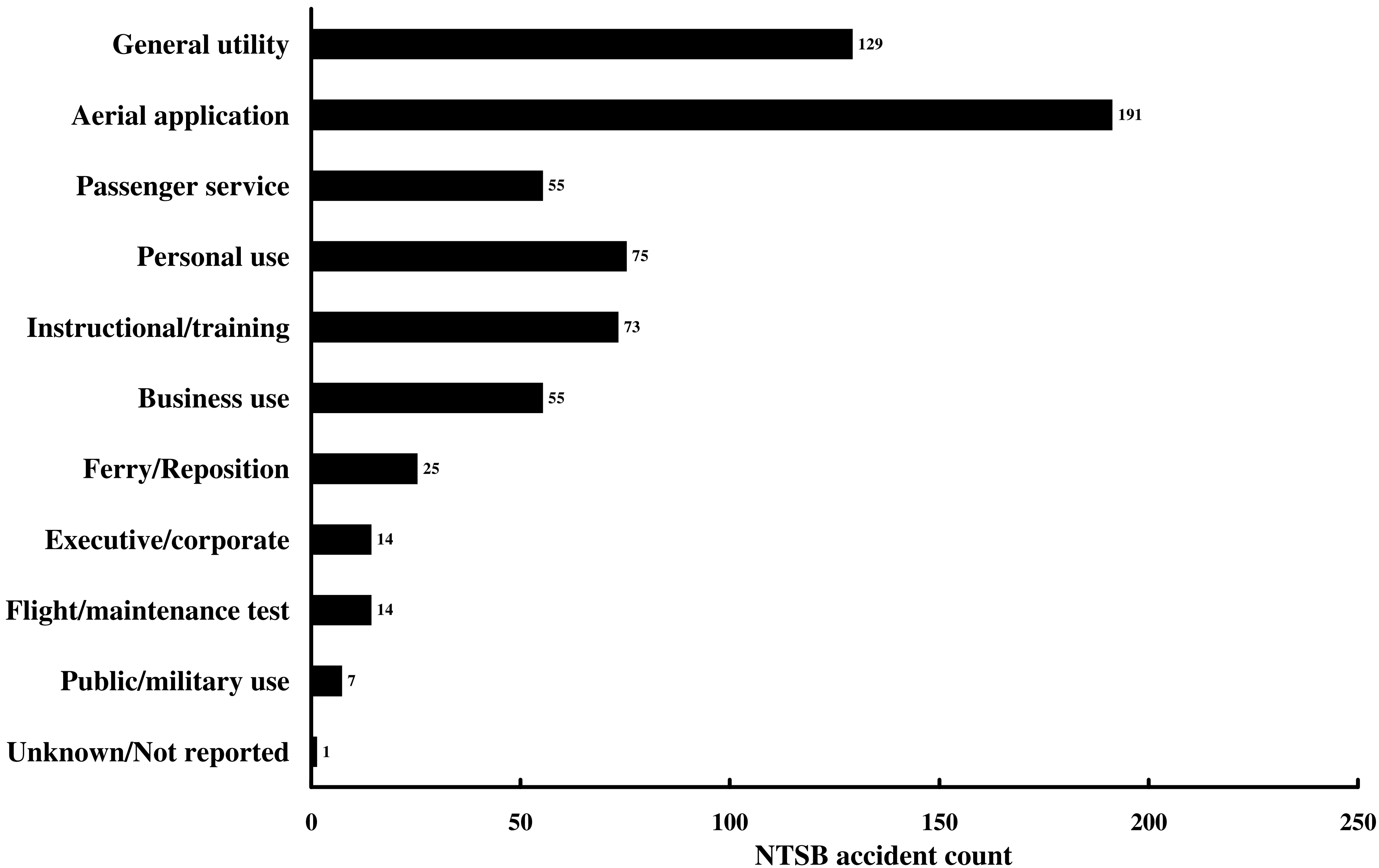


Figure 41. Airframe failure accidents by activity: single-piston helicopters (commercially manufactured).

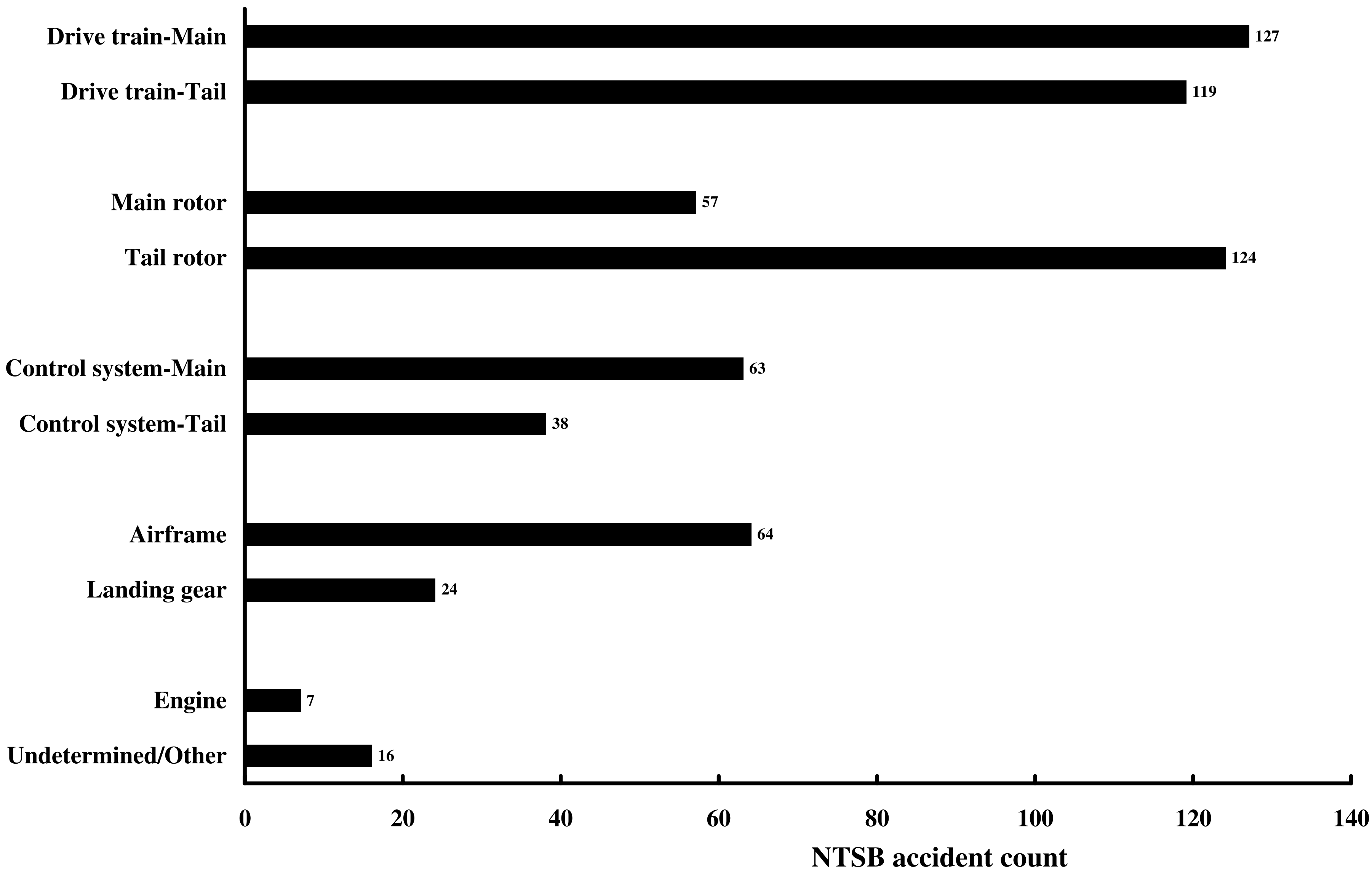


Figure 42. Airframe failure accidents by system: single-piston helicopters (commercially manufactured).

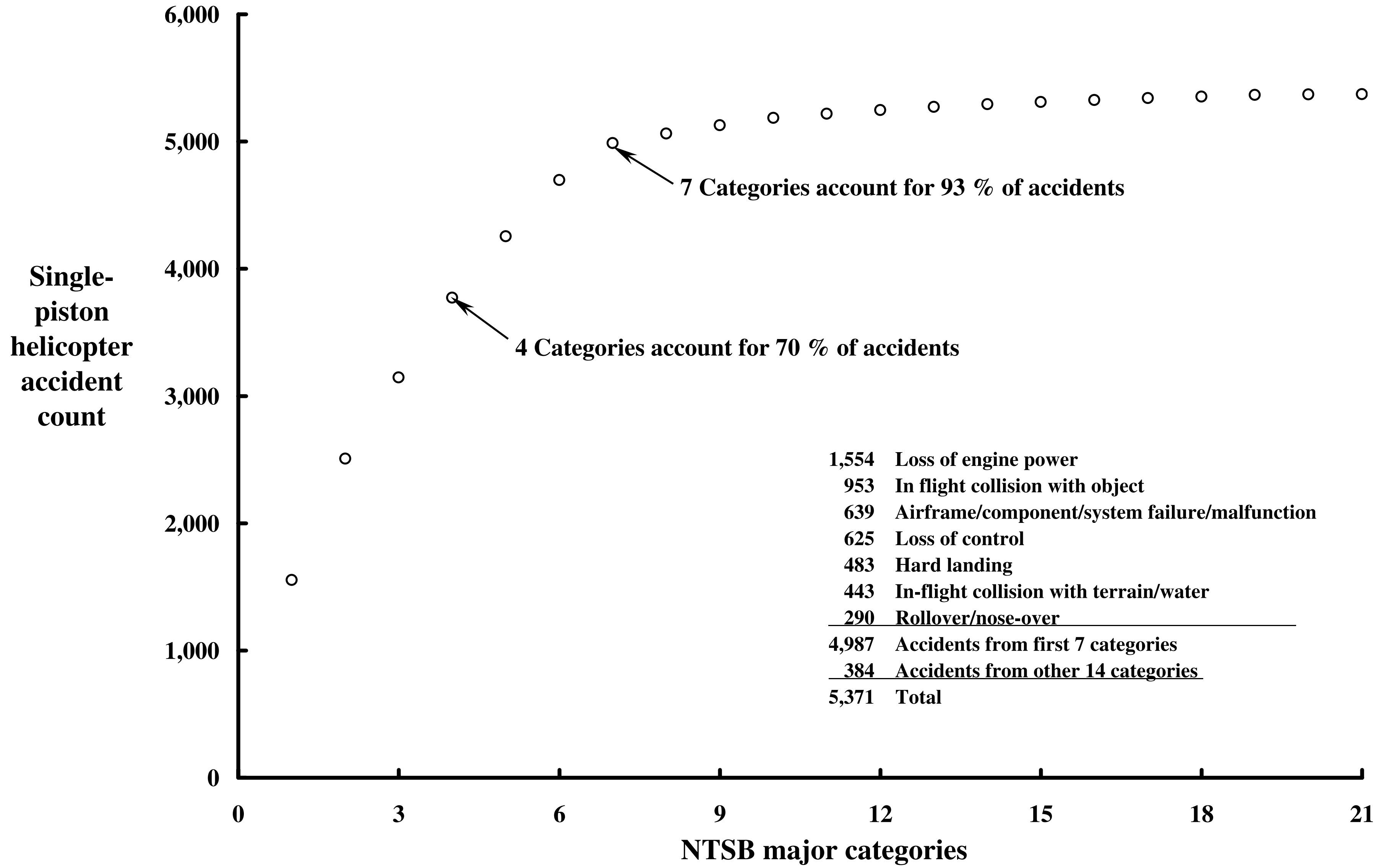


Figure 43. Summary accident statistics, mid-1963 through 1997: single-piston helicopters (commercially manufactured).

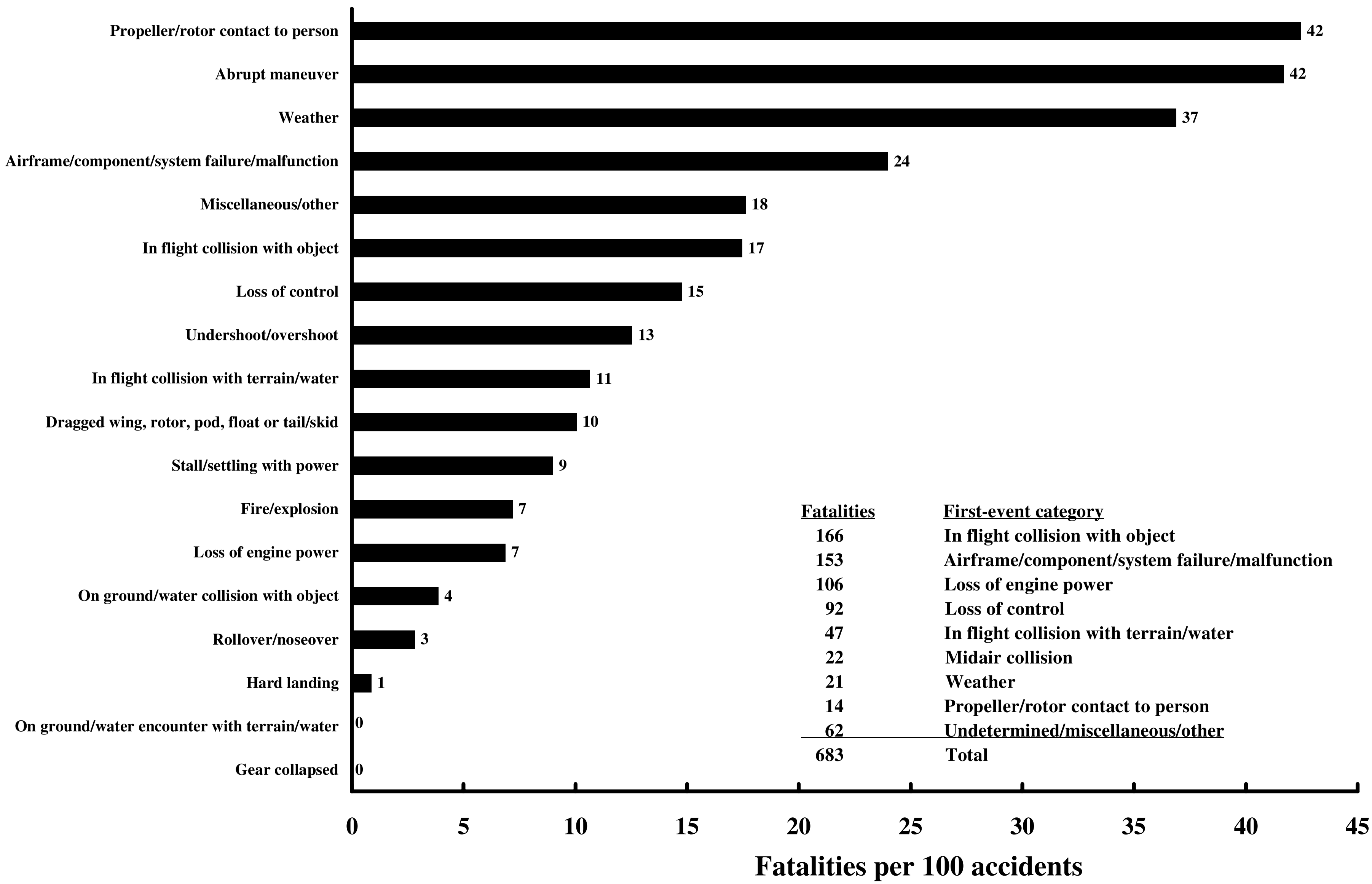


Figure 44. Fatalities per 100 accidents, mid-1963 through 1997: single-piston helicopters (commercially manufactured).

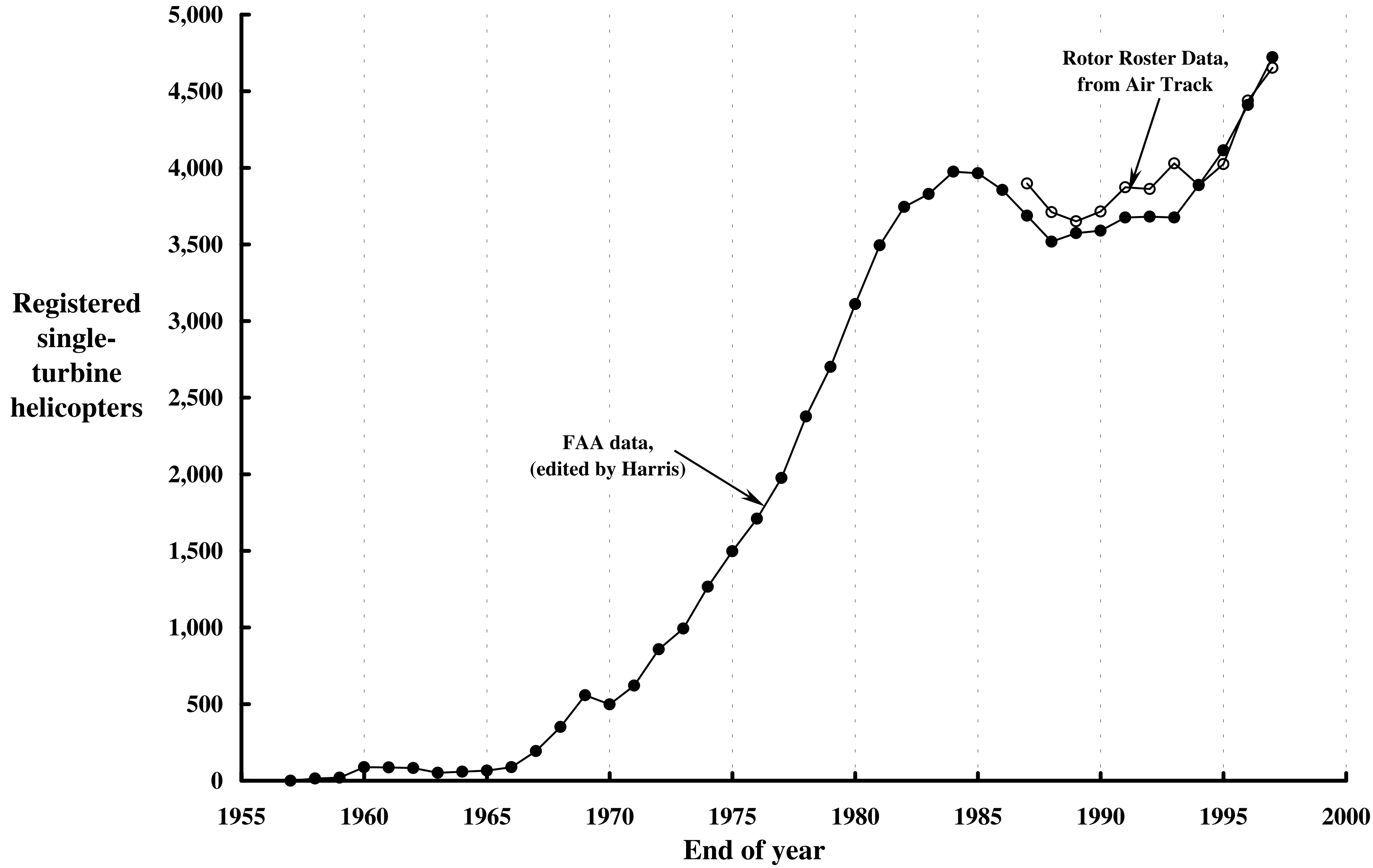


Figure 45. Single-turbine helicopter fleet size (commercially manufactured).

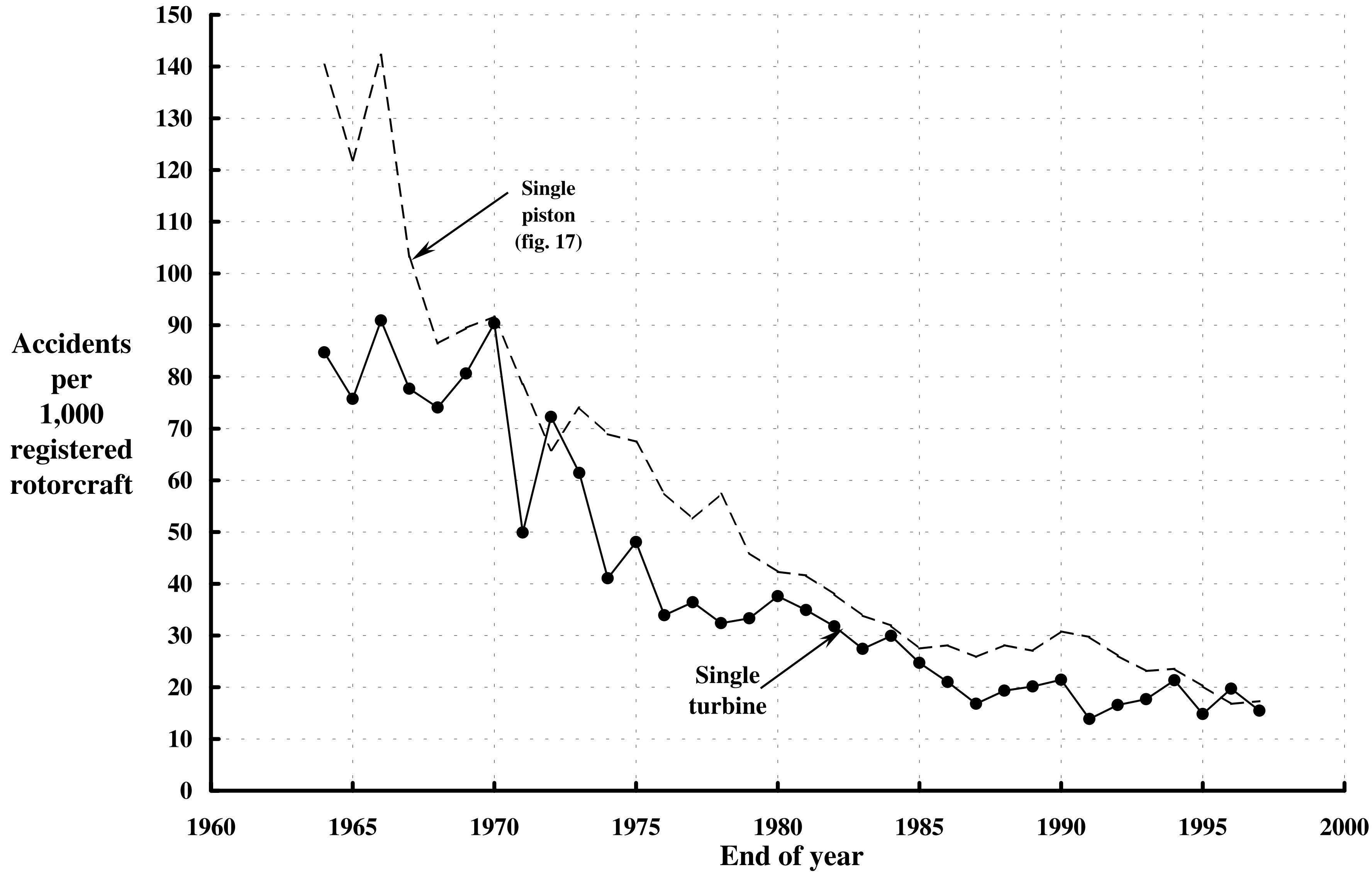


Figure 46. Accidents per 1,000 registered aircraft: single-turbine helicopters (commercially manufactured).

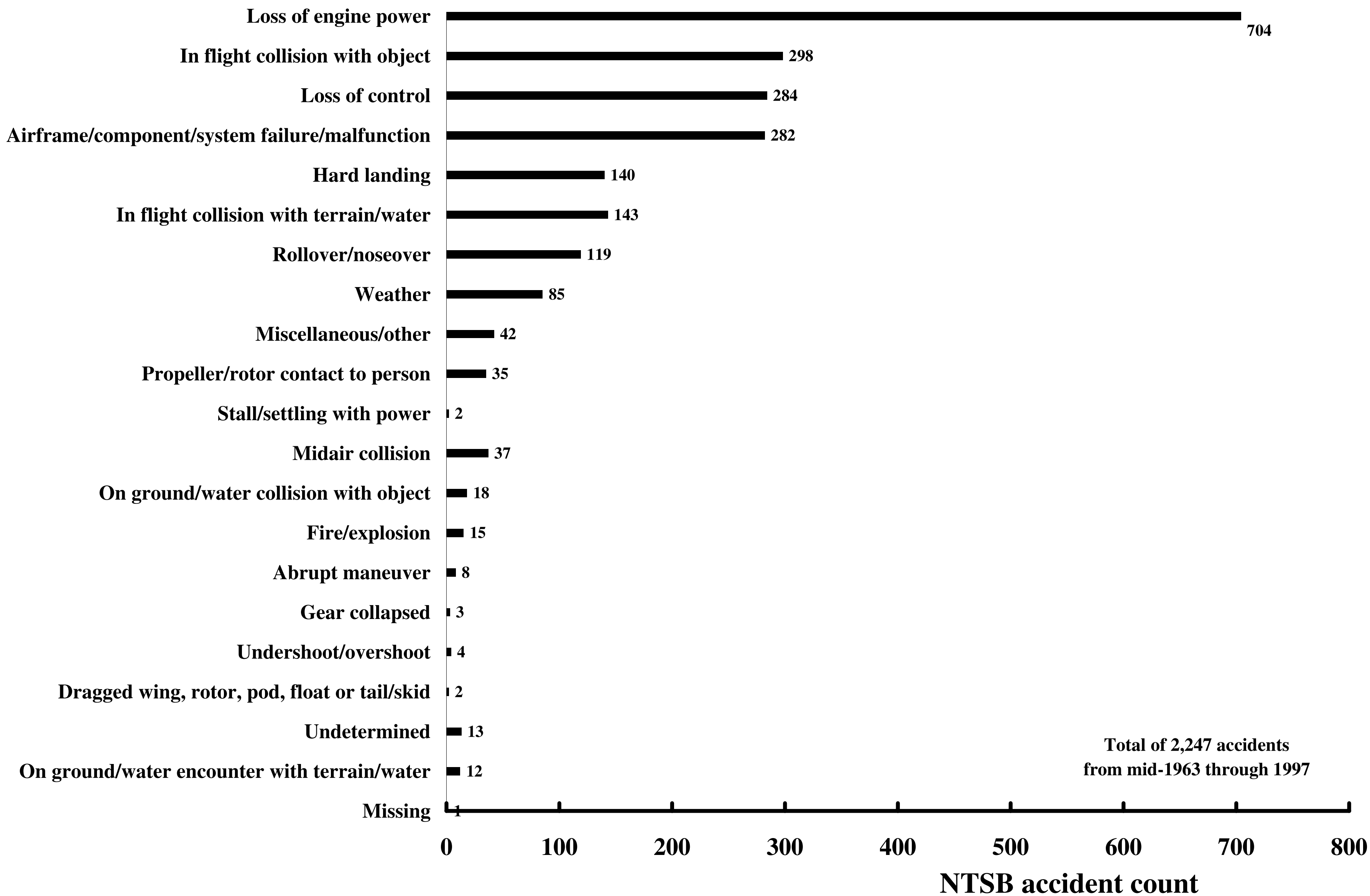


Figure 47. Accident count by first event category: single-turbine helicopters (commercially manufactured).

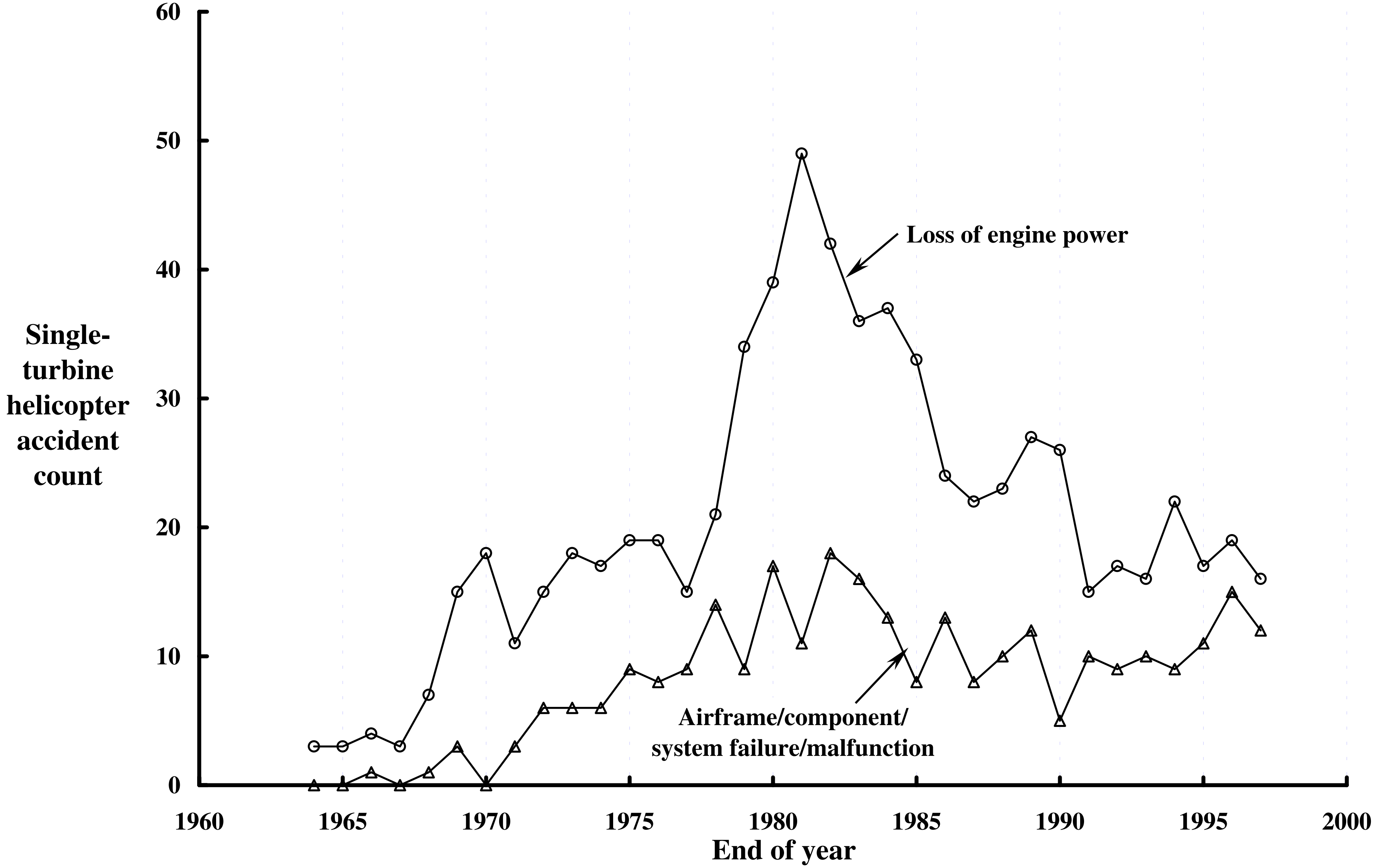


Figure 48. Loss of engine power and airframe failure or malfunction accidents: single-turbine helicopters (commercially manufactured).

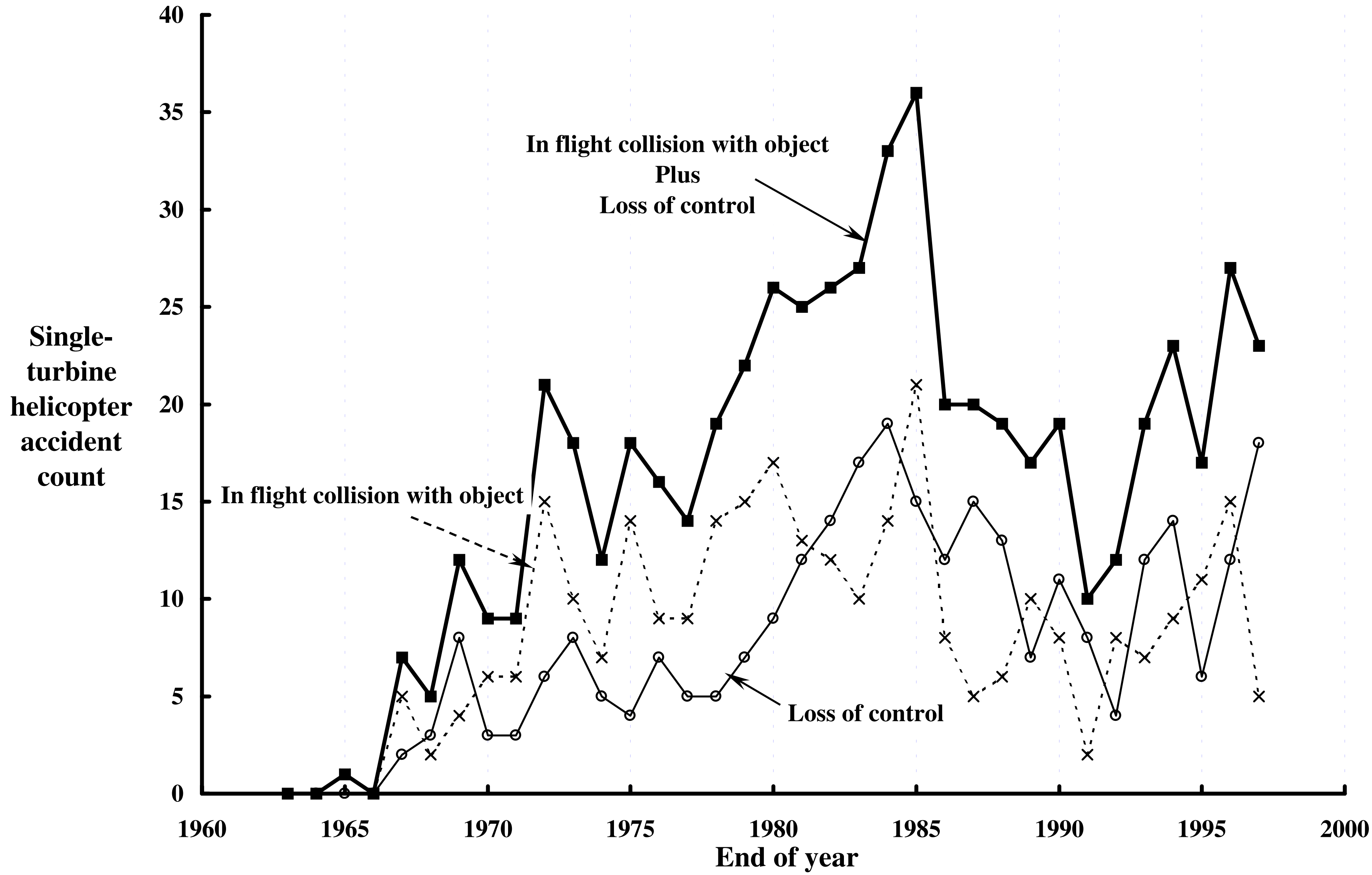


Figure 49. In flight collision with object and loss of control accidents: single-turbine helicopters (commercially manufactured).

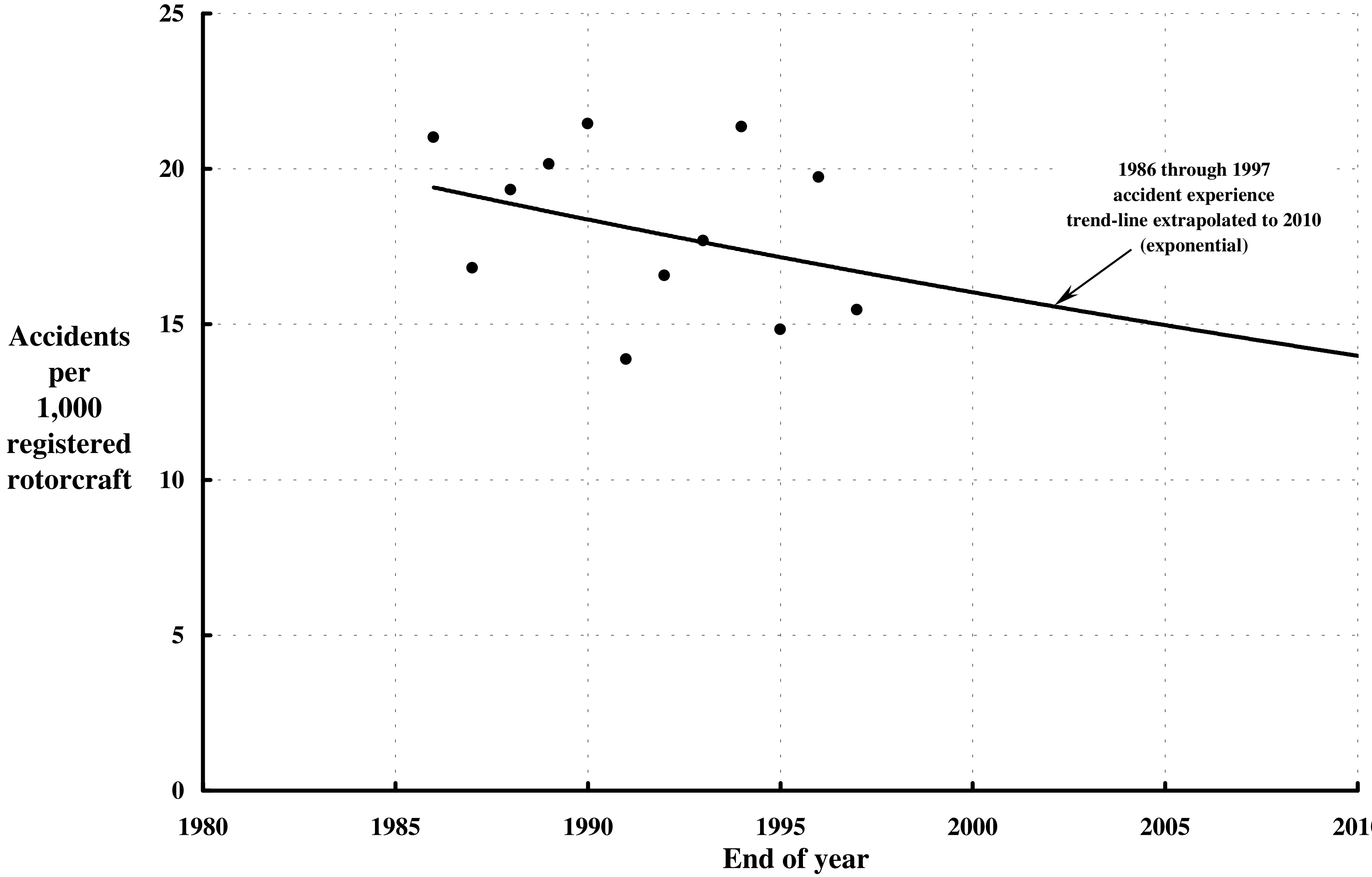


Figure 50. Accidents per 1,000 registered aircraft projected to 2010: single-turbine helicopters (commercially manufactured).

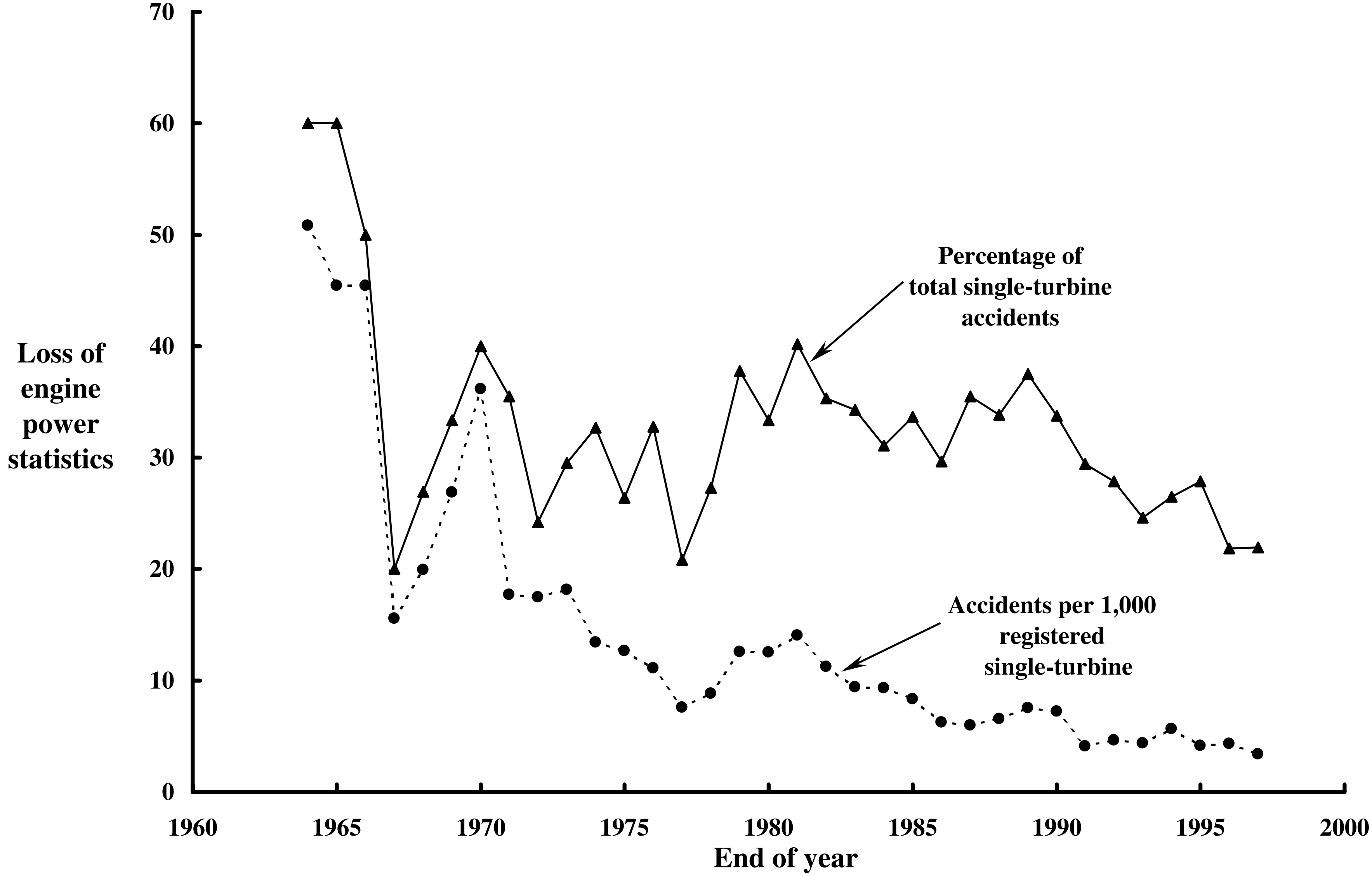


Figure 51. Loss of engine power yearly accident statistics: single-turbine helicopters (commercially manufactured).

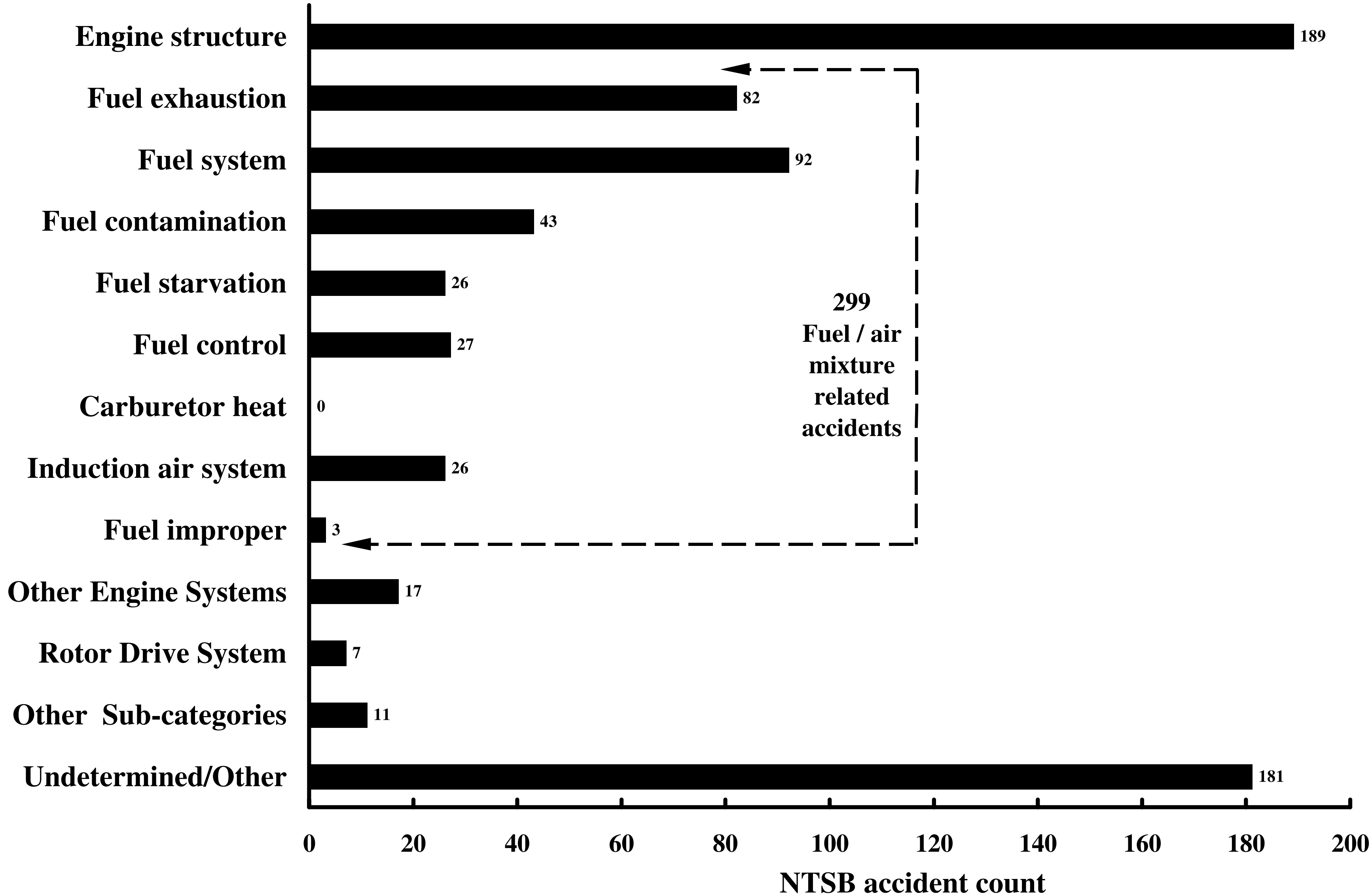


Figure 52. Loss of engine power accidents by category: single-turbine helicopters (commercially manufactured).

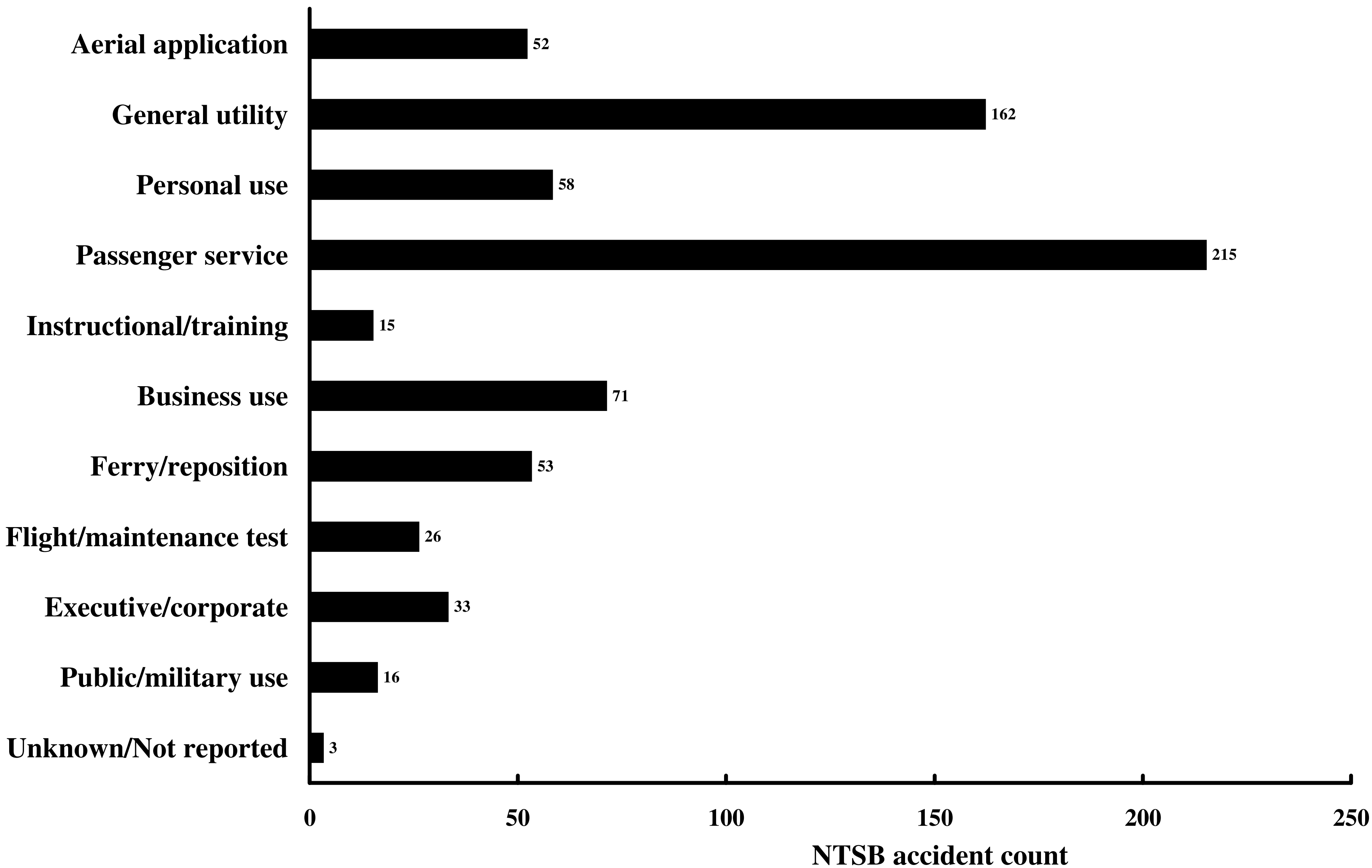


Figure 53. Loss of engine power accidents by activity: single-turbine helicopters (commercially manufactured).

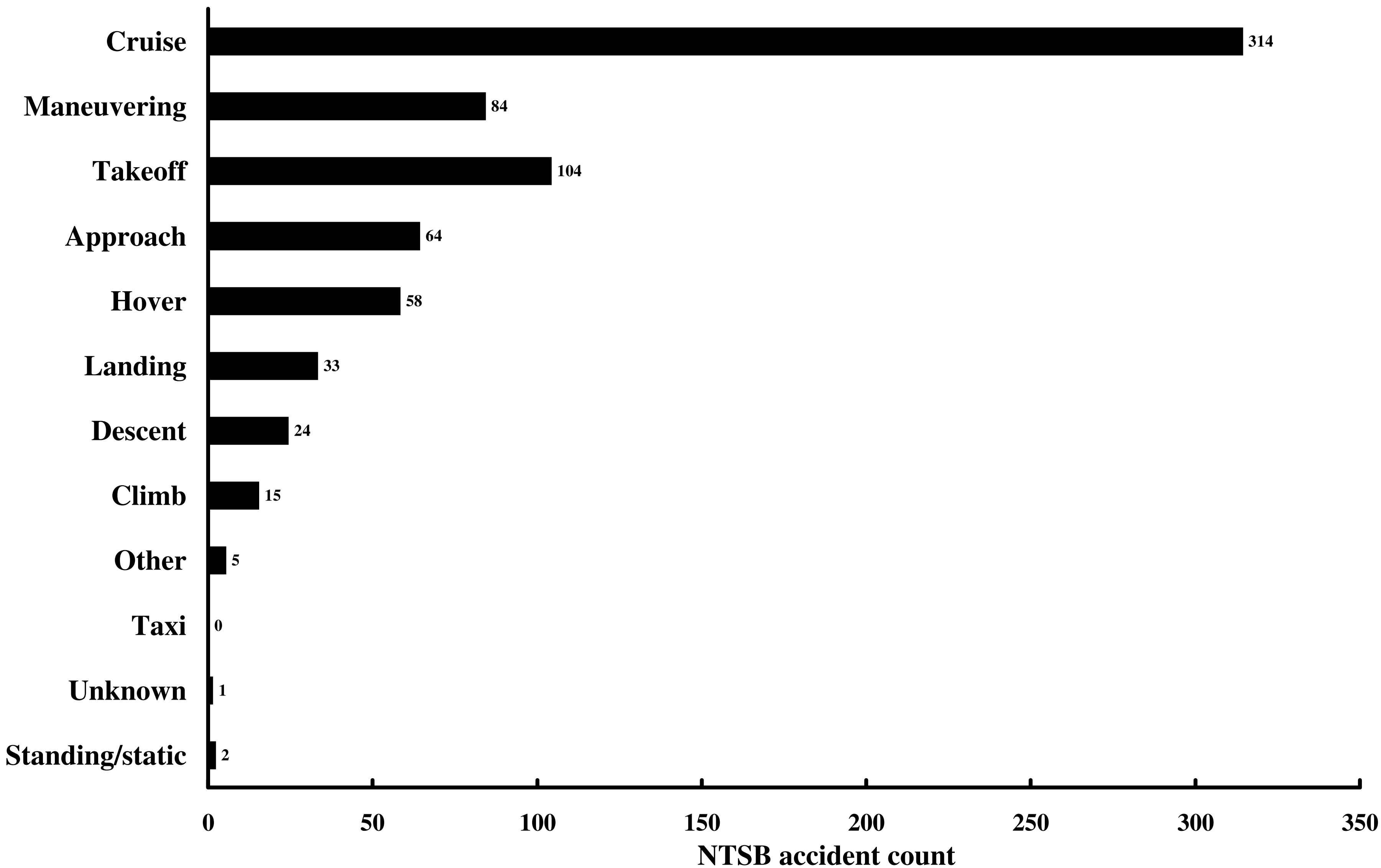


Figure 54. Loss of engine power accidents by phase of operation: single-turbine helicopters (commercially manufactured).

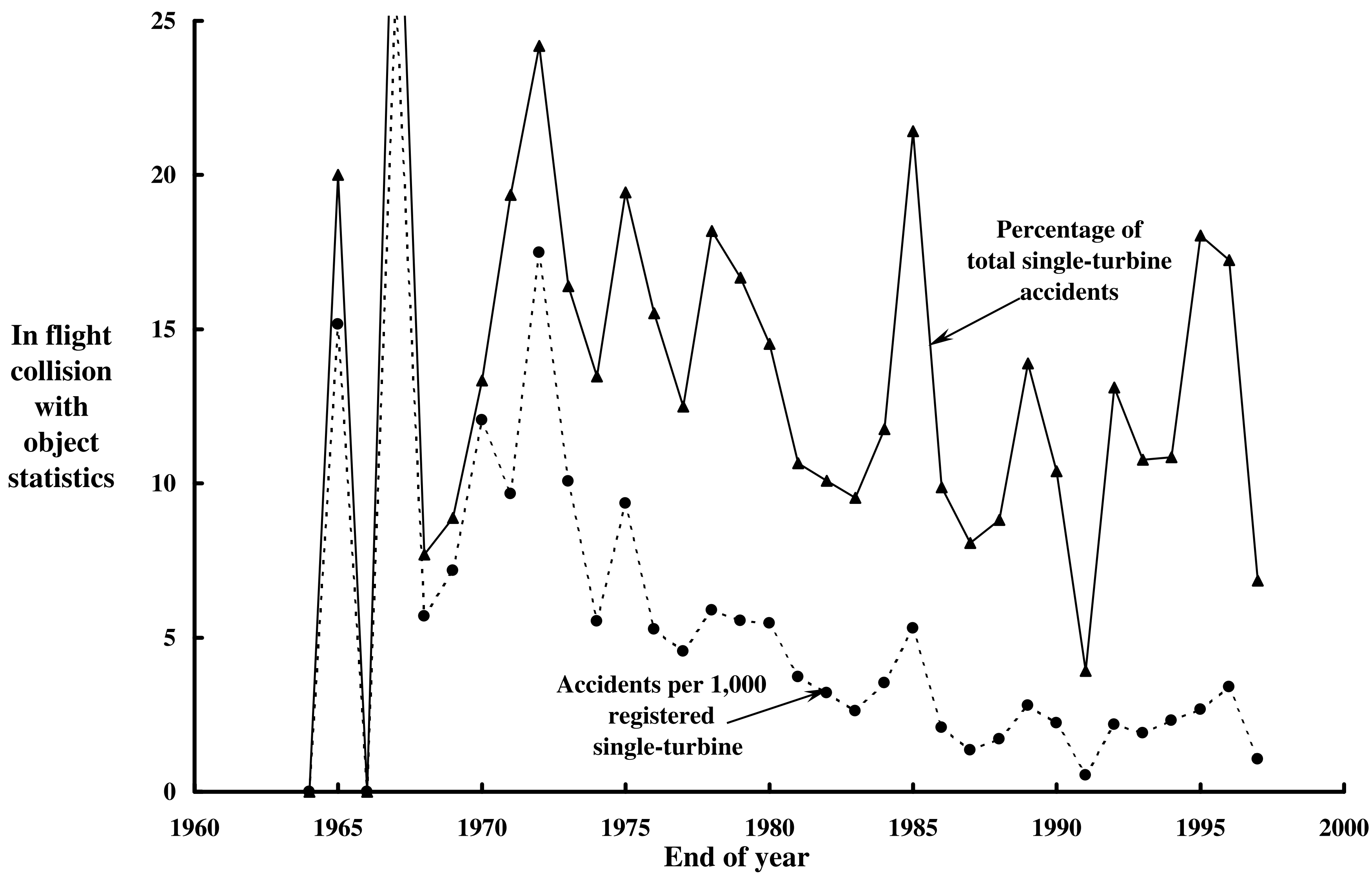


Figure 55. In flight collision with object yearly accident statistics: single-turbine helicopters (commercially manufactured).

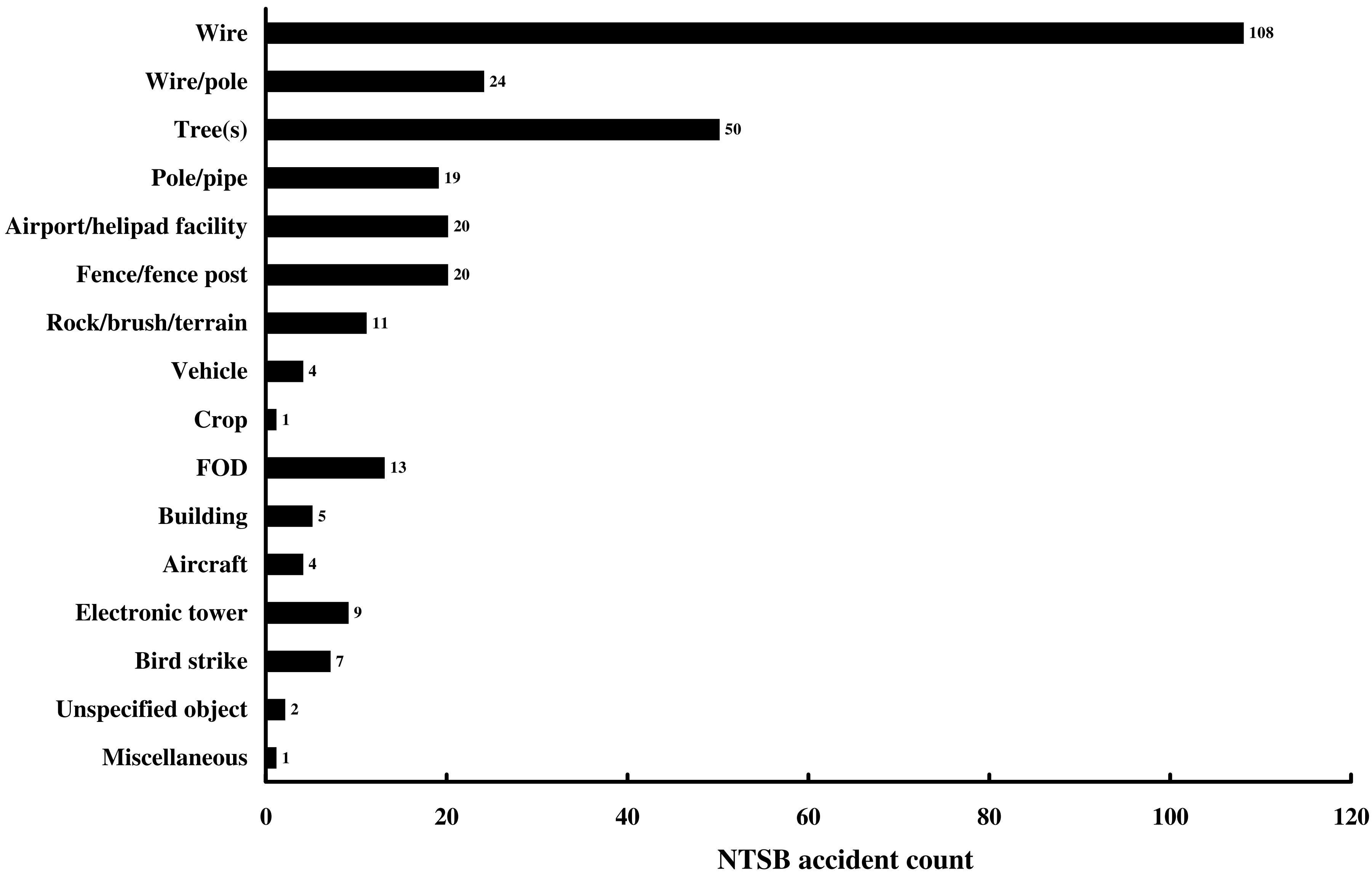


Figure 56. In flight collision with object accidents by object hit: single-turbine helicopters (commercially manufactured).

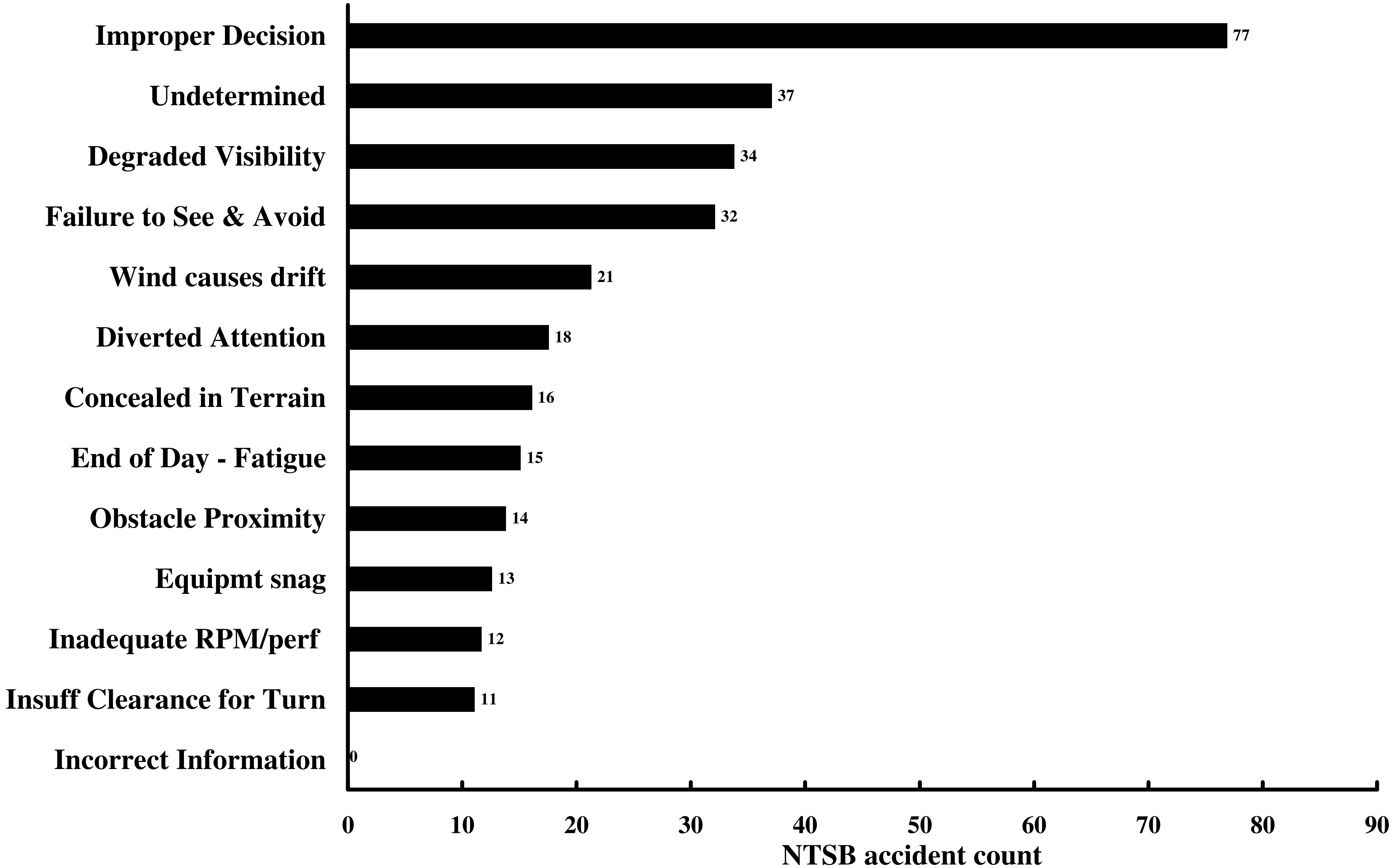


Figure 57. In flight collision with object accidents by cause: single-turbine helicopters (commercially manufactured).

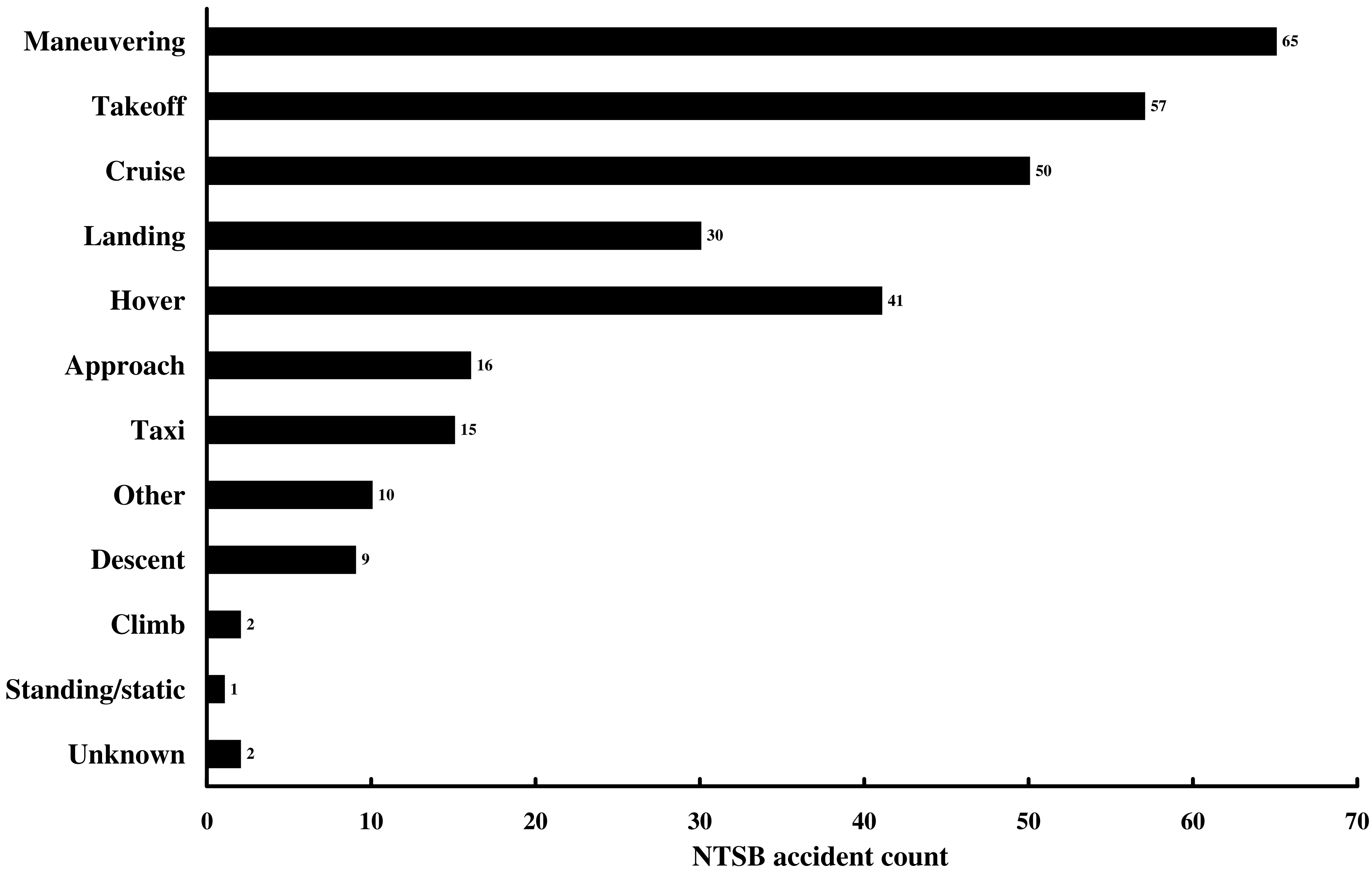


Figure 58. In flight collision with object accidents by phase of operation: single-turbine helicopters (commercially manufactured).

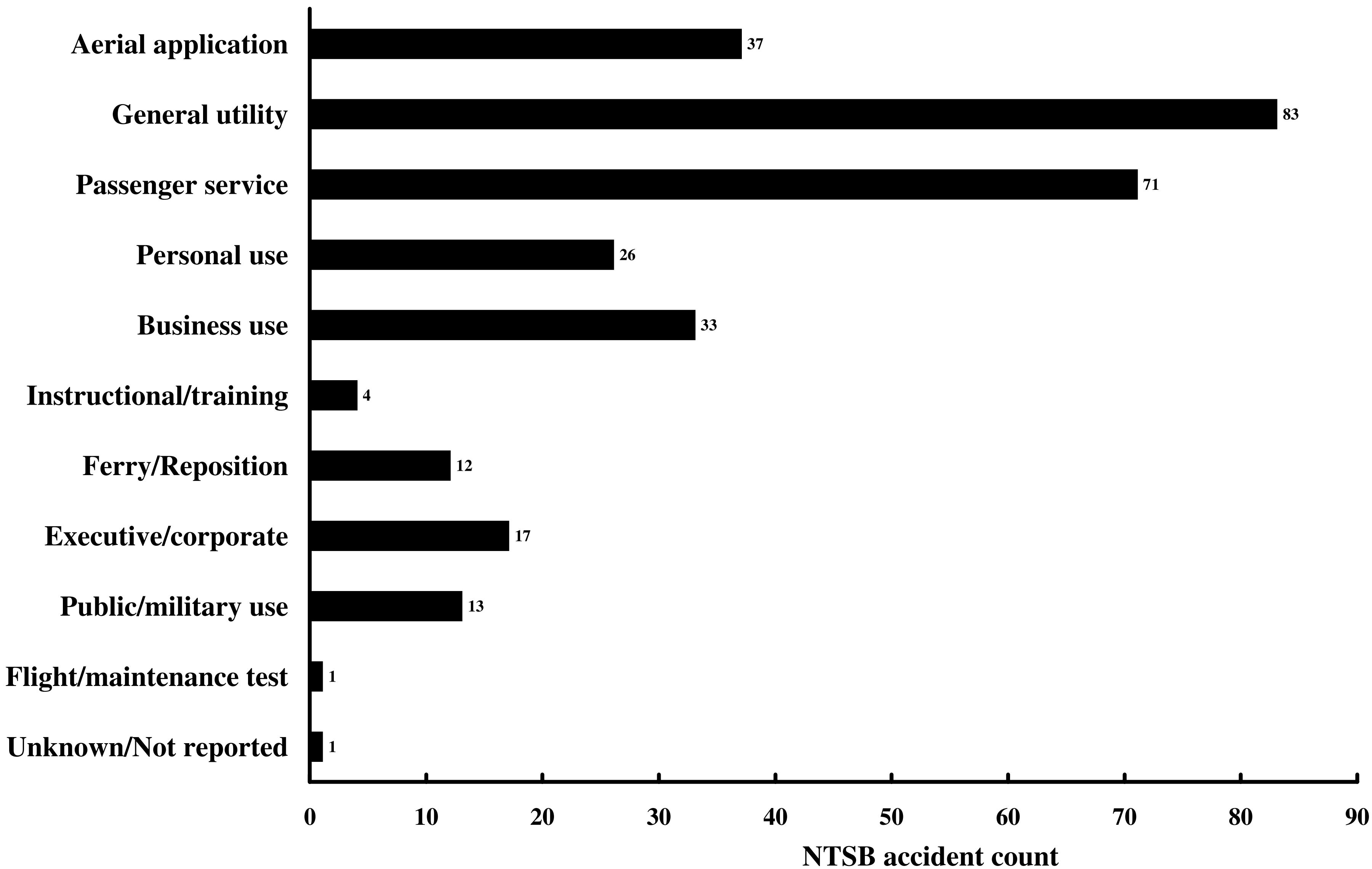


Figure 59. In flight collision with object accidents by activity: single-turbine helicopters (commercially manufactured).

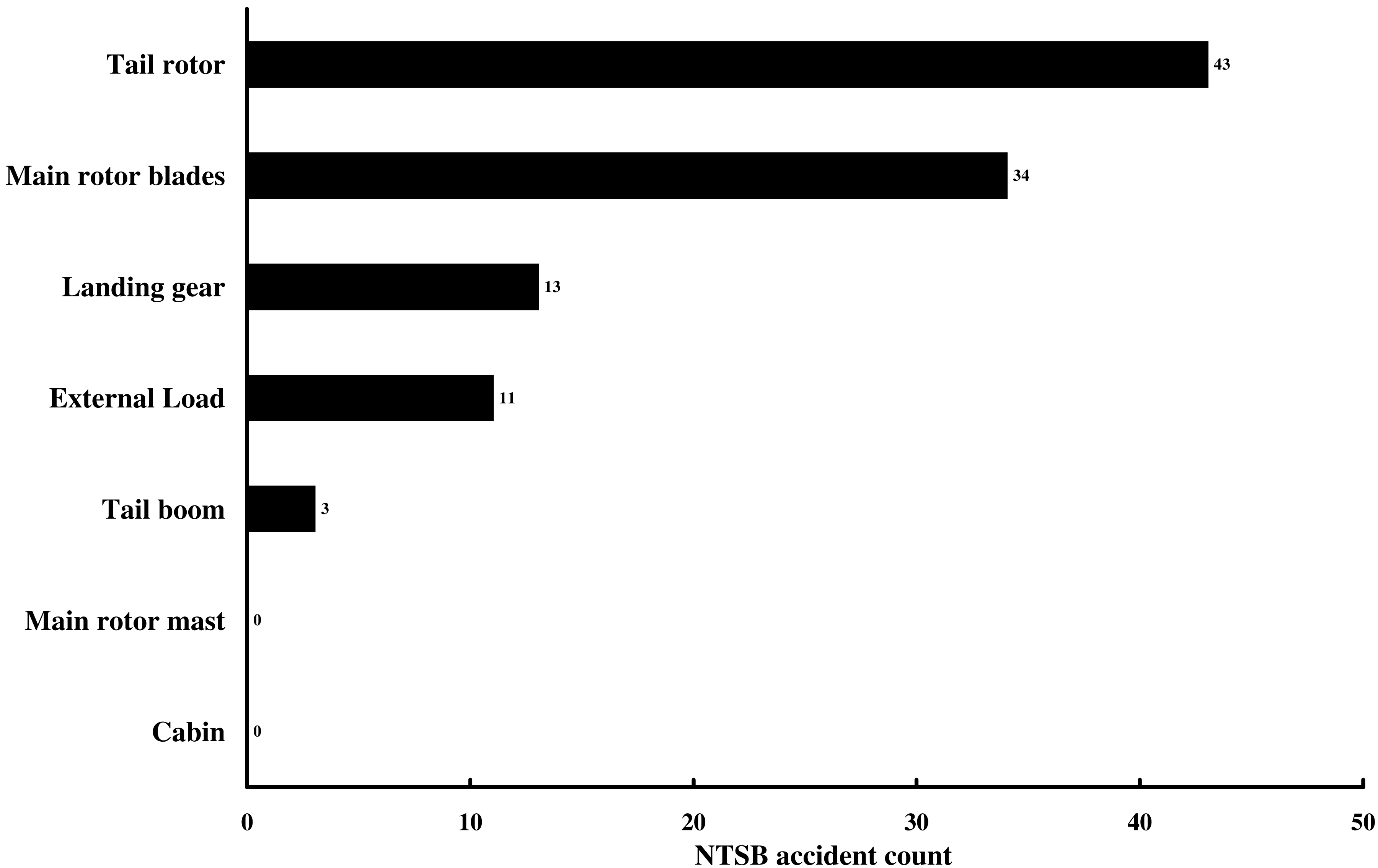


Figure 60. In flight collision with object accidents by part hit: single-turbine helicopters (commercially manufactured).

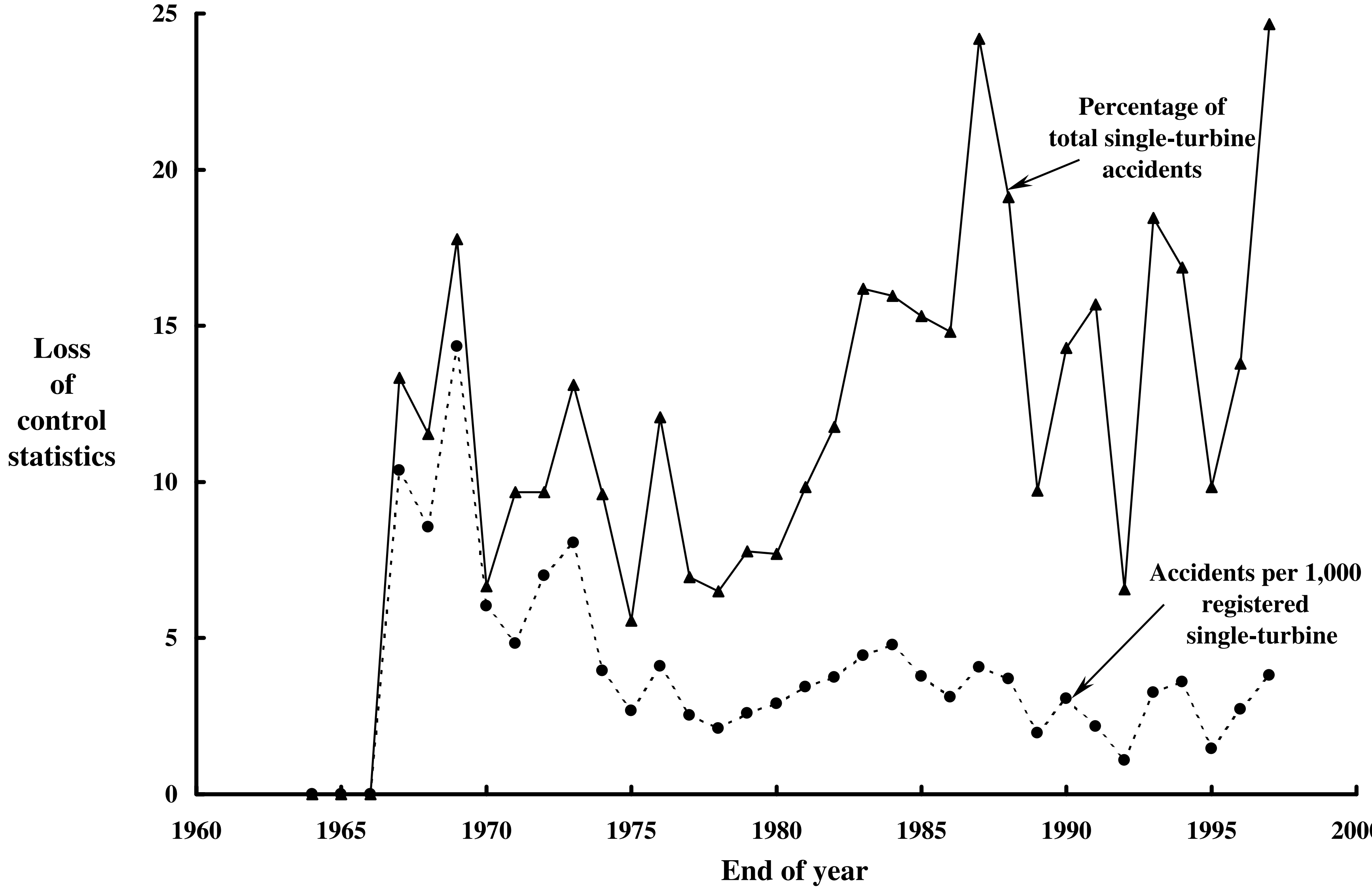


Figure 61. Loss of control yearly accident statistics: single-turbine helicopters (commercially manufactured).

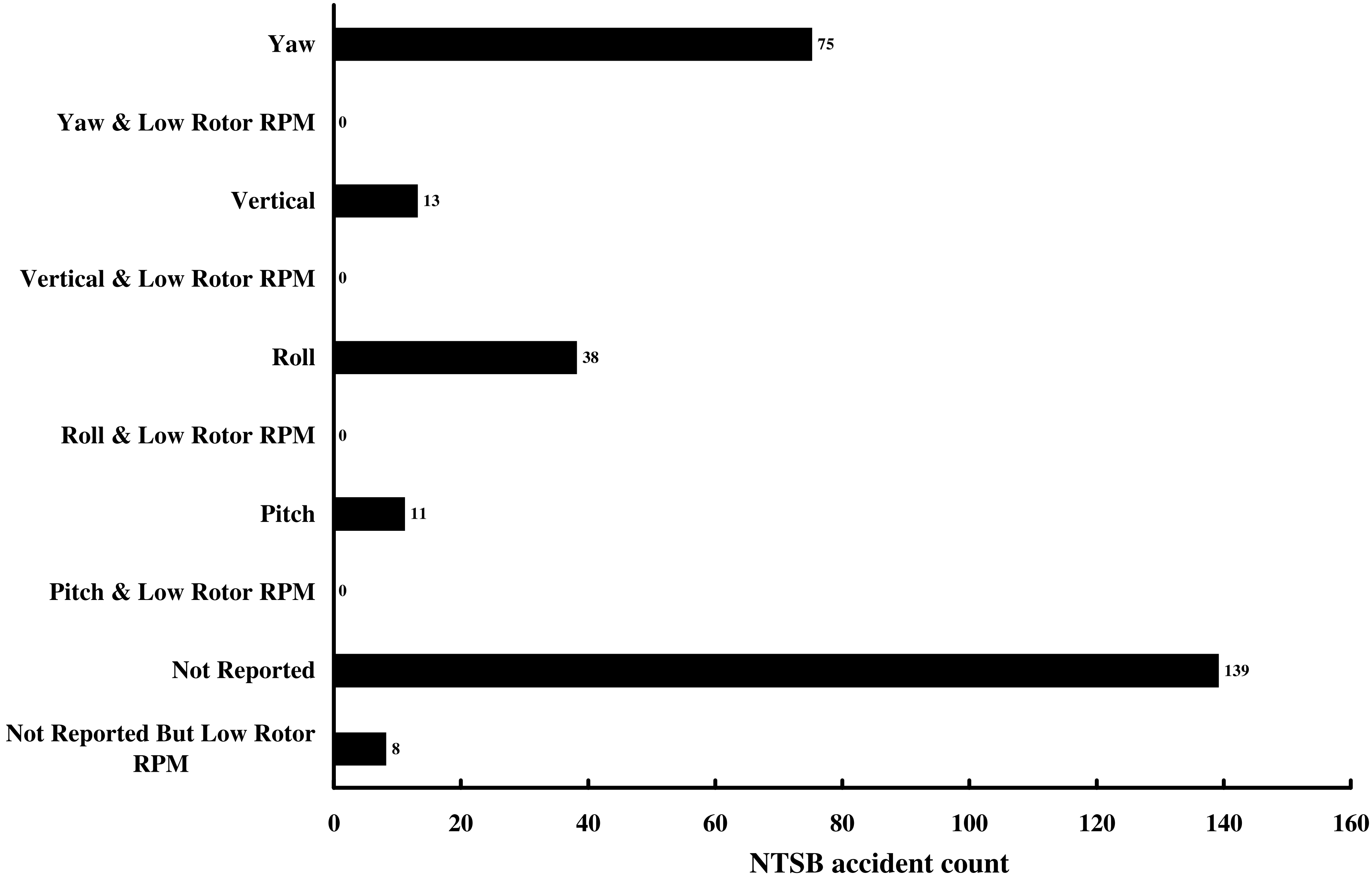


Figure 62. Loss of control accidents by axis lost: single-turbine helicopters (commercially manufactured).

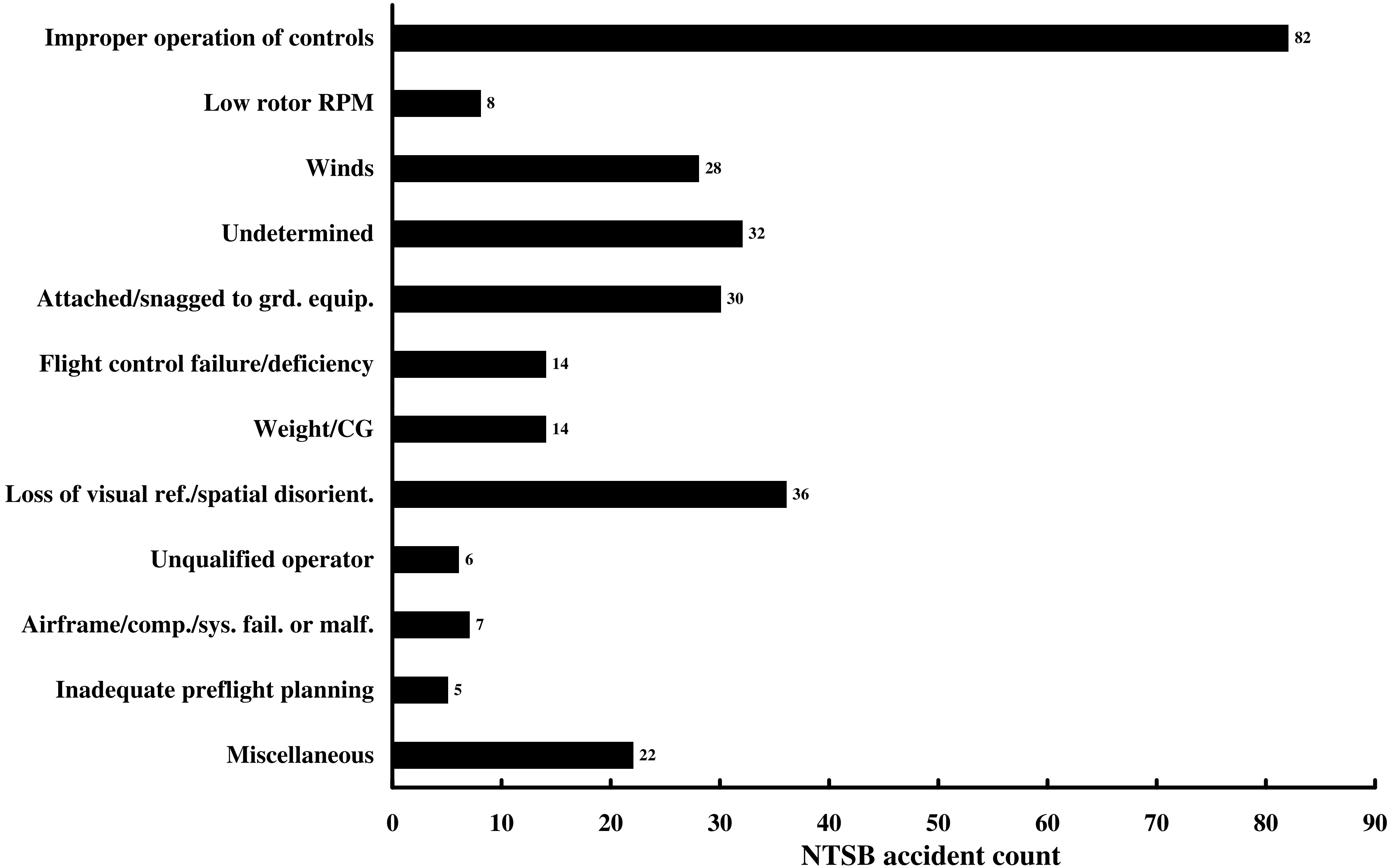


Figure 63. Loss of control accidents by cause: single-turbine helicopters (commercially manufactured).

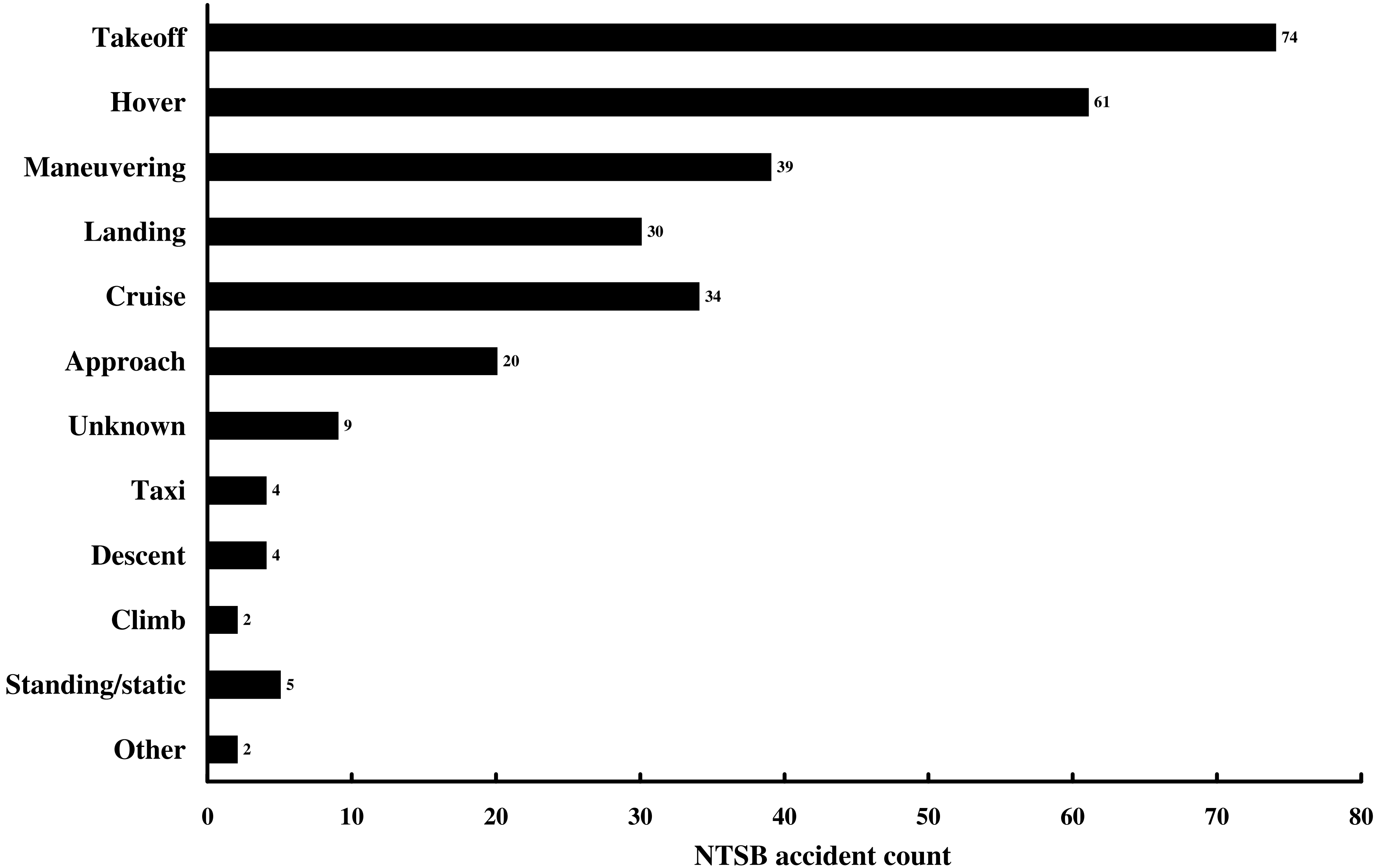


Figure 64. Loss of control accidents by phase of operation: single-turbine helicopters (commercially manufactured).

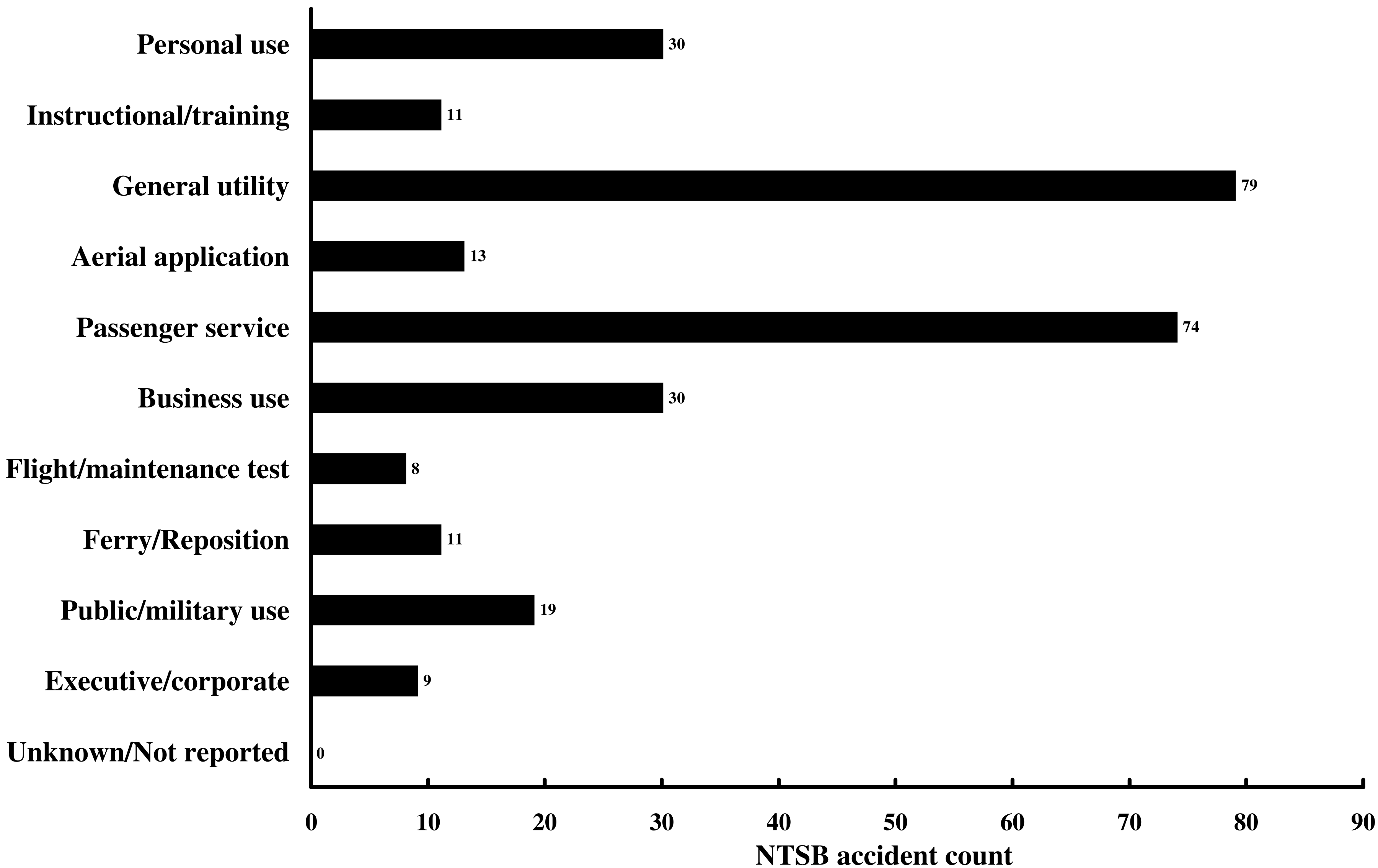


Figure 65. Loss of control accidents by activity: single-turbine helicopters (commercially manufactured).

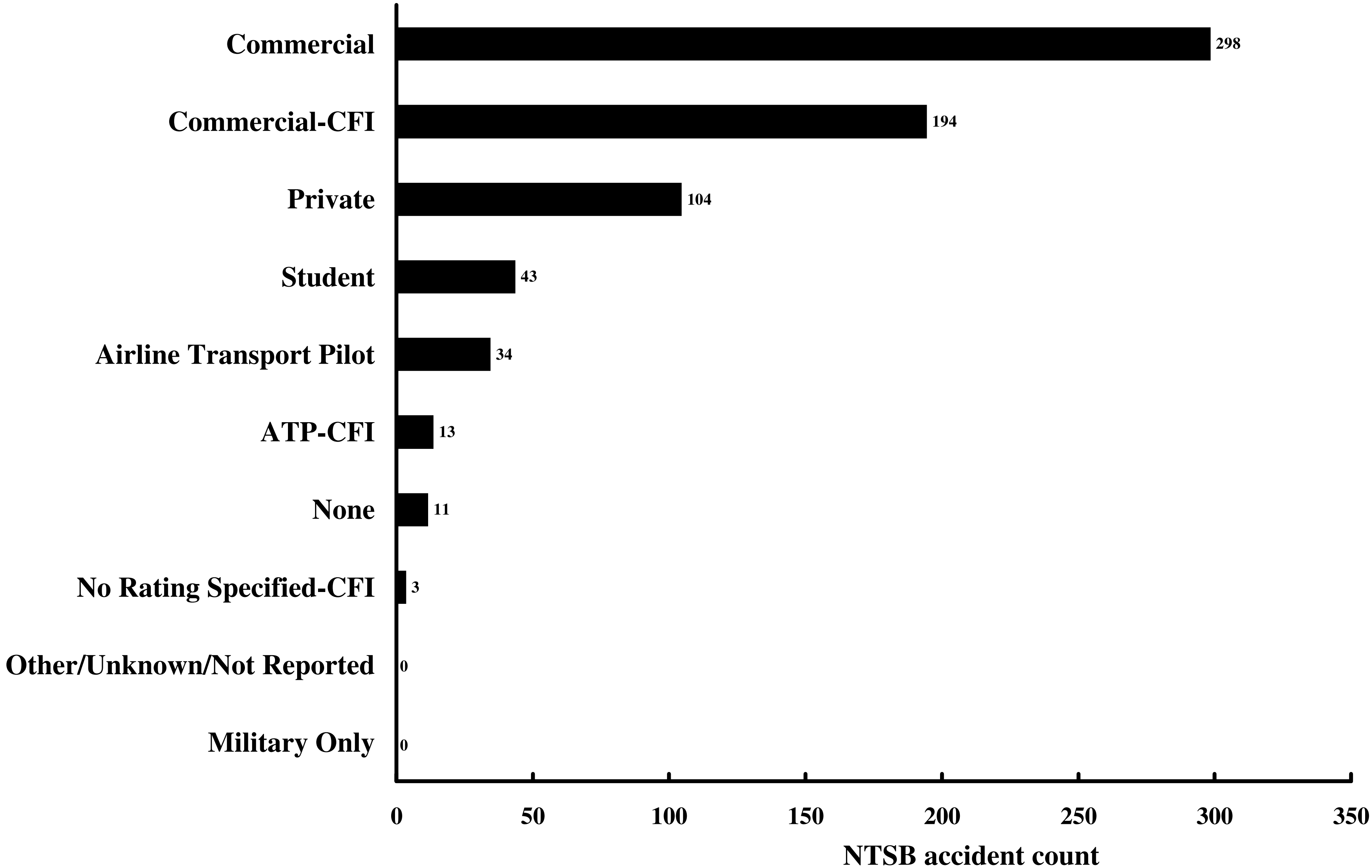


Figure 66. Loss of control accidents by pilot-in-command certification: single-turbine helicopters (commercially manufactured).

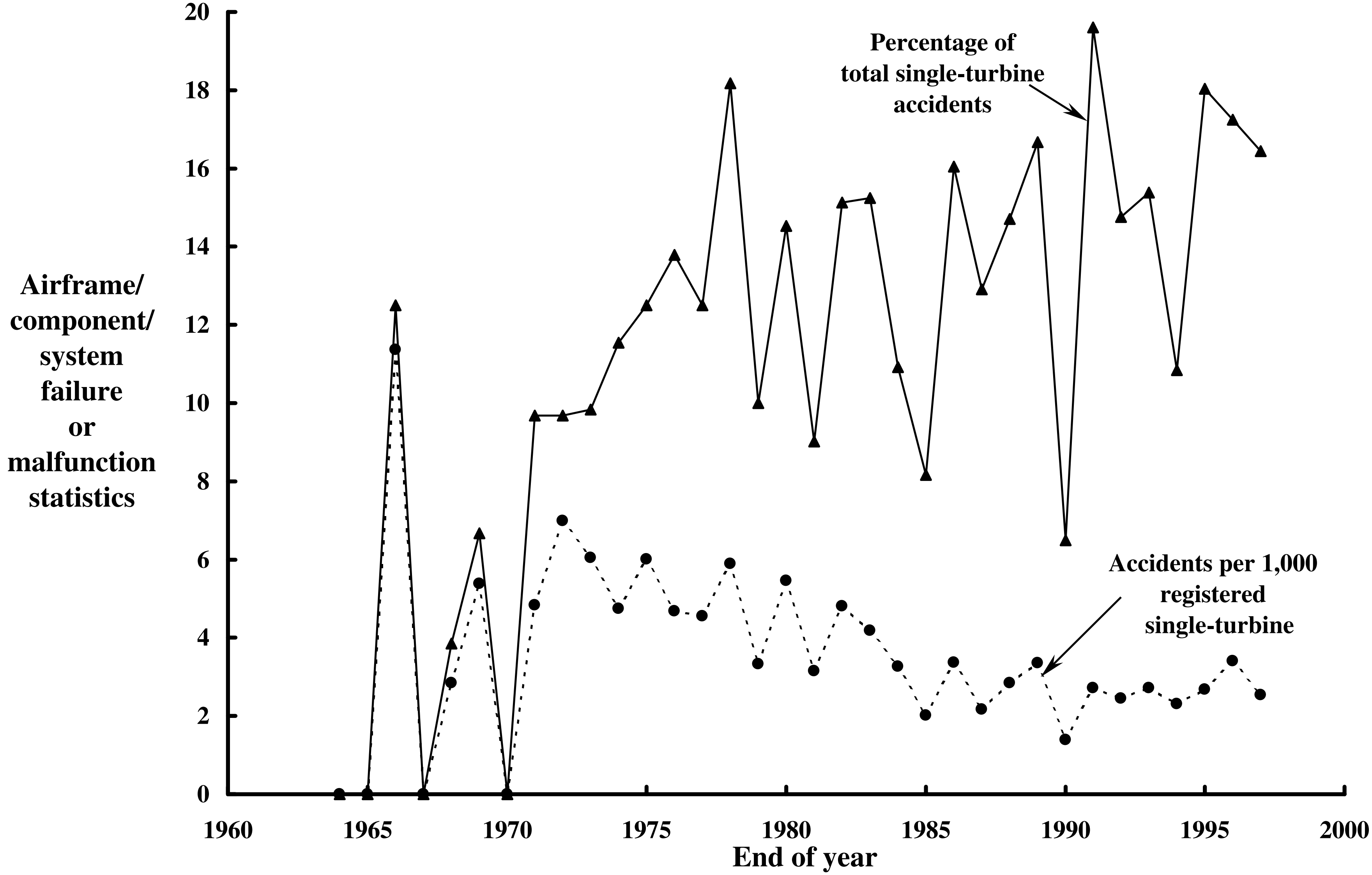


Figure 67. Airframe failure yearly accident statistics: single-turbine helicopters (commercially manufactured).

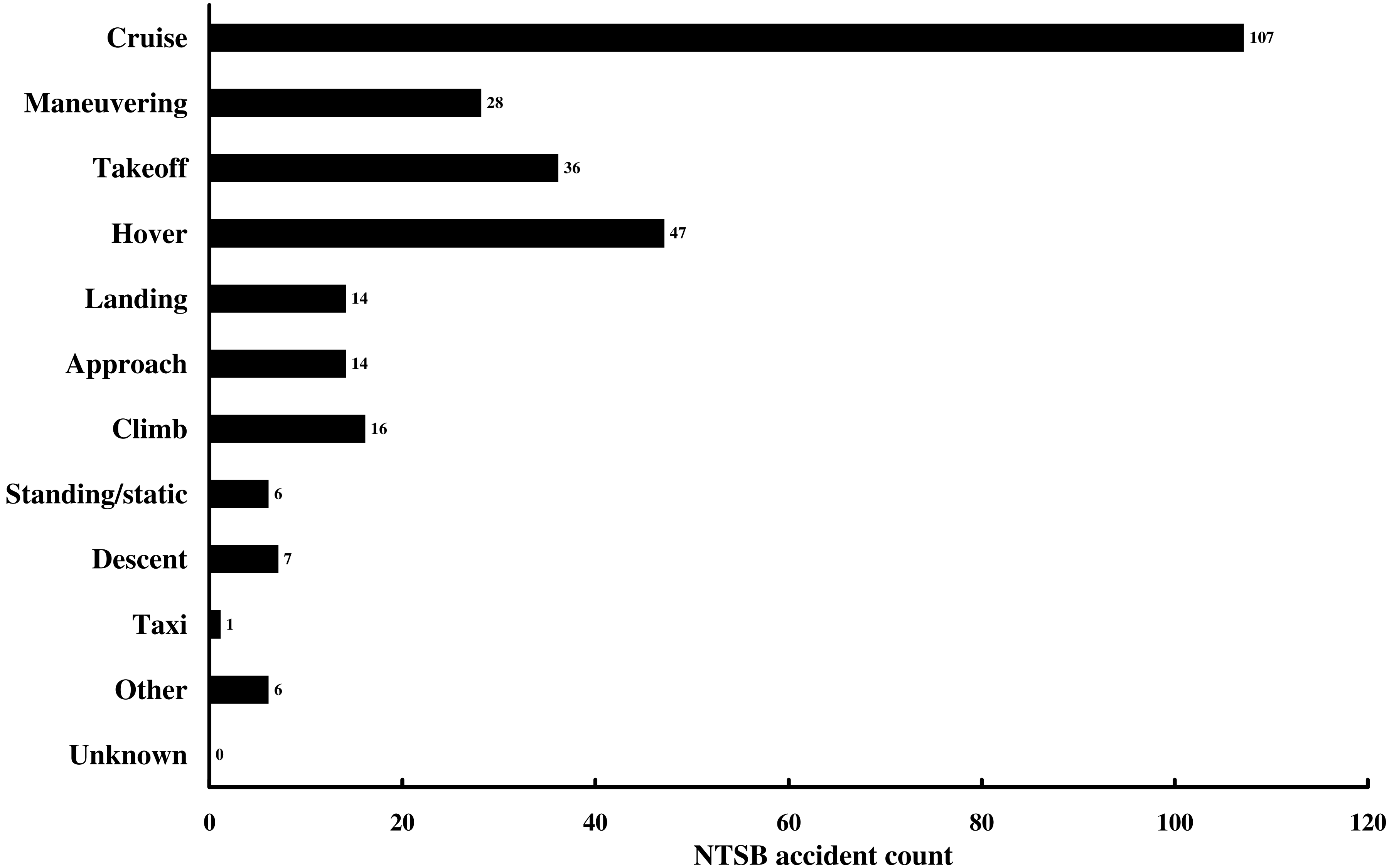


Figure 68. Airframe failure accidents by phase of operation: single-turbine helicopters (commercially manufactured).

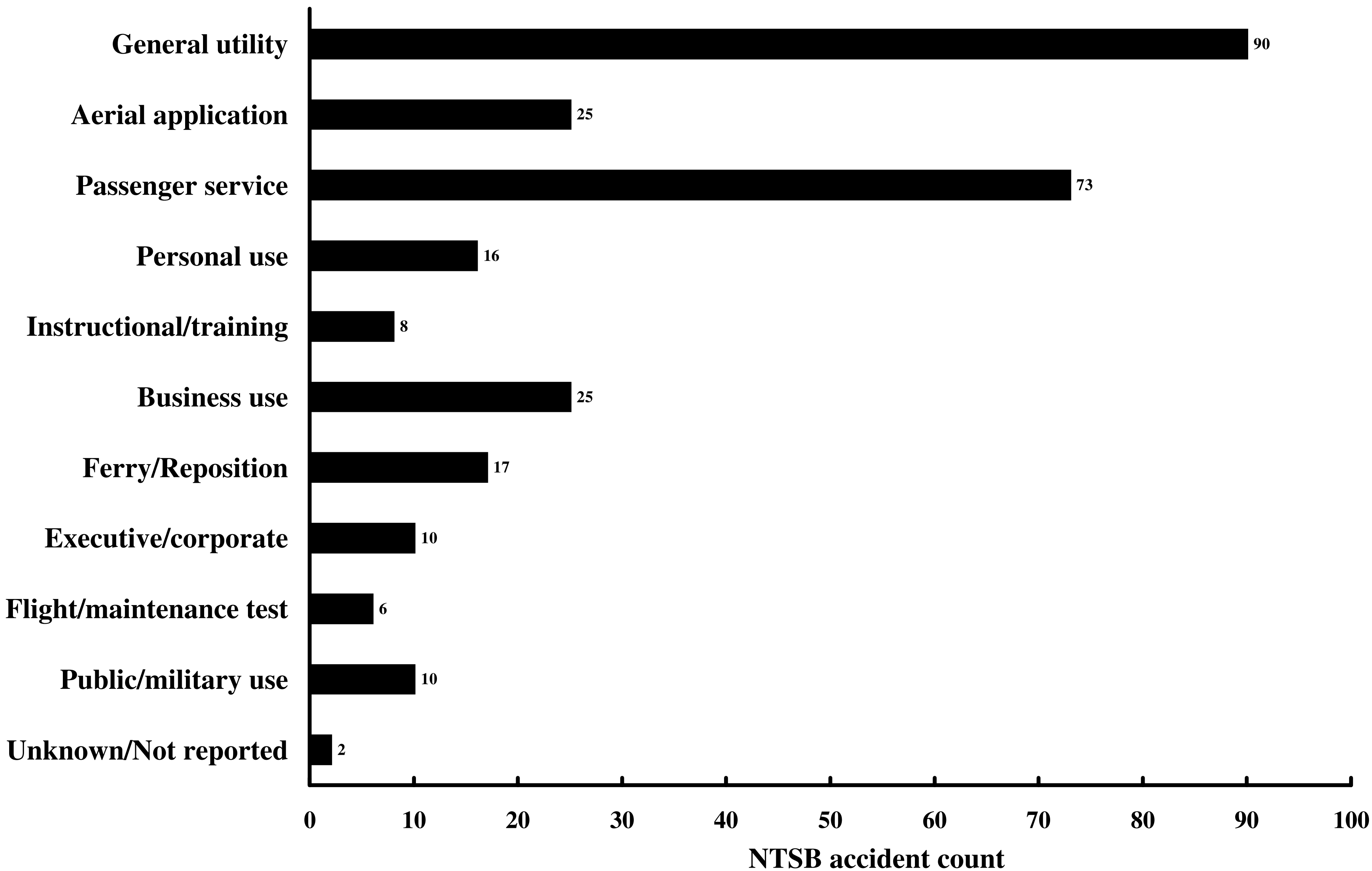


Figure 69. Airframe failure accidents by activity: single-turbine helicopters (commercially manufactured).

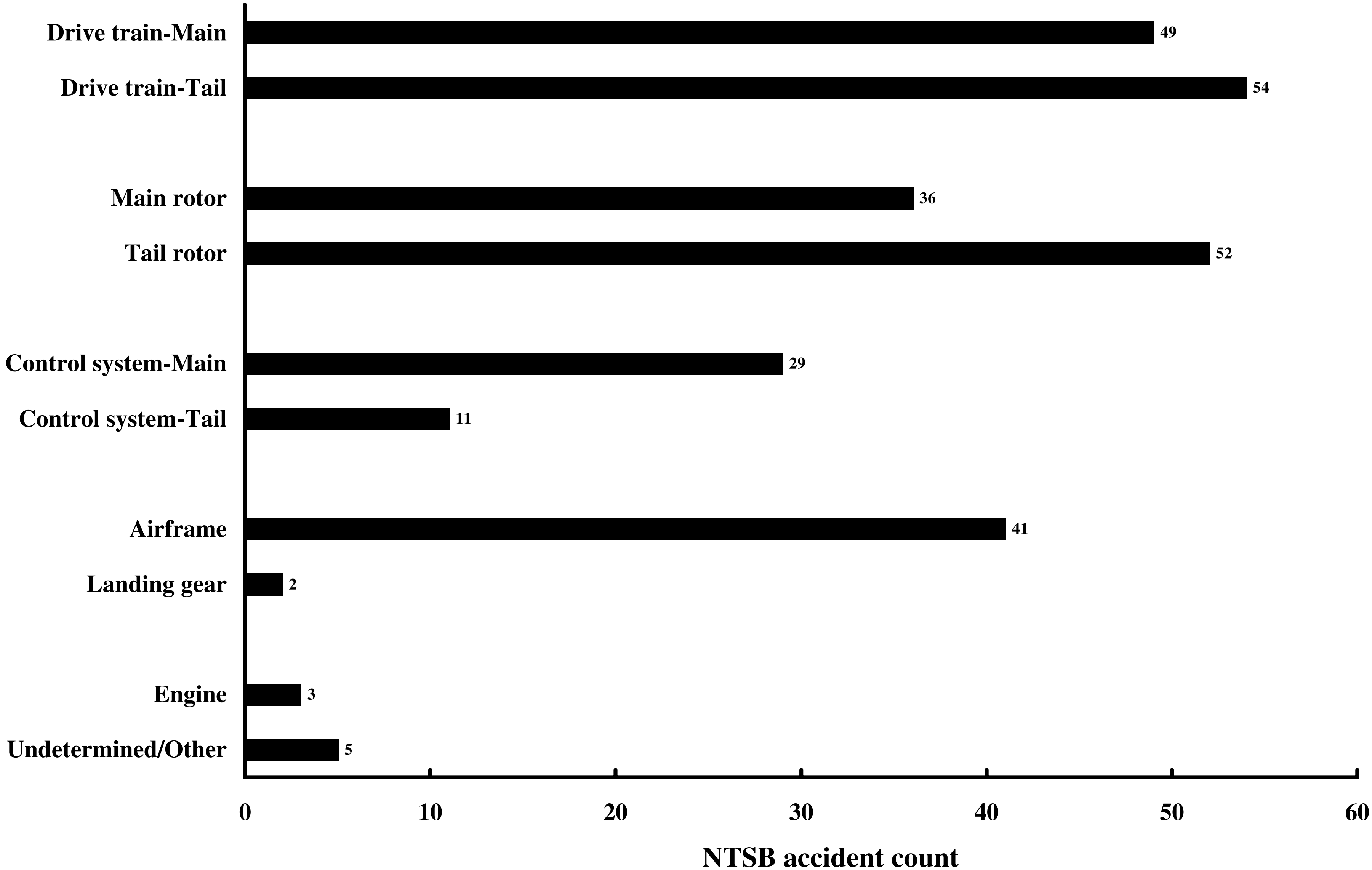


Figure 70. Airframe failure accidents by system: single-turbine helicopters (commercially manufactured).

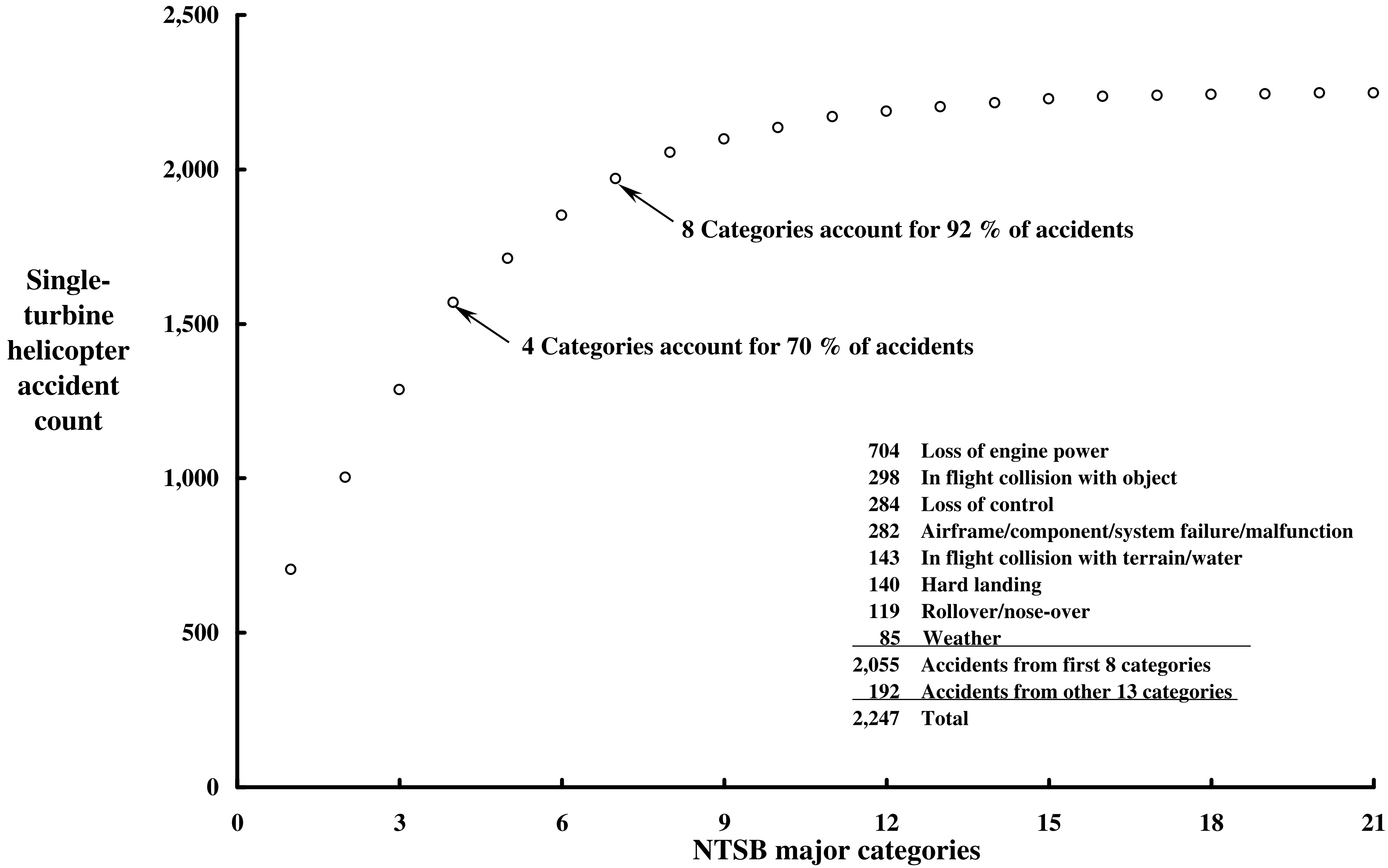


Figure 71. Summary accident statistics, mid-1963 through 1997: single-turbine helicopters (commercially manufactured).

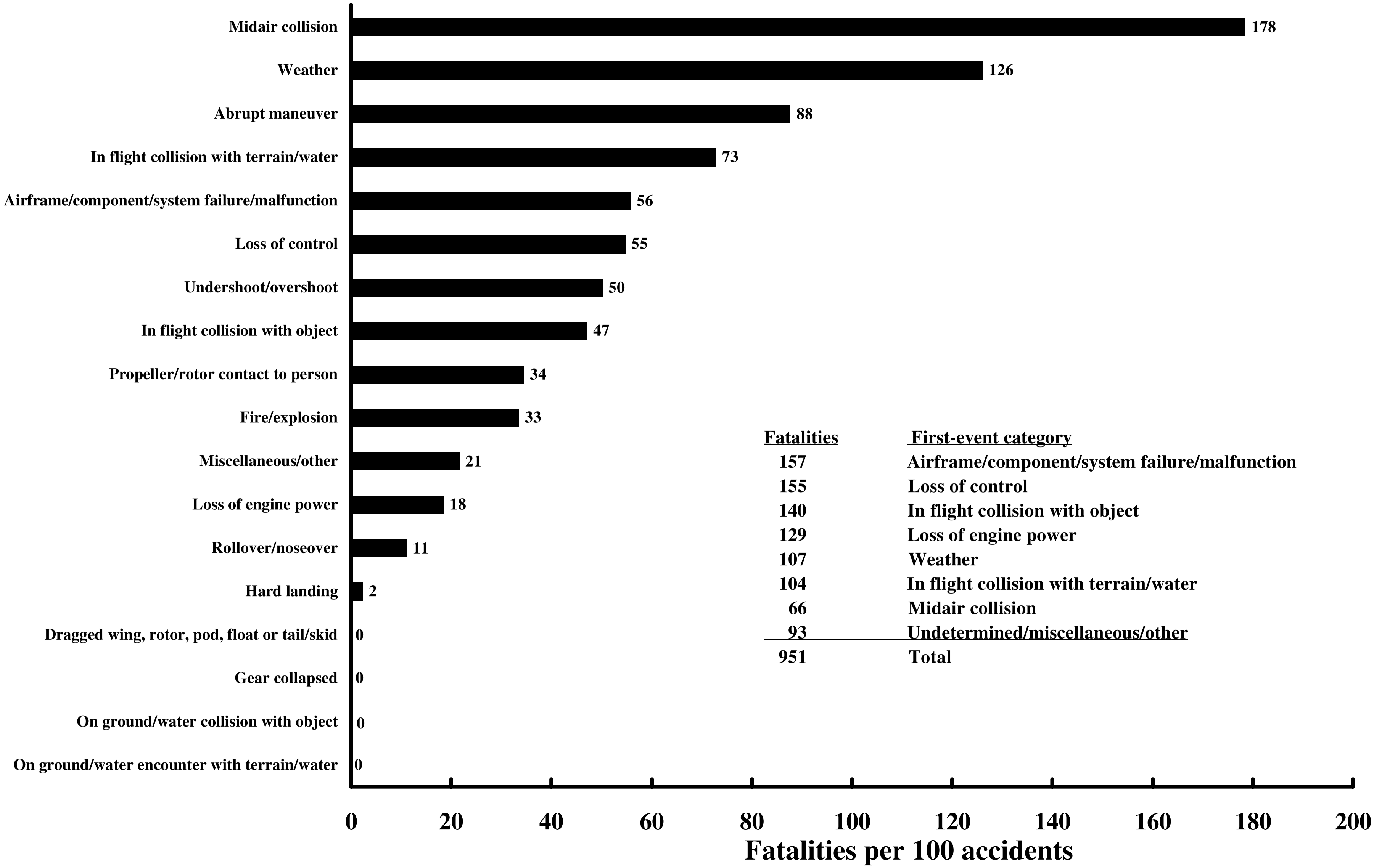


Figure 72. Fatalities per 100 accidents, mid-1963 through 1997: single-turbine helicopters (commercially manufactured).

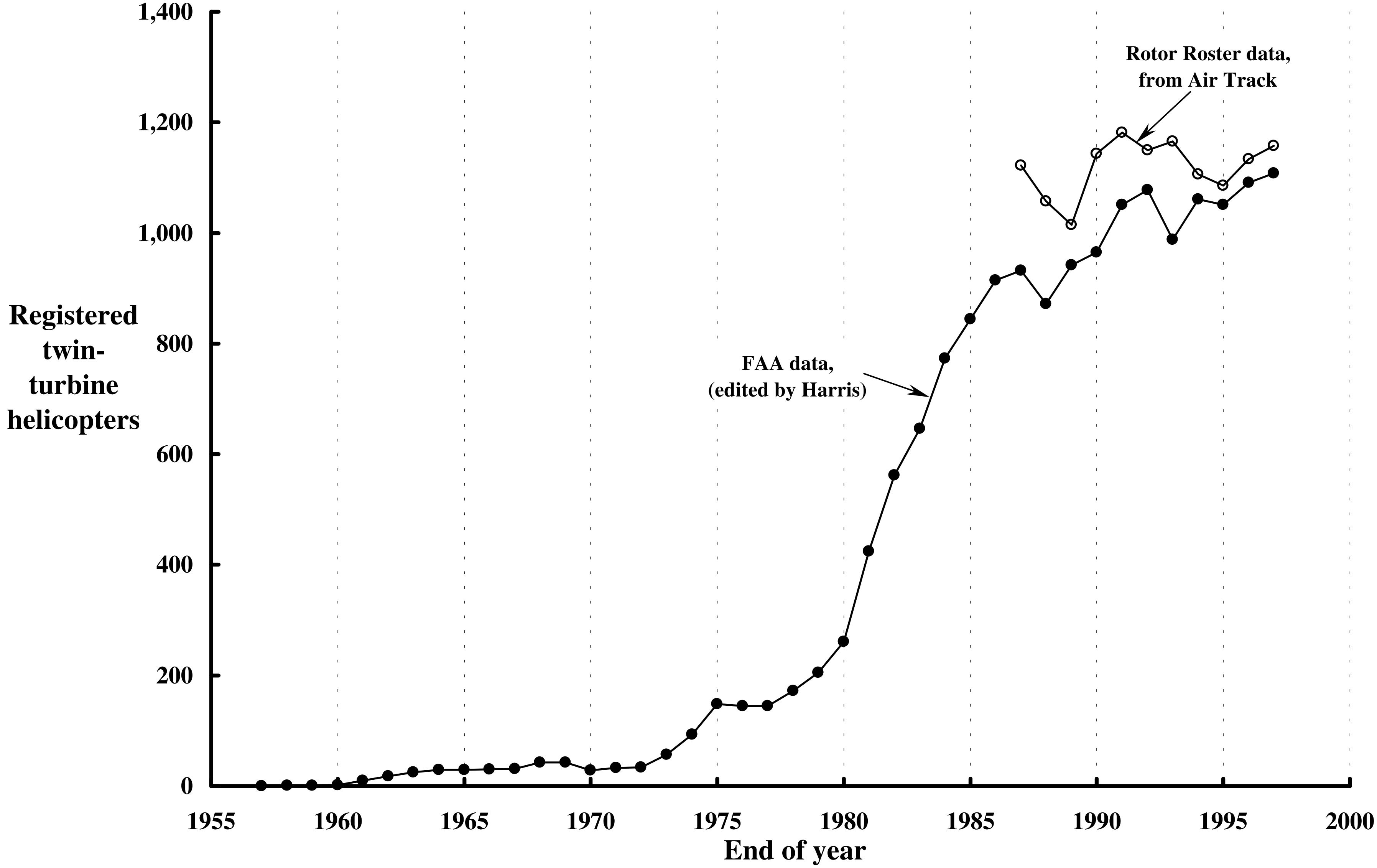


Figure 73. Twin-turbine helicopter fleet size (commercially manufactured).

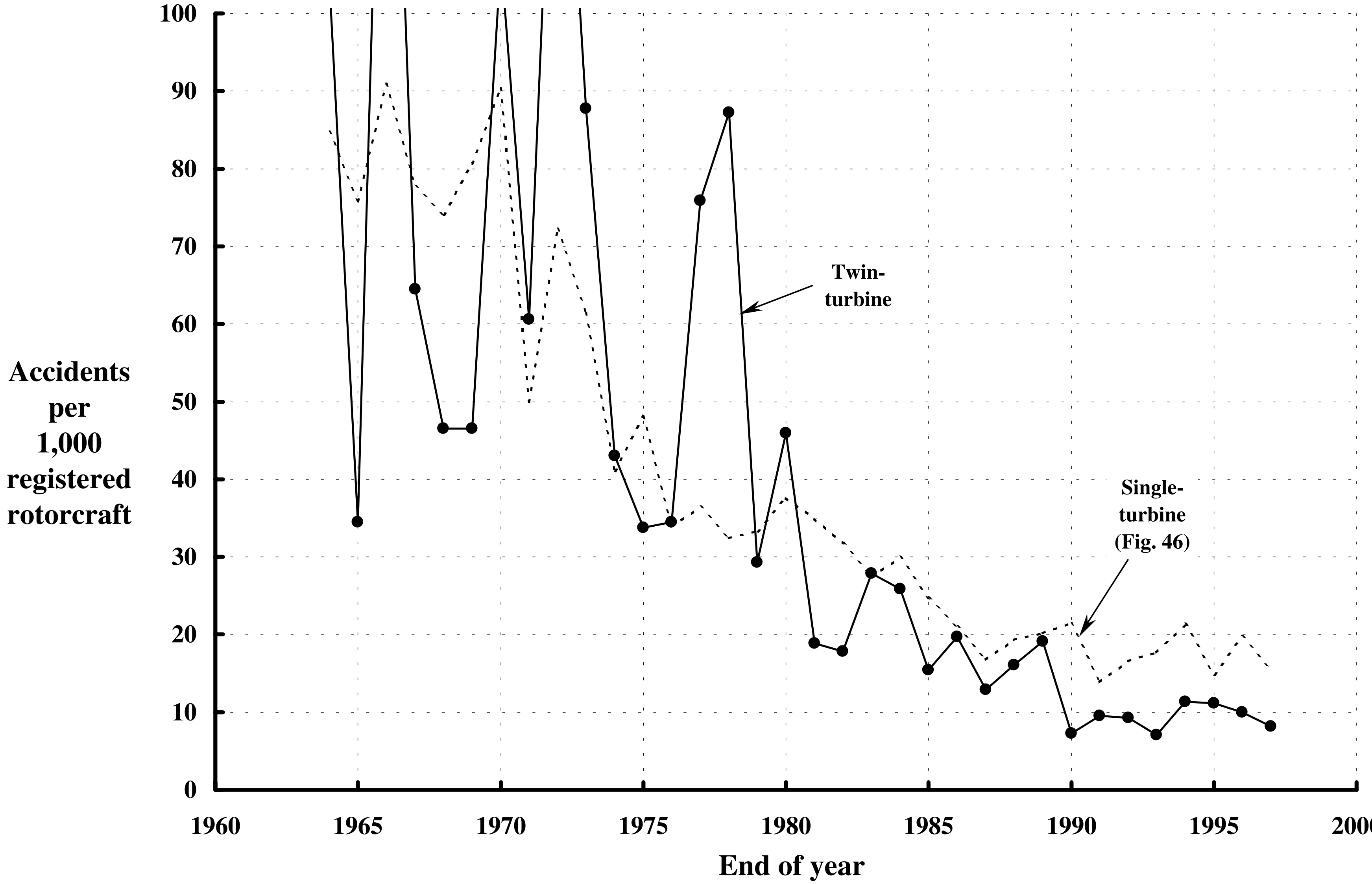


Figure 74. Accidents per 1,000 registered aircraft: twin-turbine helicopters (commercially manufactured).

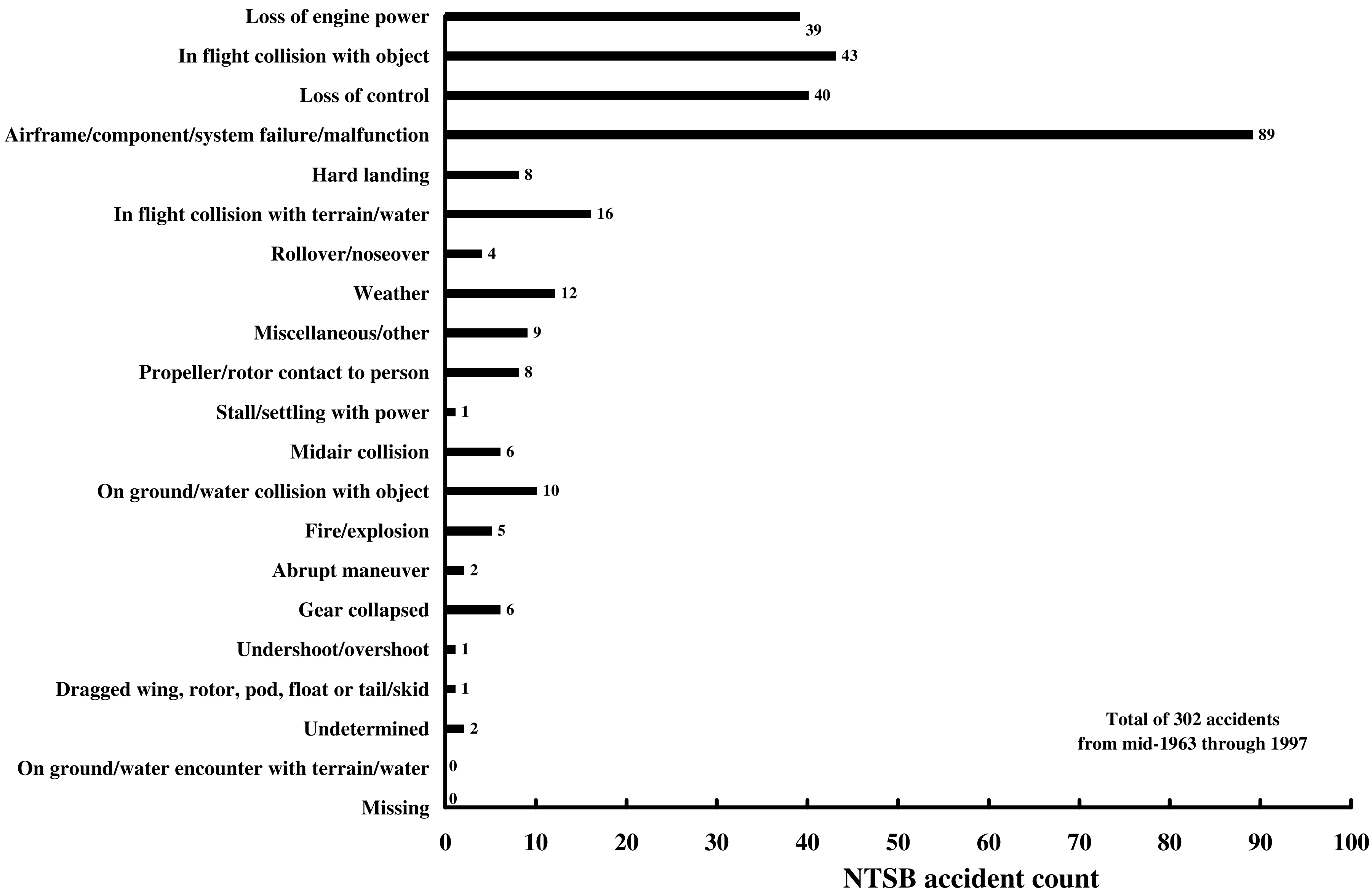


Figure 75. Accident count by first event category: twin-turbine helicopters (commercially manufactured).

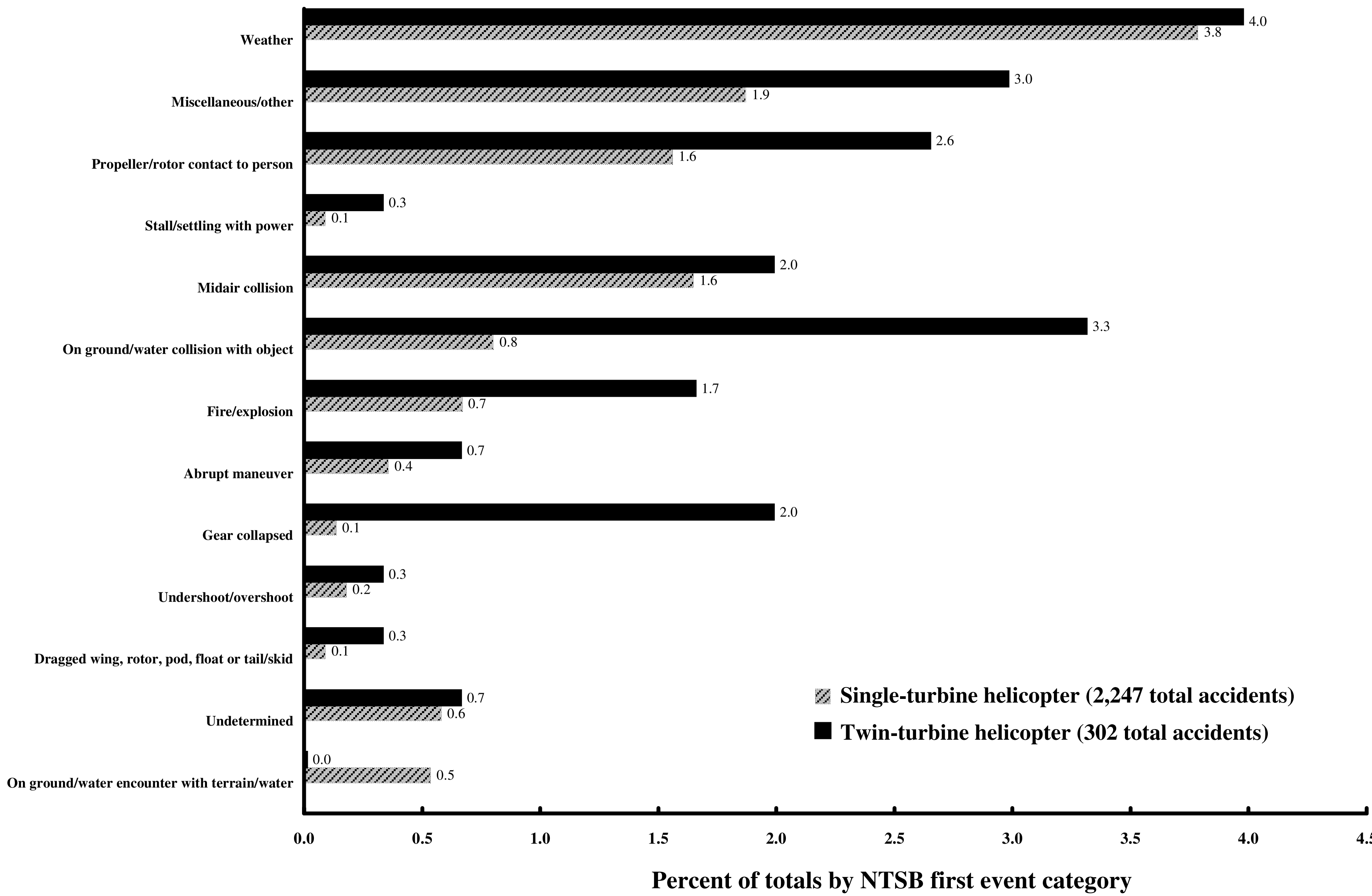


Figure 76. Other first event categories: twin-turbine vs. single-turbine helicopters (commercially manufactured).

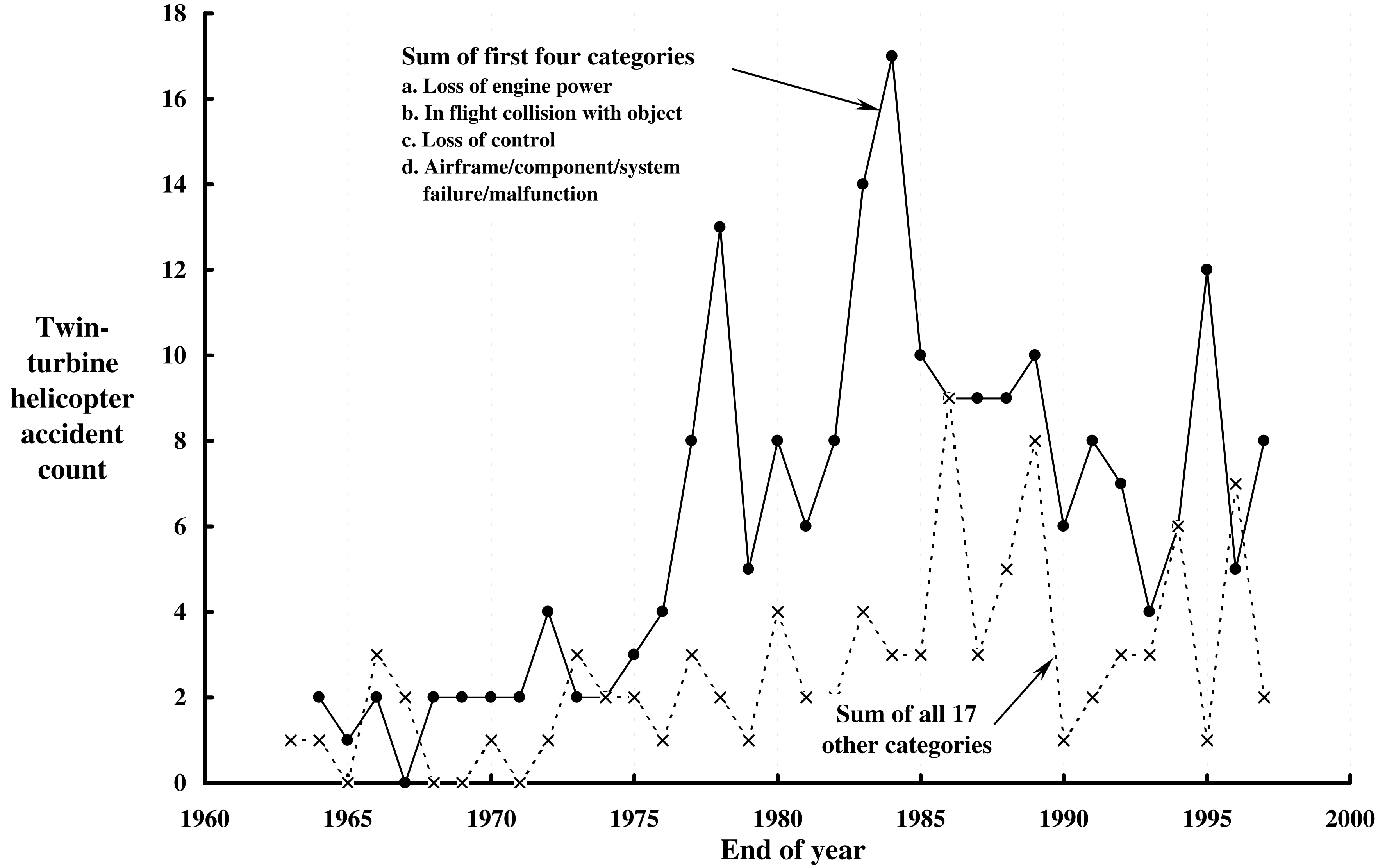


Figure 77. Accidents by first event categories: twin-turbine helicopters (commercially manufactured).

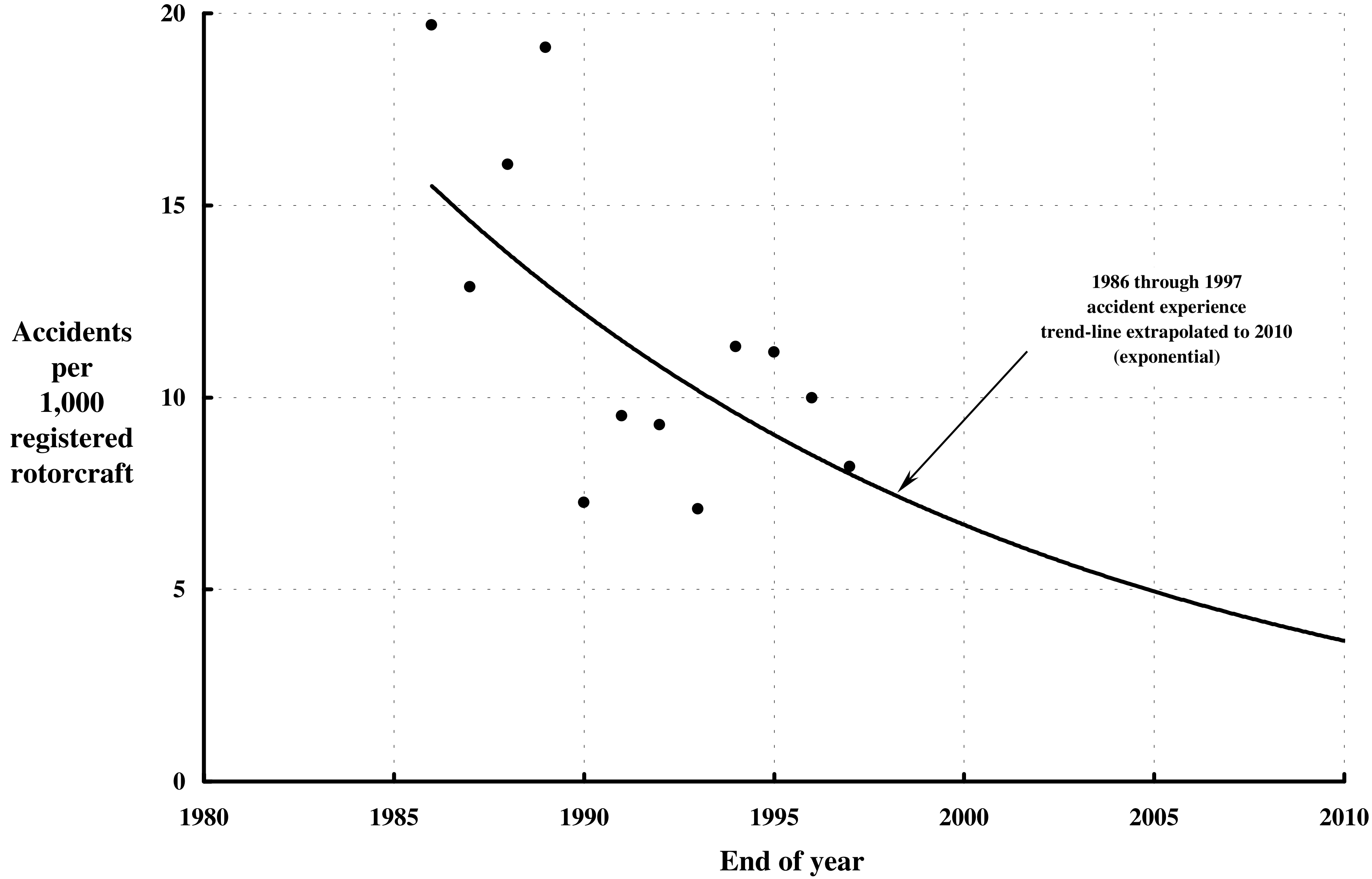


Figure 78. Accidents per 1,000 registered aircraft projected to 2010: twin-turbine helicopters (commercially manufactured).

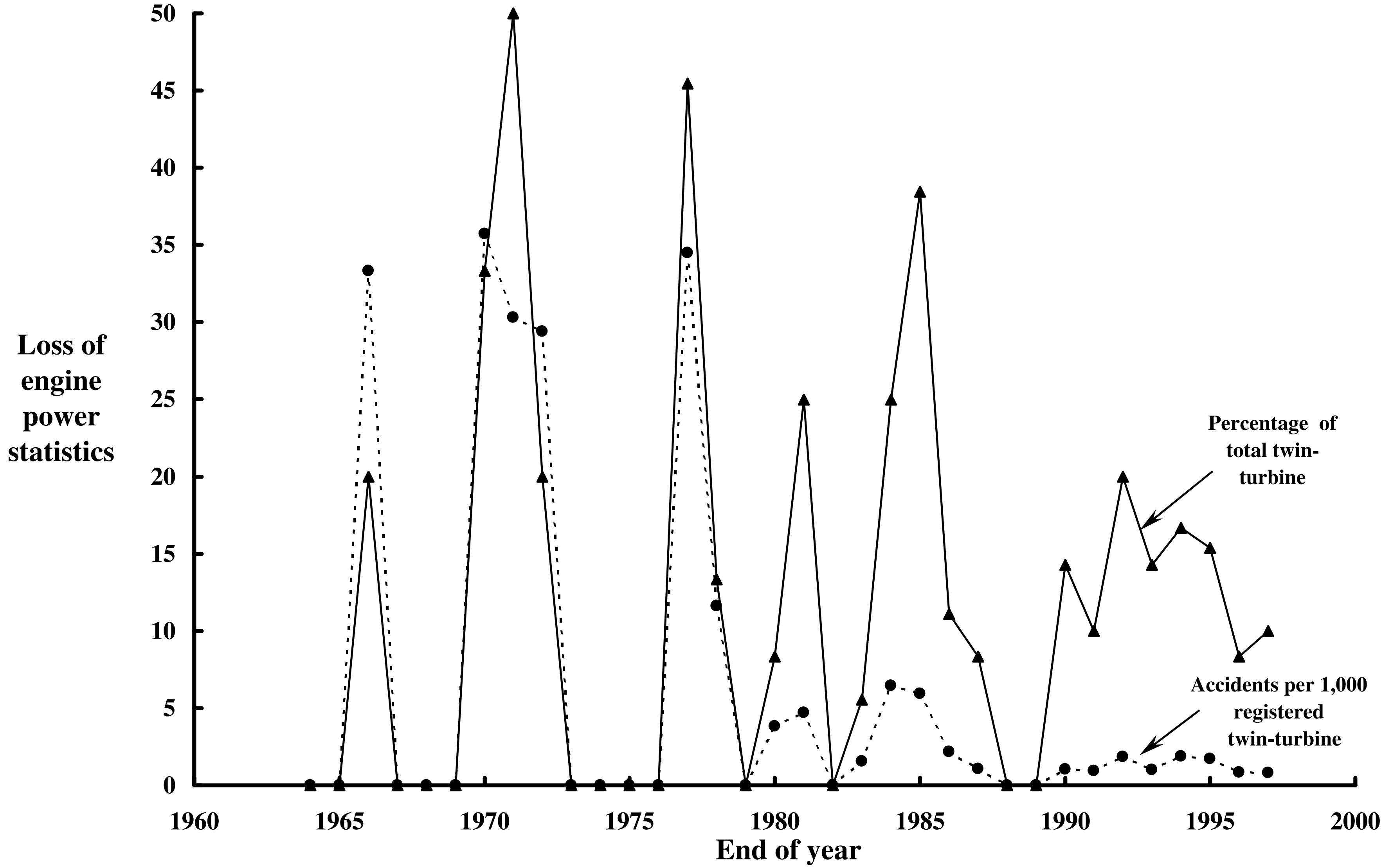


Figure 79. Loss of engine power yearly accident statistics: twin-turbine helicopters (commercially manufactured).

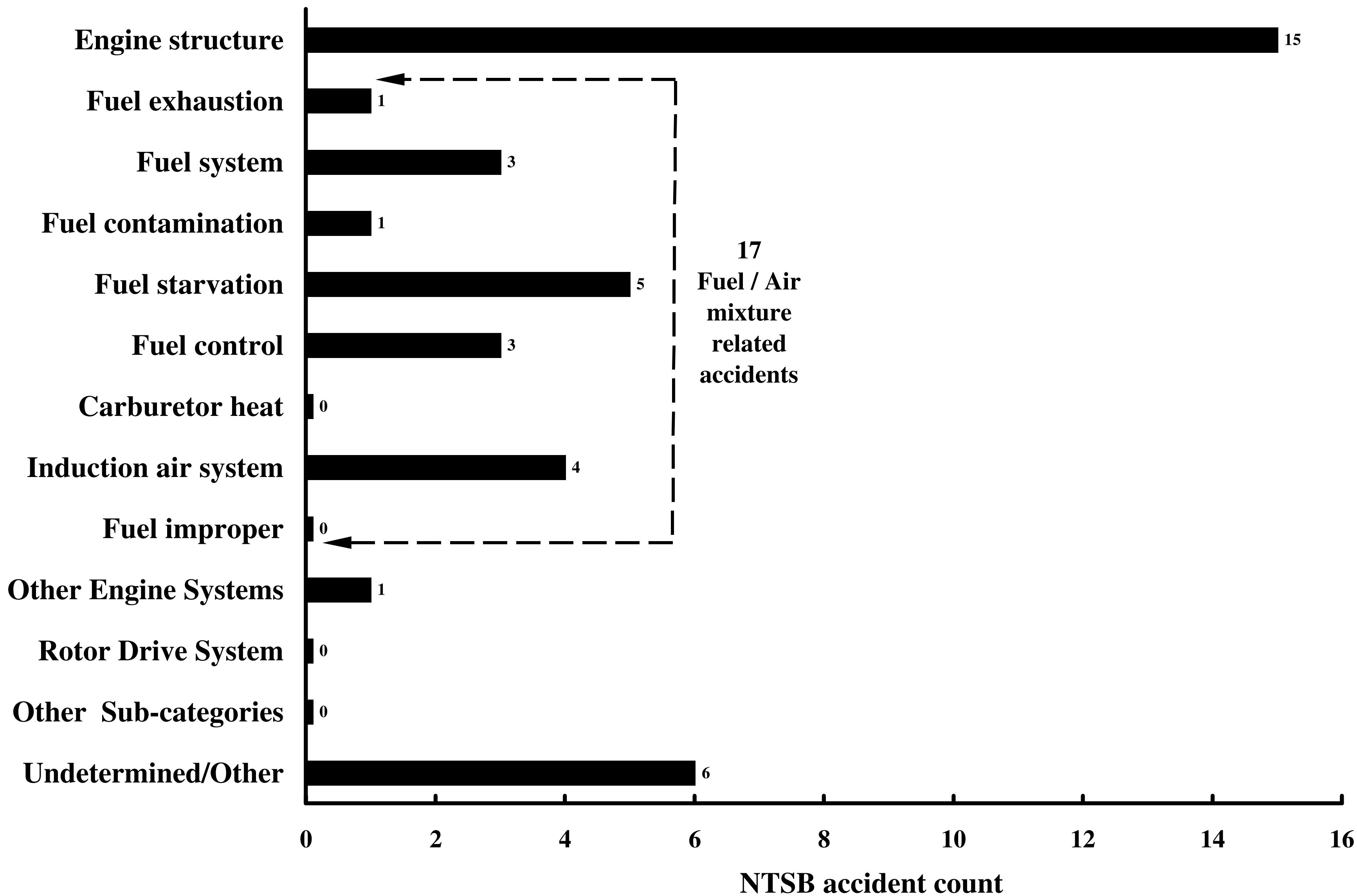


Figure 80. Loss of engine power accidents by category: twin-turbine helicopters (commercially manufactured).

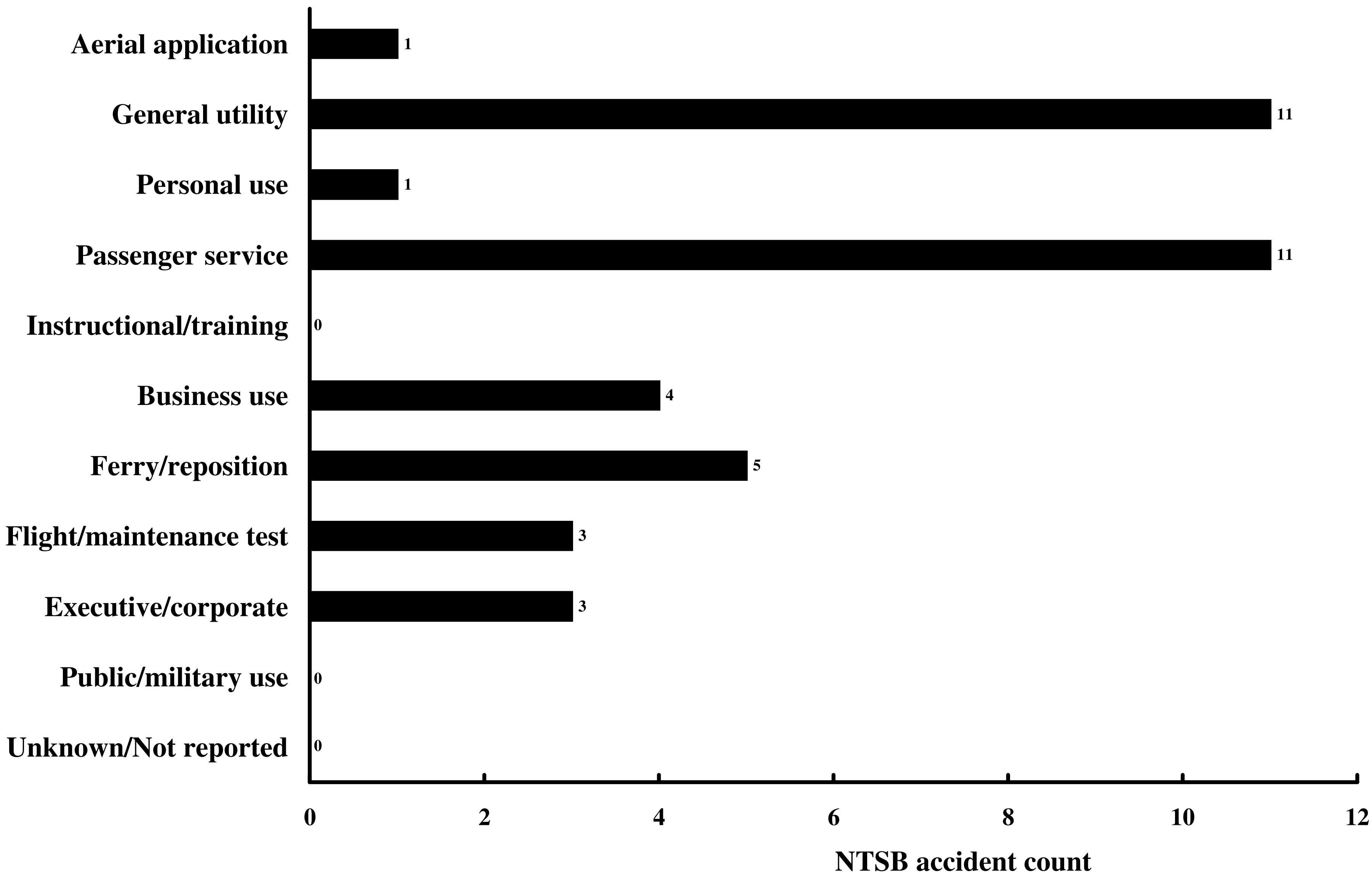


Figure 81. Loss of engine power accidents by activity: twin-turbine helicopters (commercially manufactured).

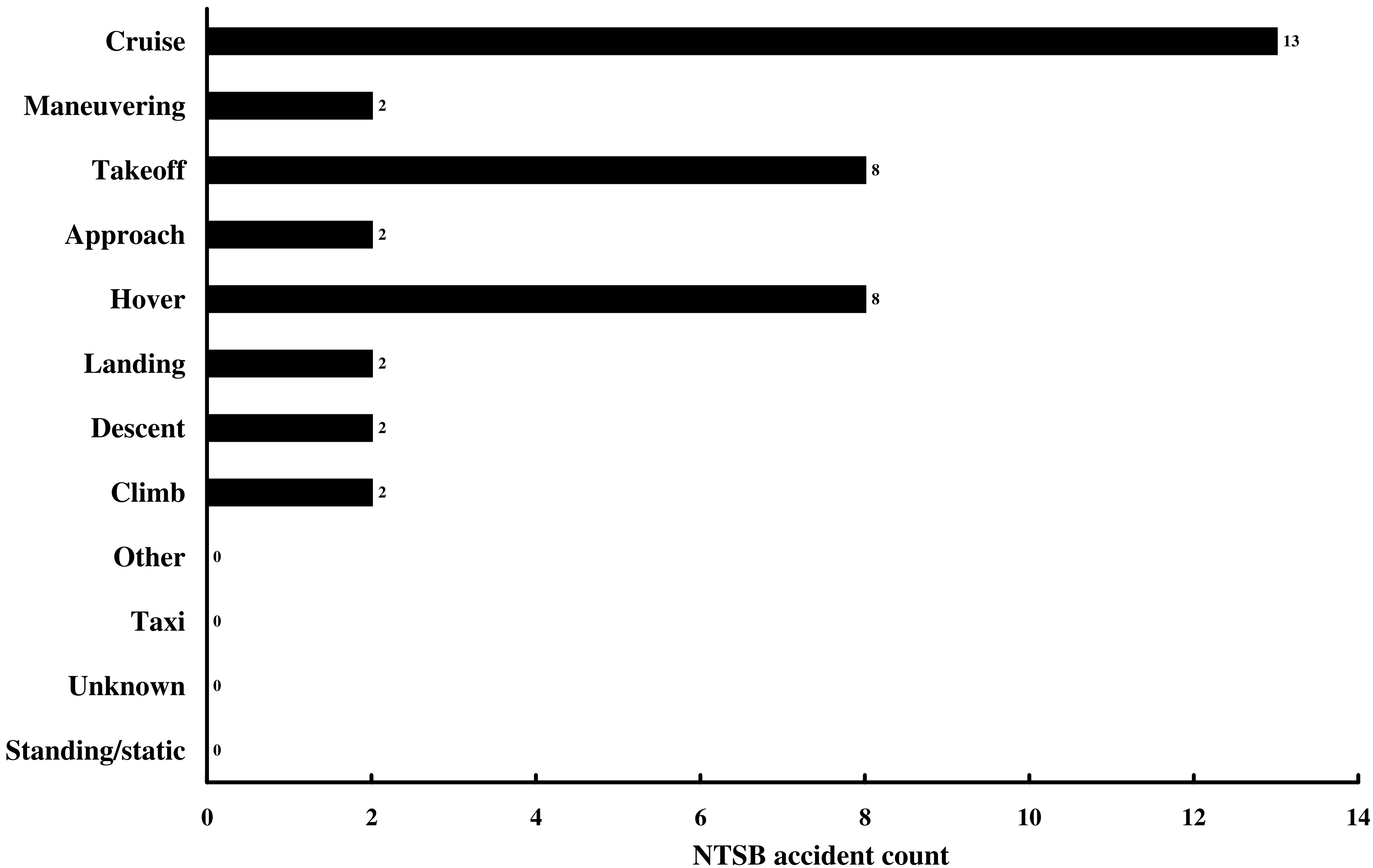


Figure 82. Loss of engine power accidents by phase of operation: twin-turbine helicopters (commercially manufactured).

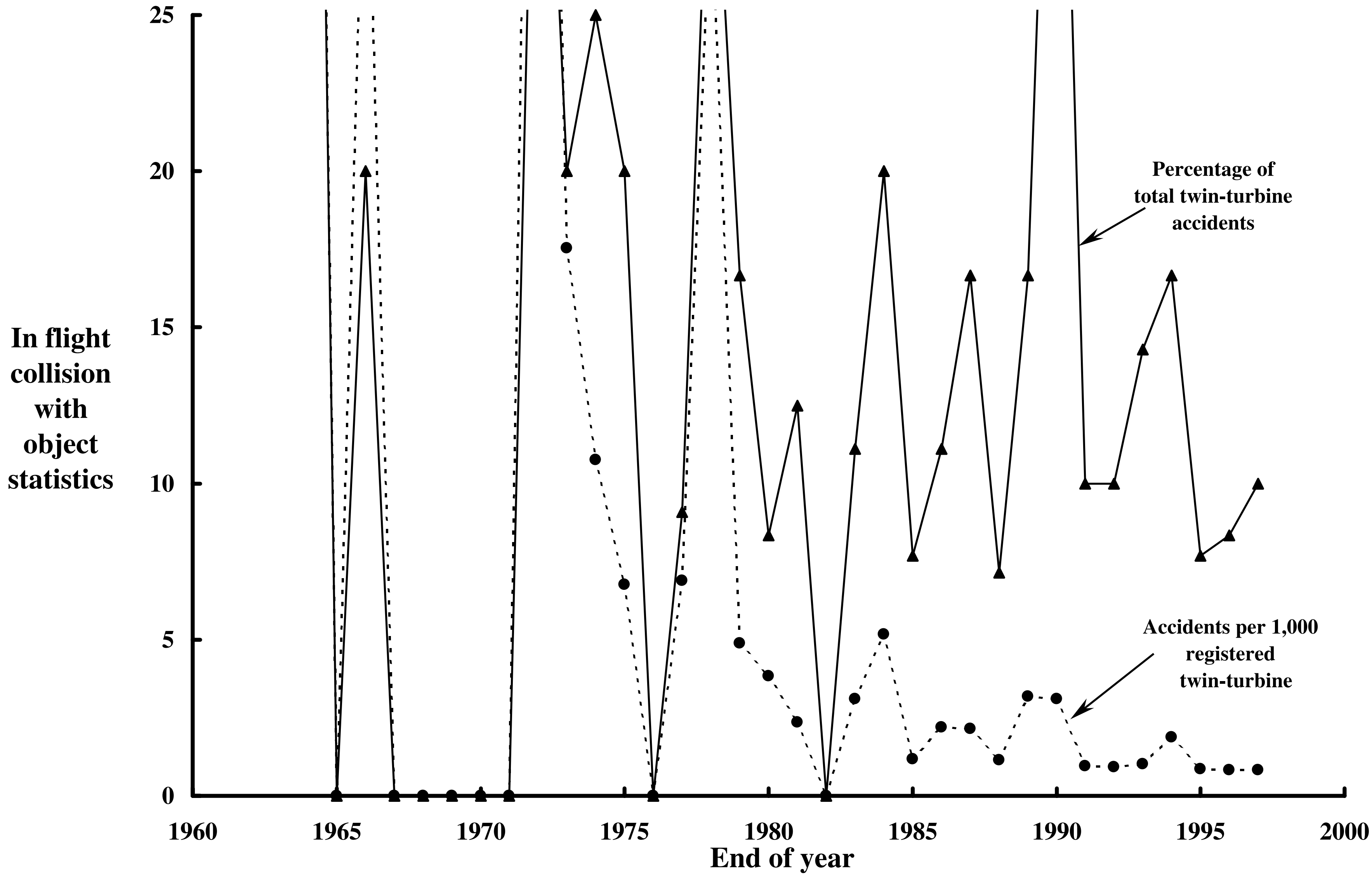


Figure 83. In flight collision with object yearly accident statistics: twin-turbine helicopters (commercially manufactured).

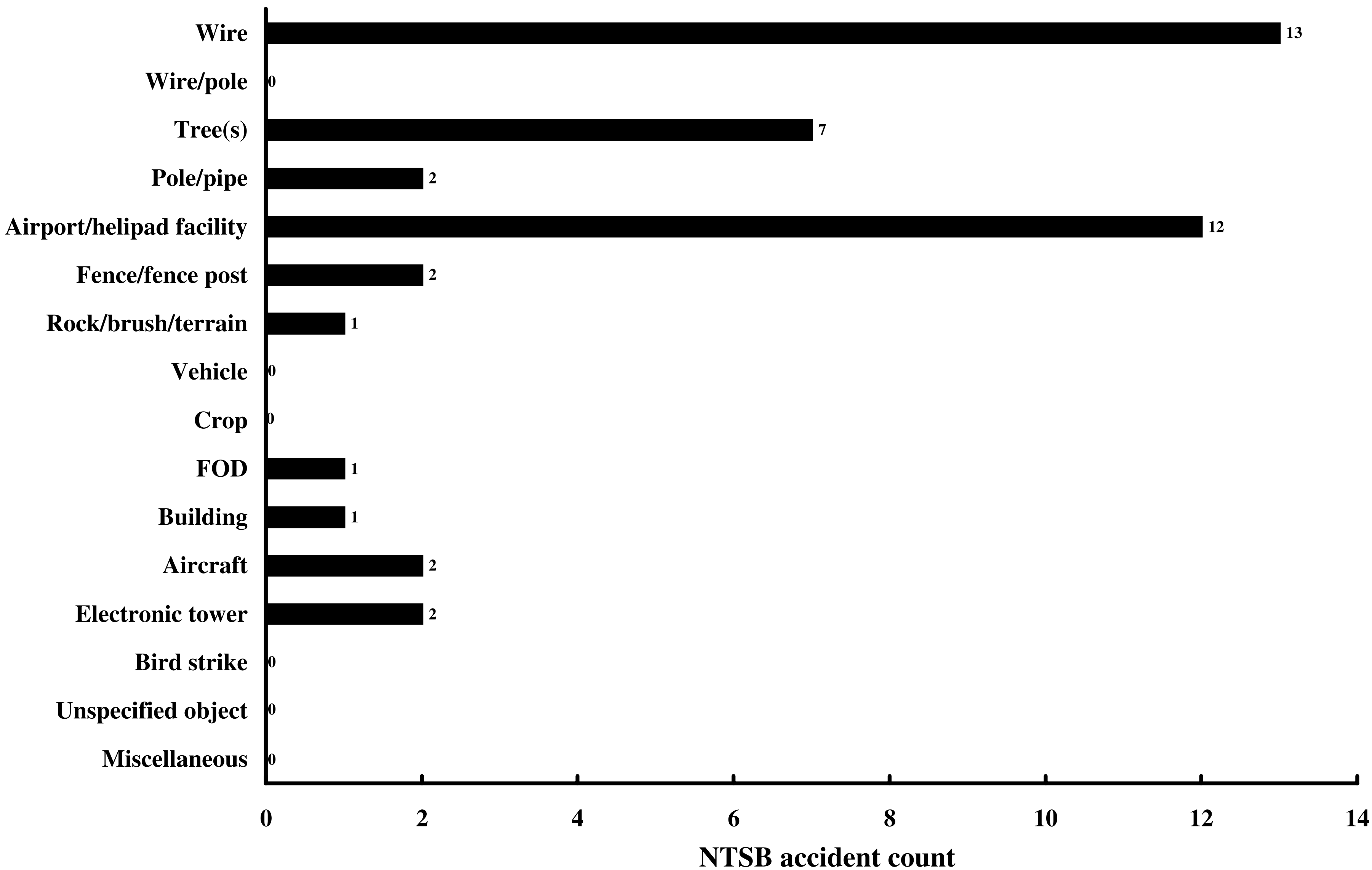


Figure 84. In flight collision with object accidents by object hit: twin-turbine helicopters (commercially manufactured).

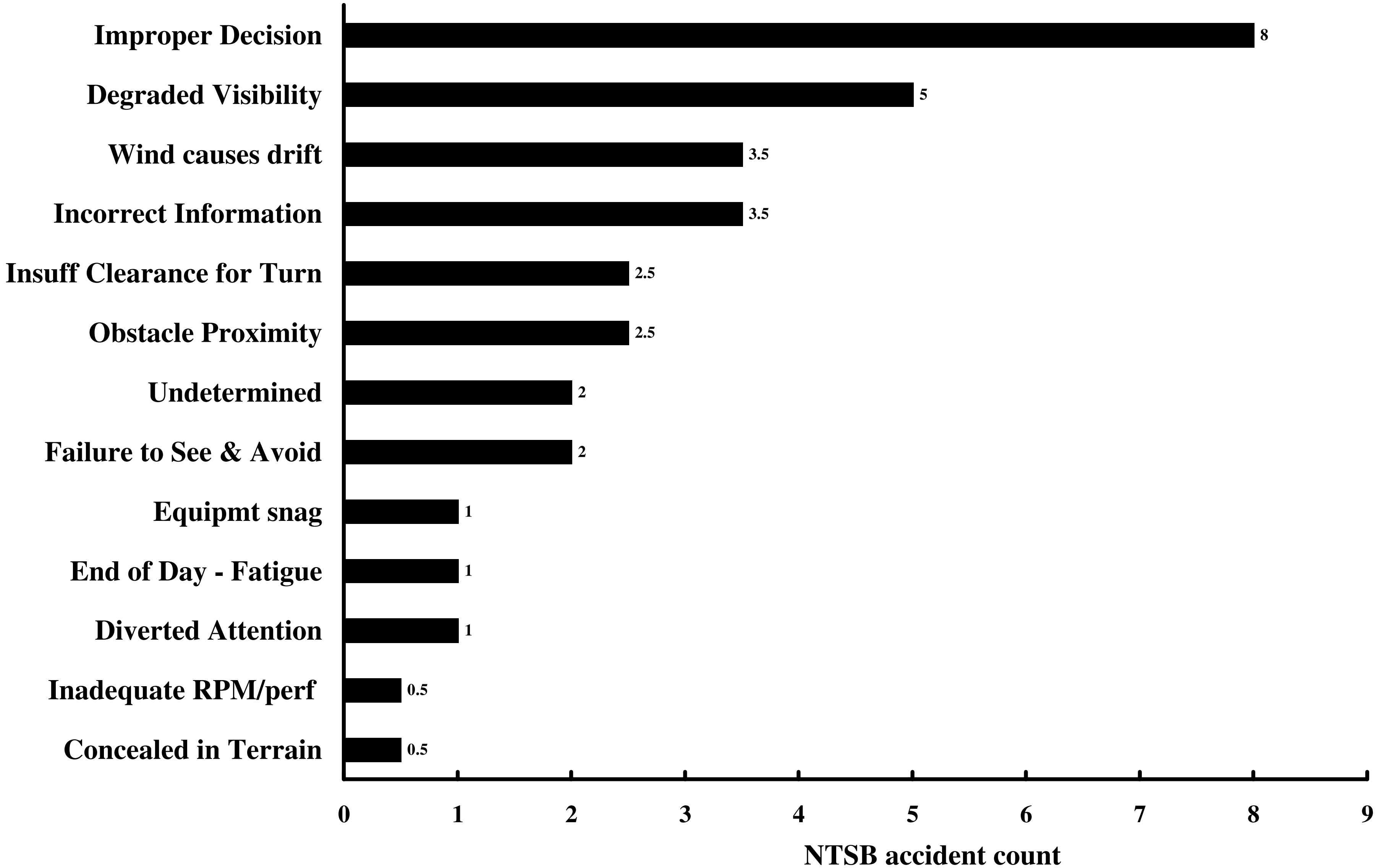


Figure 85. In flight collision with object accidents by cause: twin-turbine helicopters (commercially manufactured).

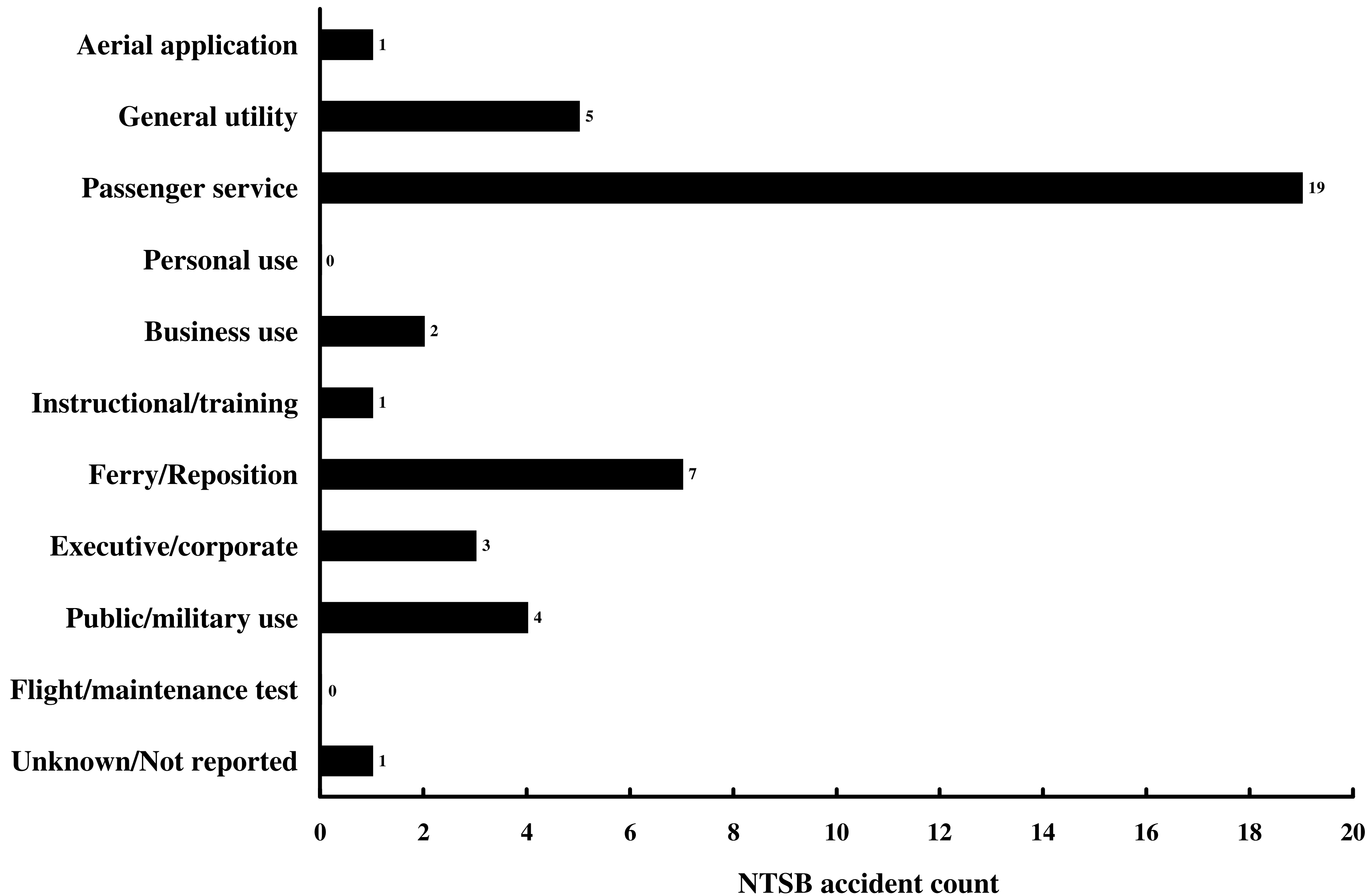


Figure 86. In flight collision with object accidents by activity: twin-turbine helicopters (commercially manufactured).

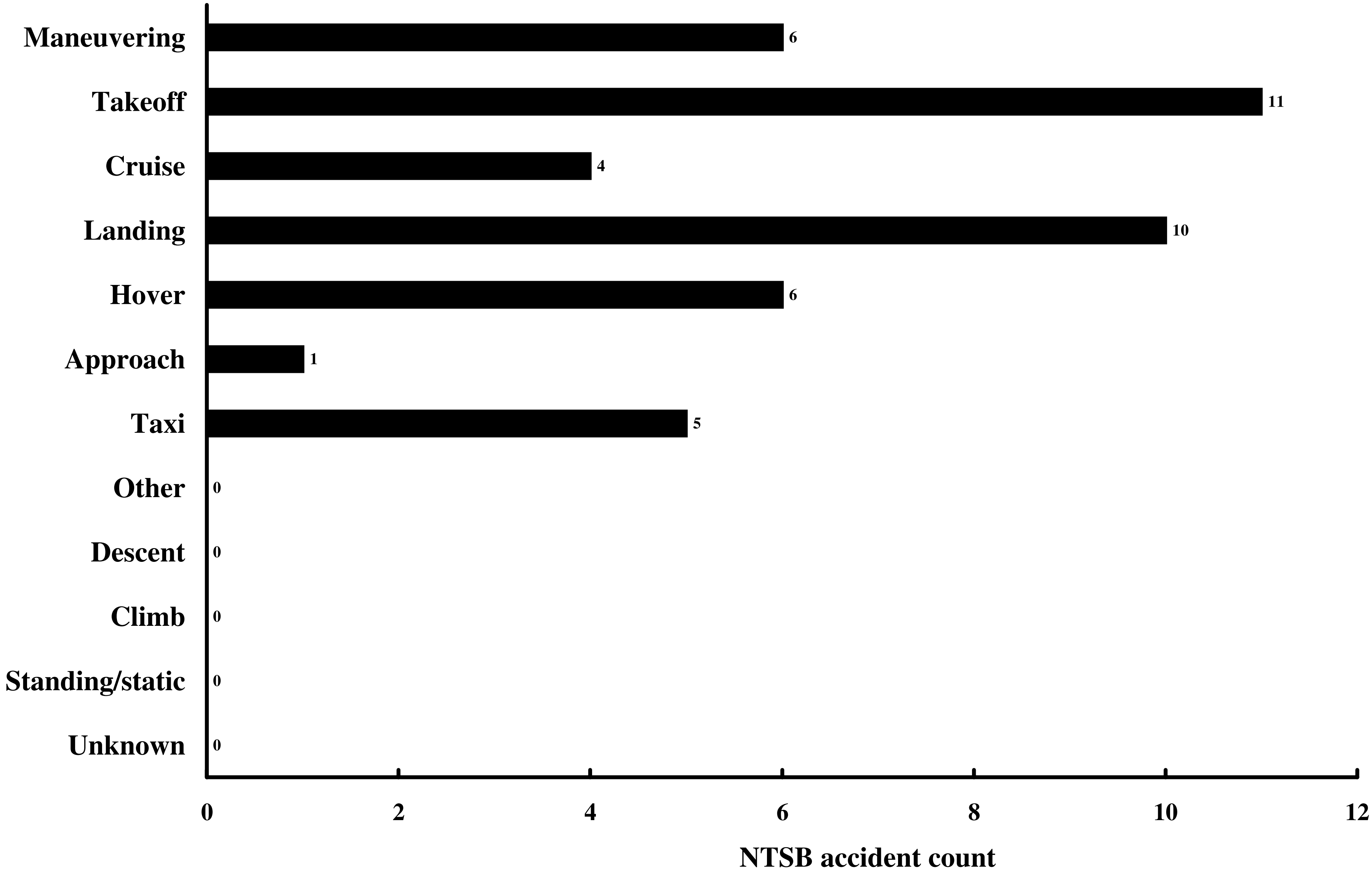


Figure 87. In flight collision with object accidents by phase of operation: twin-turbine helicopters (commercially manufactured).

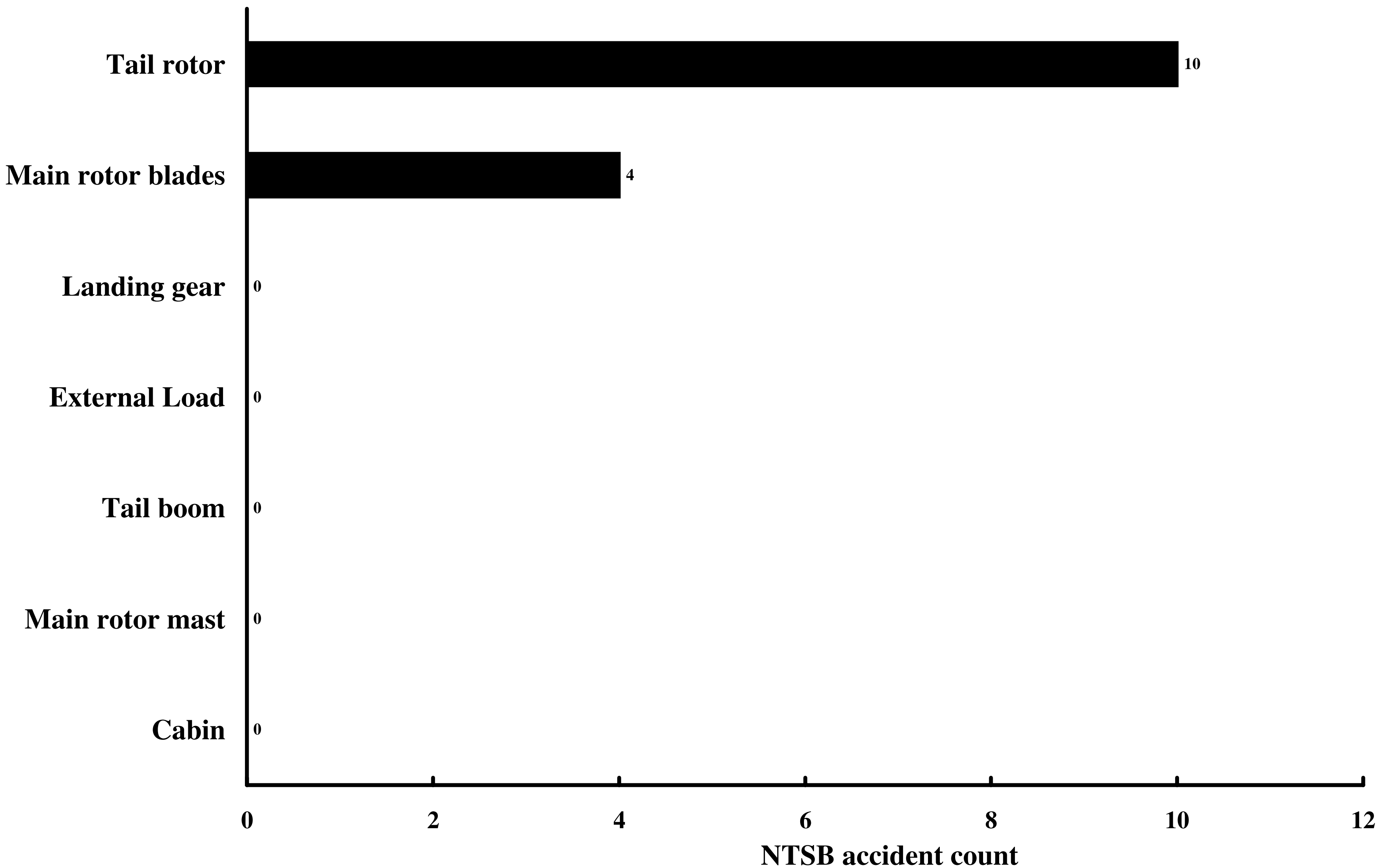


Figure 88. In flight collision with object accidents by part hit: twin-turbine helicopters (commercially manufactured).

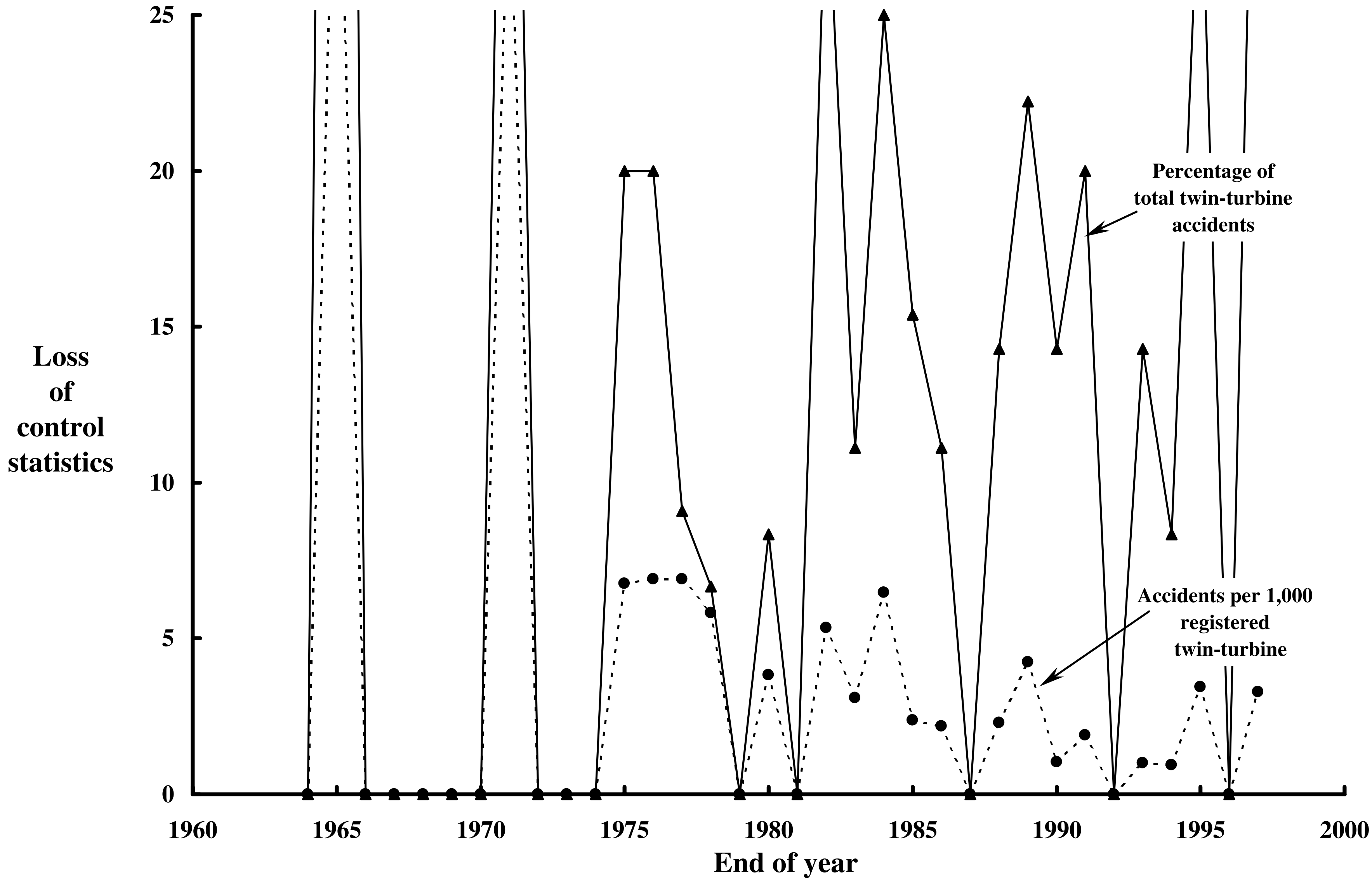


Figure 89. Loss of control yearly accident statistics: twin-turbine helicopters (commercially manufactured).

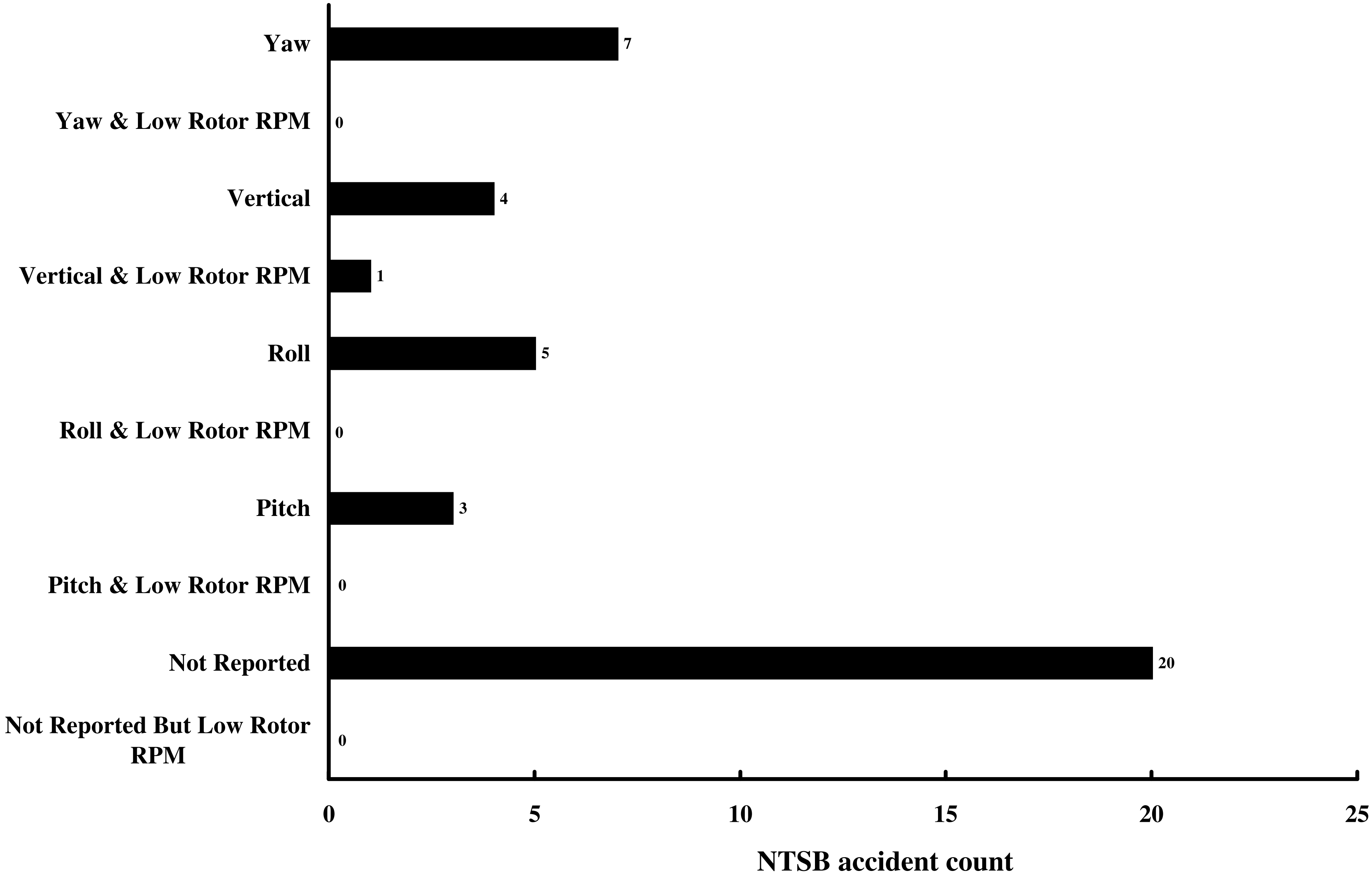


Figure 90. Loss of control accidents by axis lost: twin-turbine helicopters (commercially manufactured).

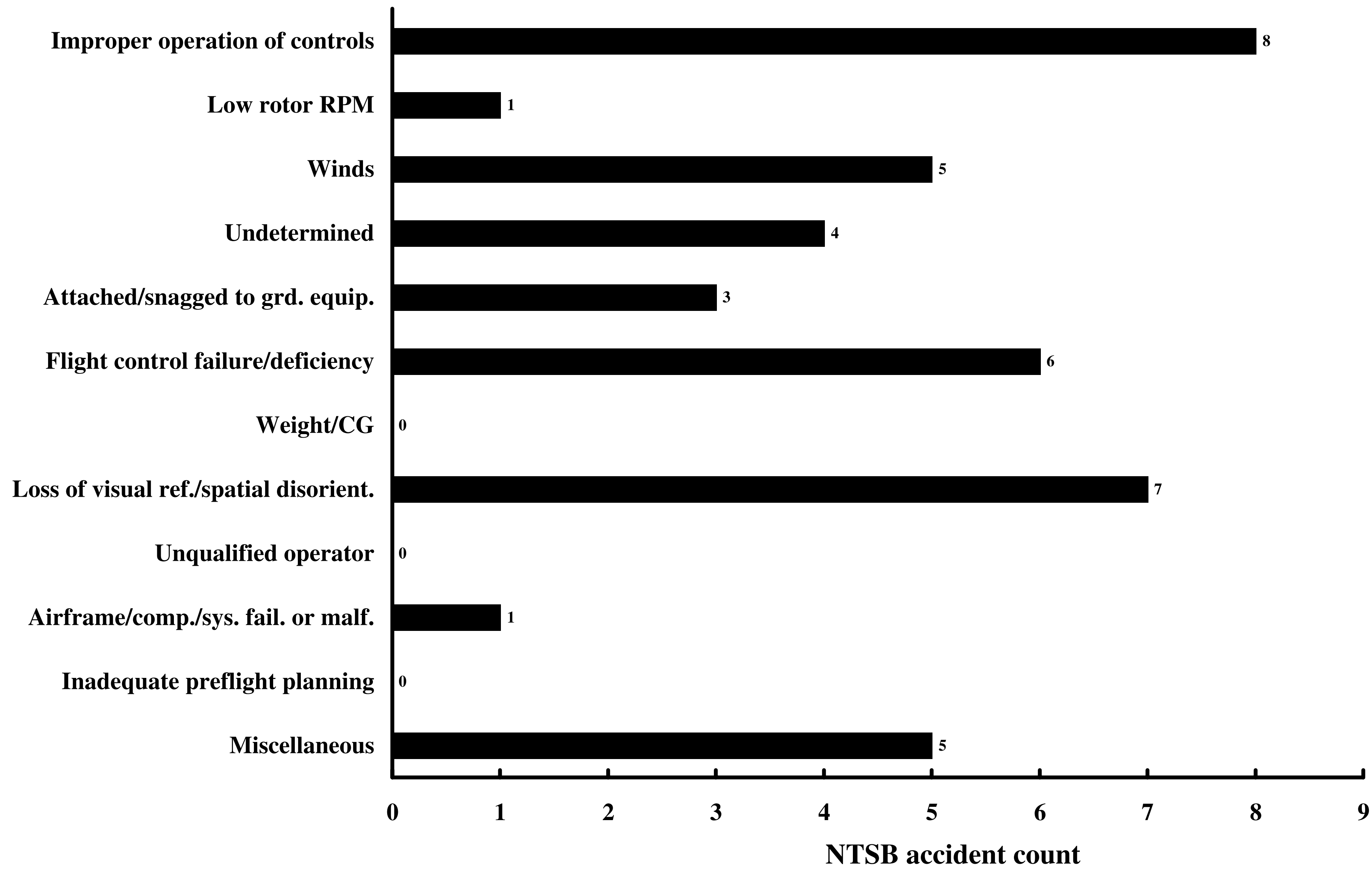


Figure 91. Loss of control accidents by cause: twin-turbine helicopters (commercially manufactured).

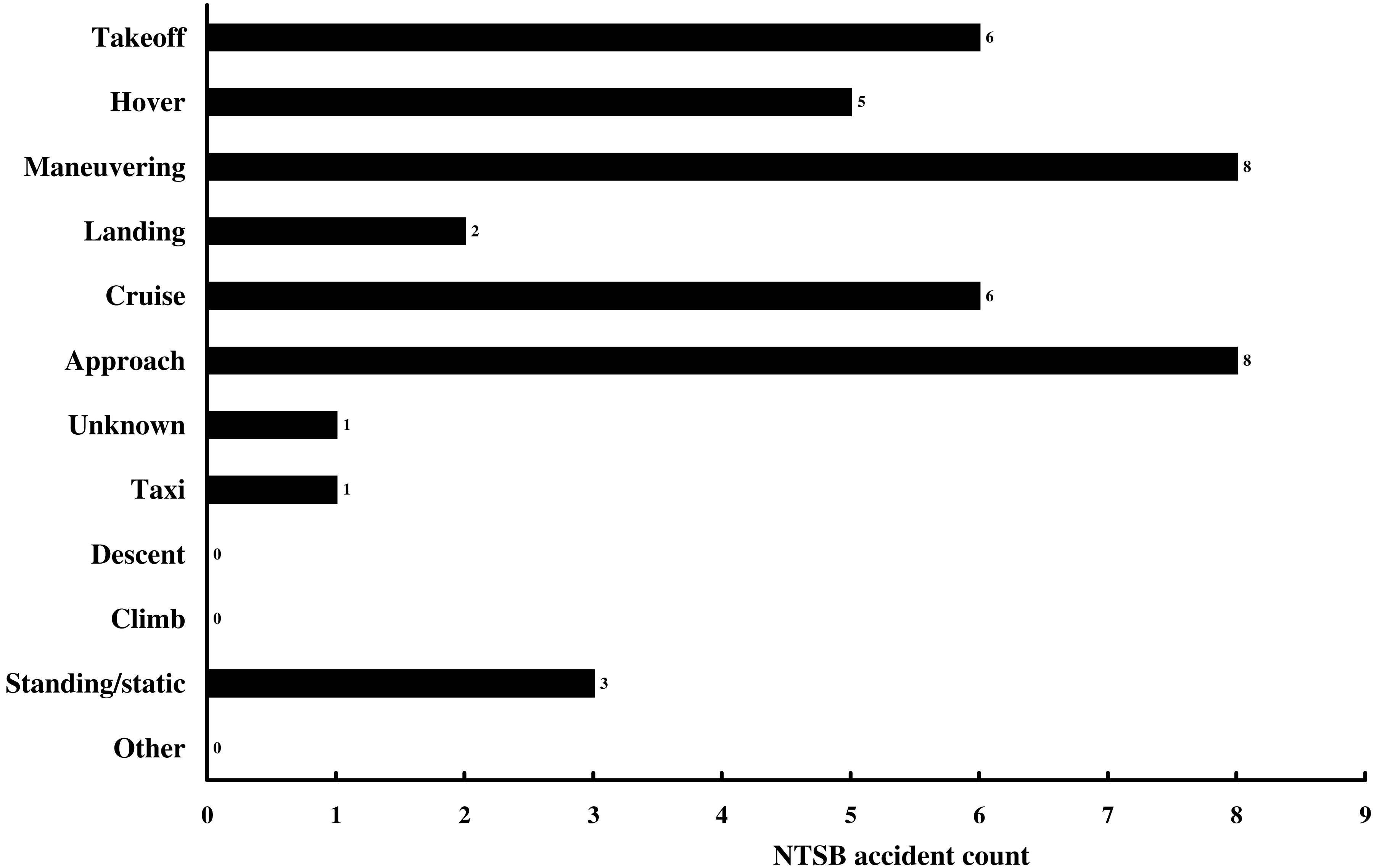


Figure 92. Loss of control accidents by phase of operation: twin-turbine helicopters (commercially manufactured).

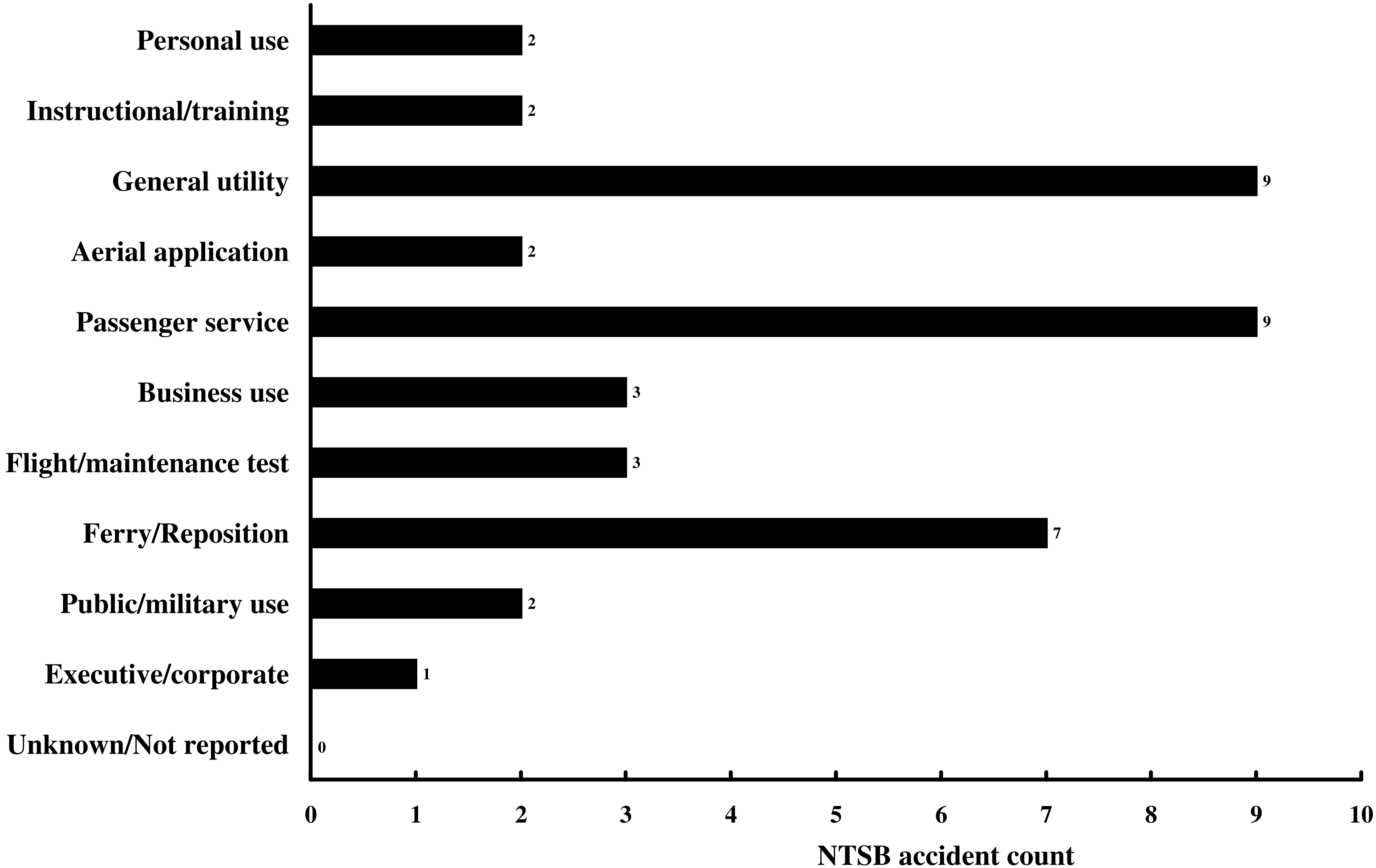


Figure 93. Loss of control accidents by activity: twin-turbine helicopters (commercially manufactured).

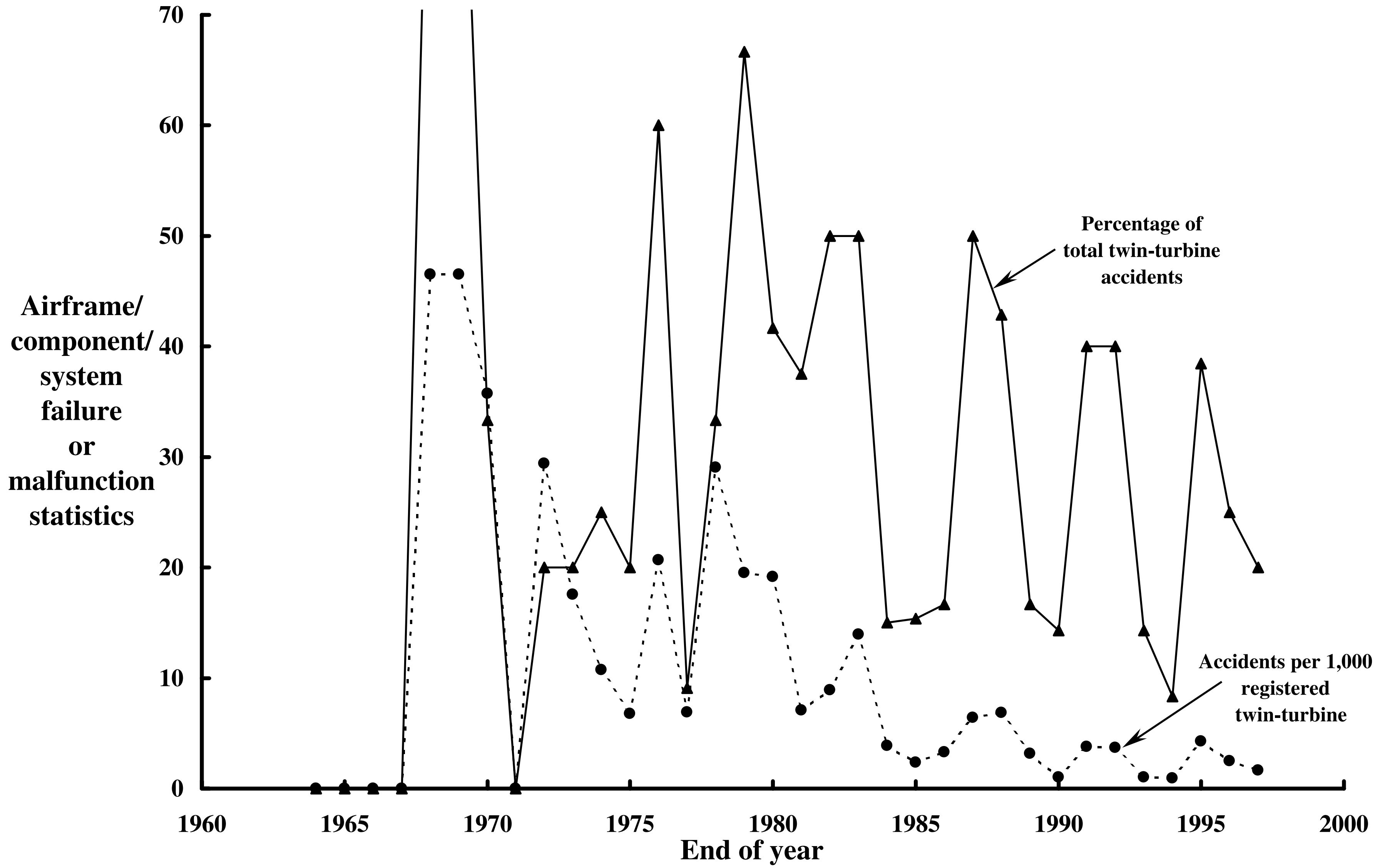


Figure 94. Airframe failure yearly accident statistics: twin-turbine helicopters (commercially manufactured).

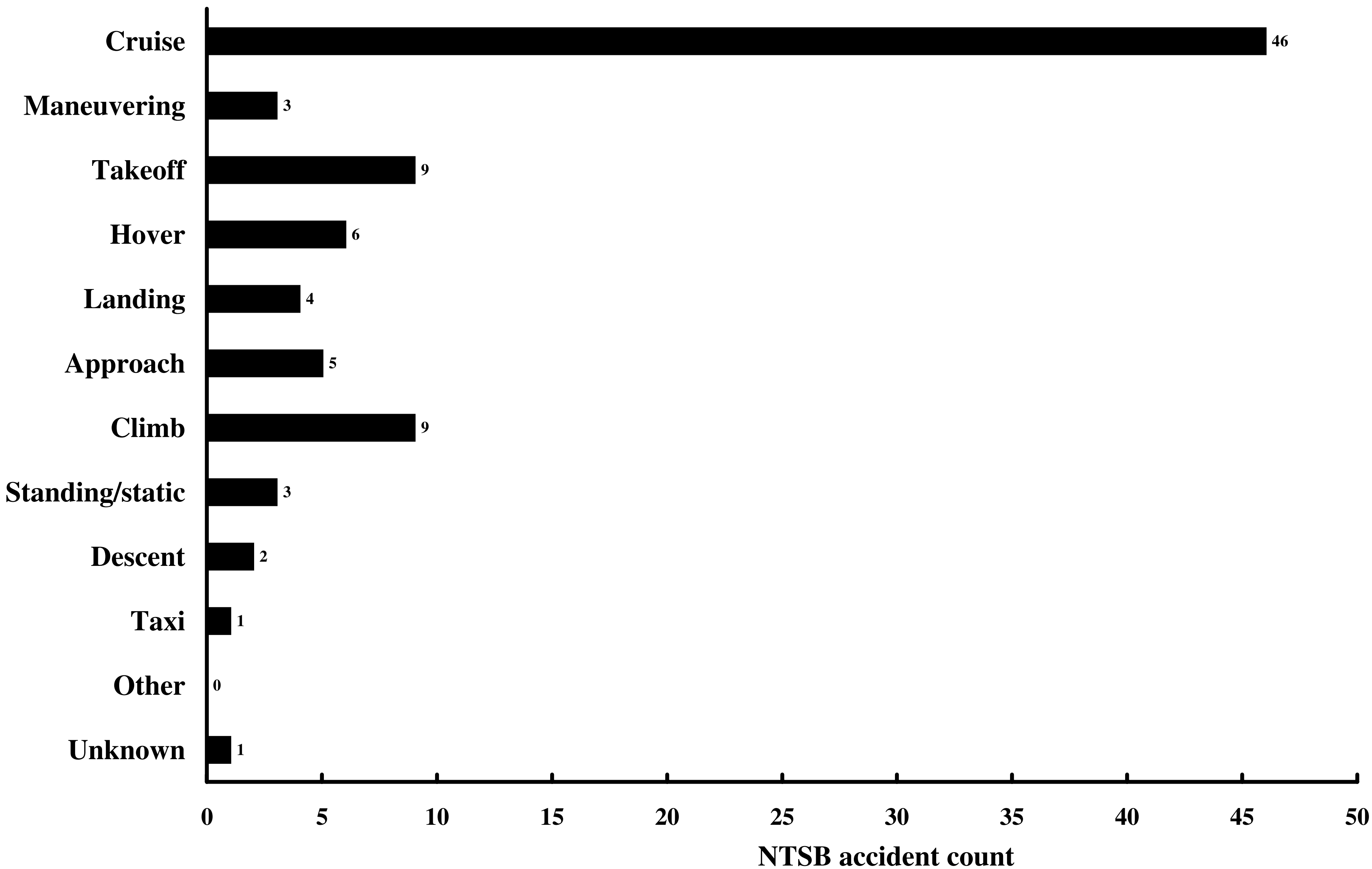


Figure 95. Airframe failure accidents by phase of operation: twin-turbine helicopters (commercially manufactured).

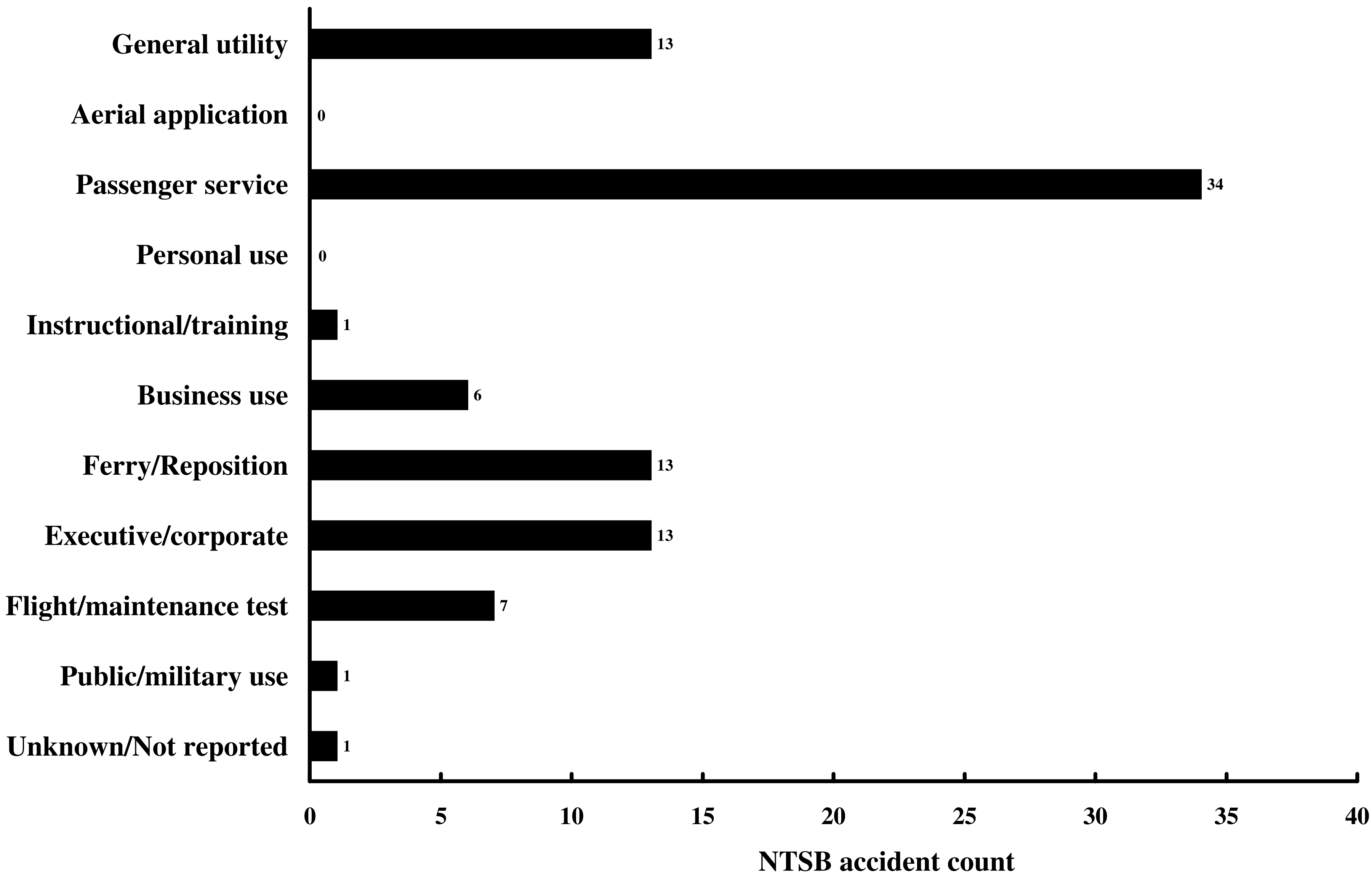


Figure 96. Airframe failure accidents by activity: twin-turbine helicopters (commercially manufactured).

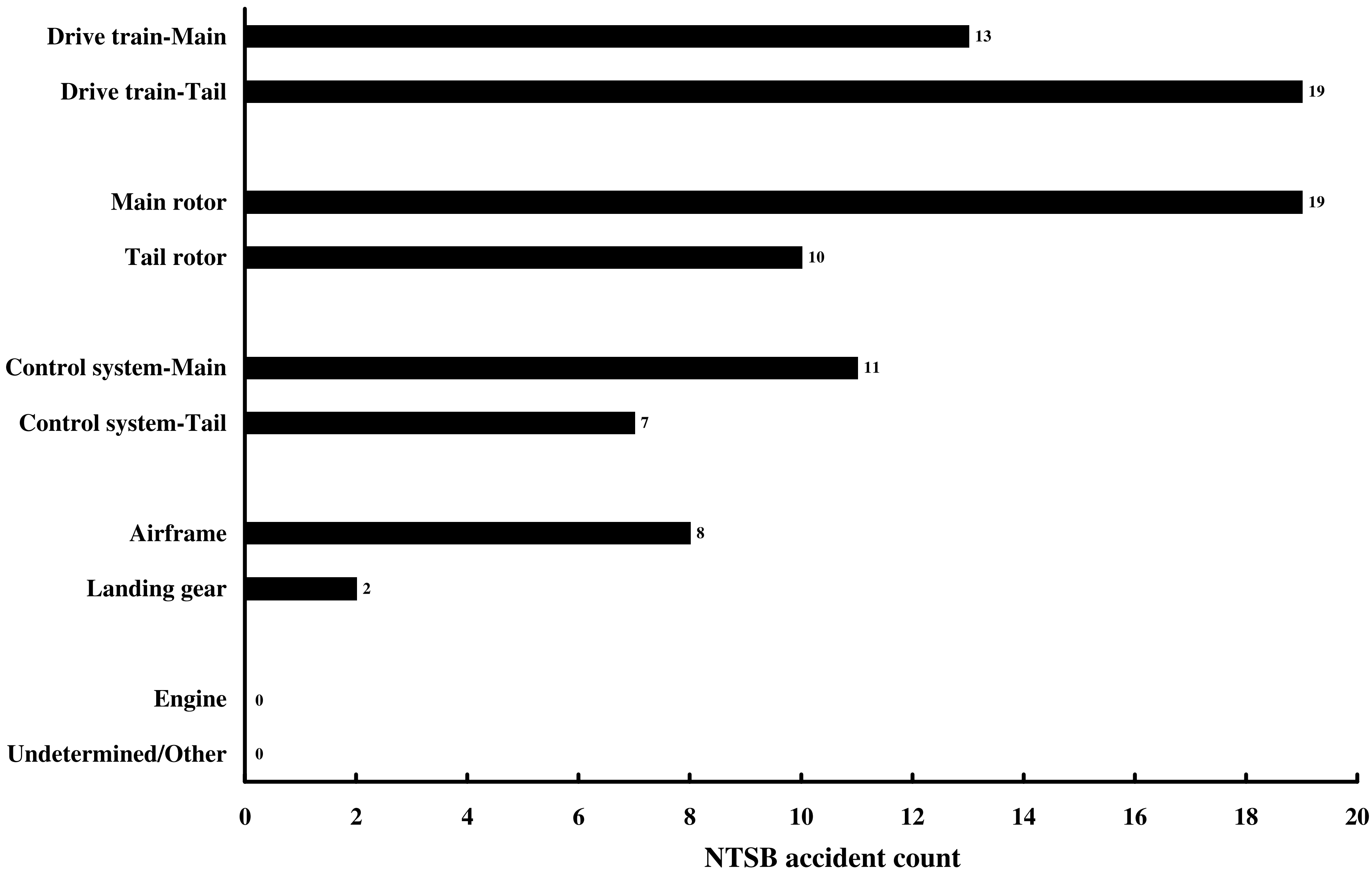


Figure 97. Airframe failure accidents by system: twin-turbine helicopters (commercially manufactured).

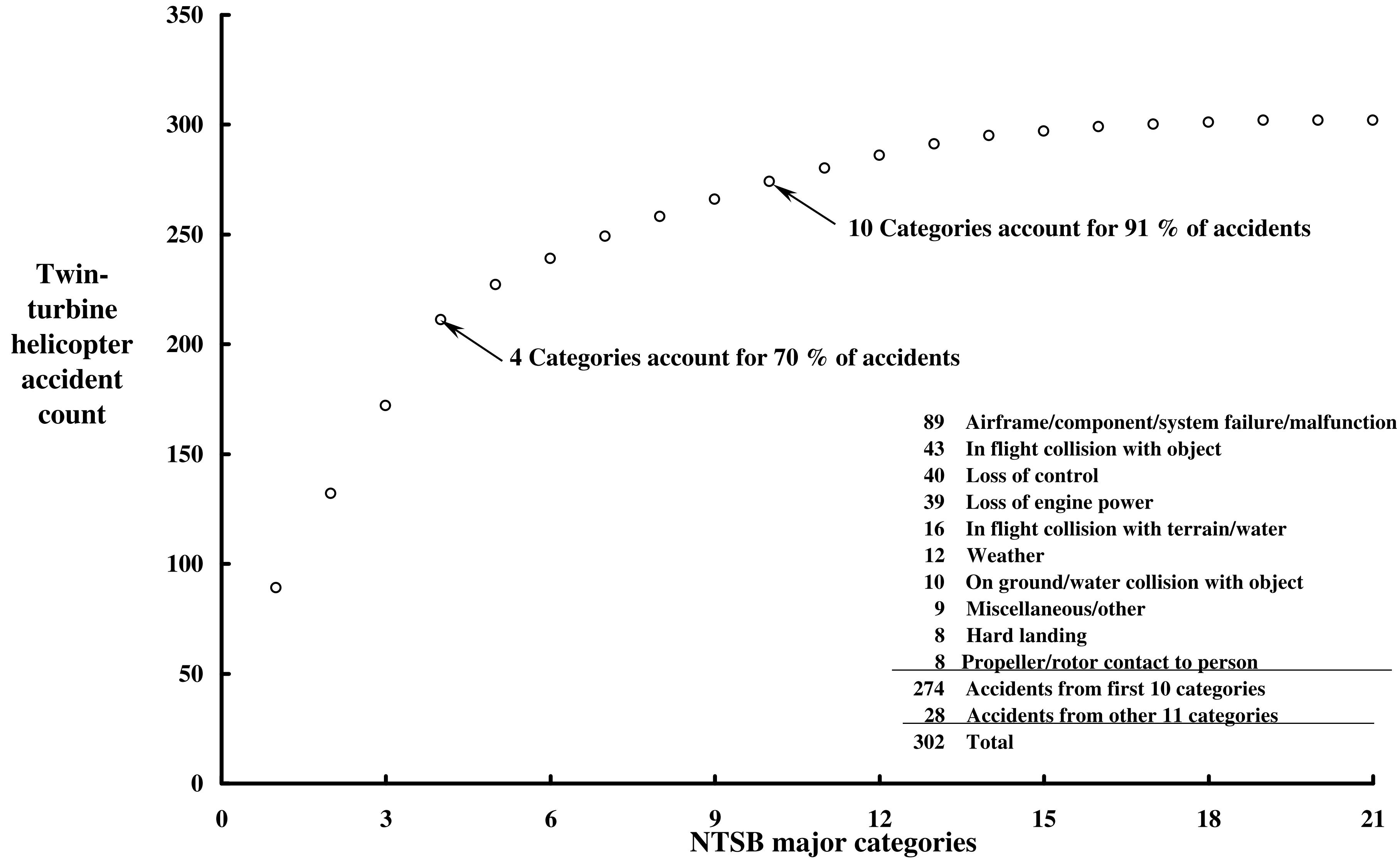
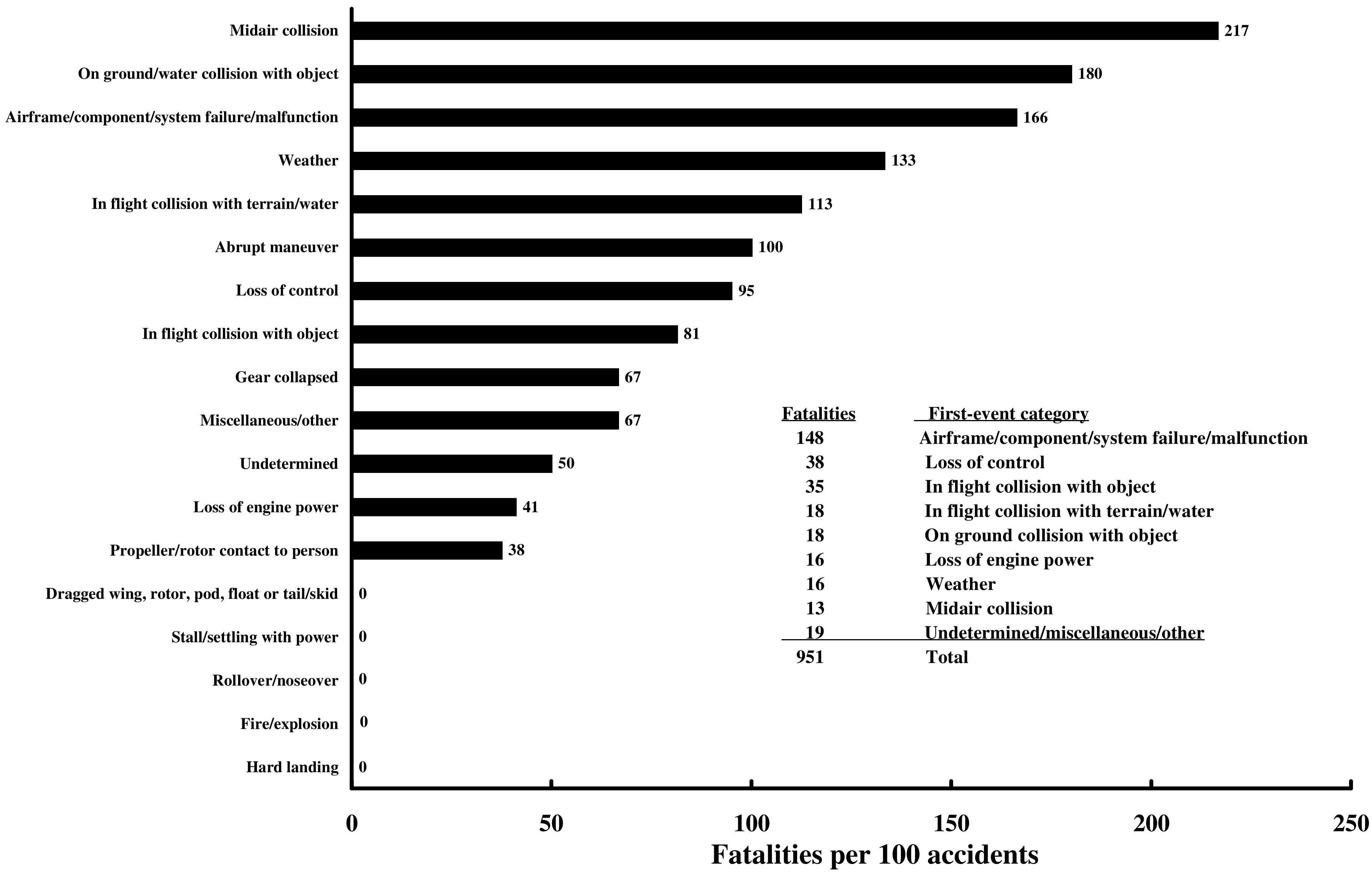


Figure 98. Summary accident statistics, mid-1963 through 1997: twin-turbine helicopters (commercially manufactured).



Fatalities	First-event category
148	Airframe/component/system failure/malfunction
38	Loss of control
35	In flight collision with object
18	In flight collision with terrain/water
18	On ground collision with object
16	Loss of engine power
16	Weather
13	Midair collision
19	Undetermined/miscellaneous/other
951	Total

Figure 99. Fatalities per 100 accidents, mid-1963 through 1997: twin-turbine helicopters (commercially manufactured).

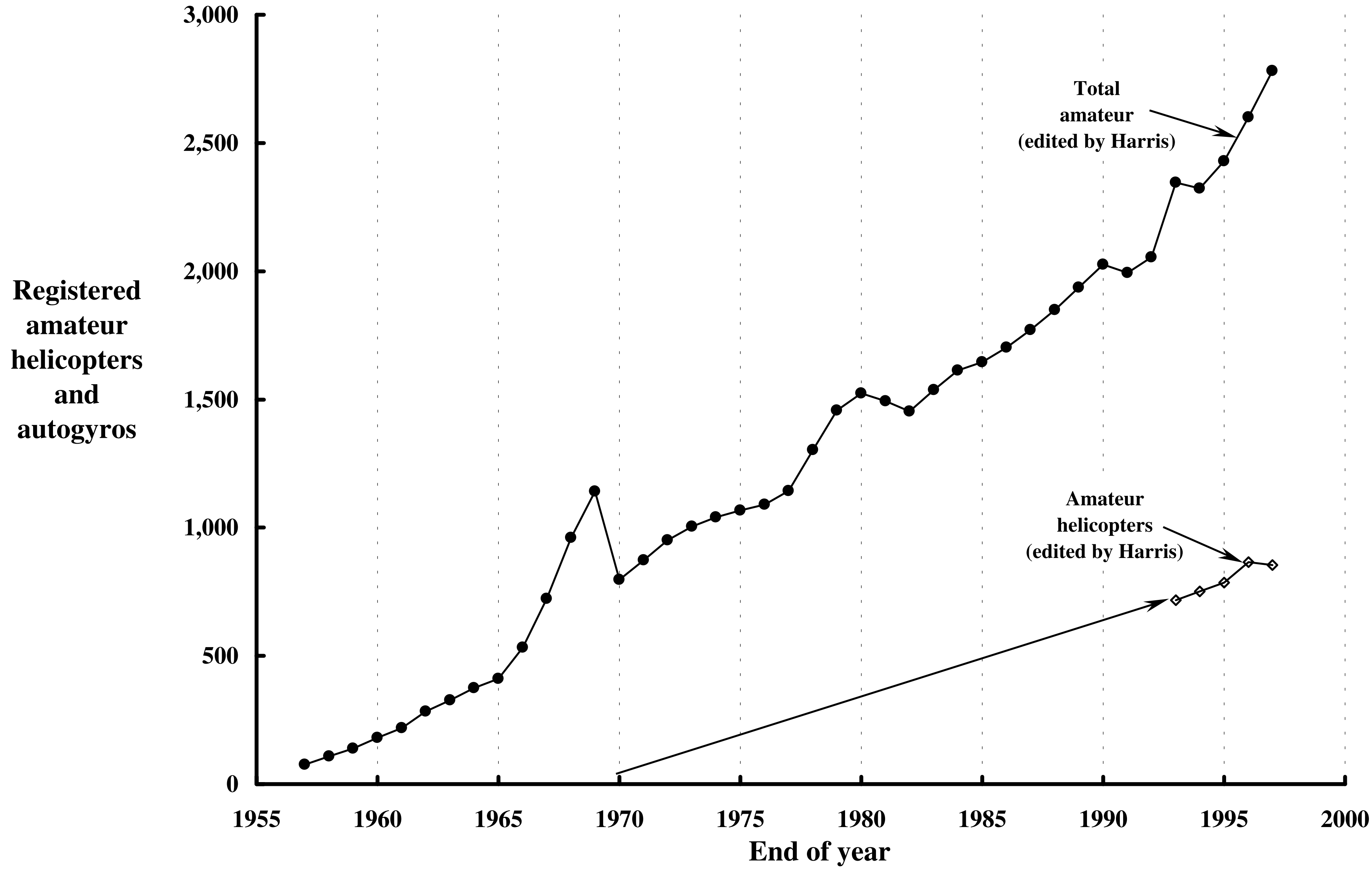


Figure 100. All other rotorcraft types fleet size.

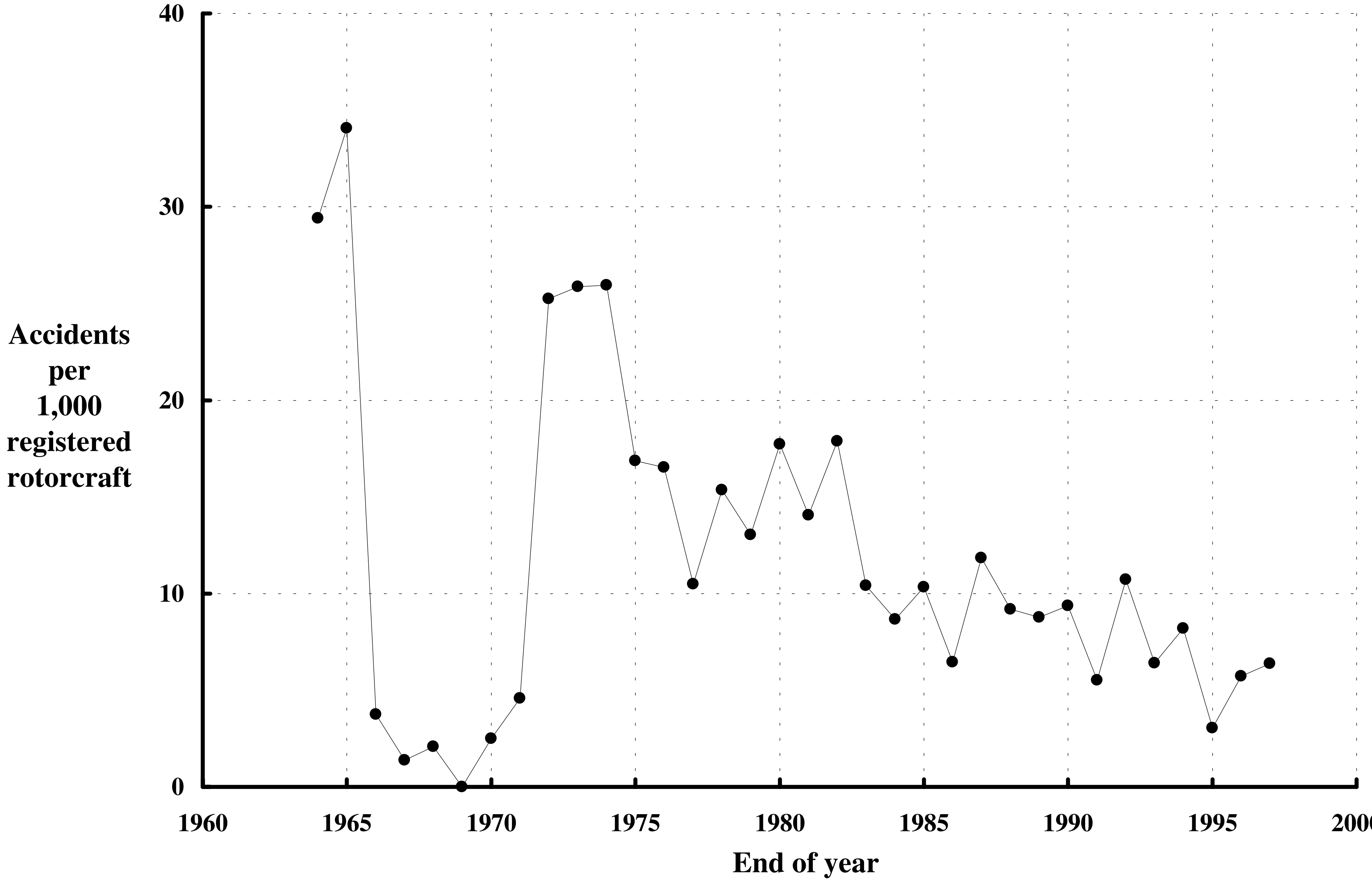


Figure 101. Accidents per 1,000 registered aircraft: all other rotorcraft types.

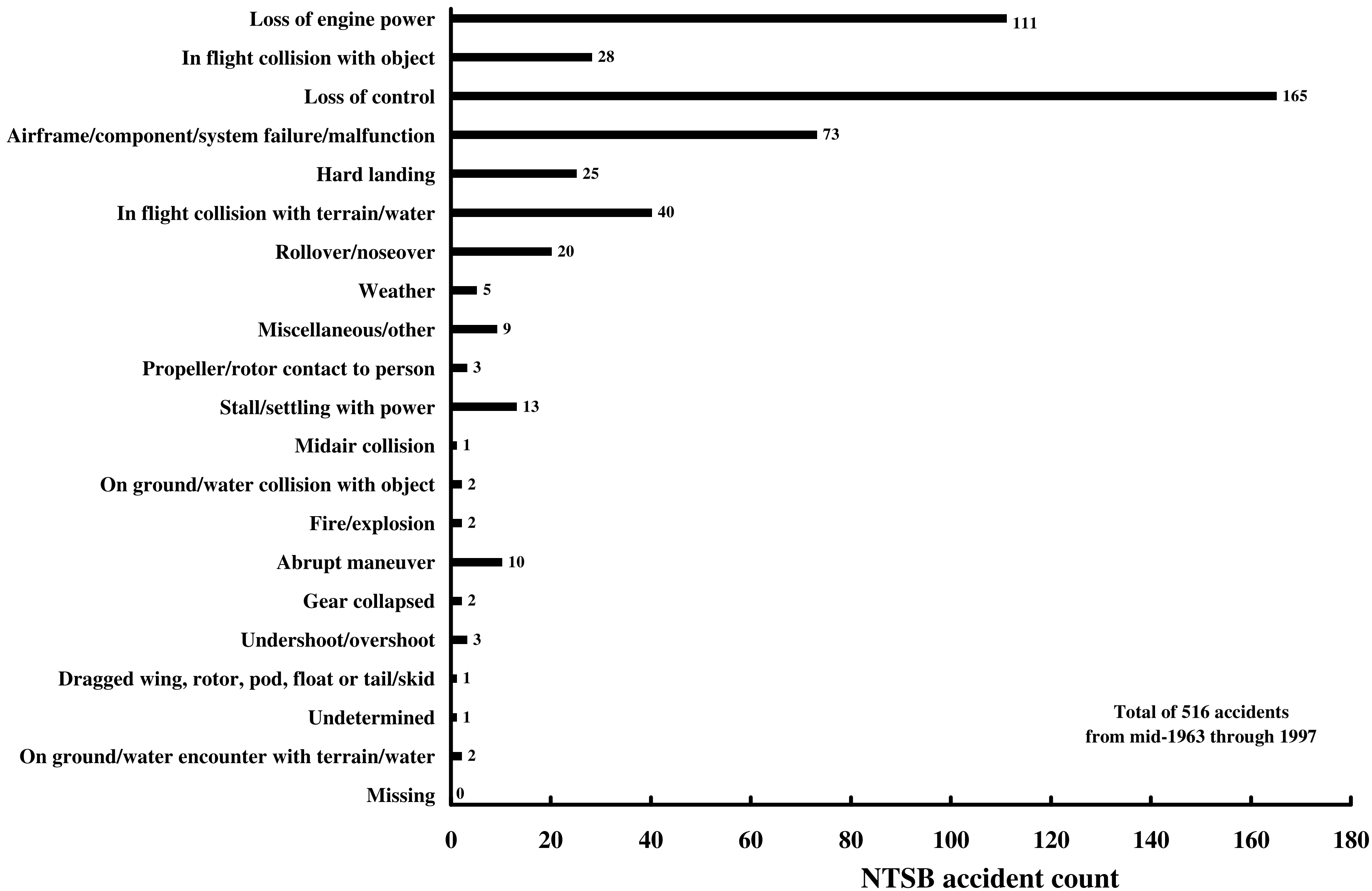


Figure 102. Accident count by first event category: all other rotorcraft types.

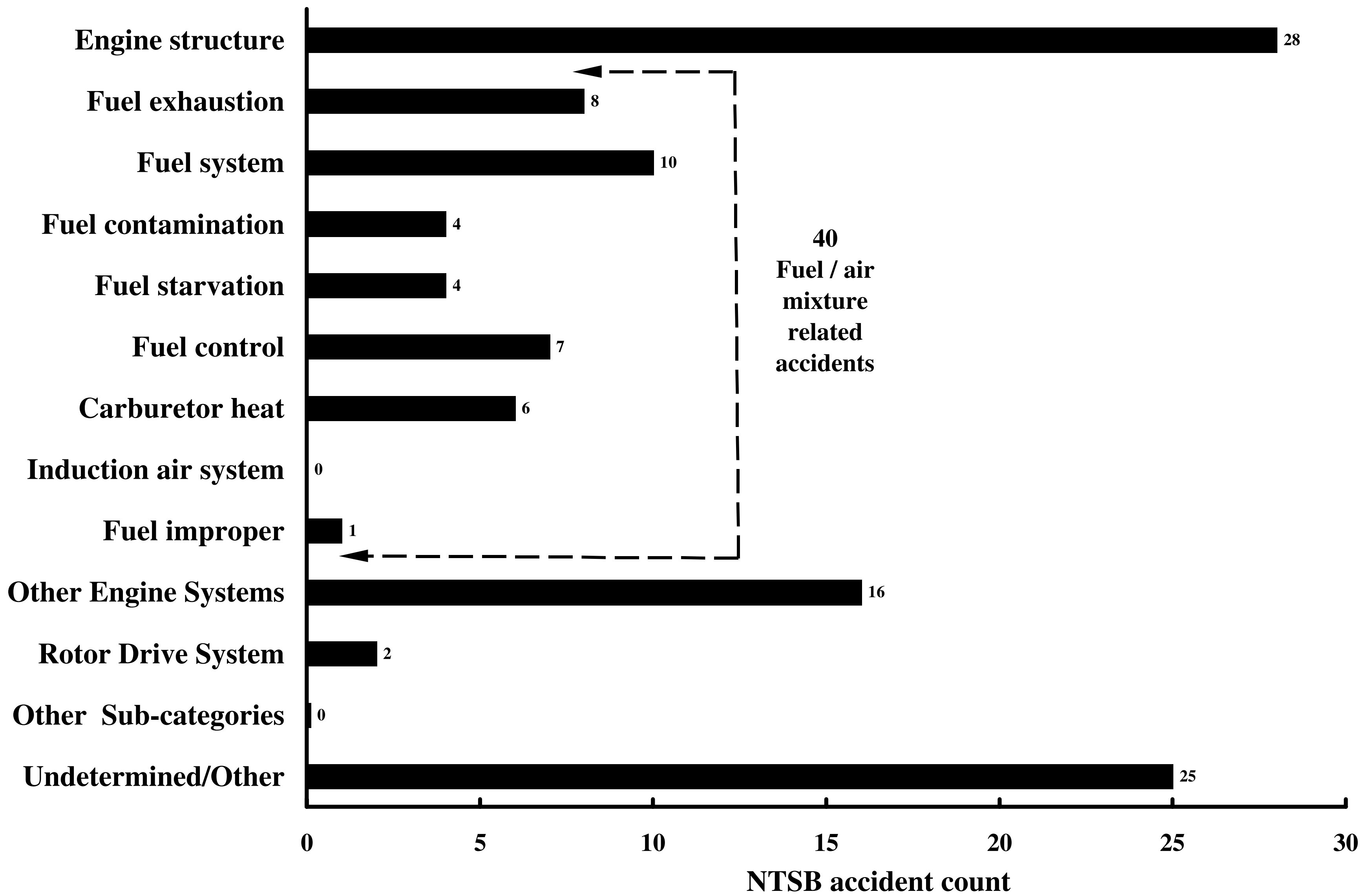


Figure 103. Loss of engine power accidents: all other rotorcraft types.

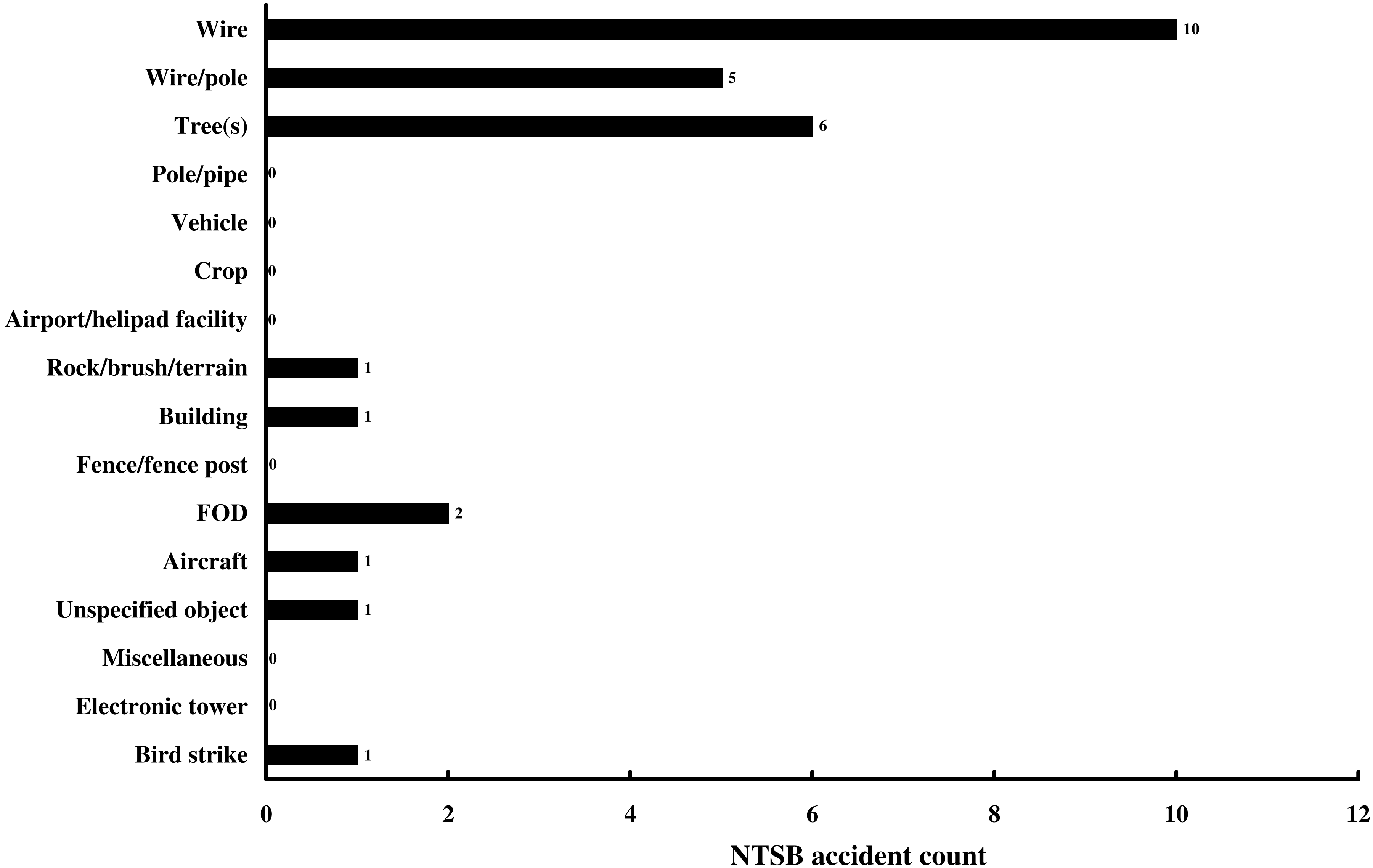


Figure 104. In flight collision with object accidents: all other rotorcraft types.

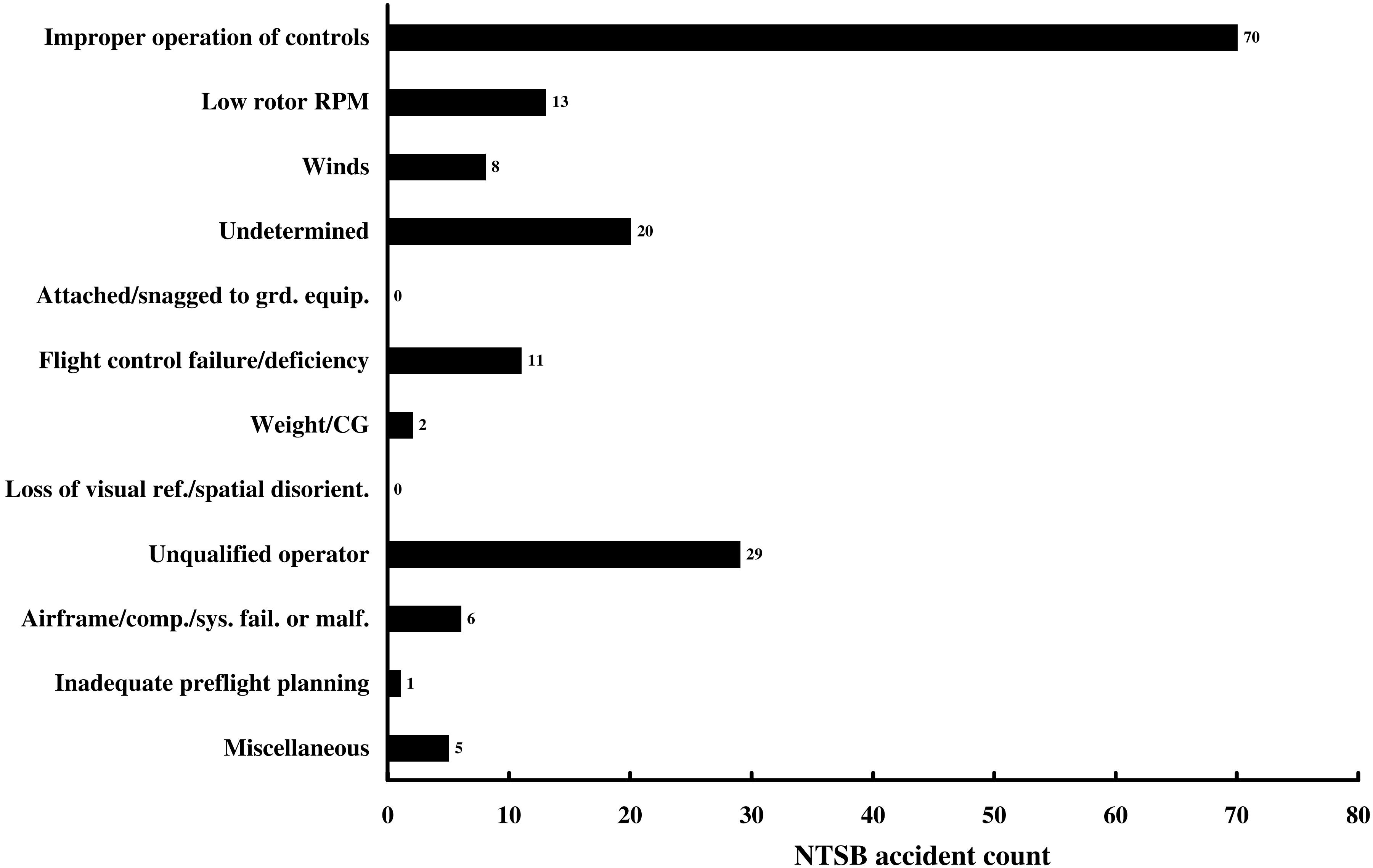


Figure 105. Loss of control accidents: all other rotorcraft types.

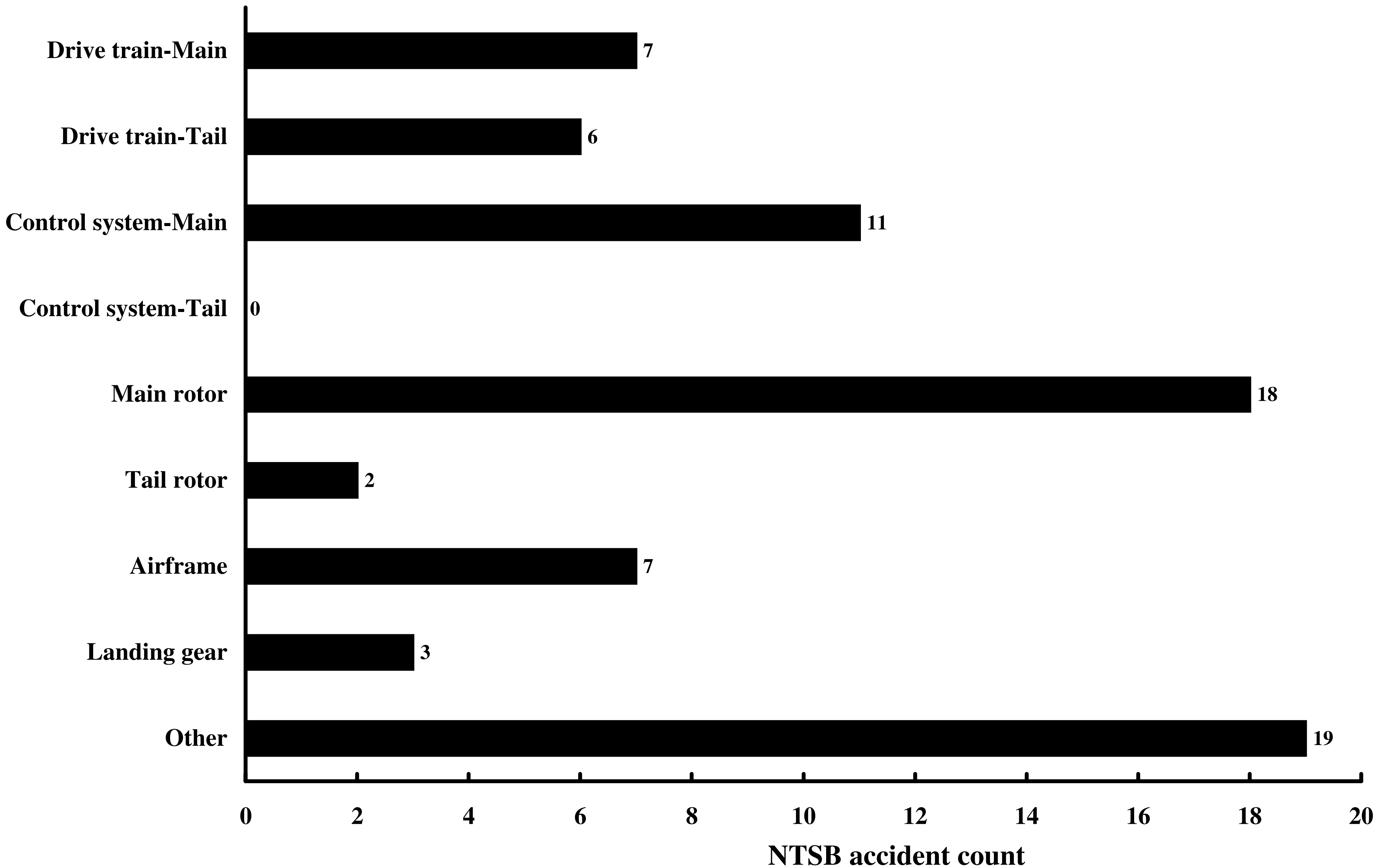


Figure 106. Airframe failure accidents: all other rotorcraft types.

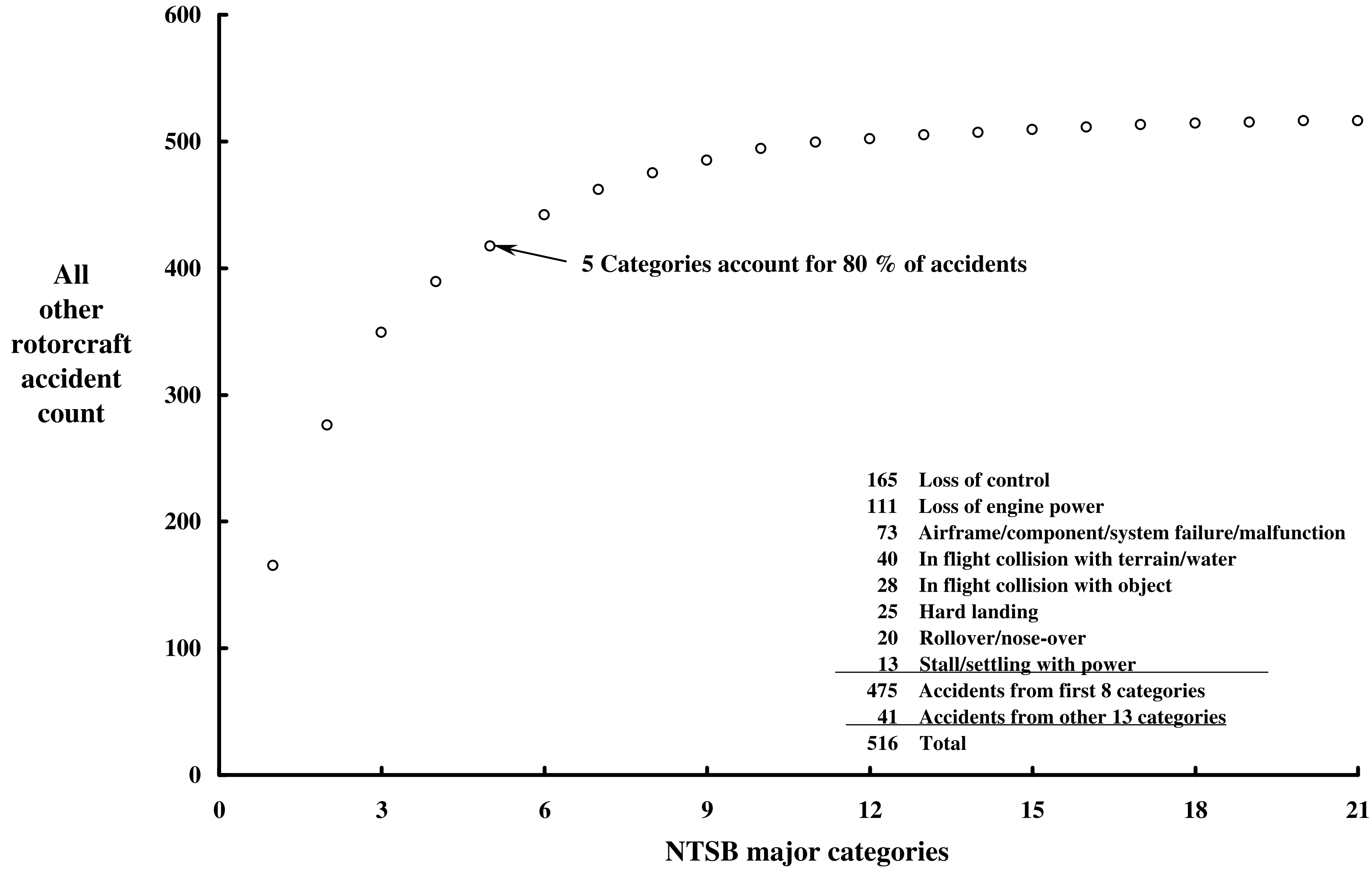
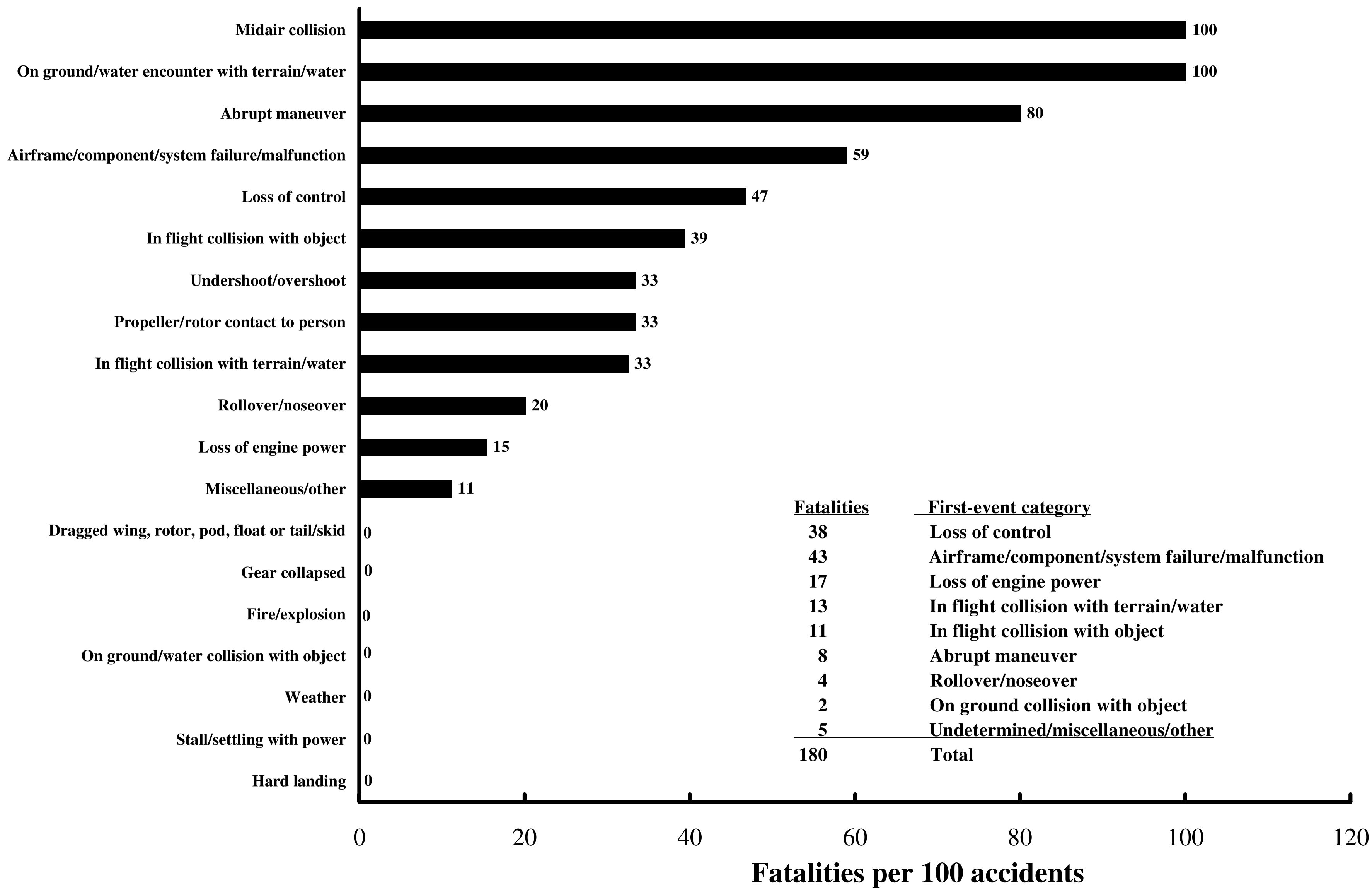


Figure 107. Summary accident statistics, mid-1963 through 1997: all other rotorcraft types.



Fatalities	First-event category
38	Loss of control
43	Airframe/component/system failure/malfunction
17	Loss of engine power
13	In flight collision with terrain/water
11	In flight collision with object
8	Abrupt maneuver
4	Rollover/noseover
2	On ground collision with object
5	Undetermined/miscellaneous/other
180	Total

Figure 108. Fatalities per 100 accidents, mid-1963 through 1997: all other rotorcraft types.

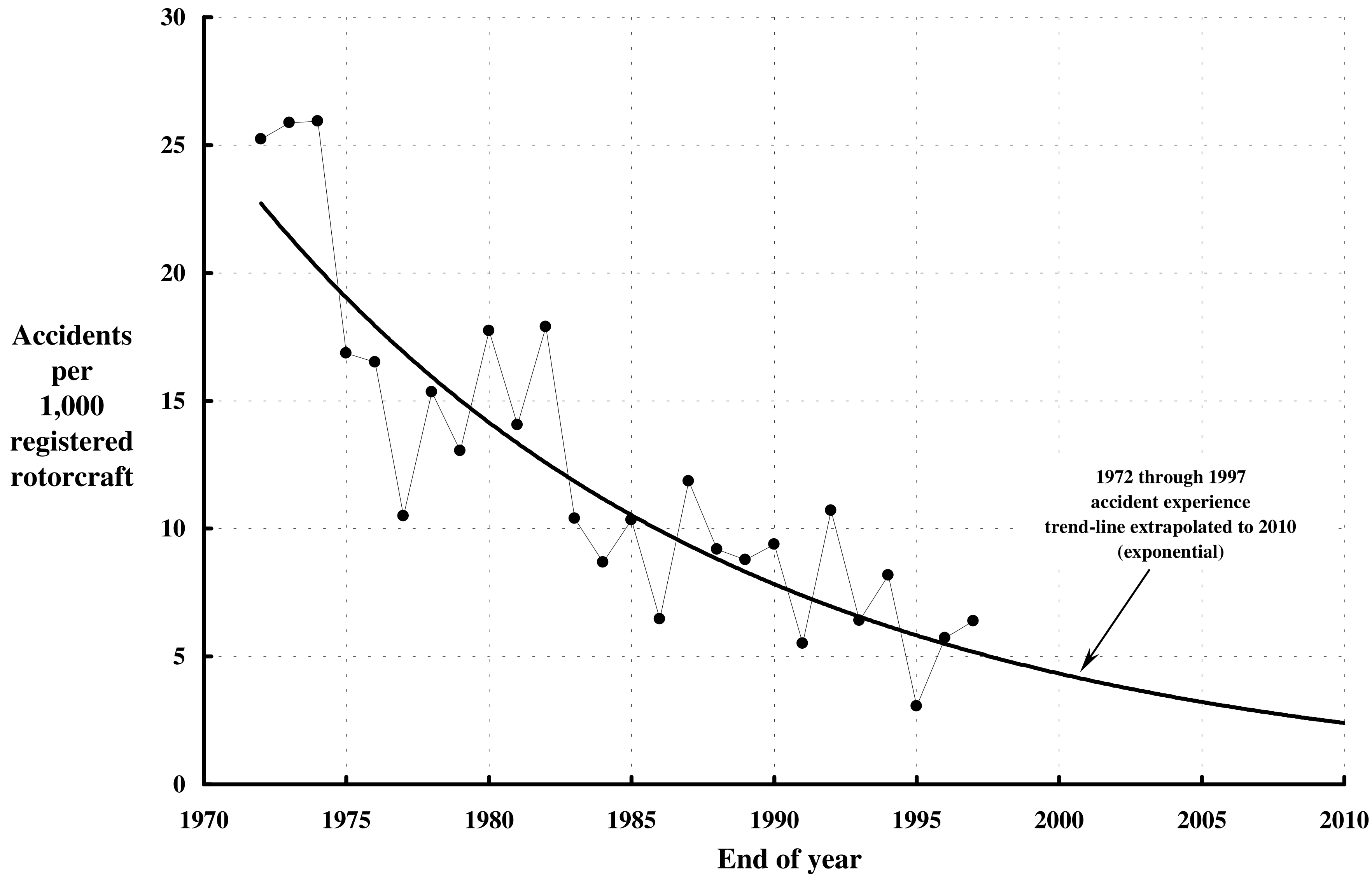


Figure 109. Accidents per 1,000 registered aircraft projected to 2010: all other rotorcraft types.

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Appendix A
NTSB DEFINITIONS

This appendix provides excerpts from the Federal Aviation Regulations that govern the National Transportation Safety Board (NTSB) and excerpts from the NTSB manual that guide investigators in reporting accidents.

A-1. Definitions of Accident/Incident

The following definitions of terms used in this report have been extracted from NTSB Part 830 of the Federal Aviation Regulations. These regulations are included in most commercially available FAR/AIM digests and should be referenced for detailed information.

Aircraft Accident—An occurrence incident to flight in which “as a result of the operation of an aircraft, any person (occupant or non-occupant) receives fatal or serious injury or any aircraft receives substantial damage.”

A **fatal injury** is one that results in death within 30 days of the accident.

A **serious injury** is one that:

1. Requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received;

2. Results in a fracture of any bone (except simple fractures of the fingers, toes, or nose);

3. Involves lacerations that cause severe hemorrhages, nerve, muscle, or tendon damage;

4. Involves injury to any internal organ; or

5. Involves second- or third-degree burns, or any burns affecting more than 5% of body surface.

A **minor injury** is one that does not qualify as fatal or serious.

Destroyed means that an aircraft was demolished beyond economical repair; that is, substantially damaged to the extent that it would be impractical to rebuild it and return it to an airworthy condition.

(This may not coincide with the definition of “total loss” for insurance purposes. Because of the variability of insurance limits carried and such additional factors as time on engines and propellers and aircraft condition before the accident, an aircraft may be “totaled” even though it is not considered “destroyed” for accident investigation purposes.)

Substantial Damage:

1. Except as provided below, substantial damage means damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected part.

2. Engine failure, damage limited to an engine, bent fairings or cowling, dented skin, small puncture holes in the skin or fabric, ground damage to rotor or propeller blades, damage to landing gear, wheels, tires, flaps, engine accessories, brakes, or wing tips are not considered "substantial damage."

(As with "destroyed" above, the definition of "substantial" for accident investigation purposes does not necessarily correlate with "substantial" in terms of financial loss. Contrary to popular misconception, there is no dollar value that defines substantial damage. Because of the high cost of many repairs, large sums may be spent to repair damage resulting from incidents that do not meet the NTSB Part 830 definition of "substantial damage.")

Minor damage is damage that does not qualify as substantial, such as that under "substantial damage" above.

A-2. Definitions of Kinds of Flying

The purpose for which the aircraft is being operated at the time of the accident:

On-Demand Air Taxi—Revenue flights conducted by commercial air carriers operating under 14 CFR 135 that are not operated in regular scheduled service, such as charter flights, and all non-revenue flights incident to such flights.

Personal—Flying by individuals in their own or rented aircraft for pleasure or personal transportation, not in furtherance of their occupation or company business. This category includes practice flying (for the purpose of increasing or maintaining proficiency) not performed under supervision of an accredited instructor and not part of an approved flight training program.

Business—The use of aircraft by pilots (not receiving direct salary or compensation for piloting) in connection with their occupation or in the furtherance of a private business.

Instruction—Flying accomplished in supervised training under the direction of an accredited instructor.

Executive/Corporate—The use of aircraft owned or leased and operated by a corporate or business firm for the transportation of personnel or cargo in furtherance of the corporation's or firm's business, and that are flown by professional pilots receiving a direct salary or compensation for piloting.

Aerial Application—The operation of aircraft for the purpose of dispensing any substance for plant nourishment, soil treatment, propagation of plant life, pest control, or fire control, including flying to and from the application site.

Aerial Observation—The operation of an aircraft for the purpose of pipeline/powerline patrol, land and animal surveys, etc. This does not include traffic observation (electronic news gathering) or sightseeing.

Other Work Use—The operation of an aircraft for the purpose of aerial photography, banner/glider towing, parachuting, demonstration or test flying, racing, aerobatics, etc.

Public Use—Any operation of an aircraft by any federal, state, or local entity.

Ferry—A non-revenue flight for the purpose of (1) returning an aircraft to base, (2) delivering an aircraft from one location to another, or (3) moving an aircraft to and from a maintenance base. Ferry flights, under certain terms, may be conducted under terms of a special flight permit.

Positioning—Positioning of the aircraft without the purpose of revenue.

Other—Any flight that does not meet the criteria of any of the above.

Unknown—A flight whose purpose is not known.

A-3. NTSB Manual Definitions and Codes

PART I—INSTRUCTIONS

Introduction

The NTSB Coding Manual is a source document for codes to be used in the Board's main frame computer for storage and retrieval of information concerning the findings of aviation accidents. This revision of the coding manual contains suggested changes that were received in the Regional Operations and General Aviation Division (AS-20). Procedures are in effect to update the manual on a periodic basis. Suggestions for changes or corrections should be forwarded to the Senior Analyst(s) in AS-20. Suggestions may be forwarded by using the form at the end of this manual or by telephone.

The codes are normally sent to the main frame computer through a network system by using the ADMS program. Entry of codes may be made by the individual investigator by using his (or her) PC or by personnel in AS-20. A computer matrix is provided in the ADMS program for entry of codes. The codes should be entered in the matrix to correspond with the sequence in which they led to the accident/incident.

Computerized findings are published for each accident and incident in a brief format (Brief-of-Accident or Brief-of-Incident). Each brief includes findings, which are identified in a sequence-of-events as occurrences, phases, causes, factors, and/or events. A probable cause (PC) statement is also published to provide a narrative presentation of the NTSB findings.

The codes and respective printout data are listed in the coding manual in an alphabetical order, within the respective categories, rather than in a sequential or number order. Printout data is listed in upper-case letters, whereas explanatory notes (that do not print out) are in parenthesis with lower-case wording.

The previous publication of the this manual was in January 1995. Codes that have been added or changed (since the previous publication) are annotated as follows:

- Pound sign (#) designates a change
- Plus sign (+) designates an addition
- Equal sign (=) designates a code for a subject (printout) that was previously used before the previous revision
- Less-than symbol (<) interim change to previous revision
- Asterisk (*) references definition in Part II of manual.

General Instructions

As previously noted, the codes in this manual are intended to be used to describe the sequence-of-events of each accident and/or incident. All entries in the sequence-of-events (and brief narrative) must be substantiated by information that is documented in the Factual Report or is available in other accessible documents or publications.

Multiple occurrences, causes, factors and/or events may be used in each sequence-of-events to describe the findings. Each occurrence is coded separately and a corresponding phase of operation must be entered with each occurrence; as of the date of this publication, only five occurrences can be recorded for each mishap. There must be at least one occurrence and one cause identified with each accident or incident. The occurrences must be chronologically numbered. For accidents with multiple causes, there is no provision to show the magnitude of each cause with respect to the others. Likewise, there is no provision to show the relative magnitude of multiple factors. For retrieval purposes, elements of the PC statement should be coded in the sequence-of-events, if feasible.

The number of findings and the size of the PC statement are limited by the amount of space available on the second page of the computer printout. Depending on the number of occurrences and number of lines used in the PC statement, about 15 to 43 causes/factors/events can be listed for any one accident or incident.

The sequence-of-events matrix (see: Sequence-of-Events Worksheet, Part III) contains entry spaces for codes in the following sections:

1. IA—Primary Non-Person-Related Findings (Aircraft/Environment)

2. IB—Primary Person-Related Findings (Operations/Performance)

3. II—Direct Underlying Events

4. III—Indirect Underlying Events.

Each section of the matrix contains columns of spaces. The spaces in the left column of each section are for "subject" codes. The long spaces to the right of the subject spaces are for modifiers/persons. The short spaces in the middle of each section are used to describe whether the subjects are causes or factors by entering "C" or "F" codes. These may be left blank, if the subject is neither a cause nor a factor, but merely an event.

Formerly, the main frame (DEC 10) computer (using System 1022) was programmed to allow entry of restricted information in the database that would not print out in the briefs. This was accomplished by putting an "X" in the middle space to denote the restricted information. This information was stored in the computer for use as statistical information only. Currently, there is no requirement for entry of restricted data, and the VAX/MV-4 computer (using System 1032) has not been programmed for entry of this information. The database, however, still contains restricted information that was previously entered via the DEC 10.

Within each section of the matrix, each line entry must be completed in its entirety; i.e., each subject code must be followed by a modifier and/or person code. Sections IA and IB are used to list the primary events/findings that led to the accident or incident. Sections II and III are used to further define or explain a primary event or finding that is listed in Section IA or IB.

Section IA is used to identify the primary non-people-related findings. It contains columns of spaces to enter non-people-related subjects and modifiers. However, a code is available to allowed the modifier to be left blank, if needed. The non-people-related subjects are grouped in the following categories:

Aircraft systems/components
Air traffic facilities
Airport facilities
Terrain conditions
Weather conditions
Light conditions
Object(s).

Section IB identifies the primary finding(s) that are people related. This section normally contains a subject, modifier, and person, although codes are available for the modifier and person to be left blank. However, the blank code for a person should only be used when no other person code can be supported by the factual report. A blank modifier code is only used in conjunction with a blank person code.

Sections II and III are used for the direct and indirect underlying findings. They are normally coded with a subject and a person (or institution), but codes are available for the person code to be left blank. Any number of underlying findings can be related to a primary finding in Section IA and/or IB. However, underlying findings in Section II or III should only be used when they are related to a primary finding in Section IA and/or IB

The computer system was previously programmed so that when more than one finding was entered on the same line, findings in sections/columns to the right would be indented to show a relationship. This feature is no longer available. Print-outs from the codes are now (without indentation), beginning with the first code entered on the left in line one of the matrix followed by those to the right and below.

Mandatory Conventions:

The coding manual is designed to provide a great degree of latitude and flexibility in formulating the findings. However, certain conventions should be followed to logically present some sequences-of-events.

For NTSB retrieval of multiengine aircraft information, the phrase “TOTAL LOSS OF ENGINE POWER” and “PARTIAL LOSS OF ENGINE POWER” are to be used in reference to the specific engine(s) being addressed, rather than to the overall power of the aircraft. Specifically, for a situation involving total loss of power for mechanical reasons in one engine of a multiengine aircraft, the code for that occurrence would be 351 (for “LOSS OF ENGINE POWER (TOTAL)—MECH FAILURE/MALFUNCTION”). Also, codes are provided in the aircraft section to identify the number of engines affected on multiengine aircraft. The following codes are intended for use with multiengine aircraft findings:

a. [16905] ONE ENGINE

b. [16906] TWO ENGINES

c. [16907] THREE OR MORE ENGINES

d. [16908] ALL ENGINES.

For occurrences involving loss of engine power in multiengine aircraft, one of the above codes would normally be used as the first entry (subject) in the sequence-of-events (in Section IA); an exception would be when the number of engines that lost power was unknown. These (subject) codes should be modified by Code 1220 (blank code), so that no modifier will print out. Typically, losses of power in more than one engine would be coded as separate occurrences, except when more than one engine loses power at the same time for the same reason. If the occurrence resulted in all engines losing power (i.e., fuel exhaustion), then Code 16908 (ALL ENGINES) should be used (even if the aircraft had two or three engines, though there are codes for two and three engines).

For example, consider a turbine disk failure of the No. 1 engine of a Boeing 727 that resulted in a total loss of power of that engine; then shortly thereafter, partial loss of power occurred in the No. 2 and No. 3 engines due to a fuel system problem.

In coding this scenario, there would be two occurrences involving loss of power; i.e. the first occurrence would be coded "LOSS OF ENGINE POWER (TOTAL)—MECH FAILURE/ MALFUNCTION." The first subject code for this occurrence would be 16905, (ONE ENGINE), which would be modified by Code 1220 (blank space). Of course, additional findings would follow to describe the appropriate cause(s) and/or factor(s).

The second occurrence would be coded "LOSS OF ENGINE POWER (PARTIAL)—MECHANICAL FAILURE/MALF." The first subject code for the second occurrence would be 16906 (TWO ENGINES) followed by Code 1220 (blank space).

For single-engine aircraft accidents/incidents, there is no reason to provide a code for the number of engines, since "one engine" would be obvious.

A progressive loss of power may be considered a single event. For example, a bearing failure may result in a partial loss of power at first, but the power loss could deteriorate until there was a total loss of power. For all practical purposes, this would be one occurrence.

Whenever an occurrence mandates a forced landing, the next occurrence in the sequence-of-events would normally be "FORCED LANDING" (180). The associated phase of operation will often be "EMERGENCY DESCENT/LANDING" (576), but the phase could be "MANEUVERING—TURN TO LANDING AREA (EMERGENCY)" (583), "EMERGENCY LANDING AFTER TAKEOFF" (575), "EMERGENCY LANDING" (574), or "LANDING" (570). Forced landings are often presented with no other findings listed for that occurrence. However, there are some typical findings that are occasionally used with forced landings, if they are appropriate and substantiated; i.e., "EMERGENCY PROCEDURE—NOT FOLLOWED—PILOT IN COMMAND" if and when appropriate, and "AUTOROTATION—PERFORMED—PILOT IN COMMAND" when a helicopter is involved in an autorotation during a forced landing.

Code 502, "STANDING—STARTING ENGINE(S)," is used for hand propping/runaway accidents. The typical convention for coding this situation would be as follows:

1st Occurrence—MISCELLANEOUS/OTHER (430)

1st Phase—STANDING-STARTING ENGINE(S) (502)

2nd Occurrence—Usually a collision with object or terrain

2nd Phase—Usually "TAXI" (510), although the aircraft could become airborne before the second occurrence, result in an in flight collision with terrain or object.

For occurrences involving carburetor ice, the sequence-of-events should include the environmental condition and the events leading to the situation as well as listing the cause/factor(s). The following is a typical convention for mechanical loss of power due to carburetor heat control failure and subsequent carburetor ice:

LOSS OF ENGINE POWER (TOTAL)—MECH FAILURE/MALF (351)

1. WEATHER—CARBURETOR ICING CONDITIONS (20000/F/2202)
2. CARB HEAT CONTROL—FAILURE, TOTAL (16400/C/1135)
3. FUEL SYSTEM, CARBURETOR—ICE (15109/C/1146).

For non-mechanical loss of power due to improper use of the carburetor heat by the pilot:

LOSS OF ENGINE POWER (TOTAL)—NON-MECHANICAL (353)

1. WEATHER—CARBURETOR ICING CONDITIONS (20000/F/2202)
2. FUEL SYSTEM, CARBURETOR—ICE (15109/C/1146)
3. CARB HEAT—IMPROPER USE OF—PIC (22304/C/3110/4000).

PART II—DEFINITIONS

ABRUPT MANEUVER: An intentional maneuver that directly results in personal injury or aircraft damage.

ALTITUDE DEVIATION, UNCONTROLLED: For an occurrence in which there is a loss-of-control that results in a loss or gain in the altitude, but recovery is accomplished (i.e., autopilot malfunction of airliner that results in altitude deviation & injury to unbelted occupant).

COLLECTIVE BIAS: A mechanism, system, or function of a helicopter that automatically adjusts engine power to maintain rotor rpm, when an increase or decrease in collective is made. (The mechanism is also known as a throttle/collective correlator box.)

DITCHING: A planned event in which a flight crew knowingly makes a controlled emergency landing in water. (Excludes float plane landings in normal water landing areas.)

DRAGGED WING, ROTOR, POD, FLOAT, OR TAIL: Use as a first occurrence only, when this results in an aircraft accident or incident during taxi, takeoff, or landing. (Not used in conjunction with a hard landing or after a gear collapse or ground loop/swerve.)

DYNAMIC ROLLOVER: Ground rollover mishap of a helicopter, which results from a cumulative effect of dynamic forces. These forces cause a roll reaction that results in the helicopter exceeding its static rollover angle.

ENGINE TEARAWAY: An occurrence in which one or more engines are torn away from an aircraft, but not due to contact with an external object. (Includes tearaway due to internal damage from foreign object damage.)

FORCED LANDING: An emergency landing involving circumstances in which the pilot does not have the option to selectively choose the time and appropriate location for landing. (See "precautionary landing" for circumstances in which the pilot has the time and option to choose an appropriate landing area.)

GEAR COLLAPSE: Collapse of the landing gear due to mechanical failure other than malfunction of the retracting system. When the landing gear collapses as a result of a hard landing, the gear collapse will be the subsequent (second) occurrence.

FIRE/EXPLOSION: Use as an occurrence for fire, explosion, or heavy smoke occurring in flight, and for aircraft fires occurring on the ground, except those resulting from impact.

GEAR RETRACTION: Retraction of the landing gear (on ground or runway) due to malfunction of the retraction system, or due to inadvertent or premature retraction by the crew. (Gear retraction on takeoff will be coded as gear retraction in the takeoff phase, and will not be recorded as a wheels-up landing. Excludes intentional gear retractions.)

GO-AROUND: A maneuver following an uncompleted approach, which involves transition to a climbing flightpath.

GROUND LOOP: An involuntary uncontrolled (abrupt) turn of an aircraft, while moving along the ground (i.e., ground taxiing or moving on the takeoff or landing run).

GROUND RESONANCE: Dangerous natural vibration of a helicopter on the ground, caused by stiffness and frequency of the landing gear legs, amplifying the primary frequency of the main rotor. (Includes the self-excited vibration of a helicopter, occurring whenever the frequency of oscillation of the blades about the lead-lag hinges of an articulated rotor becomes the same as the natural frequency of the fuselage.)

HARD LANDING: Stalling onto or flying into a runway or other intended landing area with abnormally high vertical speed. For rotorcraft, includes "tail-down" landings and those where the main rotor contacts the tail boom on landing.

HEIGHT/VELOCITY CURVE: Fundamental plot of indicated airspeed against altitude, which is included in the helicopter flight manual; indicates region(s) from which safe autorotative descent is possible, normally assuming zero wind, sea level, and maximum takeoff weight.

HELIPAD: Prepared area (of land, water or structure) designated as a takeoff/landing area for helicopters (no facilities other than markings needed); includes truck or trailer that is routinely used as heliport.

HELIPORT: A facility used for operating, basing, housing, and maintaining helicopters.

IN FLIGHT ENCOUNTER WITH WEATHER: Weather encountered that is not normal to the intended phase of operation. Use as an occurrence only when it leads to an accident or incident. (Excludes: vortex turbulence and operations in normal crosswind or IFR conditions.)

MISSING AIRCRAFT: For purposes of coding, a missing aircraft is one that is presumed to have crashed, and the location of the crash is unknown. If credible witness(es) or pieces of wreckage can reasonably verify the accident and location, then the aircraft would not be considered as missing.

NOSE DOWN: When an aircraft noses down on the ground, water, or runway without going inverted.

NOSE OVER: When an aircraft goes inverted on the ground, water, or runway, while taxiing or on takeoff or landing.

NOTAR SYSTEM: Helicopter "No Tail Rotor" System. (For McDonnell Douglas Helicopters: consists of an enclosed variable pitch fan driven by the transmission, a circulation control tail boom, direct-jet thruster, and vertical stabilators.)

OCCURRENCE: Distinct major event of relative significance that leads to an accident or incident.

ON-GROUND ENCOUNTER WITH WEATHER: An occurrence involving weather that is not normal to the phase of operation. (Excludes: vortex turbulence, jet/prop blast, and normal IFR or crosswind conditions.)

OVERRUN: The continuation of aircraft movement beyond the end of the runway; i.e., overrunning the intended landing or takeoff area. (Used in takeoff and landing phases.)

PHASE OF OPERATION: The point in aircraft operations during which an occurrence takes place.

PIBAL: Small balloon launched to check wind direction before takeoff of hot air balloon to assist in visualizing ground track relative to anticipated flightpath.

PRECAUTIONARY LANDING: A landing involving a sense of urgency due to an emergency or pending emergency, in which the pilot has the option and time to selectively choose an appropriate landing area.

PROPELLER FAILURE/MALFUNCTION: An occurrence concerning failure or malfunction of a propeller blade, hub, or related part, including separation or overspeeding of a propeller, or failure of a propeller system. (Note: When propeller failure results from engine seizure, crankshaft failure, etc., the occurrence should be coded as an engine failure.)

ROLL OVER: Refers to rotorcraft only. Includes tilting with the main rotor blades striking the ground.

ROTOR FAILURE/MALFUNCTION: An occurrence concerning failure or malfunction of a rotor blade, hub, or related part, including separation or overspeeding of a rotor or failure of the rotor drive system.

SETTLING WITH POWER: A condition of helicopter power settling, in which hover power required exceeds power available, normally resulting from an attempt to hover out of ground effect with insufficient power available to compensate for elevation, temperature, and/or humidity.

UNAPPROVED PART: A part, component, or material that has not been manufactured in accordance with the approval procedures in FAR 21.305 or repaired in accordance with FAR Part 43; does not conform to an approved type design; or does not conform to established industry or U.S. specifications (standard parts). Examples of an unapproved part include, but are not limited to: (1) Counterfeit or fraudulently marked parts, components, or materials; (2) Parts shipped directly to users by a manufacturer, supplier, or distributor who does not hold, or operate under the authority of, a production approval for the part; and (3) Parts that have been maintained or repaired and returned to service by persons or facilities not authorized under FAR Parts 43 or 145.

UNDERSHOOT: A condition that occurs during an approach to landing that results in an inadvertent landing or contact with the ground or an object short of the runway or intended landing area, normally due to misjudgment of distance, speed, and/or altitude on final approach. For IFR approaches, an undershoot will occur only after the field or intended landing area is in sight. An undershoot will always be followed by a subsequent occurrence; i.e., in flight collision-with-object or terrain, etc. (Does not include occurrences in which the aircraft could not have reached the intended landing area; i.e. after loss of engine power.)

VORTEX RING STATE: An area of nonuniform and unsteady airflow around a rotating main rotor or tail rotor in which the rotor is affected by an induced velocity of airflow that approaches or exceeds the airflow being produced by the affected rotor. It is characterized by a sudden requirement for increased power and/or rotor pitch when airflow from the affected rotor is forced back through and around the rotor.

WHEELS-UP LANDING: Code as an occurrence when the landing gear is not lowered and locked before contact with the ground/runway during a landing. (Excludes inadvertent retraction on the ground and retractions due to failure or malfunction of the gear assembly and/or retracting mechanism. Includes intentional wheels-up landing and inability to extend the gear due to malfunction of the gear extension system.)

VLOF “Lift-off speed”

VMCG “Minimum control speed on the ground” The minimum speed at which, the critical engine having been made suddenly inoperative at that speed and having been recognized by the pilot, it is possible to maintain control of the airplane with the engine still inoperative, using primary aerodynamic controls alone, and thereafter maintain a straight path parallel to that originally intended.

VMCA “Minimum control speed” The minimum speed at which, when the critical engine is suddenly made inoperative at that speed, it is possible to recover control of the airplane with the engine still inoperative and to maintain it in a straight flight at a speed, either with zero yaw or with an angle of bank not in excess of 5o.

VYSE “Best rate-of-climb single-engine speed”

VXSE “Best angle-of-climb single-engine speed”

VS “Stalling speed” The minimum speed in flight at which the airplane can develop a lift equal to the weight of the airplane.

VSO “The power off stall speed” or minimum steady flight speed in the landing configuration.

VFE “Maximum flap extended speed”

VLO “Maximum landing gear extension/retraction speed”

VLE “Maximum landing gear extended speed”

VA “Design maneuvering speed” The maximum speed for which the aircraft is designed for full abrupt control deflection without incurring structural damage.

VMO “Maximum operating limit speed”

VNE “Never-exceed speed”

VREF “Landing approach speed” The indicated airspeed that the aircraft should be at 50 feet above the landing area in the landing configuration. (1.3 × VSO)

VR “Rotation speed”

Vtoss “Takeoff safety speed” (Category A helicopter)

V1 “Takeoff decision speed” (Formerly denoted as critical engine failure speed.) The speed at which, should the critical engine fail, the pilot could elect to abandon the takeoff or continue.

V2 “Takeoff safety speed” A reference speed obtained after lift-off at which the required one-engine-inoperative climb performance can be achieved.

V2MIN “Minimum takeoff safety speed” (1.15 × VS for two and three engine propeller-driven aircraft or 1.10 × VS for four engine propeller-driven aircraft or 1.10 × VMCA, whichever is greater.)

PART IV—CODES FOR OCCURRENCES

100 ABRUPT MANEUVER*

130 AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION (incld inflt brkup)

131 PROPELLER FAILURE/MALFUNCTION

132 ROTOR FAILURE/MALFUNCTION (main or tail rotor of helicopter)

110 ALTITUDE DEVIATION, UNCONTROLLED (i.e., after auto-plt malfunction)

120 CARGO SHIFT

140 DECOMPRESSION

150 DITCHING*

160 DRAGGED WING, ROTOR, POD, FLOAT OR TAIL/SKID*

355 ENGINE TEARAWAY

170 FIRE/EXPLOSION

172 EXPLOSION

171 FIRE

180 FORCED LANDING

190 GEAR COLLAPSED

194 COMPLETE GEAR COLLAPSED

191 MAIN GEAR COLLAPSED

192 NOSE GEAR COLLAPSED

195 OTHER GEAR COLLAPSED

193 TAIL GEAR COLLAPSED

198 GEAR RETRACTION ON GROUND*

200 HARD LANDING

210 HAZARDOUS MATERIALS LEAK/SPILL (fumes/smoke therefrom)

220 IN FLIGHT COLLISION WITH OBJECT (object modifiers, 20200 series)

230 IN FLIGHT COLLISION WITH TERRAIN/WATER (trrn modfrs, 19200 series)

231 WHEELS DOWN LANDING IN WATER

232 WHEELS UP LANDING

240 IN FLIGHT ENCOUNTER WITH WEATHER* (wx modifiers, 20000 series)

250 LOSS OF CONTROL—IN FLIGHT (includes stall, spin, vmc roll, and inability to ctl acft after becoming spatially disoriented)

260 LOSS OF CONTROL—ON GROUND/WATER(excludes intentional gnd loop)

350 LOSS OF ENGINE POWER (includes loss of power for unknown reason)

352 LOSS OF ENGINE POWER(PARTIAL)—MECH FAILURE/MALF

354 LOSS OF ENGINE POWER(PARTIAL)—NONMECHANICAL

351 LOSS OF ENGINE POWER(TOTAL)—MECH FAILURE/MALFUNCTION

353 LOSS OF ENGINE POWER(TOTAL)—NONMECHANICAL

270 MIDAIR COLLISION (when both aircraft involved are airborne)

271 COLLISION BETWEEN AIRCRAFT (OTHER THAN MIDAIR) (excludes unoccupied acft)

420 MISSING AIRCRAFT*

430 MISCELLANEOUS/OTHER

280 NEAR COLLISION BETWEEN AIRCRAFT

290 NOSE DOWN*

300 NOSE OVER*

310 ON GROUND/WATER COLLISION WITH OBJECT (obj mod, 20200 series)

320 ON GROUND/WATER ENCOUNTER WITH TERRAIN/WATER (trrn/19200 series)

330 ON GROUND/WATER ENCOUNTER WITH WEATHER* (wx mod, 20000 series)

340 OVERRUN*

360 PROPELLER BLAST OR JET EXHAUST/SUCTION

370 PROPELLER/ROTOR CONTACT TO PERSON

380 ROLL OVER (normally associated with helicopter)

390 UNDERSHOOT*

400 UNDETERMINED

410 VORTEX TURBULENCE ENCOUNTERED

PART V—CODES FOR PHASES OF OPERATION

500 STANDING

501 STANDING—PRE-FLIGHT

502 STANDING—STARTING ENGINE(S)

503 STANDING—ENGINE(S) OPERATING

504 STANDING—ENGINE(S) NOT OPERATING

505 STANDING—IDLING ROTORS

510 TAXI (includes runaway while hand-propping)

511 PUSHBACK/TOW

512 TAXI TO TAKEOFF

513 TAXI—FROM LANDING

514 TAXI—AERIAL (includes air/hover taxi)

520 TAKEOFF (modify with operational code 24563, if on touch-and-go)

523 TAKEOFF—ABORTED

522 TAKEOFF—INITIAL CLIMB (to 1st power reduction or pattern altitude; includes crosswind leg)

521 TAKEOFF—ROLL/RUN (ground or water)

530 CLIMB

531 CLIMB—TO CRUISE

540 CRUISE (includes low-altitude straight and level flight)

541 CRUISE—NORMAL

550 DESCENT

551 DESCENT—NORMAL

552 DESCENT—EMERGENCY (plt initiated; i.e., after decompression)

553 DESCENT—UNCONTROLLED

560 APPROACH

561 APPROACH—VFR PATTERN—DOWNWIND

562 APPROACH—VFR PATTERN—BASE TURN

563 APPROACH—VFR PATTERN—BASE LEG/BASE TO FINAL

564 APPROACH—VFR PATTERN—FINAL APPROACH

566 APPROACH—IAF TO FAF/OUTER MARKER (IFR)

567 APPROACH—FAF/OUTER MARKER TO THRESHOLD (IFR)

568 APPROACH—CIRCLING (IFR) (in conjunction with IFR approach)

569 MISSED APPROACH (IFR)

565 GO-AROUND (VFR) (before touchdown)* (refer to 573 for after touchdown)

570 LANDING (modify with operational code 24563, if touch-and-go)

573 LANDING—ABORTED (balked—after touchdown)

571 LANDING—FLARE/TOUCHDOWN

572 LANDING—ROLL

574 EMERGENCY LANDING

575 EMERGENCY LANDING AFTER TAKEOFF (i.e., forced lndg after tkof)

576 EMERGENCY DESCENT/LANDING (i.e., with forced landing, except after takeoff or during landing approach)

580 MANEUVERING (includes buzzing)

581 MANEUVERING—AERIAL APPLICATION (includes swath run)

582 MANEUVERING—TURN TO REVERSE DIRECTION

583 MANEUVERING—TURN TO LANDING AREA (EMERGENCY)

542 MANEUVERING—HOLDING(IFR)

590 HOVER (stationary; excludes aerial taxi)

591 HOVER—IN GROUND EFFECT

592 HOVER—OUT OF GROUND EFFECT

600 OTHER

610 UNKNOWN

Appendix B
ESTIMATION OF ROTORCRAFT FLEET SIZE AND HOURS FLOWN

Some often-quoted aviation safety statistics for any given aircraft class are fatalities per 100,000 flight hours and accidents per 100,000 flight hours. These ratios are obtained by dividing two numbers. The numerator for these ratios, fatalities or accidents for a given year, comes from the NTSB's files, which are reliable. The denominator, flight hours per year, comes from the FAA files, which are frequently questioned because the statistical data are very dependent on (1) the Aircraft Registration Master File, (2) the aircraft owners' response to FAA registration and activity requests, and (3) the FAA statistical methodology. The FAA and its CAA predecessor have—since 1944—made a yearly effort to publish their Census of U.S. Civil Aircraft.* This census includes results, since 1977, from the General Aviation Activity and Avionics Survey. Rotorcraft are grouped with general aviation fixed-wing aircraft in the surveys and reports.

In the early 1980s, the census data for the active aircraft count, as well as hours flown per year by the active rotorcraft fleet, began to appear erratic, and the rotorcraft industry publicly expressed its concern (see, for example, ref. 7). Because the FAA groups rotorcraft together with general aviation fixed-wing aircraft in their yearly census, the rotorcraft industry felt that their unique rotary wing products—representing anywhere from 3% to 5% of the general aviation fleet—were likely not to be accurately represented statistically. Should the flight hours per year be substantially in error, for example, the rotorcraft accidents per 100,000 flight hours would be misleading. In turn, this could, perhaps, cast the rotorcraft industry's safety record in a bad light, with obvious consequences. In response to the rotorcraft industry's misgivings, the FAA performed a special survey of just the registered rotorcraft fleet activity in 1989 (ref. 17).

In view of the situation discussed above, an in-depth review of the FAA yearly Census of U.S. Civil Aircraft reports (1957 through 1994), and the General Aviation Activity and Avionics Survey reports (1977 through 1997) was completed. Particular attention was paid to the FAA's one-time-only Rotorcraft Activity Survey (ref. 17), which was also included in the 1987 General Aviation Activity and Avionics Survey report. The following discussion offers some insight into several issues concerning the method for gathering, evaluating, and using FAA rotorcraft fleet activity data.

The Rotorcraft Activity Survey (ref. 17) illustrates the statistical methodology used by the FAA to arrive at their 1989 reference data. The data bank accumulation process begins with the Aircraft Registration Master File (maintained by the FAA's Mike Monroney Aeronautical Center in Oklahoma City). This Master File is sent to the FAA's Statistical Analysis Branch in Washington, D.C., where the surveys are conducted and the data published. The Statistical Analysis Branch arrives at the number of *active aircraft* and the number of hours flown *by active aircraft* by sending out a questionnaire to registered owners. For example, the Rotorcraft Activity Survey questionnaire (Form 1800-55) contained 31 blanks to be filled in by respondents to the questionnaire. This questionnaire specifically asked for "(1) hours by use and the number of landings for the entire

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*The last version of this Census available as a paper copy is for 1994. In 1995, the primary data tables were put on the World Wide Web. It now looks like a Census for 1996, 1997, 1998, and 1999 will not be published at all. The FAA now appears to have no staff available for what many consider to be a very valuable service.

calendar year, 1989 and (2) total airframe hours and the aircraft's base location as of December 31, 1989." The questionnaire was sent out to 10,469 rotorcraft owners/operators. Appendix A of the Rotorcraft Activity Survey report describes the methodology for the survey in additional detail.

After reading the Rotorcraft Activity Survey and its appendix several times, it is concluded that:

1. The final tally of 10,469 rotorcraft represents some culling from the Aircraft Registration Master File, which is approximately 10% greater in number. For example, questionnaires were not sent for rotorcraft registered to dealers; rotorcraft with "Sale Reported" or "Registration Pending" appearing in the record instead of the owner's name; rotorcraft with a known, inaccurate owner's address; and rotorcraft with missing state of registration, aircraft make-model-series code, or aircraft type information.

2. The return rate on the 10,469 questionnaires with three mailings was: first mailing, March 1990 of 10,469 with return of 5,786; second mailing, May 1990 of 4,683 with return of 619; and third mailing, July 1990 of 2,181 with return of 319.

Thus, the overall response totaling 6,724 was 64% of the 10,469 questionnaires mailed. The second mailing *included* a repeat mailing to postal returns from the first mailing. The third mailing *excluded* 1,883 postal returns. Between these first two factors, a large percentage of the rotorcraft fleet is unaccounted for. The last sentence in the Survey's appendix (Paragraph 5.3.2, Non-Sampling Error) states: "Unfortunately, the high rate of postal returns reflects a seriously out-of-date rotorcraft file." With about 275,000 aircraft to keep track of, rotorcraft represented slightly less than 4% of the civil aircraft fleet.

The Rotorcraft Activity Survey appendix describes, in paragraph 5.2, how the responses from 6,724 owners were extrapolated to the baseline 10,469 population. Apparently, any rotorcraft owner who answered at least one question on a 31 blank form was counted as a "respondent." Paragraph 5.2 then goes on to describe a weighting computation based on respondents, "census frame" and "response rate for a cell," words that were undefined. Despite other hints about the method, we were unable to follow the details.* However, the 1989 results of the extrapolation were provided in table 2.1, chapter II, of the Rotorcraft Activity Survey. The key data from that table are reproduced below.

Using data from the Rotorcraft Activity Survey as a 1989 reference point, a detailed review of available census tabulations and surveys from 1964 through 1997 was completed. Based on that review, the principal author is of the opinion that the rotorcraft industry (representing just one aircraft type) has every reason to question the validity of the FAA published count of active rotorcraft—as well as the hours flown by the active rotorcraft fleet—in any given year *after* 1979. A basis for the rotorcraft industry concern is given by figures B-1 through B-9 or tables D-20, D-21, and D-22.

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*A more detailed and helpful explanation of the method is included as an appendix in each General Aviation Activity and Avionics Survey report. The reports for 1996 and 1997 can be found at Web page http://api.hq.faa.gov/apo_pubs.htm on the Internet.

Rotorcraft type	Population size	Estimate of number active	Estimate of total hours flown (in 1989 by active aircraft)[a]	Estimate of average hours flown (per year by active aircraft)[a]
Manufacturer built				
Piston total	3,994	2,684	728,125	277.8
Single turbine	3,616	3,248	1,532,270	480.5
Twin turbine	1,069	984	546,471	551.8
Turbine total	4,685	4,232	2,078,741	496.5
Manufacturer total	8,679	6,916	2,806,866	417.3
Amateur built total	1,790	572	21,830	38.2
Total all rotorcraft	**10,469**	**7,488**	**2,828,697**	**390.2**

[a]It is not clear why column three divided by column two does not equal column four in the above table.

As figures B-1 and B-2 suggest, the trend in FAA quoted hours flown by the “active” portion of the registered rotorcraft fleet in any given year *after* 1979 appears quite erratic relative to the trend shown for earlier years. Figure B-1 suggests that the timing of this erratic appearance might be consistent with the downturn in the rotorcraft industry’s growth in the 1980s (see figs. 8, 16, 45, or 73). However, when yearly hours flown are graphed versus registered fleet size (i.e., active plus inactive rotorcraft), as shown in figure B-2, an entirely different impression is made. Figure B-2 suggests that registered fleet size growth after 1979 was accompanied by *fewer* hours flown per year. This would be at odds with the historical trend shown prior to 1979. One interpretation of figure B-2 might be, that the active fleet (i.e., those rotorcraft that flew at least 1 hour in the year) decreased, that the active fleet flew fewer hours, and that 1,000 to 2,000 rotorcraft were simply “mothballed.” (This possible explanation will be discussed shortly.) Similar contradictory impressions are shown individually by the piston-engine-powered portion of the fleet (figs. B-3 and B-4) and the turbine-engine-powered portion of the fleet (figs. B-3 and B-5). In fact, the generally erratic trend in census and fleet activity borders on the absurd for the piston-powered fleet shown in figure B-4. The post-1979 trend (shown by the long dashed line) suggests that when the Aircraft Registration Master File lists 8,000 piston-powered rotorcraft, all rotorcraft of this type will be “inactive” and the total fleet will accumulate no flight hours in that year.

The more likely explanation for the picture presented by figures B-1 through B-5 is that the method of gathering data changed in the 1977-1979 period. A hint that this is exactly what happened is provided by the FAA Census of U.S. Civil Aircraft for calendar year 1979. In the section entitled "ACTIVE GENERAL AVIATION AIRCRAFT AND HOURS FLOWN," beginning on page 51, several key statements are made. These statements (along with comments by the principal author in brackets) are as follows:

From paragraph 1: These data [tables 3.1 onward] are for the active fleet, as opposed to the registered fleet data shown in preceding tables.

From paragraph 2: Beginning in 1977, General Aviation Aircraft Activity information [where rotorcraft are grouped] was obtained using the General Aviation Activity and Avionics Survey. Heretofore, the activity data were collected from *each owner of a registered aircraft* [principal author's italics] using the Aircraft Registration, Eligibility, Identification, and Activity report.

From paragraph 3: [The General Aviation Activity and Avionics Survey, which replaced the Aircraft Registration, Eligibility, Identification, and Activity report, used a sampling method.] The sample of 31,208 aircraft was selected from approximately 234,000 registered general aviation aircraft. The sample is a scientifically designed random sample which represents all general aviation aircraft registered in the United States.

From paragraph 4: Because the estimates [of active aircraft and hours flown] are derived from a sample—not the total population of aircraft—a certain amount of sampling error is introduced. …Although the exact value of the sample error is unknown, a quantity known as the standard error is used to approximate it [etc.].

From paragraph 5: If, for example, the estimate for the total number of active piston powered rotorcraft were 2,658 and the standard error were 176, then the 95% confidence interval would be 2,658 ± 2(176) or (2,306; 3010). One would say that there is a 95% chance that the number of active piston-powered rotorcraft lies between 2,306 and 3,010.

From last paragraph: More detail estimates and a more detailed discussion of the survey and its method are available in the 1978 General Aviation Activity and Avionics Survey. [The first GAAA Survey was conducted in 1978 to examine fleet activity for the calendar year 1977. The results were published in April 1979 as Report No. FAA-MS-79-5.]

The FAA initiative to unburden the public and save money in the data gathering effort by relying more heavily on statistical methods than it did in earlier years was not a blind step.* The reliance on the General Aviation Activity and Avionics Survey appears to have been a smart decision even for 1978 and 1979. However, as figures B-6 and B-7 show (see also tables D-21A, D-21B, and D-21C), the results throughout the 1980s, and so far in the 1990s, shows a diverging pattern of erratic behavior that is not reflected in the total registered fleet census data of figures 8, 16, 45, or 73.

In itself, the erratic character of the FAA data shown in figures B-1 through B-7 may be considered relatively inconsequential by many people. After all, the major rotorcraft manufacturers maintain much more accurate records of where their rotorcraft are, what they are being used for, and the status of each type's fleet hours. However, when potentially misleading FAA data are used as the denominator in a safety ratio (such as accidents per 100,000 flight hours) and this ratio then creates a misleading impression—either way—a disservice is being done to the public and to the aviation industry.

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*The first GAAA Survey states in Paragraph 1.1.2, Background, that "Specifically, the public reporting burden was reduced by an estimated 13,000 hours annually, and the cost savings to the public and Government were estimated to be one million dollars annually." Figures 1.4, 1.5 and 1.6 of this first GAAA Survey show 1977 data obtained by the new statistical methodology connected quite well with data from 1973, 1974, 1975, and 1976.

A more practical view of the statistical situation is given in figures B-8 and B-9. These two figures show that the error in hours flown using the General Aviation Activity and Avionics Survey method adopted in 1978 might easily be ±30% for piston-powered rotorcraft and ±25% for turbine-powered rotorcraft *when calculated at constant active rotorcraft fleet size*. More specifically, suppose in figure B-8, the active piston count in 1983 is truly 2,541 rotorcraft. Then the possibility exists that the hours flown in that year could be as low as 480,000 or as high as 790,000. Now, according to the NTSB's report (see table D-1), 150 accidents occurred with piston-powered rotorcraft of all types in 1983. Thus, the safety statistic could be anywhere from 150 accidents per 4.8 hundred thousand hours (i.e., 31 accidents per 100,000 hours) down to 150 accidents per 7.9 hundred thousand hours (i.e., 19 accidents per 100,000 hours).

The chronology of this ambiguity—a growing uncertainty of rotorcraft fleet flight hours accumulated in any given year and the number of rotorcraft actually flying—is documented in the General Aviation Activity and Avionics Survey reports (1977 through 1997). Table D-22 provides a data summary from selected GAAA survey yearly reports to examine the chronology. To begin with, the first GAAA Survey (covering 1977) provided encouragement that a "statistically designed sample of about 14.4% of the registered general aviation fleet" would be accurate enough for FAA purposes. Data obtained by the new statistical method correlated reasonably well with data from 1973, 1974, 1975, and 1976. For rotorcraft, instead of sending out 6,845 questionnaires (the census count after some culling to yield the approximate population), only 1,924 questionnaires were sent, which defined the "sample size" of 1,924 in table D-22. The 80.5% response rate yielded the statisticians 1,548 returns from which the total "population's" activity could be constructed. Results differentiating piston- from turbine-powered rotorcraft were obtained, but a breakdown to specific make and model was not published; nor were results comparing single-turbine against multi-turbine powered rotorcraft.

This first GAAA Survey was actually conducted in 1978 and was published in April 1979. It contained information of additional note. Again, principal author comments are in brackets.

1. "In 1978, the FAA replaced AC Form 8050-73 with a new system [Form 1800-54]." The new system changed the mandatory aircraft registration renewal requirement from once a year to a "triennial registration program." (Par. 1.1.2)

2. The sample size was constructed using the Aircraft Registration Master File as of December 31, 1977. "This file is the official record of registered civil aircraft in the U.S., containing one record per aircraft. It accurately represents the current civil air fleet, being updated continuously for new registrations, change in ownership, etc." (Par. 1.3.1)

3. The population "consisted of 212,598 general aviation aircraft records from which 30,643 records were sampled, yielding a 14.4% sample." "These [figures] clearly demonstrate the disproportionality of the sample to the population, an intended result of the sample design to gain efficiency and to control errors." (Par. 1.3.1)

4. “Errors associated with estimates derived from sample survey results fall into two categories: sampling and non-sampling errors.” [Reference is made to the U.S. Dept. of Commerce, Bureau of the Census document entitled Standards for Discussion and Presentation of Errors in Data, 1974, pp. I1–I4.] “Sampling errors occur because the estimates are based on a sample—not the entire population. Non-sampling errors arise from a number of sources such as non-response, inability or unwillingness of respondents to provide correct information [etc.].” (Par. 1.3.3)

5. A second mailing and telephone survey of a sample of non-respondents were conducted in addition to the original mailing to improve the response rate, since a low response rate is a major cause of non-sampling error.” “[Ultimately] 80% of those aircraft sampled responded to at least one question of the survey.” (Par. 1.3.3.2)

As figure B-1 and table D-22 strongly suggest, the inadequacy of the “new system” and associated GAAA Survey method quickly became evident. From 1977 to 1987, response rate dropped from 80% to roughly 50%. The 1987 GAAA Survey, in its Appendix B, paragraph B.1, adequately summed up the dilemma the new system was creating by stating:

1. Instead of requiring all owners to revalidate and update their aircraft registration annually, FAA required revalidation for only those owners who had not contacted the registry for 3 years. The less frequent updating affected the accuracy of the file and its representativeness. Two major consequences for the survey results are discussed below:

A. The accuracy of owner’s addresses deteriorated causing the percentage of questionnaires returned by the post office to almost triple from 1977 to 1982. Post office returns have since increased to nearly 13% in 1987, of the original sample of aircraft selected. This partially accounted for the lower survey response rates experienced since 1977.

B. The [Aircraft Registration Master] file contained a residue of aircraft which under the old revalidation system would have been deregistered and purged from the file, but remained under the new system. Consequently, the population counts were inflated resulting in artificially large increases in the estimates of the number of active general aviation aircraft from 1977 to 1978, and from 1978 to 1979.

2. Also during this period the entire Aircraft Registration System was installed on a new computer system. At the same time, FAA modified many of the updating and processing procedures. It is quite possible that these changes affected the registration file, although it is not known in what way.

These three basic themes—points 1 and 1.A and 1.B above—along with a continued unsatisfactory response rate of around 50% are repeated in each GAAA Survey report from 1987 to 1997. *It should be noted that at no time over this 20-year period did the FAA arbitrarily increase its sample size from approximately 30,000, which might have offset the reduced response rate and increasing* *number of post office returns.* In 1977, the defined general aviation aircraft population was 212,598 aircraft, 30,643 questionnaires were sent out and about 24,500 (i.e., 80% response rate) respondents filled in at least 1 blank on Form 1800-54. In 1987, the corresponding numbers were 267,400 aircraft, 29,719, questionnaires and about 18,100 respondents (i.e., 61.1% response rate). By 1996, the defined population was 247,821 aircraft with 29,952 questionnaires sent out. The Post Office returned 1,641 envelopes, and 19,362 responses were counted to give a response rate of 68.7%. A footnote on page A-12 of the 1996 GAAA Survey report states that "The 68.7% response rate is computed by subtracting the Post Master Returns (1,641) and museum pieces (126) from the total valid sample size of 29,952." This method change, among several others, as well as a recompilation of survey results over the 1987 to 1996 period (to account for a "nonresponse bias") is discussed in the 1996 GAAA Survey report. This 1996 report and the 1997 report are available at Web page http://api.hq.faa.gov/apo_pubs.htm on the Internet.

From the rotorcraft industry point of view shown in table D-22, the statisticians began in 1988 to deflate the census count given by the Aircraft Registration Master File to arrive at the defined population. Apparently dealing with an outdated, unpurged Master File was considered unsatisfactory. How the size of the population and then the sample size were arrived at is, however, not clear. One thing is clear and that is: to statistically infer the activity of 8,000 to 12,000 rotorcraft from 750 to 1,500 responses is a very bold extrapolation—regardless of the perceived intentions "to gain efficiency and to control errors."

Safety statistics can be constructed, of course, at face value irrespective of the concerns about FAA-provided fleet hours raised in the preceding discussion. Some results, when approached in this fashion, are provided in figures B-10, B-11, B-12, and B-13, based on the tabulations of table D-23. These results are provided without further discussion.

A very real danger exists given the possibility that safety statistical trends could be influenced and varied as much as discussed above. For example, reference 22 notes that on 12 February 1997, the White House Gore Commission on Aviation Safety issued a report. Based upon the recommendations of this report, President William J. Clinton announced a national goal of reducing aviation fatal accident rate 80% over the next 10 years.*

One meaning to the rotorcraft community of this national goal can be interpreted first with figure B-14 and, perhaps more familiarly in ratio form, with figure B-15. Figure B-14 shows the number of people who lost their lives each year in civil rotorcraft accidents in the United States. These are yearly fatalities as recorded by the NTSB—not the number of fatal accidents in the year or the fatal accident rate referred to by President Clinton. These yearly fatalities are graphed with the solid-black, circled points shown in the figure. These "data" are associated with the left-hand vertical scale, as the arrow labeled Fatalities (NTSB) points out. The second set of data is the graph of hours accumulated in a year of flying by the active rotorcraft fleet in each year from 1965 through 1997. This FAA published data use the × symbol and the right-hand vertical scale that the arrow labeled Hours (FAA) points to. The hours are in units of 100,000. Note that the last 5 years of FAA data were abruptly displaced downward relative to the preceding 5 or 7 years by about 25%. This change reflects the apparent decision to define the rotorcraft population independently of the

* The actual goal contained in the FAA's Strategic Plan aims to "reduce the U.S. aviation fatal accident rate per aircraft departure, as measured by a 3-year moving average, by 80% from the 3-year average from 1994–1996" by 2007.

Aircraft Registration Master File census as discussed above and shown in table D-22 for years 1991, 1992, and 1993.

The statistical ratio of fatalities per 100,000 hours is obtained for each year from figure B-14 by dividing the number of fatalities by the number of 100,000-hour units. The result of this division is shown in figure B-15 and table D-23. An exponential trend, shown as the heavy solid line in figure B-15, gives a sense of how the rotorcraft industry is generally improving despite considerable year-to-year ups and downs. The national goal announced by President Clinton could, in fact, be applied to the fatality rate (i.e., *fatalities* per 100,000 hours—not fatal accidents per 100,000 hours). If this were done, then a reference point for 1997 might be 2.5 fatalities per 100,000 hours, which lies at the end of the exponential trend line. Should the 80% goal then be applied, it follows that the rotorcraft industry would be striving for less than 0.5 fatalities per 100,000 hours by the year 2007.

Figure B-15 suggests an ambitious goal irrespective of accuracy questions concerning FAA fleet activity data. Of course, the true aviation goal is—unquestionably—no fatalities or injuries.

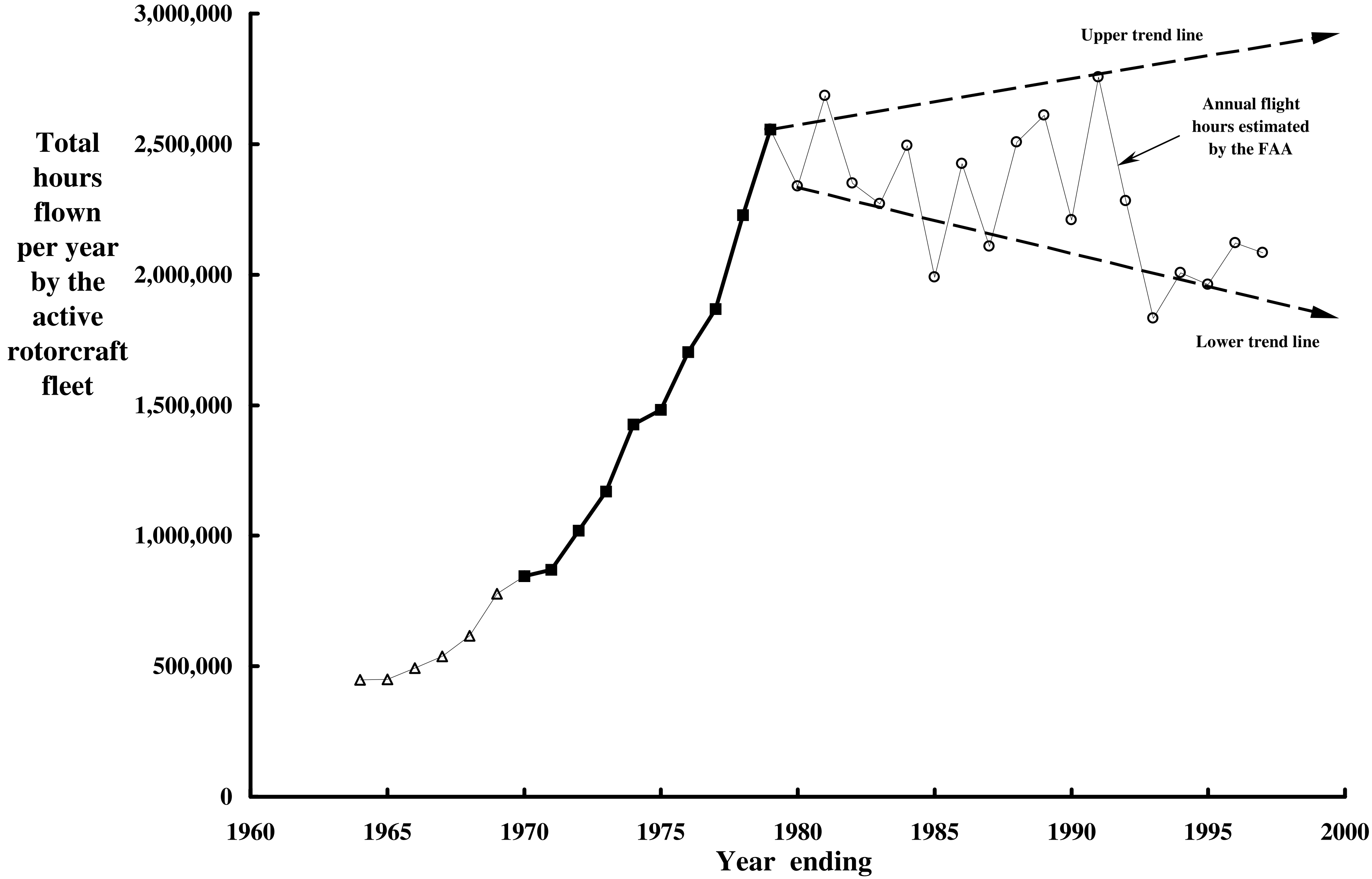

Figure B-1. Annual hours flown by the active rotorcraft fleet.

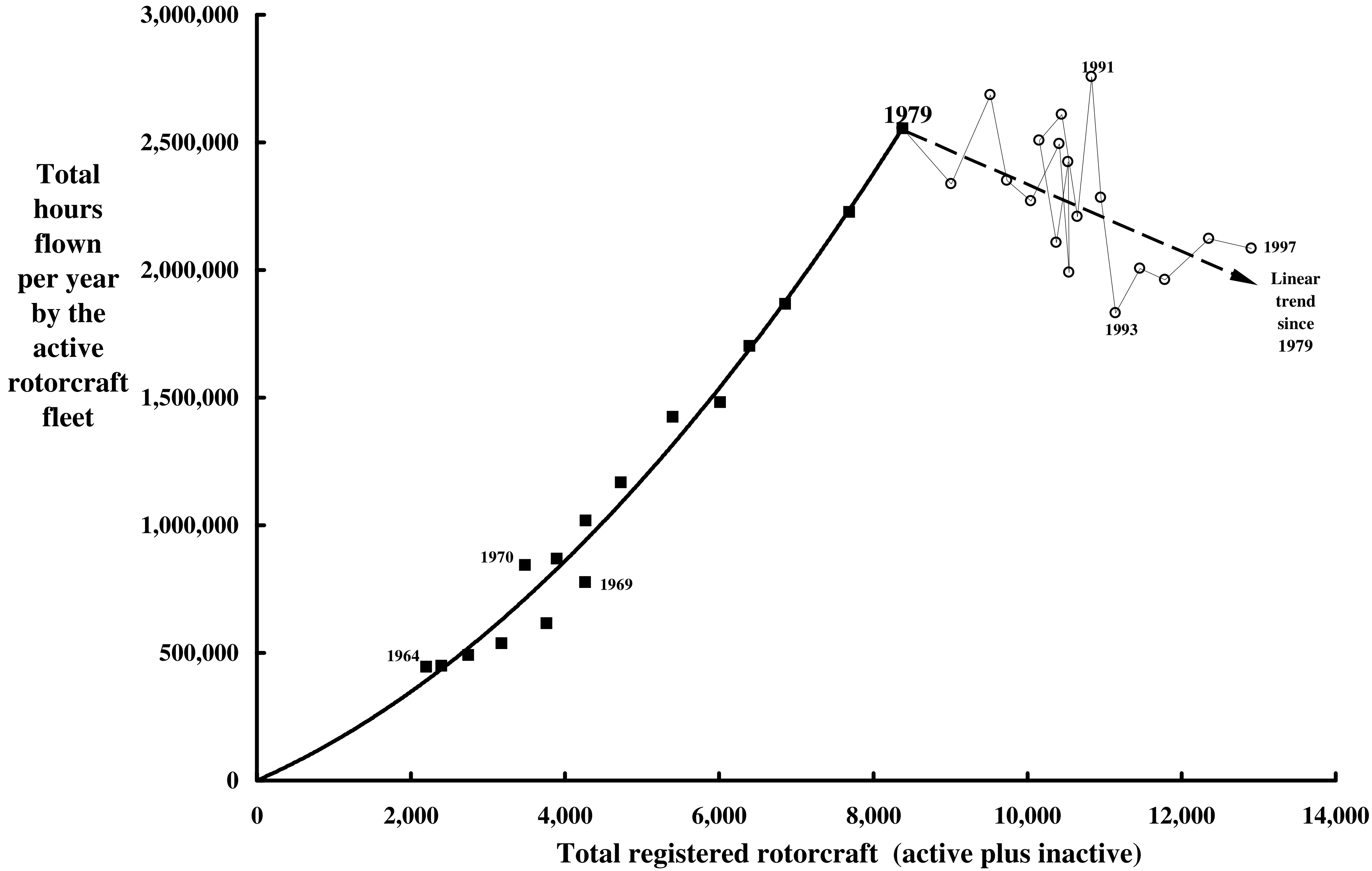

Figure B-2. Annual hours flown vs. registered rotorcraft yearly count.

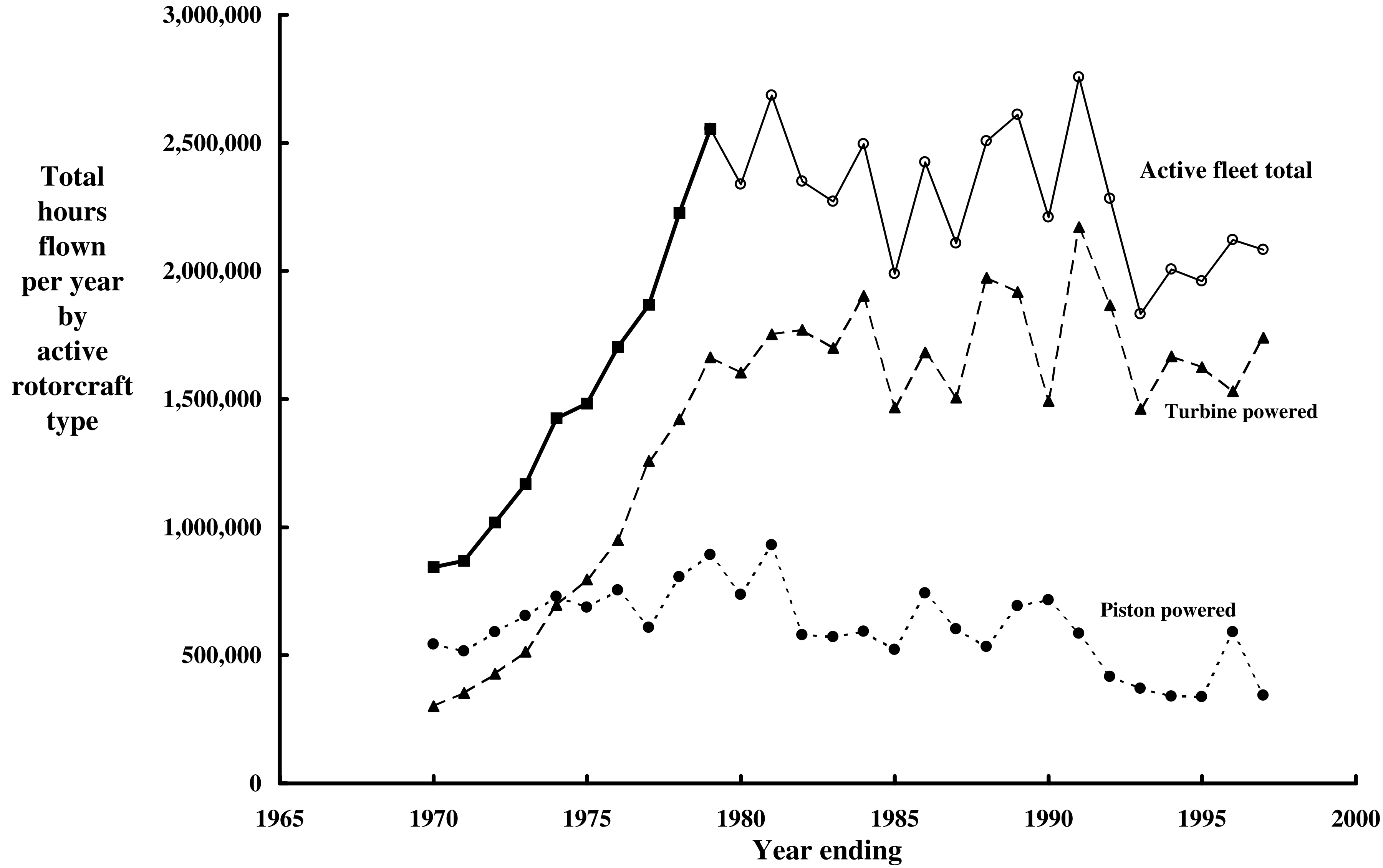

Figure B-3. Annual hours flown by rotorcraft type.

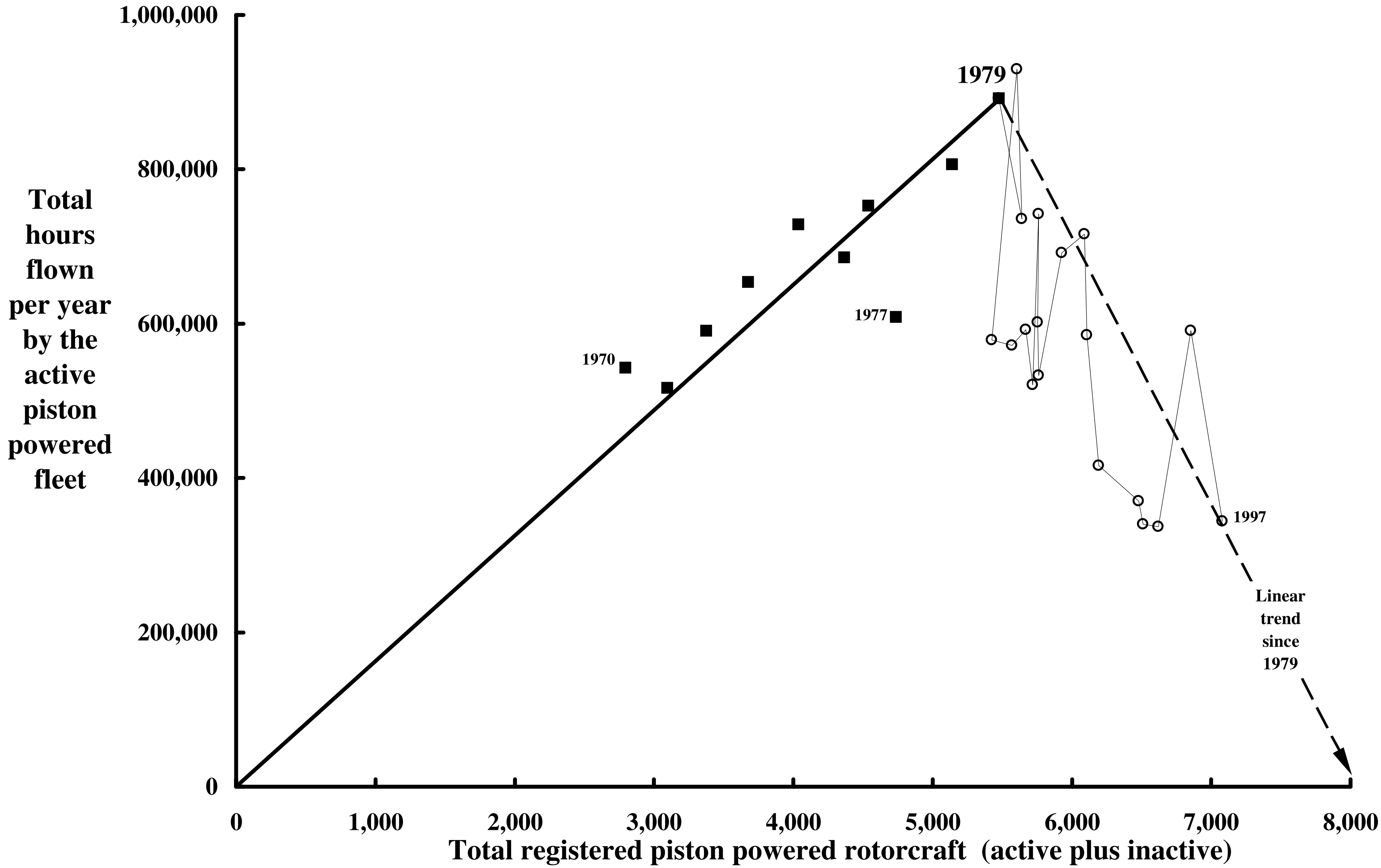

Figure B-4. Annual hours flown vs. registered piston powered rotorcraft.

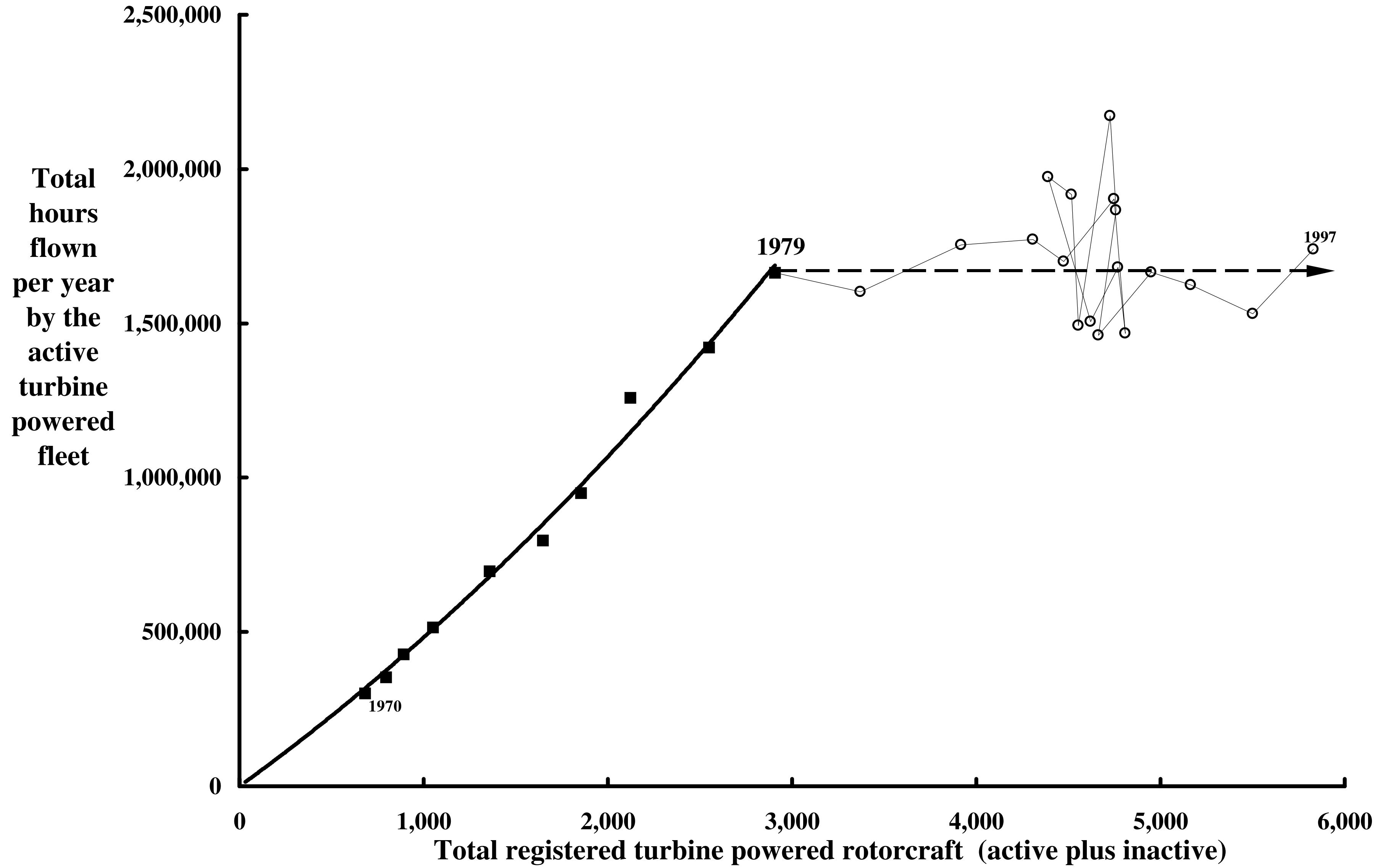

Figure B-5. Annual hours flown vs. registered turbine powered fleet.

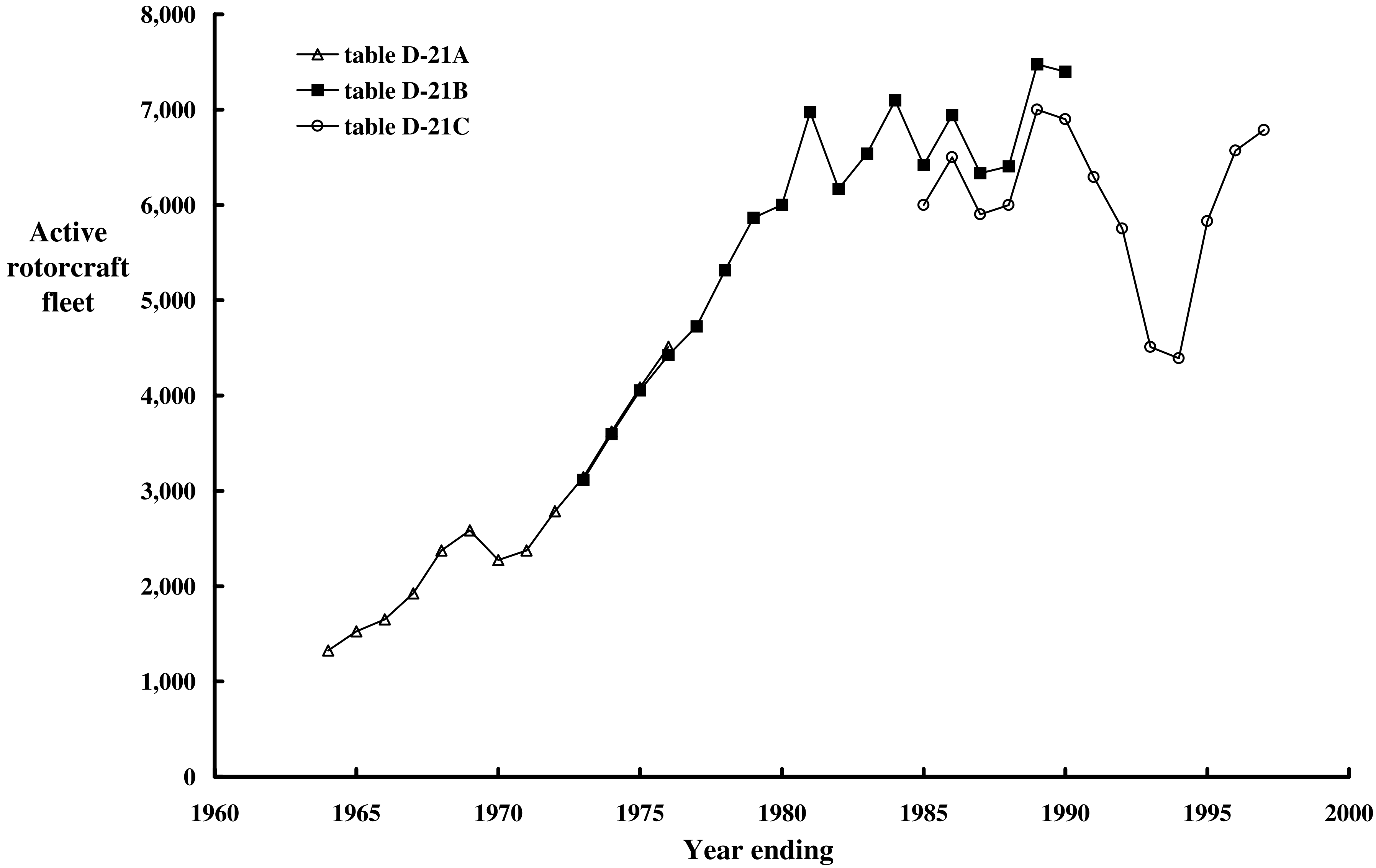

Figure B-6. Total active rotorcraft fleet count by year (including revisions).

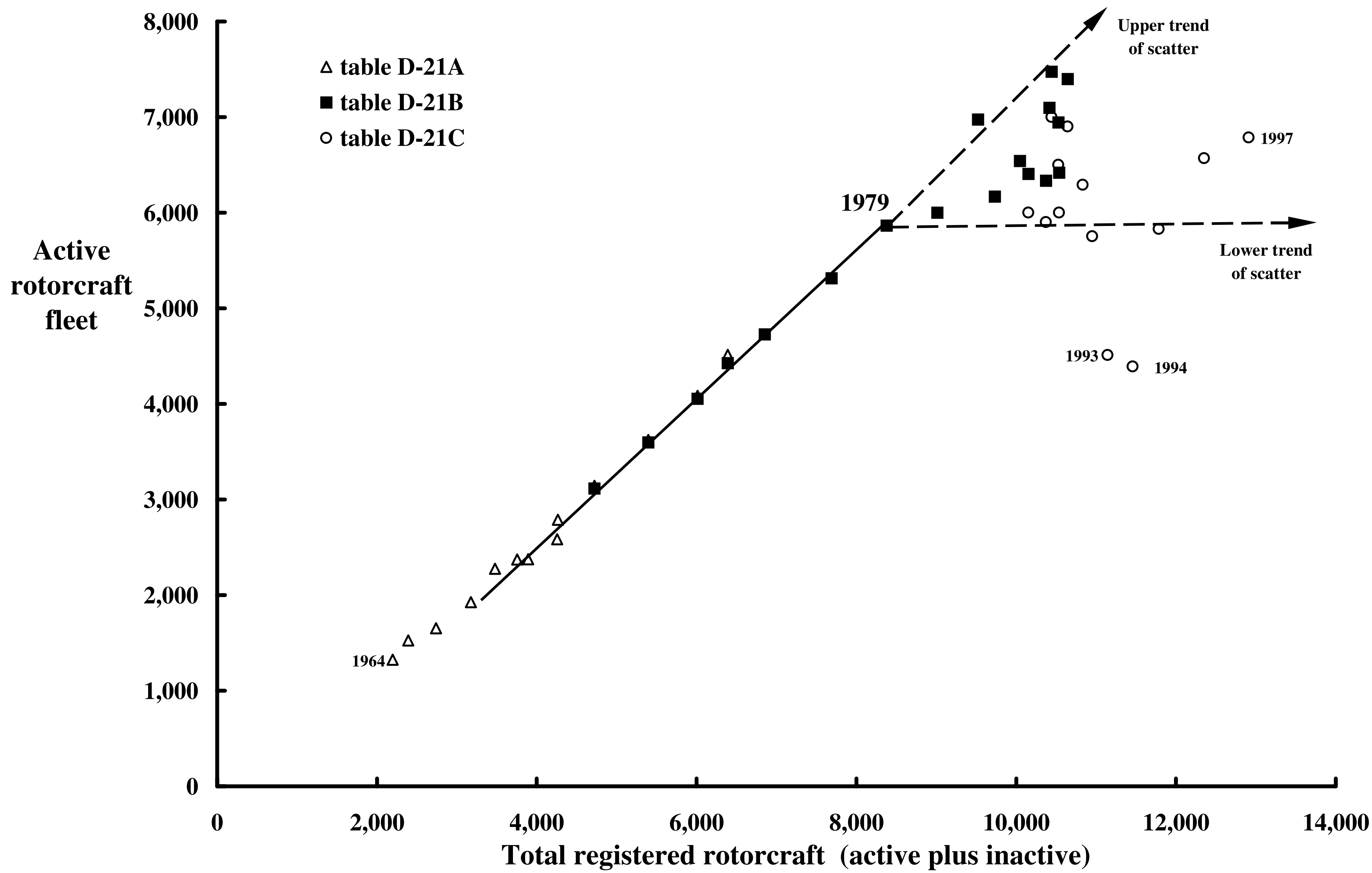

Figure B-7. Active count vs. total count by year (including revisions).

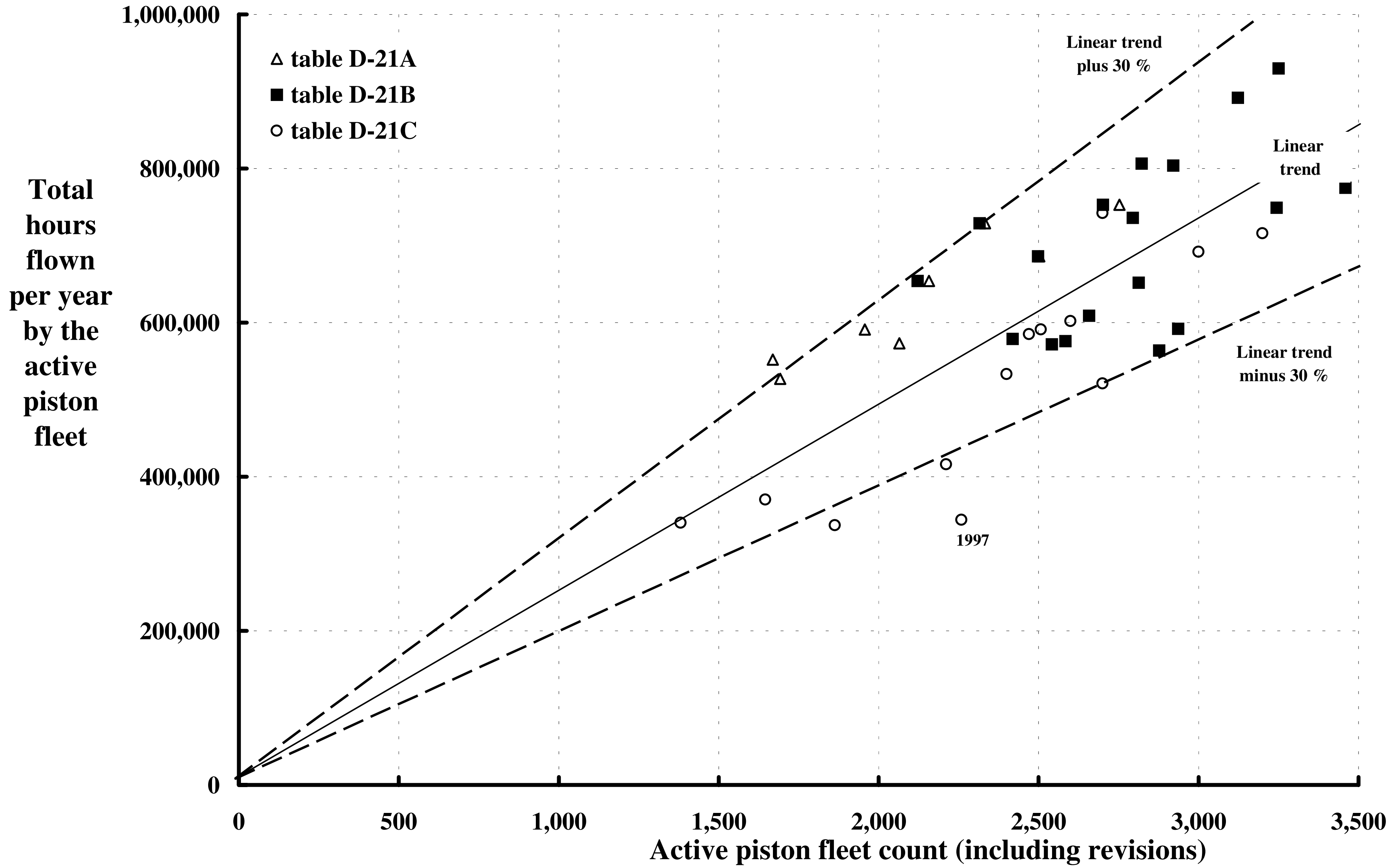

Figure B-8. Annual hours flown by active piston fleet vs. active piston fleet.

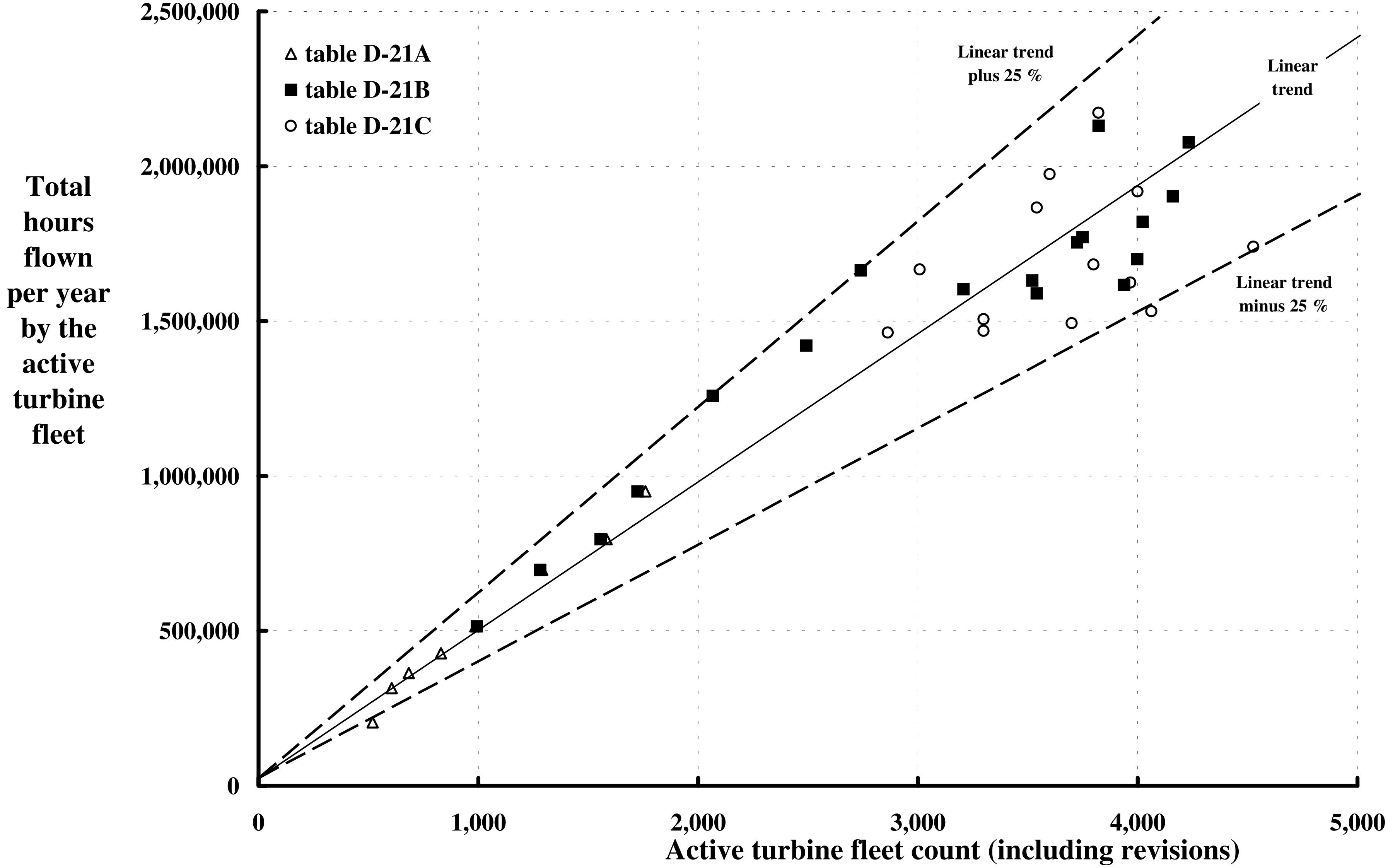

Figure B-9. Annual hours flown by active turbine fleet vs. active turbine fleet.

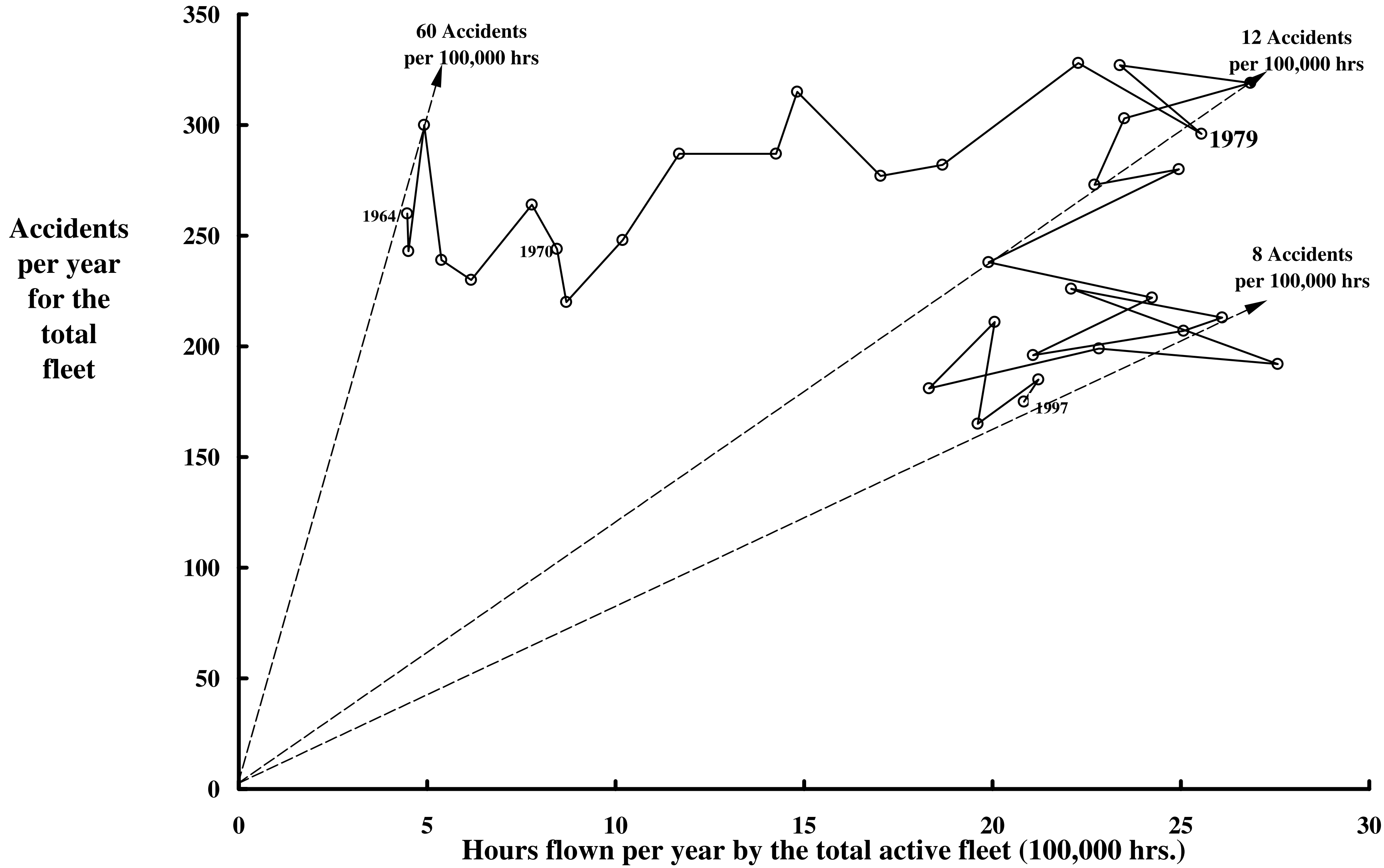

Figure B-10. Annual accident count vs. annual hours flown for the active fleet.

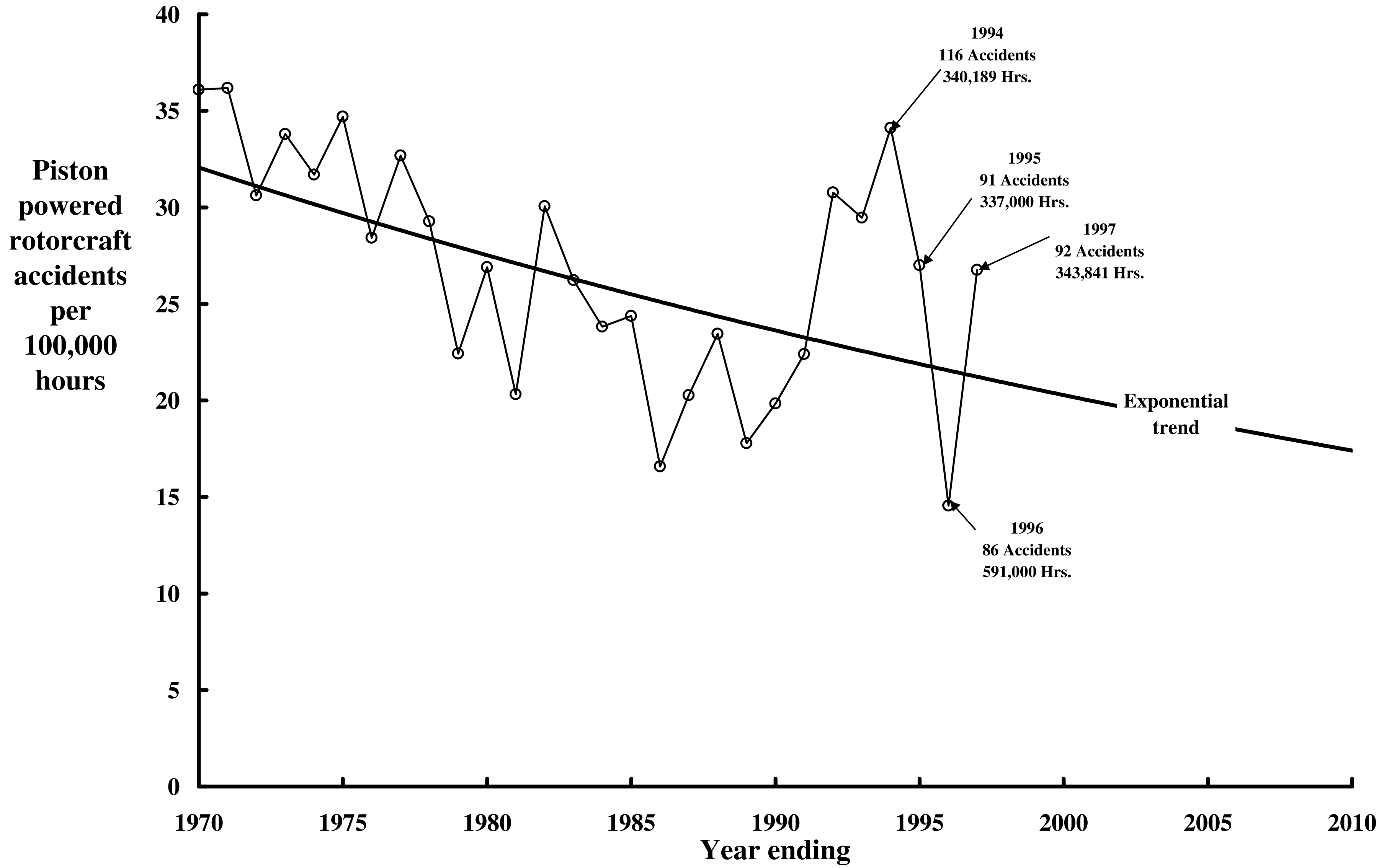

Figure B-11. An accident statistic for piston powered rotorcraft.

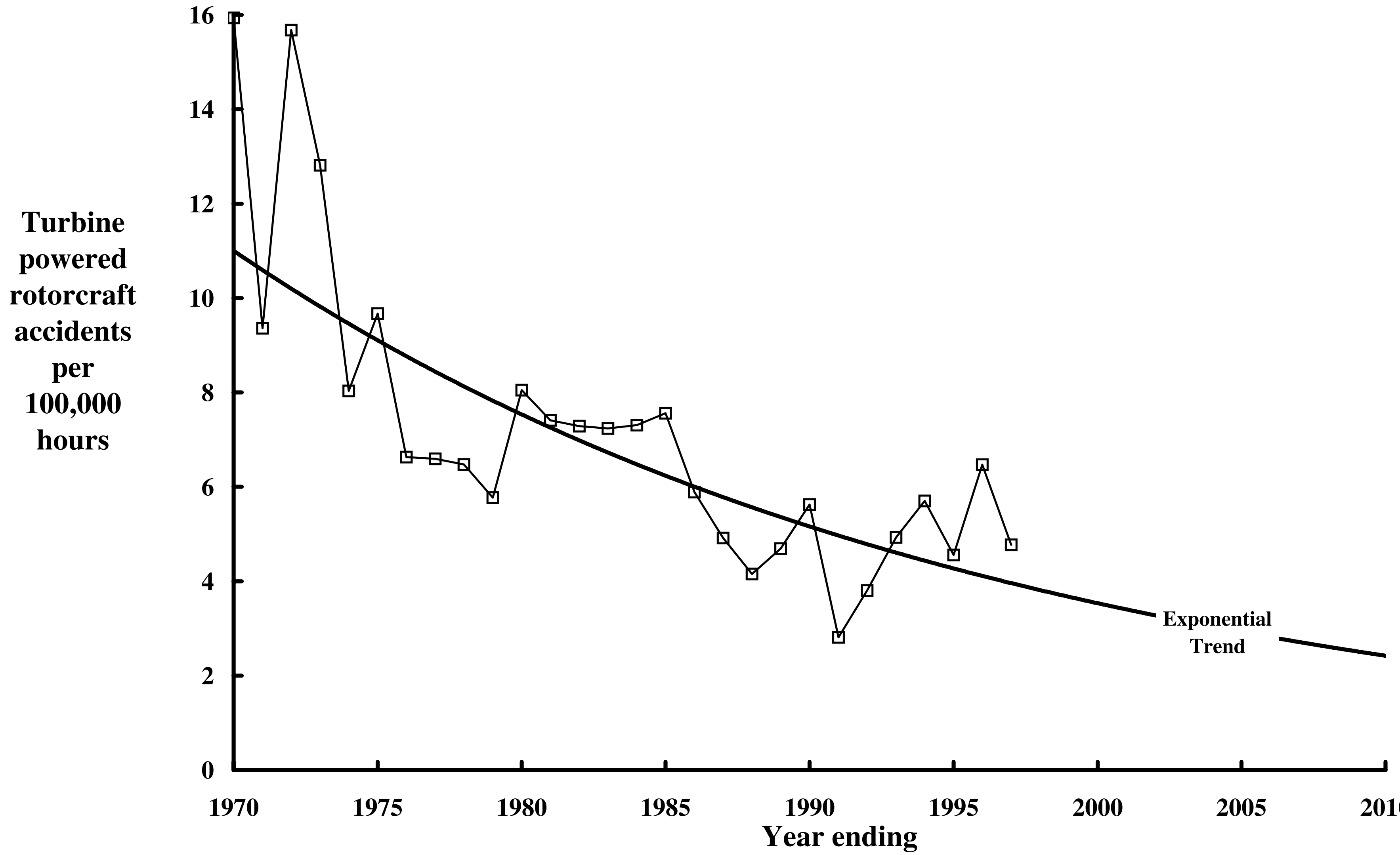

Figure B-12. An accident statistic for turbine powered rotorcraft.

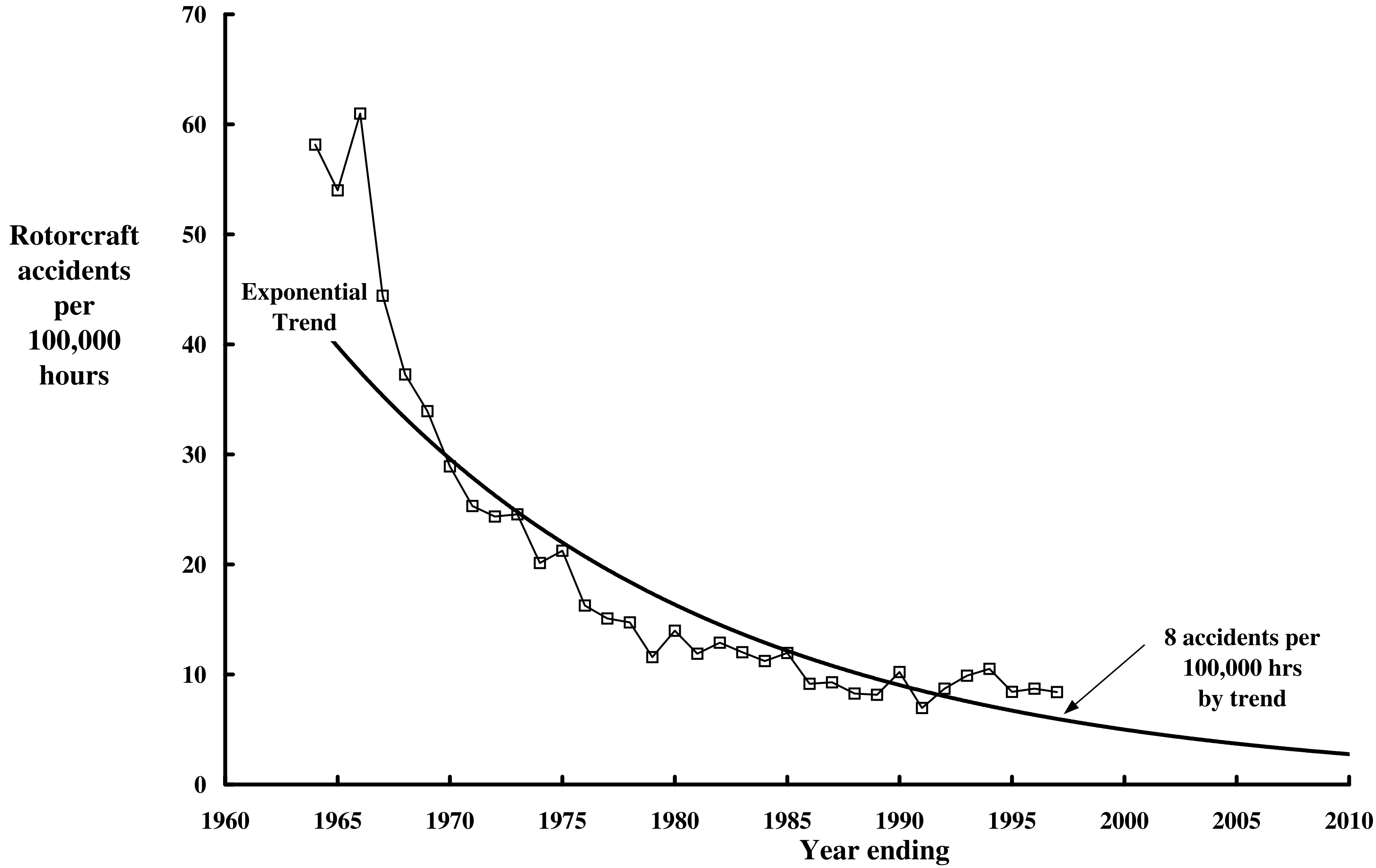

Figure B-13. An accident statistic for all rotorcraft.

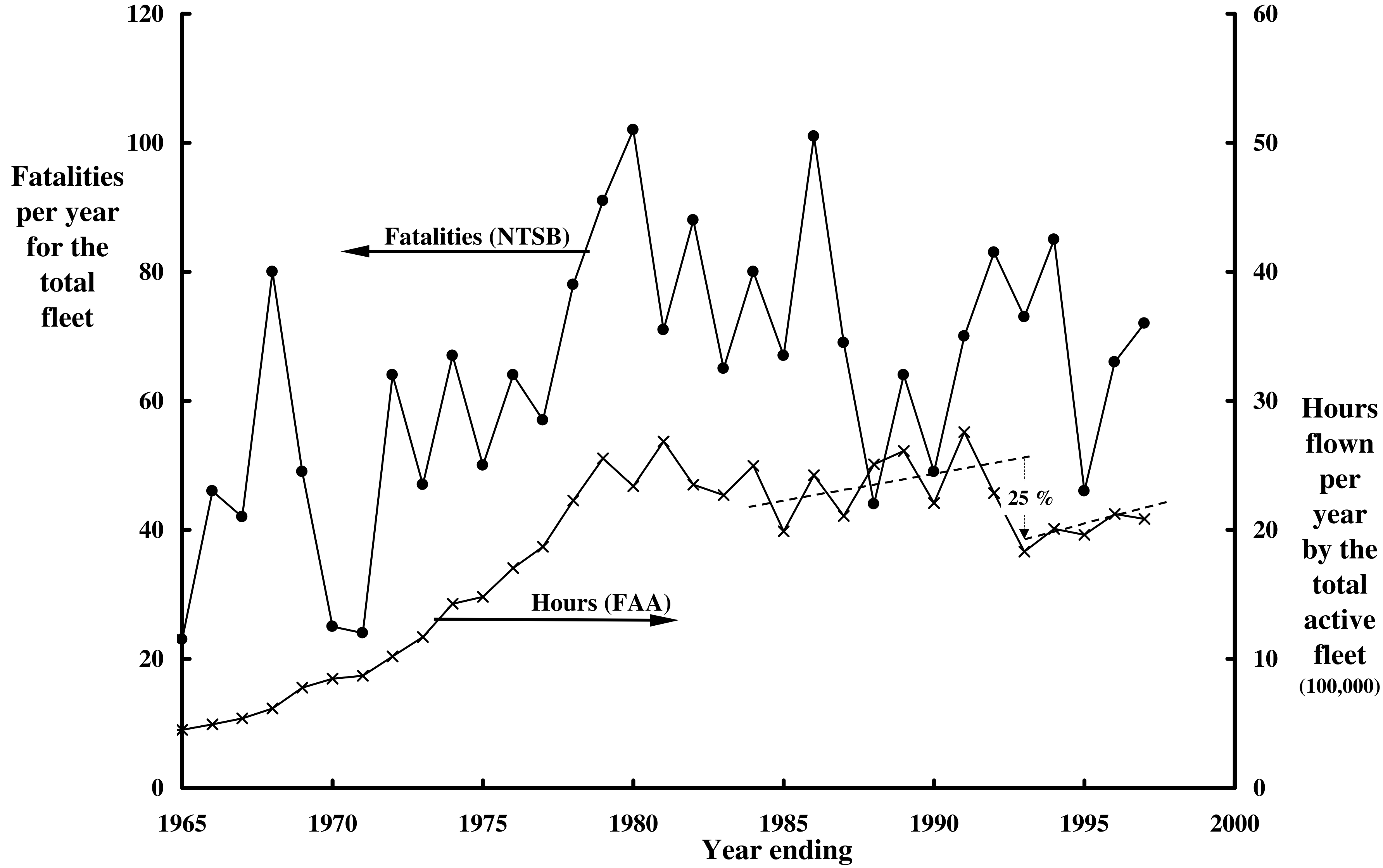

Figure B-14. Rotorcraft trends in fatalities per year and annual hours flown.

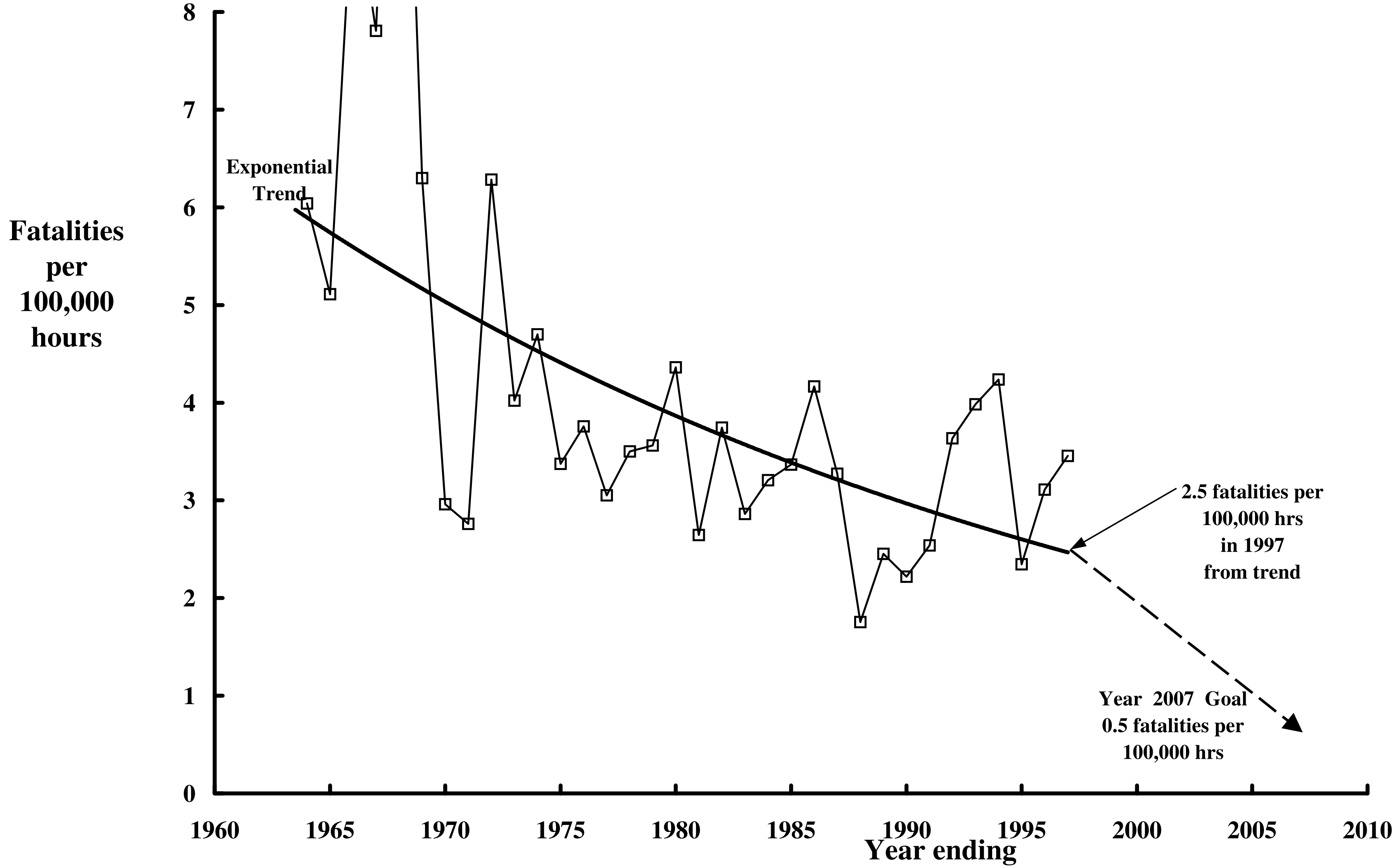

Figure B-15. A possible aviation goal for rotorcraft.

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Appendix C
AUTOROTATION-RELATED ACCIDENTS

A fairly common issue for discussion among rotorcraft pilots, operators, designers, manufacturers, and regulators is the value of autorotation training. The question, similar to ongoing discussions regarding spin training in fixed-wing aircraft, is whether autorotation training (with its inherent risks) would result in a reduction of autorotation accidents in case of actual emergency. The NTSB database used in this study provides information that interested parties can use to explore this issue.

For this analysis, accidents from 1987 through 1997 were extracted from the NTSB database. The accident summaries for the subgroup were searched for the terms “autorotation,” “autorotational,” and “autorotative.” Summaries with any of those terms were examined; if the summary showed that the accident involved an autorotation, the information was placed on a new spreadsheet. After review of all such accidents, a new subgrouping containing autorotation-related accidents was available for use.

For the 11-year period under consideration (1987 through 1997), 713 accidents were identified as autorotation related. Of these, 401 (56.2%) involved piston-engine-powered rotorcraft, 295 (41.4%) involved single-turbine-engine helicopters, and 17 (2.4%) involved twin-turbine-engine helicopters. Annual numbers of autorotation-related accidents for each aircraft type and rates per 1,000 airframes were also extracted and are presented in figures C-1 and C-2.

In figure C-2, the annual rate of autorotation accidents per 1000 aircraft varies about an average of 8 per 1000 aircraft. What is interesting is that the rates are approximately the same for both single-piston and turbine helicopters—in other words, this metric does not show an improvement resulting from the use of turbine engines over piston engines.

The long-term ratio of autorotation-related accidents to all accidents is 0.33 for the entire rotorcraft fleet, 0.32 for piston-engine rotorcraft, 0.39 for single-turbine helicopters, and 0.14 for twins (fig. C-3). The yearly ratios for single turbines are consistently above the annual fleet ratio, whereas the ratios for piston rotorcraft generally remain below those of the entire fleet. The ratios are remarkably consistent from year to year. Even the twin-turbine ratios remain fairly close to the long-term type mean if 1993 and 1997 are disregarded. Thus, as a rule of thumb, one can estimate that 35% of rotorcraft accidents involve an autorotation.

The question, “does the autorotation capability of rotorcraft decrease the severity of accidents (i.e., increase the survivability)?” may be raised. Figure C-4 shows two comparative ratios of accidents involving fatalities. The upper curve in figure C-4 gives the ratio of fatal accidents to all accidents. The lower curve on figure C-4 shows the ratio of fatal autorotation accidents to all autorotation accidents. The annual ratios of fatal autorotation-related accidents to total autorotation accidents remain consistently below the corresponding ratio of fatal accidents to all accidents. The difference in the long-term averages (0.09 for autorotations and 0.19 for all fatal accidents) represents the survivability advantage provided by the ability to autorotate. In other words, if the accident sequence permits the pilot to enter autorotation, survival chances improve.

What are the reasons pilots enter autorotation? Figure C-5 shows the distribution of precipitating events that led to autorotation-related accidents. Two major events stand out: engine problems and practice. The dominance of the single-engine rotorcraft types drives this characteristic. When flying a single-engine rotorcraft, the pilot normally reacts to any loss of engine power by entering autorotation. Figure C-5 shows that 21% of autorotations-related accidents take place during practice of the maneuver. However, it is important to note that this statistic (indeed all the percentages shown on this chart) does not measure the *risk per autorotation event*, since, for the most part, successful autorotations are not reported. In addition, some autorotation accidents that took place during practice autorotations actually involved some mechanical or operational problem, which turned the practice maneuver into an actual forced landing. This is also true for some of the small number of autorotations during test flights. Figure C-6 amplifies figure C-5 by reallocating these actual forced landings during practice or test into the appropriate reason bin. When reallocated, practice autorotations account not for 21%, but for 17%.

This reallocation further increases the proportion of autorotation accidents precipitated by some sort of engine problem (i.e., from 44.18% in fig. C-5 to 47.41% in fig. C-6). It thus appears that the true proportion of accidents caused by poorly executed practice autorotations is about 17% to 18%. Flight instructors, flight schools, pilot examiners, and regulators should seriously consider this statistic when evaluating the risk of practice autorotations compared with the benefits it offers in improved survivability.

Engine problems are further broken down to determine their underlying events in figure C-7. Mechanical failures are the major causal factor in both engine-problem-related autorotation accidents and all autorotation accidents. Almost a quarter of all autorotations that resulted in accidents are due to some mechanical failure of the engines. Further, and troubling, is that the reasons for one-quarter of the engine problems could not be determined. Additionally, as was discussed in the main part of this report, fuel exhaustion (the principal problem directly under the control of the pilot) accounted for nearly one-fifth of the autorotation-related accidents. The large number of undetermined-cause accidents is troublesome, because without knowing what actually took place, no corrective action can be proposed.

Figure C-8 depicts the first event categories that virtually describe the end of an unsuccessful autorotation. Hard landings and collisions with the terrain are the major problems with autorotative landings. There is a degree of overlap between these categories. A basic distinction is that a hard landing is normally a result of inadequate flare or collective pitch pull, whereas collision with the terrain implies either no flare or the existence of a terrain feature the pilot could not avoid. In any event, it appears that these two problem areas can be considered together and, taken together, imply that the main difficulty in autorotative landings is judgment and application of the flare and collective pitch pull. Together, almost two-thirds of the autorotation accidents involve hard landings or collisions. This is another consideration for instructors, flight schools, pilot examiners, and regulators in evaluating the benefits of practice autorotations in reducing errors during actual forced landings.

Further examination of the data led to developing a distribution of problems identified in autorotation accidents. The results of this examination are shown in figure C-9. A clearly evident problem is the difficulty in maintaining autorotational RPM. This factor relates to the hard landing problem since low rotor RPM, especially in the flare, will almost inevitably result in a hard landing. This leads to a basic question: How can instructors, designers, manufacturers, regulators, and pilots themselves improve RPM awareness and controllability (i.e., how to make low RPM conditions more difficult to encounter or how to make corrections easier)?

The second major problem area identified by figure C-9 is difficulty in the flare. A successful flare is the product of awareness of and correction for a wide variety of operational and environmental factors such as aircraft performance, wind, altitude, presence of obstacles, type of terrain, and many others. The required situational awareness and judgment develops with practice. However, as has been discussed above, the practice autorotation is itself a fairly risky maneuver. Thus, a balance must be struck between the risks of autorotation practice and the benefits of improved pilot performance.

Several key questions remain to be answered before the rotorcraft industry improves its autorotation experience; several examples follow:

1 Given the risk and cost of aircraft-based autorotation training, is it really necessary?

2. Will the development and availability of low-cost, medium-fidelity small computer-based simulators permit initial and recurrent training, which will improve pilot performance?

3. Can currently available low-cost simulation systems provide the necessary fidelity for realistic training?

4. Are there other possible methods of improving pilot performance during forced landings?

5. Can low-cost advanced pilot cueing systems be developed and fielded to improve RPM awareness and correction of low RPM conditions?

6. Can the pilot be provided “flare now” cues?

7. Can the pilot be provided cues to indicate that the aircraft is nearing or is inside the “avoid” areas of the height-velocity diagram?

It is not the purpose of this report to suggest specific systems. However, the hope is that by presenting the reduced and analyzed autorotation data, the rotorcraft industry will have information that is necessary to develop and implement the systematic changes required to reduce accidents.

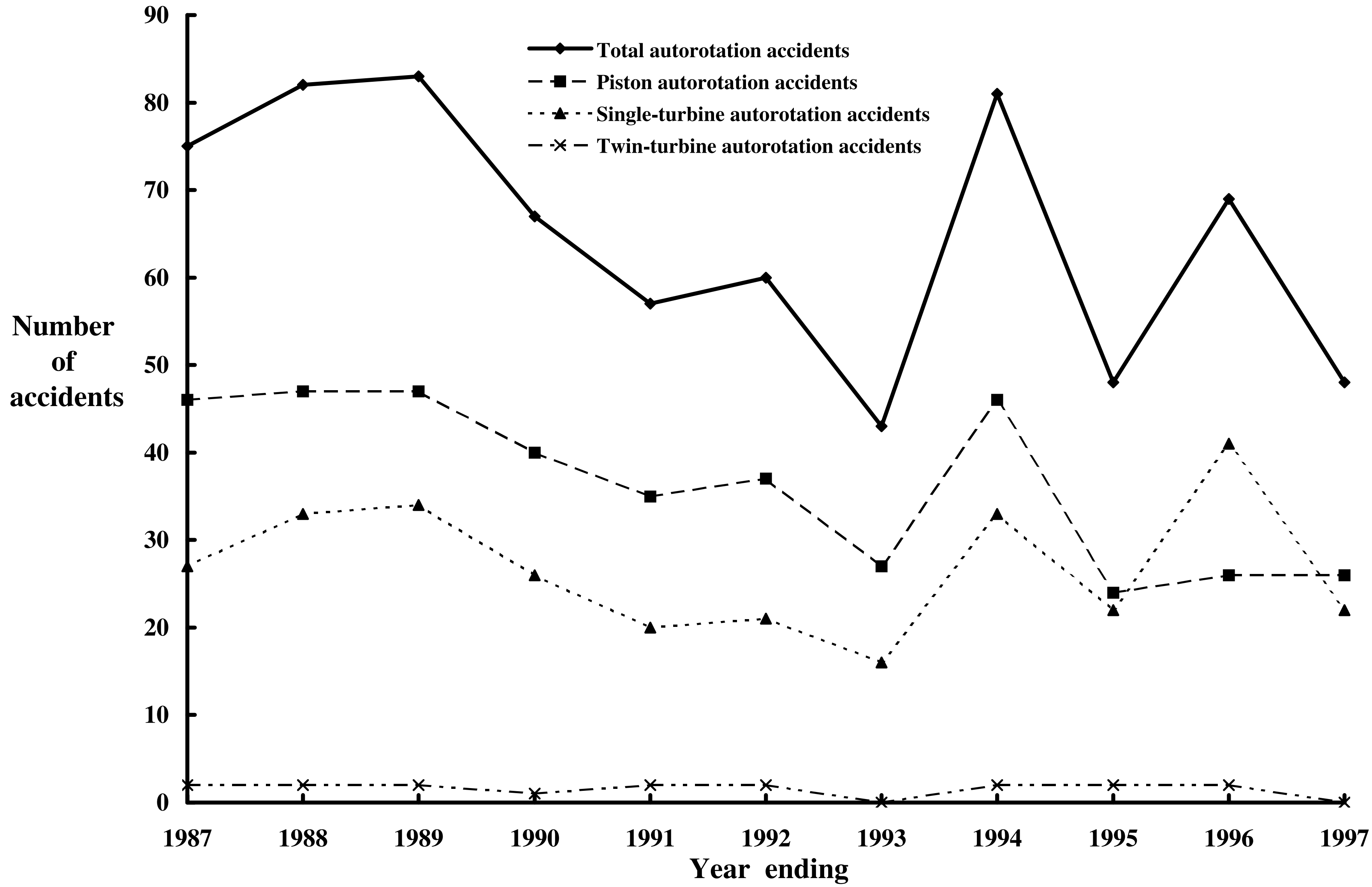

Figure C-1. Autorotation-related accidents by year.

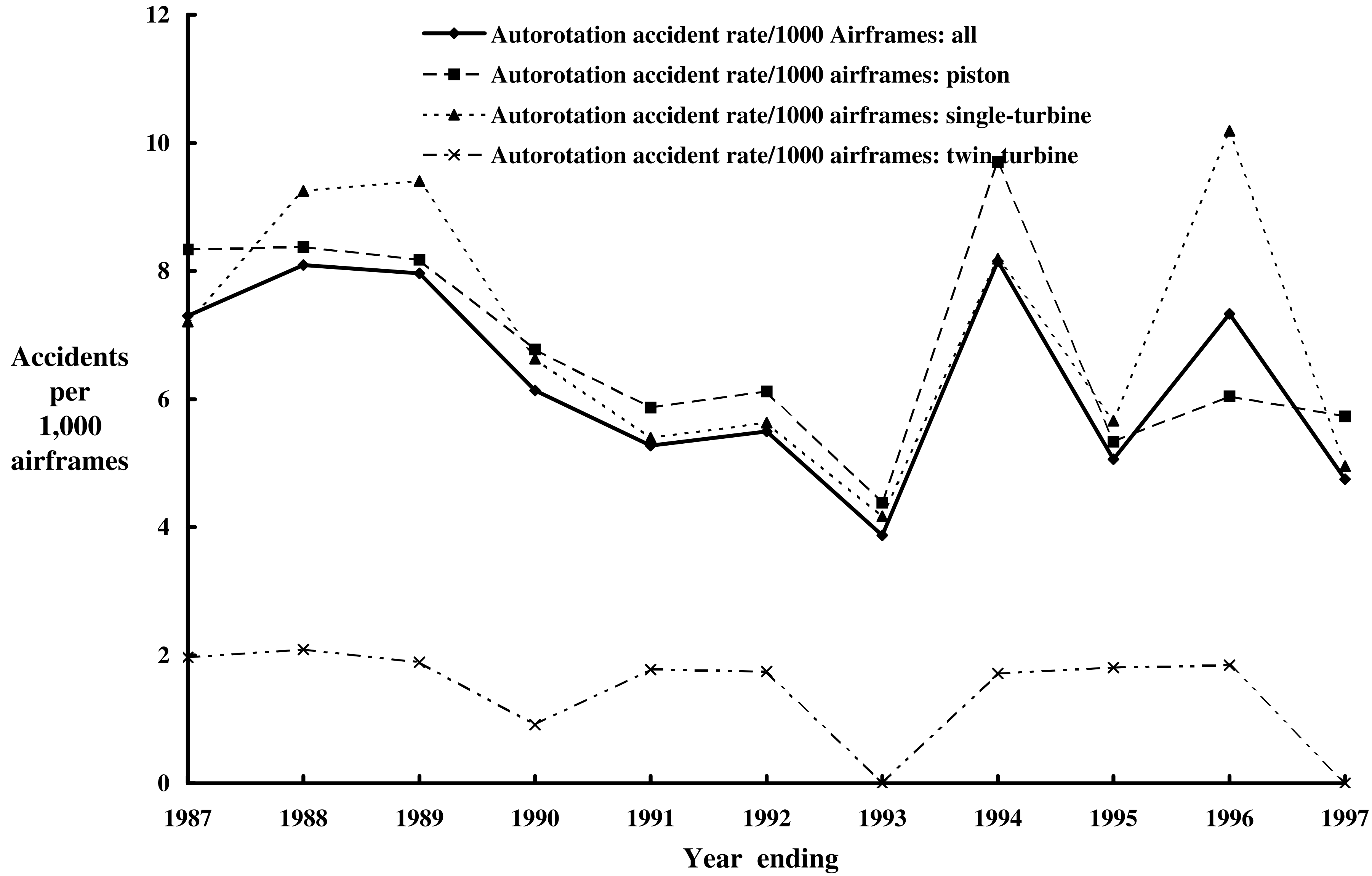

Figure C-2. Autorotation-related accidents per 1,000 airframes

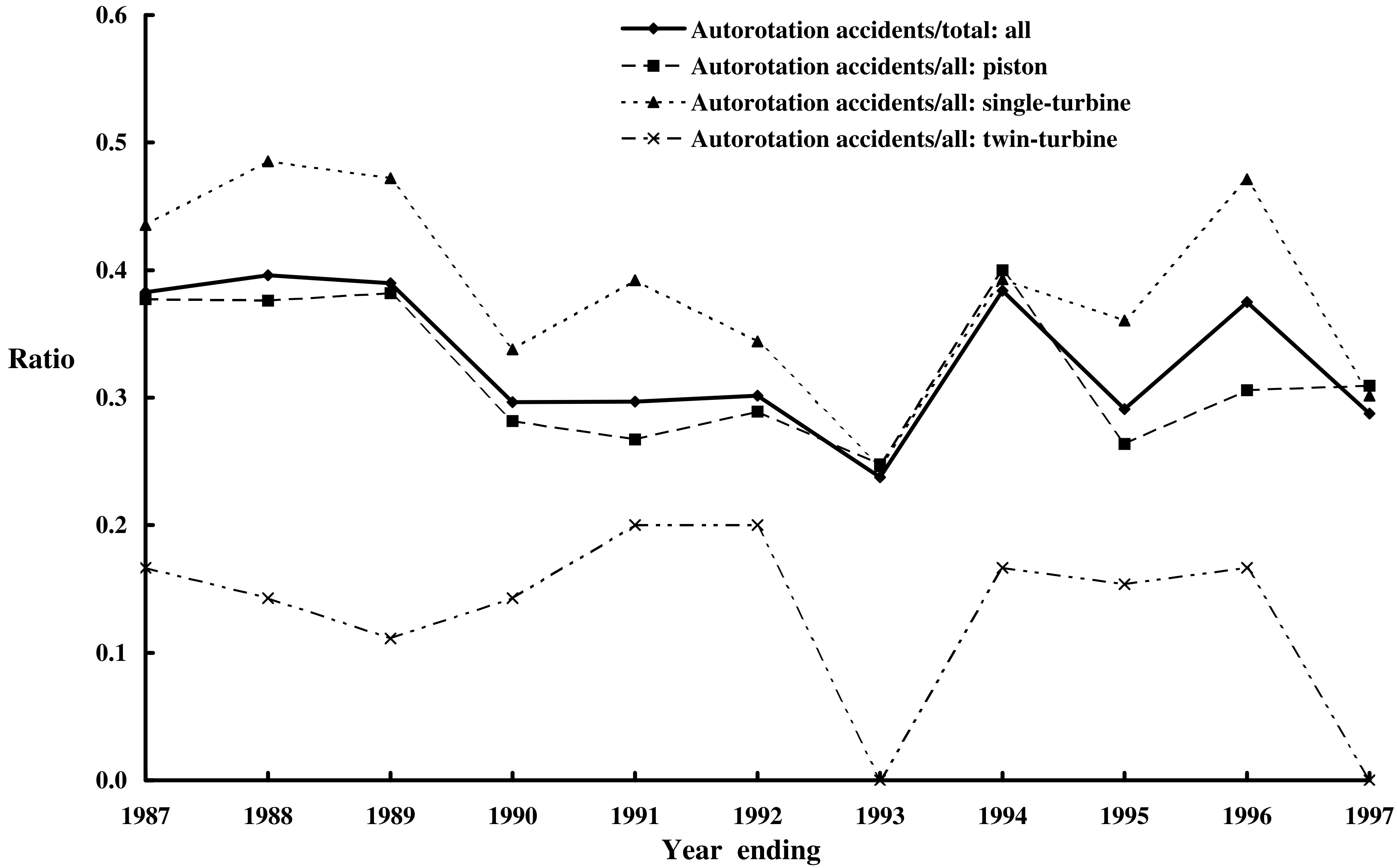

Figure C-3. Autorotation-related accident/total accident ratio.

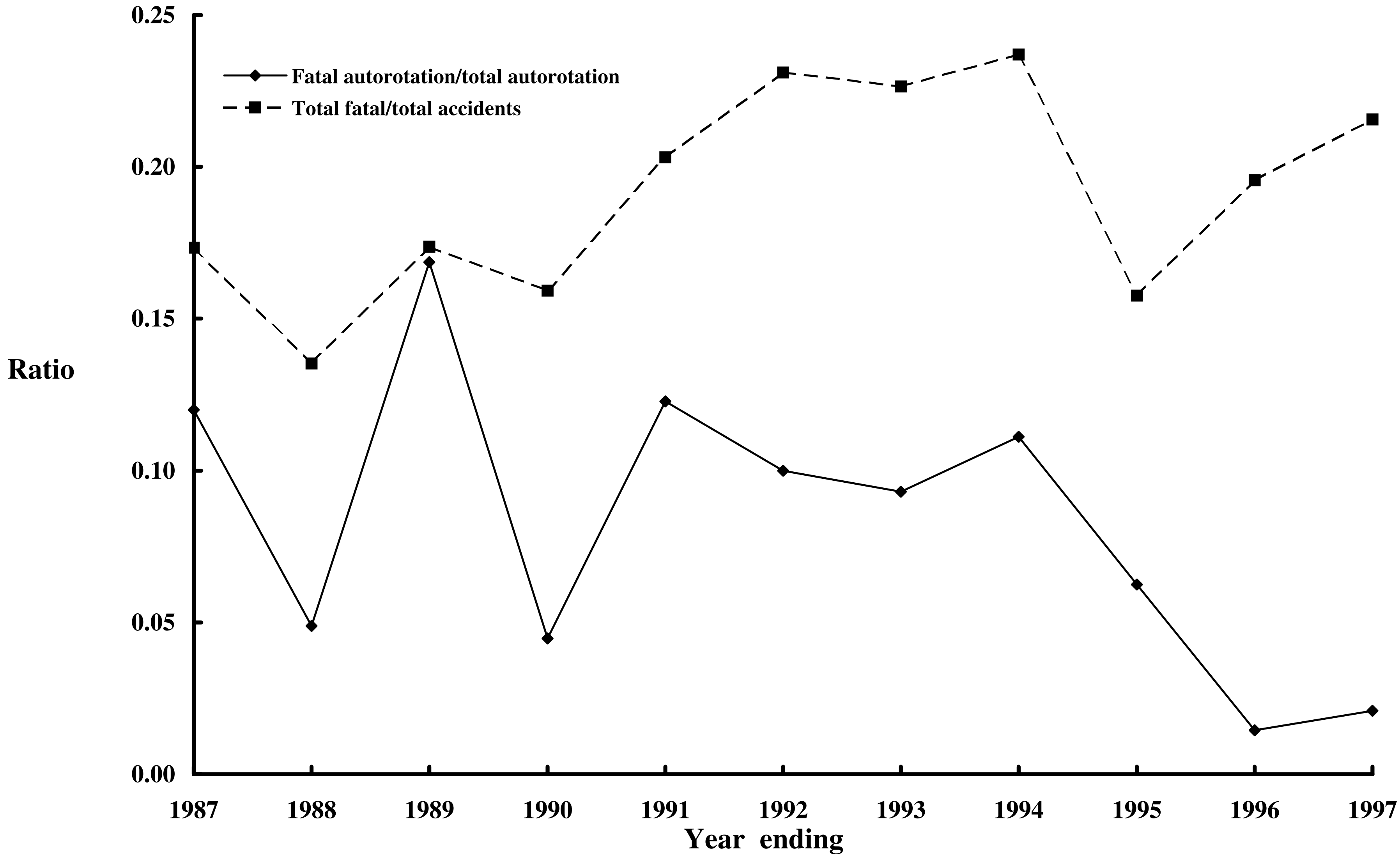

Figure C-4. Autorotation-to-total autorotation and fatal accidents-to-total accident ratios.

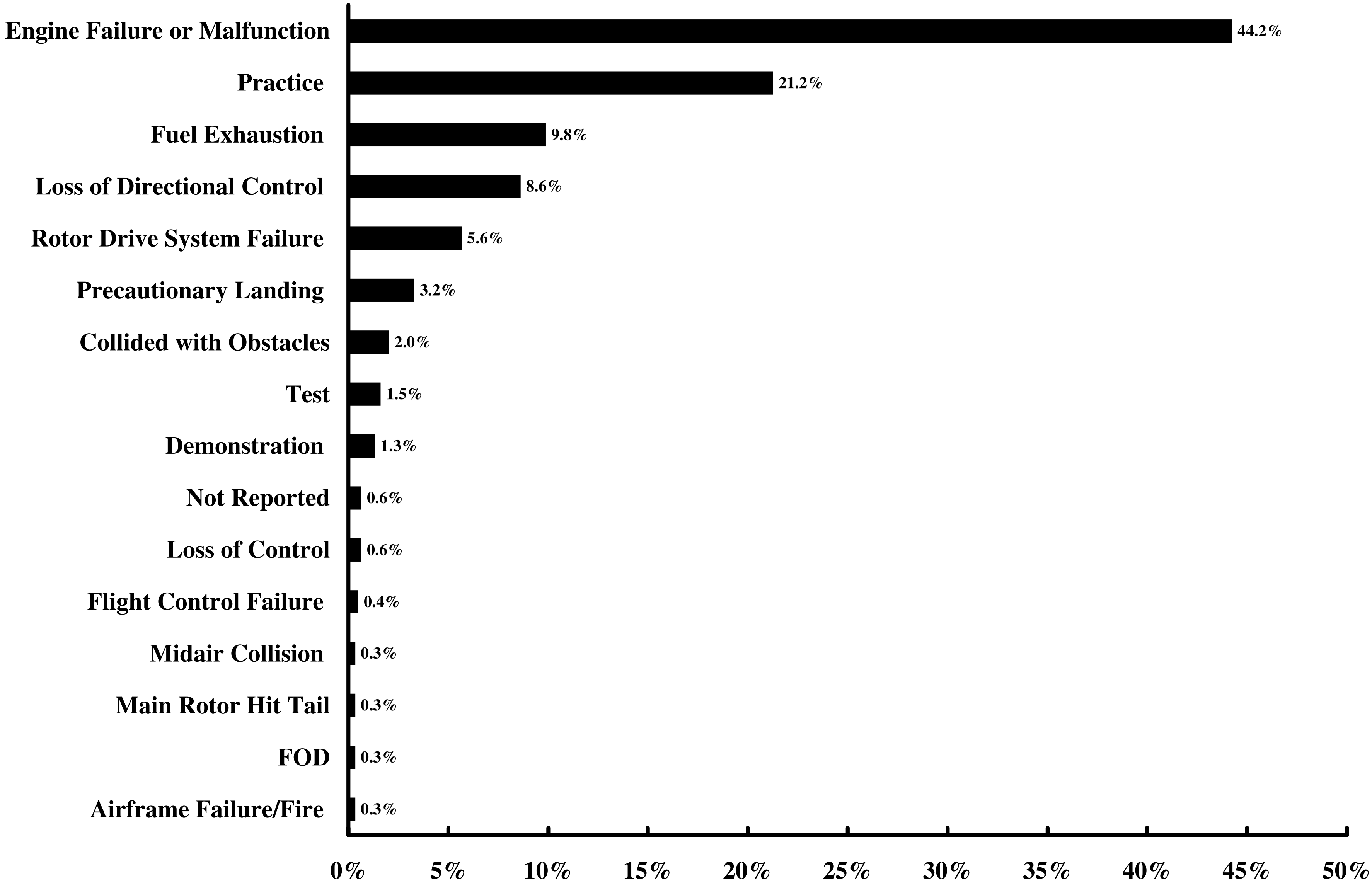

Figure C-5. Reasons for autorotation.

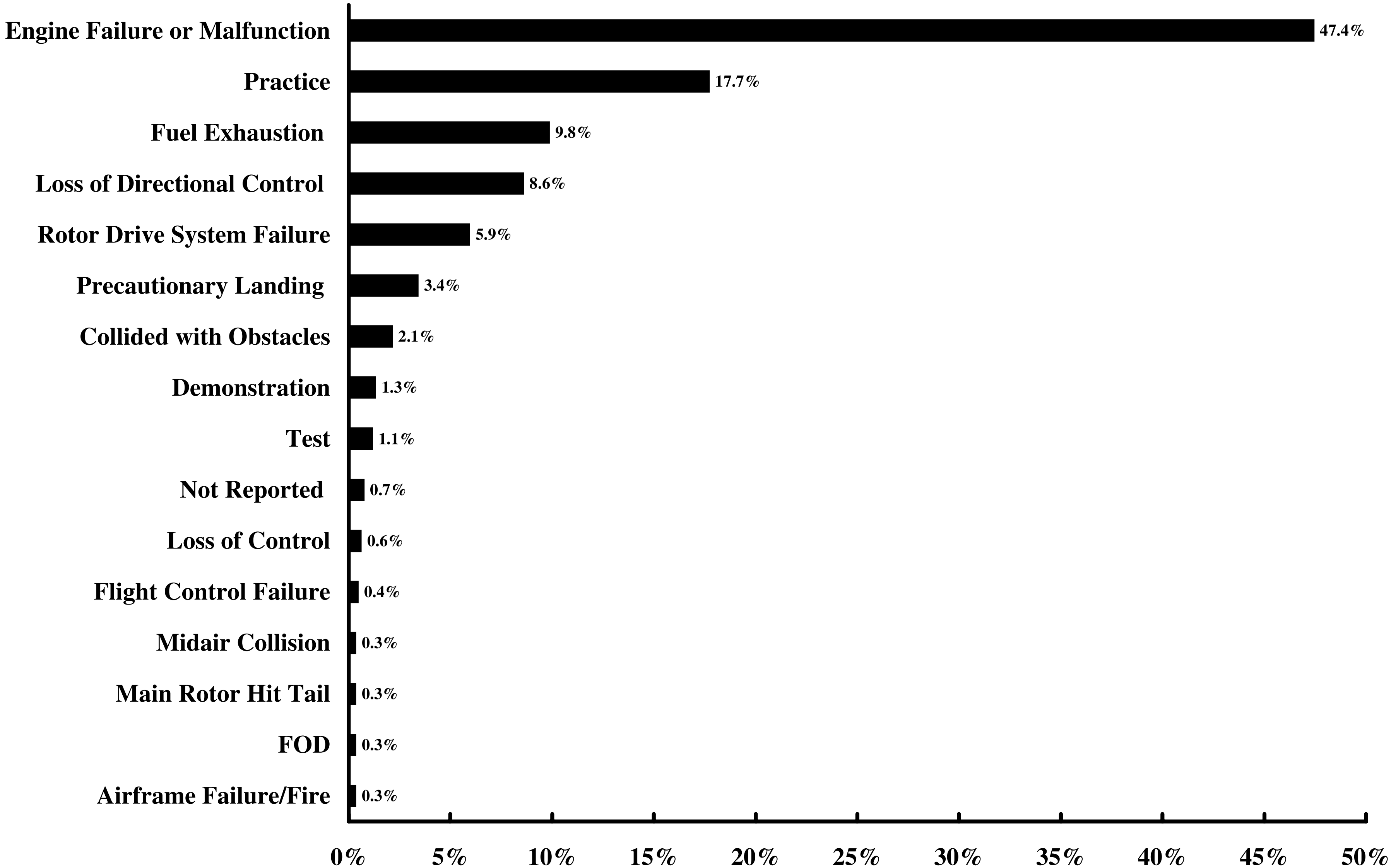

Figure C-6. Reasons for autorotation (problems during practice distributed to reasons).

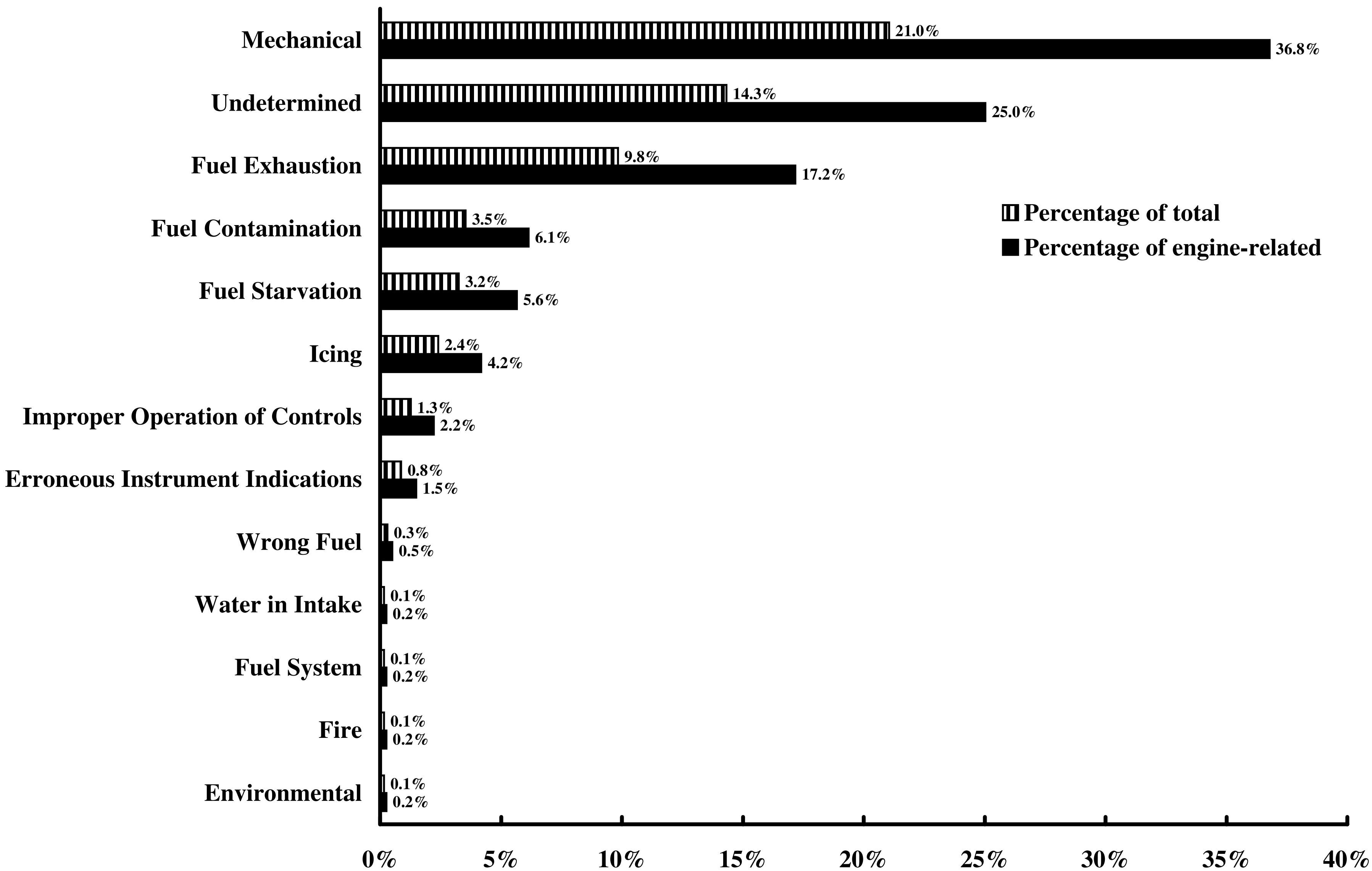

Figure C-7. Engine problems involved in autorotation accidents.

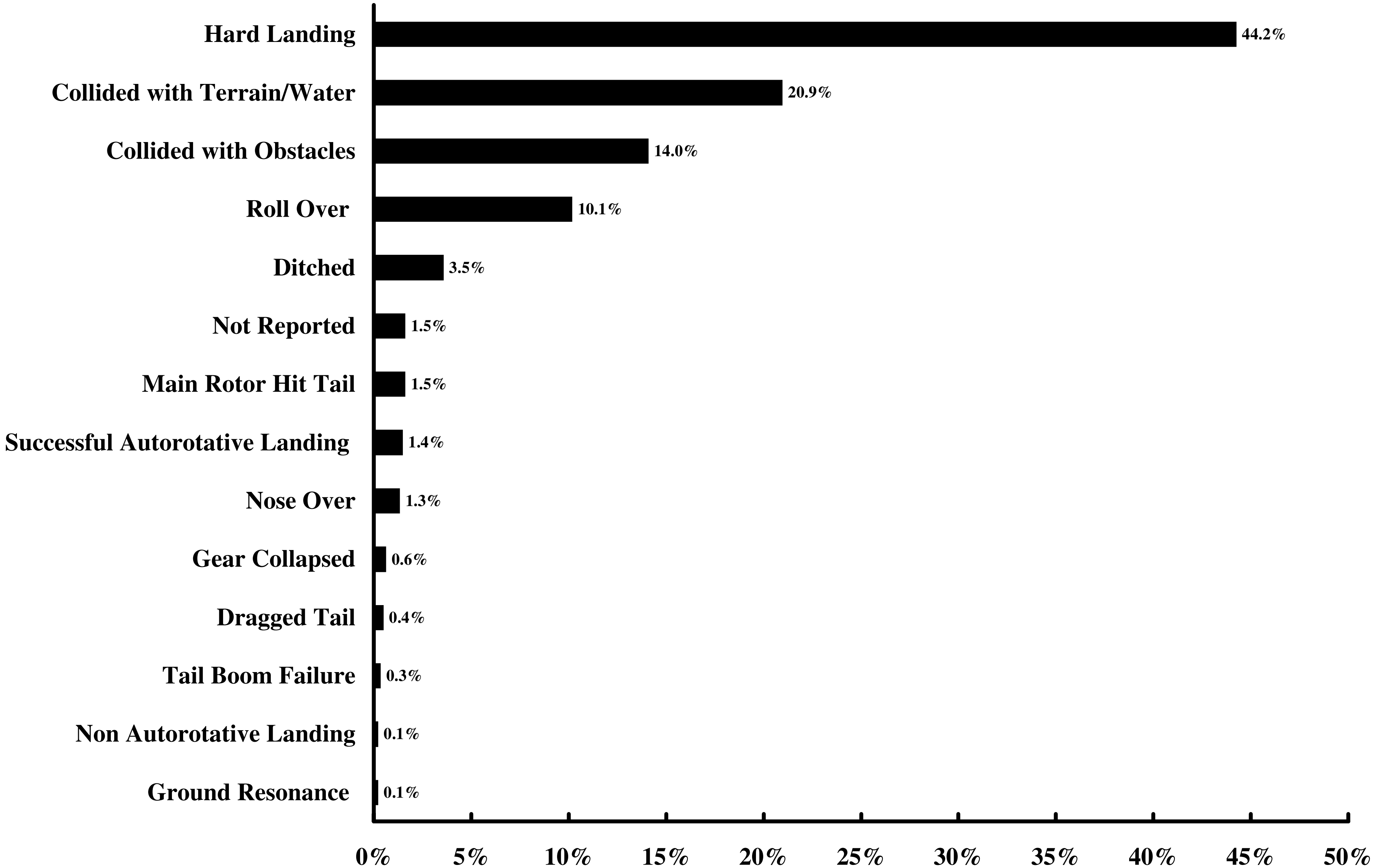

Figure C-8. Results of autorotative accident landings.

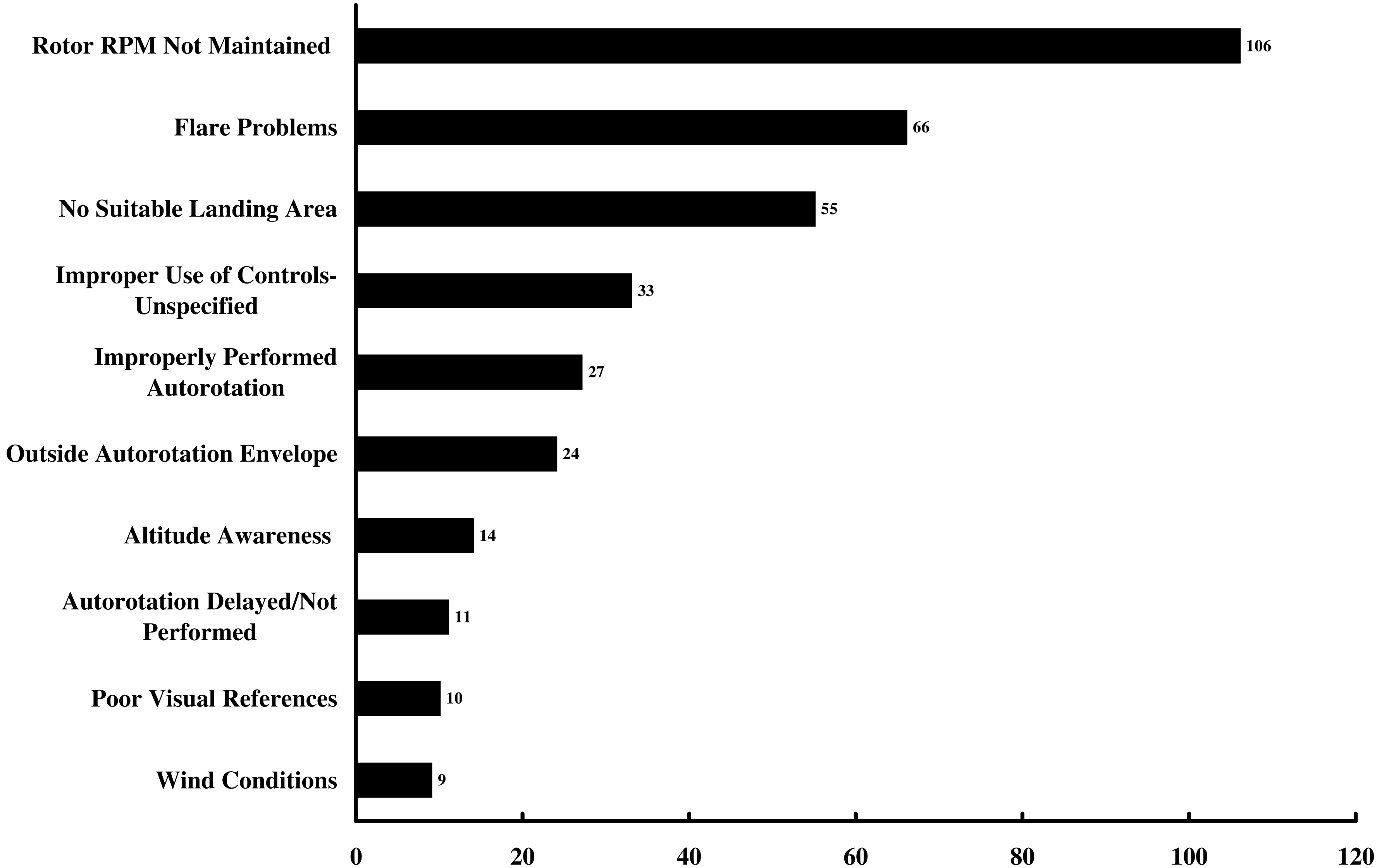

Figure C-9. Identified problems in autorotation mishaps.

Appendix D
OTHER STATISTICAL DATA TABLES

In preparing this report, the master data file was sorted into a number of data tables. Some of the most useful tables (tables D-1 through D-31) are included in this appendix. Most of figures 1 through 109 were created from these tables.

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TABLE D-1. NTSB ACCIDENT COUNT BY YEAR AND TYPE

	Count	Cum	Commercially manufactured helicopters						All other rotorcraft types							
Year	per year	count	Single Piston		Single Turbine		Twin Turbine		Auto. man.		Amateur hel.		Amateur auto.		Unknown	
end	all types	all types	Per yr	Cum	Per yr	Cum	Per yr	Cum	Per yr	Cum	Per yr	Cum	Per yr	Cum	Per yr	Cum
1963	4	4	0	0	2	2	2	2	0	0	0	0	0	0	0	0
1964	260	264	241	241	5	7	3	5	0	0	0	0	9	9	2	2
1965	243	507	223	464	5	12	1	6	8	8	0	0	4	13	2	4
1966	300	807	285	749	8	20	5	11	0	8	0	0	1	14	1	5
1967	239	1,046	221	970	15	35	2	13	0	8	0	0	0	14	1	6
1968	230	1,276	200	1,170	26	61	2	15	0	8	0	0	1	15	1	7
1969	264	1,540	217	1,387	45	106	2	17	0	8	0	0	0	15	0	7
1970	244	1,784	194	1,581	45	151	3	20	0	8	0	0	0	15	2	9
1971	220	2,004	183	1,764	31	182	2	22	0	8	3	3	0	15	1	10
1972	248	2,252	157	1,921	62	244	5	27	7	15	2	5	14	29	1	11
1973	287	2,539	195	2,116	61	305	5	32	2	17	4	9	17	46	3	14
1974	287	2,826	204	2,320	52	357	4	36	4	21	2	11	18	64	3	17
1975	315	3,141	220	2,540	72	429	5	41	0	21	3	14	11	75	4	21
1976	277	3,418	196	2,736	58	487	5	46	4	25	4	18	8	83	2	23
1977	282	3,700	187	2,923	72	559	11	57	1	26	2	20	9	92	0	23
1978	328	4,028	216	3,139	77	636	15	72	1	27	3	23	13	105	3	26
1979	296	4,324	181	3,320	90	726	6	78	0	27	6	29	12	117	1	27
1980	327	4,651	171	3,491	117	843	12	90	1	28	7	36	17	134	2	29
1981	319	4,970	168	3,659	122	965	8	98	2	30	5	41	13	147	1	30
1982	303	5,273	148	3,807	119	1,084	10	108	1	31	9	50	14	161	2	32
1983	273	5,546	134	3,941	105	1,189	18	126	1	32	2	52	10	171	3	35
1984	280	5,826	127	4,068	119	1,308	20	146	1	33	5	57	7	178	1	36
1985	238	6,064	110	4,178	98	1,406	13	159	2	35	3	60	8	186	4	40
1986	222	6,286	112	4,290	81	1,487	18	177	2	37	1	61	6	192	2	42
1987	196	6,482	101	4,391	62	1,549	12	189	2	39	7	68	11	203	1	43
1988	207	6,689	108	4,499	68	1,617	14	203	1	40	3	71	9	212	4	47
1989	213	6,902	106	4,605	72	1,689	18	221	4	44	6	77	5	217	2	49
1990	226	7,128	123	4,728	77	1,766	7	228	2	46	6	83	10	227	1	50
1991	192	7,320	120	4,848	51	1,817	10	238	1	47	3	86	6	233	1	51
1992	199	7,519	106	4,954	61	1,878	10	248	0	47	12	98	9	242	1	52
1993	181	7,700	94	5,048	65	1,943	7	255	1	48	3	101	6	248	5	57
1994	211	7,911	97	5,145	83	2,026	12	267	2	50	7	108	3	251	7	64
1995	165	8,076	83	5,228	61	2,087	13	280	0	50	5	113	2	253	1	65
1996	185	8,261	70	5,298	87	2,174	12	292	0	50	11	124	4	257	1	66
1997	175	8,436	73	5,371	73	2,247	10	302	0	50	13	137	4	261	2	68

TABLE D-2. CAA/FAA ROTORCRAFT CENSUS

Year end	Census all types	Commercially manufactured helicopters Single piston	Twin piston	Single turbine	Twin turbine	Total helicopter mfg.	Total autogyro mfg.	Amateur/ experimental total all types
1952	150	150	0	0	0	150	0	0
1953	171	171	0	0	0	171	0	0
1954	192	192	0	0	0	192	0	0
1955	306	306	0	0	0	306	0	0
1956	413	413	0	0	0	413	0	0
1957	540	463	0	0	0	463	0	77
1958	700	576	0	14	1	591	0	108
1959	882	713	1	20	1	735	9	139
1960	1,096	817	1	88	2	908	9	180
1961	1,331	1,006	0	87	10	1,103	9	219
1962	1,606	1,211	2	83	18	1,314	9	283
1963	1,915	1,501	2	52	25	1,580	8	327
1964	2,196	1,717	0	59	29	1,805	17	374
1965	2,390	1,830	0	66	29	1,925	54	411
1966	2,740	2,003	0	88	30	2,121	87	532
1967	3,175	2,141	0	193	31	2,365	88	722
1968	3,755	2,313	0	351	43	2,707	88	960
1969	4,256	2,426	0	558	43	3,027	88	1,141
1970	3,476	2,116	0	498	28	2,642	36	798
1971	3,892	2,328	1	621	33	2,983	36	873
1972	4,265	2,385	3	858	34	3,280	34	951
1973	4,723	2,633	3	993	57	3,686	32	1,005
1974	5,395	2,959	4	1,266	93	4,322	32	1,041
1975	6,011	3,260	5	1,498	148	4,911	32	1,068
1976	6,391	3,411	5	1,710	145	5,271	30	1,090
1977	6,855	3,558	5	1,976	145	5,684	28	1,143
1978	7,688	3,763	47	2,377	172	6,359	26	1,303
1979	8,380	3,942	47	2,701	205	6,895	28	1,457
1980	9,012	4,041	47	3,111	261	7,460	29	1,523
1981	9,522	4,036	47	3,494	424	8,001	27	1,494
1982	9,733	3,897	47	3,745	562	8,251	28	1,454
1983	10,047	3,960	47	3,829	646	8,482	27	1,538
1984	10,416	3,980	47	3,975	773	8,775	27	1,614
1985	10,539	4,000	47	3,965	844	8,856	28	1,645
1986	10,530	3,983	47	3,856	914	8,800	27	1,703
1987	10,374	3,909	46	3,688	932	8,575	27	1,772
1988	10,153	3,840	46	3,518	872	8,276	28	1,849
1989	10,445	3,920	46	3,574	942	8,482	27	1,936
1990	10,646	3,993	46	3,590	965	8,594	26	2,026
1991	10,834	4,037	45	3,676	1,051	8,809	31	1,994
1992	10,952	4,061	45	3,681	1,078	8,865	33	2,054
1993	11,144	4,061	45	3,676	988	8,770	29	2,345
1994	11,459	4,114	45	3,888	1,061	9,109	29	2,322
1995	11,785	4,110	45	4,114	1,051	9,322	35	2,430
1996	12,354	4,172	45	4,410	1,091	9,720	35	2,601
1997	12,911	4,220	45	4,722	1,108	10,097	34	2,782

* 1995, 1996, and 1997 are preliminary

Table D-3. FATALITIES, INJURIES AND AIRCRAFT DAMAGE (CUMULATIVE)

Year end	Cum accident count	People affected: Cum	Killed	Serious injury	Minor/ none	Rotorcraft damage (S = substantial, D = destroyed): Single piston S	Single piston D	Single turbine S	Single turbine D	Twin turbine S	Twin turbine D	Auto. man. S	Auto. man. D	Amateur hel. S	Amateur hel. D	Amateur auto. S	Amateur auto. D	Unknown S	Unknown D
1963	4	22	6	0	16	0	0	2	0	1	1	0	0	0	0	0	0	0	0
1964	264	471	33	44	394	187	52	6	1	4	1	0	0	0	0	6	3	2	0
1965	507	886	56	84	746	361	100	8	4	5	1	6	2	0	0	9	4	3	1
1966	807	1,462	102	146	1,214	575	169	14	6	10	1	6	2	0	0	9	5	4	1
1967	1,046	1,904	144	187	1,573	745	220	25	10	12	1	6	2	0	0	9	5	4	2
1968	1,276	2,389	224	220	1,945	892	272	43	17	12	3	6	2	0	0	9	6	5	2
1969	1,540	2,897	273	254	2,370	1,057	323	74	31	13	4	6	2	0	0	9	6	5	2
1970	1,784	3,376	298	278	2,800	1,205	366	110	37	15	5	6	2	0	0	9	6	6	3
1971	2,004	3,768	322	311	3,135	1,334	418	136	42	16	6	6	2	3	0	9	6	7	3
1972	2,252	4,306	386	351	3,569	1,447	459	176	59	20	7	12	3	4	1	18	10	8	3
1973	2,539	4,881	433	404	4,044	1,597	504	217	77	22	7	14	3	7	2	29	16	8	6
1974	2,826	5,410	500	451	4,459	1,728	575	251	94	24	8	17	4	9	2	41	22	10	7
1975	3,141	6,019	550	503	4,966	1,892	630	308	108	26	10	17	4	12	2	49	25	13	8
1976	3,418	6,552	614	581	5,357	2,026	692	350	124	31	10	20	5	15	3	53	29	15	8
1977	3,700	7,083	671	630	5,782	2,164	741	397	143	38	14	21	5	16	4	58	33	15	8
1978	4,028	7,713	749	698	6,266	2,313	805	443	172	47	19	22	5	18	5	64	40	17	9
1979	4,324	8,259	840	750	6,669	2,446	848	507	197	53	19	22	5	23	6	71	45	18	9
1980	4,651	8,927	942	813	7,172	2,568	897	584	232	57	24	22	6	30	6	82	51	20	9
1981	4,970	9,548	1,013	874	7,661	2,685	948	659	271	59	27	23	7	34	7	88	58	21	9
1982	5,273	10,167	1,101	952	8,114	2,797	984	730	316	62	32	23	8	38	12	96	64	21	11
1983	5,546	10,768	1,166	1,013	8,589	2,901	1,014	799	347	70	38	24	8	39	13	101	69	22	13
1984	5,826	11,382	1,246	1,088	9,048	2,988	1,050	880	379	80	46	25	8	40	17	104	73	22	14
1985	6,064	11,896	1,313	1,162	9,421	3,074	1,071	933	421	87	52	27	8	43	17	109	76	23	17
1986	6,286	12,435	1,414	1,218	9,803	3,154	1,101	975	456	99	57	27	10	43	18	110	81	23	19
1987	6,482	12,832	1,483	1,259	10,090	3,229	1,125	1,016	477	102	63	29	10	47	21	118	84	24	19
1988	6,689	13,255	1,527	1,320	10,408	3,312	1,148	1,061	497	107	68	30	10	48	23	122	89	25	22
1989	6,902	13,681	1,591	1,376	10,714	3,388	1,177	1,108	520	116	77	33	11	51	26	124	92	26	23
1990	7,128	14,147	1,640	1,427	11,080	3,481	1,206	1,157	541	120	79	35	11	57	26	128	97	27	23
1991	7,320	14,558	1,710	1,480	11,368	3,572	1,235	1,190	559	124	84	36	11	59	27	131	100	27	24
1992	7,519	14,951	1,793	1,527	11,631	3,653	1,260	1,230	579	128	88	36	11	69	29	136	104	27	25
1993	7,700	15,321	1,866	1,573	11,882	3,719	1,285	1,271	601	130	91	37	11	71	30	138	108	30	27
1994	7,911	15,763	1,951	1,623	12,189	3,792	1,309	1,320	633	135	98	38	12	75	33	138	111	36	28
1995	8,076	16,080	1,997	1,657	12,426	3,857	1,326	1,363	651	141	103	38	12	80	33	140	111	37	28
1996	8,261	16,437	2,063	1,692	12,682	3,910	1,343	1,430	669	147	108	38	12	87	37	142	112	38	28
1997	8,436	16,825	2,135	1,760	12930	3,971	1,354	1,468	702	152	112	38	12	95	42	145	113	40	28

TABLE D-4. ALL ROTORCRAFT ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	2	58	56	79	64	57	74	72	72	65	86	77	104	86	86	96	80	98	107	99	90	82	85
In flight collision with object	0	50	52	70	47	38	45	53	47	61	51	58	58	51	42	56	56	52	38	33	26	36	34
Loss of control	0	21	17	16	22	29	42	26	26	23	38	33	26	22	26	20	17	23	22	48	45	52	38
Airframe/component/system failure/malfunction	1	22	24	29	30	31	29	17	19	27	31	39	36	42	39	53	53	56	45	41	47	30	20
Hard landing	0	42	31	22	15	27	21	29	24	22	28	22	27	26	28	24	30	33	31	12	11	9	10
In flight collision with terrain/water	0	19	21	27	20	13	13	18	17	12	22	19	29	13	27	39	30	23	38	25	19	22	13
Rollover/noseover	0	15	13	10	12	15	26	15	5	15	8	24	28	32	15	23	20	21	29	9	10	10	3
Weather	0	0	0	4	2	3	0	0	1	1	1	0	0	0	0	0	2	1	1	17	8	18	11
Miscellaneous/other	0	12	9	3	4	1	0	1	0	2	2	0	4	1	2	4	2	0	1	8	4	7	9
Propeller/rotor contact to person	0	2	1	2	2	3	3	5	4	7	2	5	1	0	1	4	1	5	2	3	2	4	3
Stall/settling with power	0	9	10	20	11	6	5	1	1	5	4	0	0	1	2	2	1	1	0	0	0	0	0
Midair collision	0	0	1	4	0	0	2	2	0	0	2	4	1	0	2	0	2	5	2	2	1	2	4
On ground/water collision with object	0	3	4	5	6	0	2	0	3	2	4	1	0	0	2	3	0	0	0	3	0	3	0
Fire/explosion	0	2	1	1	1	1	0	2	1	3	2	2	1	3	3	1	0	6	2	0	3	2	2
Abrupt maneuver	0	0	0	1	2	0	0	0	0	0	2	0	0	0	0	0	0	0	1	1	3	0	2
Gear collapsed	1	1	2	3	0	1	1	1	0	2	1	1	0	0	2	0	1	1	0	0	2	0	1
Undershoot/overshoot	0	3	1	4	0	3	0	0	0	1	1	2	0	0	2	1	0	0	0	2	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Undetermined	0	1	0	0	1	2	1	1	0	0	2	0	0	0	2	2	1	2	0	0	0	1	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
Missing	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Total by year	**4**	**260**	**243**	**300**	**239**	**230**	**264**	**244**	**220**	**248**	**287**	**287**	**315**	**277**	**282**	**328**	**296**	**327**	**319**	**303**	**273**	**280**	**238**

TABLE D-4. ALL ROTORCRAFT ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB First Event Category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	65	55	60	56	62	46	55	43	61	38	43	49	**2,408**
In flight collision with object	26	21	18	31	26	12	22	25	24	24	19	20	**1,322**
Loss of control	35	43	49	40	48	43	31	41	42	32	32	46	**1,114**
Airframe/component/system failure/malfunction	32	26	32	30	26	29	23	20	22	28	32	22	**1,083**
Hard landing	8	13	10	12	7	16	12	7	16	11	10	10	**656**
In flight collision with terrain/water	11	10	8	16	14	23	22	19	16	10	10	4	**642**
Rollover/noseover	3	4	8	3	13	4	9	6	6	5	10	4	**433**
Weather	18	9	9	6	9	4	8	7	5	6	3	5	**159**
Miscellaneous/other	7	4	4	3	7	6	7	2	3	3	8	4	**134**
Propeller/rotor contact to person	4	0	2	1	4	0	1	1	1	0	1	2	**79**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	2	2	**83**
Midair collision	2	2	1	3	5	2	0	1	4	0	3	2	**61**
On ground/water collision with object	0	0	0	5	0	1	0	5	2	0	2	0	**56**
Fire/explosion	3	2	0	0	1	0	3	1	1	0	0	0	**50**
Abrupt maneuver	3	5	3	2	1	2	1	0	2	0	1	0	**32**
Gear collapsed	1	1	0	1	0	0	1	0	0	1	1	0	**27**
Undershoot/overshoot	1	1	0	0	1	0	0	0	0	0	1	0	**24**
Dragged wing, rotor, pod, float or tail/skid	3	0	3	3	2	3	2	1	0	3	1	1	**24**
Undetermined	0	0	0	0	0	0	1	1	3	0	3	4	**28**
On ground/water encounter with terrain/water	0	0	0	1	0	1	1	1	3	4	3	0	**19**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Total by year	**222**	**196**	**207**	**213**	**226**	**192**	**199**	**181**	**211**	**165**	**185**	**175**	**8,436**

TABLE D-5. MANUFACTURER SINGLE-PISTON ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	53	53	74	60	50	59	53	59	45	61	56	81	62	63	66	42	53	48	51	49	39	45
In flight collision with object	0	46	50	69	42	36	41	47	41	43	40	48	42	40	32	37	38	32	22	19	13	18	11
Loss of control	0	20	14	16	20	26	34	22	20	10	22	20	13	13	15	10	7	8	6	20	20	19	16
Airframe/component/system failure/malfunction	0	21	22	28	30	27	24	15	16	15	21	26	25	27	26	31	34	32	29	17	19	13	8
Hard landing	0	38	30	20	13	23	18	23	21	16	19	12	19	18	19	22	20	21	22	8	8	4	7
In flight collision with terrain/water	0	19	18	27	20	12	8	17	15	6	15	14	20	11	17	30	21	11	21	17	11	13	9
Rollover/noseover	0	13	12	10	11	13	22	9	4	12	6	15	17	21	7	14	13	10	16	7	7	5	3
Weather	0	0	0	4	2	2	0	0	1	0	1	0	0	0	0	0	1	1	1	6	2	5	2
Miscellaneous/other	0	11	9	2	4	1	0	0	0	1	1	0	2	0	1	1	1	0	0	3	1	6	4
Propeller/rotor contact to person	0	2	1	2	2	1	1	1	3	3	1	3	0	0	0	2	1	0	1	0	0	2	1
Stall/settling with power	0	8	7	19	11	6	5	1	0	1	3	0	0	1	2	1	0	1	0	0	0	0	0
Midair collision	0	0	1	3	0	0	2	2	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0
On ground/water collision with object	0	3	3	5	3	0	1	0	2	0	2	1	0	0	0	0	0	0	0	0	0	1	0
Fire/explosion	0	2	1	1	1	0	0	1	1	3	2	2	1	3	0	1	0	2	1	0	2	1	1
Abrupt maneuver	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Gear collapsed	0	1	2	1	0	0	1	1	0	2	0	1	0	0	1	0	1	0	0	0	0	0	1
Undershoot/overshoot	0	3	0	3	0	3	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Undetermined	0	1	0	0	0	0	1	1	0	0	1	0	0	0	2	1	1	0	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Missing	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**0**	**241**	**223**	**285**	**221**	**200**	**217**	**194**	**183**	**157**	**195**	**204**	**220**	**196**	**187**	**216**	**181**	**171**	**168**	**148**	**134**	**127**	**110**
Registered fleet size	1501	1717	1830	2003	2141	2313	2426	2116	2328	2385	2633	2959	3260	3411	3558	3763	3942	4041	4036	3897	3960	3980	4000
Accidents per 1,000 aircraft		140	122	142	103	86	89	92	79	66	74	69	67	57	53	57	46	42	42	38	34	32	28

TABLE D-5. MANUFACTURER SINGLE-PISTON ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	36	28	35	26	33	30	31	22	33	15	19	24	**1,554**
In flight collision with object	14	13	11	17	15	9	11	17	12	12	3	12	**953**
Loss of control	20	19	28	21	26	29	17	20	19	21	15	19	**625**
Airframe/component/system failure/malfunction	15	11	14	13	18	12	9	7	8	12	9	5	**639**
Hard landing	5	9	4	8	4	10	8	5	11	8	5	5	**483**
In flight collision with terrain/water	6	5	6	11	8	17	12	11	3	5	5	2	**443**
Rollover/noseover	1	3	4	1	9	4	6	4	2	3	4	2	**290**
Weather	6	5	2	1	3	1	3	4	1	1	2	0	**57**
Miscellaneous/other	3	3	2	2	3	3	3	1	2	1	2	1	**74**
Propeller/rotor contact to person	2	0	0	1	1	0	1	1	0	0	0	0	**33**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	1	**67**
Midair collision	0	1	0	0	1	0	0	1	0	0	1	0	**17**
On ground/water collision with object	0	0	0	2	0	1	0	0	1	0	1	0	**26**
Fire/explosion	0	0	0	0	0	0	1	0	1	0	0	0	**28**
Abrupt maneuver	0	3	0	0	1	1	0	0	2	0	0	0	**12**
Gear collapsed	1	0	0	0	0	0	1	0	0	1	1	0	**16**
Undershoot/overshoot	1	1	0	0	0	0	0	0	0	0	1	0	**16**
Dragged wing, rotor, pod, float or tail/skid	2	0	2	3	1	3	1	1	0	3	1	1	**20**
Undetermined	0	0	0	0	0	0	1	0	1	0	1	1	**12**
On ground/water encounter with terrain/water	0	0	0	0	0	0	1	0	1	1	0	0	**5**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Total by year	**112**	**101**	**108**	**106**	**123**	**120**	**106**	**94**	**97**	**83**	**70**	**73**	**5,371**
Registered fleet size	3983	3909	3840	3920	3993	4037	4061	4061	4114	4110	4172	4220	
Accidents per 1,000 aircraft	28	26	28	27	31	30	26	23	24	20	17	17	

TABLE D-6. MANUFACTURER SINGLE-TURBINE ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	2	3	3	4	3	7	15	18	11	15	18	17	19	19	15	21	34	39	49	42	36	37	33
In flight collision with object	0	0	1	0	5	2	4	6	6	15	10	7	14	9	9	14	15	17	13	12	10	14	21
Loss of control	0	0	0	0	2	3	8	3	3	6	8	5	4	7	5	5	7	9	12	14	17	19	15
Airframe/component/system failure/malfunction	0	0	0	1	0	1	3	0	3	6	6	6	9	8	9	14	9	17	11	18	16	13	8
Hard landing	0	2	0	1	2	3	3	6	3	6	7	3	7	5	9	2	10	10	7	3	2	4	2
In flight collision with terrain/water	0	0	0	0	0	1	5	1	2	4	3	4	7	1	9	7	7	8	14	6	5	8	4
Rollover/noseover	0	0	0	0	1	2	4	6	1	3	2	9	9	9	7	6	6	6	12	2	3	5	0
Weather	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	11	6	10	7
Miscellaneous/other	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	2	0	0	1	5	2	1	3
Propeller/rotor contact to person	0	0	0	0	0	2	2	4	1	4	0	1	1	0	1	2	0	4	1	1	2	2	1
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Midair collision	0	0	0	1	0	0	0	0	0	0	2	0	1	0	2	0	1	5	1	2	1	2	3
On ground/water collision with object	0	0	1	0	1	0	1	0	1	1	2	0	0	0	1	3	0	0	0	2	0	1	0
Fire/explosion	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	1	1	0	1	1	1
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Gear collapsed	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Total by year	**2**	**5**	**5**	**8**	**15**	**26**	**45**	**45**	**31**	**62**	**61**	**52**	**72**	**58**	**72**	**77**	**90**	**117**	**122**	**119**	**105**	**119**	**98**
Registered fleet size	52	59	66	88	193	351	558	498	621	858	993	1266	1498	1710	1976	2377	2701	3111	3494	3745	3829	3975	3965
Accidents per 1,000 aircraft		85	76	91	78	74	81	90	50	72	61	41	48	34	36	32	33	38	35	32	27	30	25

TABLE D-6. MANUFACTURER SINGLE-TURBINE ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	24	22	23	27	26	15	17	16	22	17	19	16	**704**
In flight collision with object	8	5	6	10	8	2	8	7	9	11	15	5	**298**
Loss of control	12	15	13	7	11	8	4	12	14	6	12	18	**284**
Airframe/component/system failure/malfunction	13	8	10	12	5	10	9	10	9	11	15	12	**282**
Hard landing	1	4	5	3	2	6	4	2	5	2	4	5	**140**
In flight collision with terrain/water	2	3	0	2	4	4	8	5	10	4	4	1	**143**
Rollover/noseover	1	1	2	2	4	0	3	2	4	0	5	2	**119**
Weather	11	1	5	3	5	3	4	3	3	5	1	5	**85**
Miscellaneous/other	1	0	1	1	4	2	3	1	1	2	4	3	**42**
Propeller/rotor contact to person	1	0	1	0	2	0	0	0	1	0	0	1	**35**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	1	1	**2**
Midair collision	2	1	1	2	4	1	0	0	1	0	2	2	**37**
On ground/water collision with object	0	0	0	0	0	0	0	4	0	0	0	0	**18**
Fire/explosion	2	2	0	0	1	0	0	1	0	0	0	0	**15**
Abrupt maneuver	2	0	1	2	0	0	0	0	0	0	1	0	**8**
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Undershoot/overshoot	0	0	0	0	1	0	0	0	0	0	0	0	**4**
Dragged wing, rotor, pod, float or tail/skid	1	0	0	0	0	0	1	0	0	0	0	0	**2**
Undetermined	0	0	0	0	0	0	0	1	2	0	1	2	**13**
On ground/water encounter with terrain/water	0	0	0	1	0	0	0	1	2	3	3	0	**12**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Total by year	**81**	**62**	**68**	**72**	**77**	**51**	**61**	**65**	**83**	**61**	**87**	**73**	**2,247**
Registered fleet size	3856	3688	3518	3574	3590	3676	3681	3676	3888	4114	4410	4722	
Accidents per 1,000 aircraft	21	17	19	20	21	14	17	18	21	15	20	15	

TABLE D-7. MANUFACTURER TWIN TURBINE ACCIDENT COUNT BY YEAR END AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	0	0	1	0	0	0	1	1	1	0	0	0	0	5	2	0	1	2	0	1	5	5
In flight collision with object	0	2	0	1	0	0	0	0	0	2	1	1	1	0	1	5	1	1	1	0	2	4	1
Loss of control	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1	0	1	0	3	2	5	2
Airframe/component/system failure/malfunction	1	0	0	0	0	2	2	1	0	1	1	1	1	3	1	5	4	5	3	5	9	3	2
Hard landing	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0
In flight collision with terrain/water	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	2	0	0
Rollover/noseover	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Miscellaneous/other	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	2	0	0	0
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
On ground/water collision with object	0	0	0	0	2	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0
Fire/explosion	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gear collapsed	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**2**	**3**	**1**	**5**	**2**	**2**	**2**	**3**	**2**	**5**	**5**	**4**	**5**	**5**	**11**	**15**	**6**	**12**	**8**	**10**	**18**	**20**	**13**
Registered fleet size	25	29	29	30	31	43	43	28	33	34	57	93	148	145	145	172	205	261	424	562	646	773	844
Accidents per 1,000 aircraft		103	34.5	167	64.5	46.5	46.5	107	60.6	147	87.7	43	33.8	34.5	75.9	87.2	29.3	46	18.9	17.8	27.9	25.9	15.4

TABLE D-7. MANUFACTURER TWIN TURBINE ACCIDENT COUNT BY YEAR END AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	2	1	0	0	1	1	2	1	2	2	1	1	**39**
In flight collision with object	2	2	1	3	3	1	1	1	2	1	1	1	**43**
Loss of control	2	0	2	4	1	2	0	1	1	4	0	4	**40**
Airframe/component/system failure/malfunction	3	6	6	3	1	4	4	1	1	5	3	2	**89**
Hard landing	2	0	0	0	0	0	0	0	0	0	1	0	**8**
In flight collision with terrain/water	1	0	0	2	0	1	1	2	2	1	1	0	**16**
Rollover/noseover	0	0	1	0	0	0	0	0	0	0	0	0	**4**
Weather	1	1	1	2	1	0	1	0	1	0	0	0	**12**
Miscellaneous/other	3	1	0	0	0	0	0	0	0	0	2	0	**9**
Propeller/rotor contact to person	1	0	1	0	0	0	0	0	0	0	0	1	**8**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	1	0	**1**
Midair collision	0	0	0	1	0	1	0	0	2	0	0	0	**6**
On ground/water collision with object	0	0	0	2	0	0	0	1	1	0	1	0	**10**
Fire/explosion	1	0	0	0	0	0	1	0	0	0	0	0	**5**
Abrupt maneuver	0	1	1	0	0	0	0	0	0	0	0	0	**2**
Gear collapsed	0	0	0	1	0	0	0	0	0	0	0	0	**6**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Dragged wing, rotor, pod, float or tail/skid	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Undetermined	0	0	0	0	0	0	0	0	0	0	1	1	**2**
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total by year	**18**	**12**	**14**	**18**	**7**	**10**	**10**	**7**	**12**	**13**	**12**	**10**	**302**
Registered fleet size	914	932	872	942	965	1051	1078	988	1061	1163	1203	1220	
Accidents per 1,000 aircraft	19.7	12.9	16.1	19.1	7.25	9.51	9.28	7.09	11.3	11.2	9.98	8.2	

TABLE D-8. MANUFACTURER AUTOGYRO ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB First Event Category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0	1	0	0	0	0
In flight collision with object	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Loss of control	0	0	2	0	0	0	0	0	0	2	0	1	0	0	0	0	0	1	0	1	0	0	0
Airframe/component/system failure/malfunction	0	0	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0
Hard landing	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0
In flight collision with terrain/water	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Rollover/noseover	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Miscellaneous/other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Stall/settling with power	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undershoot/overshoot	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**7**	**2**	**4**	**0**	**4**	**1**	**1**	**0**	**1**	**2**	**1**	**1**	**1**	**2**

TABLE D-8. MANUFACTURER AUTOGYRO ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB First Event Category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	0	0	0	0	0	0	0	0	1	0	0	0	**6**
In flight collision with object	1	0	0	0	0	0	0	0	0	0	0	0	**3**
Loss of control	0	1	1	2	1	0	0	1	1	0	0	0	**14**
Airframe/component/system failure/malfunction	0	0	0	1	0	1	0	0	0	0	0	0	**7**
Hard landing	0	0	0	1	0	0	0	0	0	0	0	0	**5**
In flight collision with terrain/water	1	0	0	0	1	0	0	0	0	0	0	0	**5**
Rollover/noseover	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Weather	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Miscellaneous/other	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Gear collapsed	0	1	0	0	0	0	0	0	0	0	0	0	**1**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total by year	**2**	**2**	**1**	**4**	**2**	**1**	**0**	**1**	**2**	**0**	**0**	**0**	**50**

TABLE D-9. AMATEUR HELICOPTER ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	0	0	0	0	0	0	0	1	0	2	1	0	0	1	1	2	1	2	3	1	0	0
In flight collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loss of control	0	0	0	0	0	0	0	0	2	1	2	0	1	0	1	0	2	1	2	4	1	4	1
Airframe/component/system failure/malfunction	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	2	0	0	0	0	0	0
Hard landing	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0
In flight collision with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	2	0	0	0
Rollover/noseover	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	3	1	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous/other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total By Year	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**2**	**4**	**2**	**3**	**4**	**2**	**3**	**6**	**7**	**5**	**9**	**2**	**5**	**3**

TABLE D-9. AMATEUR HELICOPTER ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	0	3	1	1	0	0	4	1	2	3	2	8	**40**
In flight collision with object	0	1	0	0	0	0	2	0	0	0	0	1	**4**
Loss of control	0	2	0	4	2	1	3	2	2	0	4	2	**44**
Airframe/component/system failure/malfunction	0	0	0	1	2	1	1	0	3	0	4	2	**19**
Hard landing	0	0	0	0	1	0	0	0	0	0	0	0	**4**
In flight collision with terrain/water	0	1	0	0	0	1	1	0	0	0	0	0	**8**
Rollover/noseover	1	0	0	0	0	0	0	0	0	2	1	0	**11**
Weather	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Miscellaneous/other	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Fire/explosion	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Abrupt maneuver	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total by year	**1**	**7**	**3**	**6**	**6**	**3**	**12**	**3**	**7**	**5**	**11**	**13**	**137**

TABLE D-10. AMATEUR AUTOGYRO ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	2	0	0	0	0	0	0	0	3	5	2	3	3	2	5	1	4	5	3	3	1	2
In flight collision with object	0	0	0	0	0	0	0	0	0	1	0	2	1	1	0	0	2	2	2	1	1	0	0
Loss of control	0	1	0	0	0	0	0	0	0	4	5	5	5	1	4	4	1	3	2	5	3	4	3
Airframe/component/system failure/malfunction	0	1	0	0	0	1	0	0	0	2	2	5	1	1	2	1	4	2	2	1	2	1	1
Hard landing	0	1	1	0	0	0	0	0	0	0	1	3	0	1	0	0	0	1	0	1	0	0	1
In flight collision with terrain/water	0	0	2	0	0	0	0	0	0	1	2	1	0	0	0	1	2	3	2	0	1	1	0
Rollover/noseover	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0	0	0	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous/other	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stall/settling with power	0	1	1	1	0	0	0	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**0**	**9**	**4**	**1**	**0**	**1**	**0**	**0**	**0**	**14**	**17**	**18**	**11**	**8**	**9**	**13**	**12**	**17**	**13**	**14**	**10**	**7**	**8**

TABLE D-10. AMATEUR AUTOGYRO ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	1	1	1	1	1	0	1	1	0	0	1	0	**52**
In flight collision with object	1	0	0	1	0	0	0	0	1	0	0	0	**16**
Loss of control	1	6	4	2	7	3	6	3	1	1	1	3	**88**
Airframe/component/system failure/malfunction	1	0	2	0	0	1	0	2	0	0	1	0	**36**
Hard landing	0	0	1	0	0	0	0	0	0	1	0	0	**12**
In flight collision with terrain/water	1	1	1	1	1	0	0	0	1	0	0	1	**23**
Rollover/noseover	0	0	0	0	0	0	0	0	0	0	0	0	**6**
Weather	0	2	0	0	0	0	0	0	0	0	0	0	**2**
Miscellaneous/other	0	0	0	0	0	1	1	0	0	0	0	0	**5**
Propeller/rotor contact to person	0	0	0	0	1	0	0	0	0	0	1	0	**2**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	**8**
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Abrupt maneuver	1	1	0	0	0	1	1	0	0	0	0	0	**6**
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	**1**
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total by year	**6**	**11**	**9**	**5**	**10**	**6**	**9**	**6**	**3**	**2**	**4**	**4**	**261**

TABLE D-11. UNKNOWN CONFIGURATION ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0
In flight collision with object	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Loss of control	0	0	0	0	0	0	0	1	0	0	1	2	2	0	0	0	0	0	0	1	2	1	1
Airframe/component/system failure/malfunction	0	0	1	0	0	0	0	1	0	1	1	0	0	0	0	2	0	0	0	0	1	0	1
Hard landing	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
In flight collision with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Rollover/noseover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous/other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stall/settling with power	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undershoot/overshoot	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**0**	**2**	**2**	**1**	**1**	**1**	**0**	**2**	**1**	**1**	**3**	**3**	**4**	**2**	**0**	**3**	**1**	**2**	**1**	**2**	**3**	**1**	**4**

TABLE D-11. UNKNOWN CONFIGURATION ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	2	0	0	1	1	0	0	2	1	1	1	0	**13**
In flight collision with object	0	0	0	0	0	0	0	0	0	0	0	1	**5**
Loss of control	0	0	1	0	0	0	1	2	4	0	0	0	**19**
Airframe/component/system failure/malfunction	0	1	0	0	0	0	0	0	1	0	0	1	**11**
Hard landing	0	0	0	0	0	0	0	0	0	0	0	0	**4**
In flight collision with terrain/water	0	0	1	0	0	0	0	1	0	0	0	0	**4**
Rollover/noseover	0	0	1	0	0	0	0	0	0	0	0	0	**2**
Weather	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Miscellaneous/other	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Midair collision	0	0	0	0	0	0	0	0	1	0	0	0	**1**
On ground/water collision with object	0	0	0	1	0	0	0	0	0	0	0	0	**1**
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	**0**
On ground/water encounter with terrain/water	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total by year	**2**	**1**	**4**	**2**	**1**	**1**	**1**	**5**	**7**	**1**	**1**	**2**	**68**

TABLE D-12. LOSS OF ENGINE POWER BY TYPE AND SUBCATEGORY

	Single piston	Single turbine	Twin turbine	All other types	Totals
Loss of engine power	**1,554**	**704**	**39**	**111**	**2408**
Mech failure/malf	413	293	22	53	781
Non-mechanical	735	227	11	35	1008
Undetermined	406	184	6	23	619
Sub - Category Classification					
Engine structure	**263**	**189**	**15**	**28**	**495**
Fuel / Air Mixture Related	**686**	**299**	**17**	**40**	**1042**
Fuel exhaustion	326	82	1	8	417
Fuel contamination	97	43	1	4	145
Fuel starvation	72	26	5	4	107
Carburetor heat	70	0	0	6	76
Fuel system	67	92	3	10	172
Fuel control	42	27	3	7	79
Fuel improper	6	3	0	1	10
Induction air system	6	26	4	0	36
Other Systems	**101**	**17**	**1**	**16**	**135**
Ignition system	69	0	0	13	82
Lubricating system	24	15	1	3	43
Accessory drive assy	8	2	0	0	10
Rotor Drive System	**53**	**7**	**0**	**2**	**62**
Clutch assembly	33	1	0	1	35
Transmission to main rotor	14	1	0	0	15
Engine to transmission drive	4	4	0	1	9
Freewheeling unit	2	1	0	0	3
Other Sub-categories	**54**	**11**	**0**	**0**	**65**
Simulated power failure	36	8	0	0	44
Rotor rpm not maintained	18	3	0	0	21
Undetermined/Other	**397**	**181**	**6**	**25**	**609**

TABLE D-13. AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION BY TYPE AND SUBCATEGORY

	Single piston		Single turbine		Twin turbine		All other types		Totals	
	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%
Drive train-main	129	20.2	44	15.6	13	14.6	7	9.6	193	17.8
Drive train-tail	111	17.4	55	19.5	18	20.2	6	8.2	190	17.5
Main rotor	54	8.5	25	8.9	15	16.9	18	24.7	112	10.3
Tail rotor	113	17.7	19	6.7	8	9.0	2	2.7	142	13.1
Control system-main	64	10.0	31	11.0	11	12.4	11	15.1	117	10.8
Control system-tail	35	5.5	19	6.7	8	9.0	0	0.0	62	5.7
Airframe	50	7.8	36	12.8	14	15.7	7	9.6	107	9.9
Landing gear	23	3.6	2	0.7	1	1.1	3	4.1	29	2.7
Other	60	9.4	51	18.1	1	1.1	19	26.0	131	12.1
Totals	**639**		**282**		**89**		**73**		**1083**	

TABLE D-14. LOS OF CONTROL BY TYPE AND SUBCATEGORY

	Single piston		**Single turbine**		**Twin turbine**		**All other types**		**Totals**	
	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%
Improper operation of controls	209	33.4	82	28.9	8	20.0	70	42.4	369	33.1
Low rotor RPM	105	16.8	8	2.8	1	2.5	13	7.9	127	11.4
Winds	72	11.5	28	9.9	5	12.5	8	4.8	113	10.1
Undetermined	44	7.0	32	11.3	4	10.0	20	12.1	100	9.0
Attached/snagged to grd. equip.	38	6.1	30	10.6	3	7.5	0	0.0	71	6.4
Flight control failure/deficiency	33	5.3	14	4.9	6	15.0	11	6.7	64	5.7
Weight/CG	29	4.6	14	4.9	0	0.0	2	1.2	45	4.0
Loss of visual ref./spatial disorient.	21	3.4	36	12.7	7	17.5	0	0.0	64	5.7
Unqualified operator	20	3.2	6	2.1	0	0.0	29	17.6	55	4.9
Airframe/comp./sys. fail. or malf.	13	2.1	7	2.5	1	2.5	6	3.6	27	2.4
Inadequate preflight planning	12	1.9	5	1.8	0	0.0	1	0.6	18	1.6
Other	9	1.4	8	2.8	1	2.5	0	0.0	18	1.6
FOD	8	1.3	7	2.5	2	5.0	1	0.6	18	1.6
Aircraft performance	6	1.0	3	1.1	0	0.0	0	0.0	9	0.8
Passenger interference	4	0.6	1	0.4	1	2.5	0	0.0	6	0.5
Pilot impairment/incapacitation	2	0.3	3	1.1	1	2.5	4	2.4	10	0.9
Totals	**625**		**284**		**40**		**165**		**1114**	

TABLE D-15. IN FLIGHT COLLISION WITH OBJECT BY TYPE AND SUBCATEGORY

	Single piston		Single turbine		Twin turbine		All other types		Totals	
	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%
Wire	310	32.5	108	36.2	13	30.2	10	35.7	441	33.4
Wire/pole	197	20.7	24	8.1	0	0.0	5	17.9	226	17.1
Tree(s)	148	15.5	50	16.8	7	16.3	6	21.4	211	16.0
Pole/pipe	47	4.9	19	6.4	2	4.7	0	0.0	68	5.1
Crop	35	3.7	1	0.3	0	0.0	0	0.0	36	2.7
Vehicle	35	3.7	4	1.3	0	0.0	0	0.0	39	3.0
Airport/helipad facility	32	3.4	20	6.7	12	27.9	0	0.0	64	4.8
Rock/brush/terrain	30	3.1	11	3.7	1	2.3	1	3.6	43	3.3
Building	27	2.8	5	1.7	1	2.3	1	3.6	34	2.6
Fence/fence post	26	2.7	20	6.7	2	4.7	0	0.0	48	3.6
FOD	19	2.0	13	4.4	1	2.3	2	7.1	35	2.6
Aircraft	14	1.5	4	1.3	2	4.7	1	3.6	21	1.6
Unspecified object	10	1.0	2	0.7	0	0.0	1	3.6	13	1.0
Electronic tower	8	0.8	9	3.0	2	4.7	0	0.0	19	1.4
Miscellaneous	8	0.8	1	0.3	0	0.0	0	0.0	9	0.7
Bird strike	7	0.7	7	2.3	0	0.0	1	3.6	15	1.1
Totals	**953**		**298**		**43**		**28**		**1322**	

TABLE D-16. HARD LANDING PLUS IN FLIGHT COLLISION WITH TERRAIN/WATER PLUS ROLLOVER/NOSEOVER BY TYPE AND SUBCATEGORY

	Single piston		Single turbine		Twin turbine		All other types		Total	
	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%
Practice/demo autorotation	318	26.2	89	22.1	3	10.7	1	1.2	411	23.7
Misjudged altitude/speed/descent rate/distance/flare	231	19.0	98	24.4	8	28.6	25	29.4	362	20.9
Improper operation of flight/throttle/power controls	197	16.2	49	12.2	6	21.4	26	30.6	278	16.1
Failed to maintain adequate rotor RPM	174	14.3	24	6.0	2	7.1	11	12.9	211	12.2
Adverse/unfavorable weather/wind	78	6.4	47	11.7	4	14.3	5	5.9	134	7.7
Emergency/precautionary landing	71	5.8	14	3.5	0	0.0	1	1.2	86	5.0
Other causes	43	3.5	26	6.5	4	14.3	9	10.6	82	4.7
Selected unsuitable terrain	34	2.8	24	6.0	0	0.0	3	3.5	61	3.5
Lift-off restricted	35	2.9	20	5.0	0	0.0	2	2.4	57	3.3
Improper weight/cg	24	2.0	5	1.2	1	3.6	1	1.2	31	1.8
Poorly maintained/Airframe failure	11	0.9	6	1.5	0	0.0	1	1.2	18	1.0
Totals	**1216**		**402**		**28**		**85**		**1731**	

TABLE D-17. ALL OTHER ROTORCRAFT TYPES ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY

NTSB first event category	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Loss of engine power	0	2	0	0	1	0	0	0	1	4	7	4	4	5	3	7	4	5	8	6	4	1	2
In flight collision with object	0	2	1	0	0	0	0	0	0	1	0	2	1	2	0	0	2	2	2	2	1	0	1
Loss of control	0	1	2	0	0	0	0	1	2	7	8	8	8	1	5	4	3	5	4	11	6	9	5
Airframe/component/system failure/malfunction	0	1	2	0	0	1	0	1	0	5	3	6	1	4	3	3	6	2	2	1	3	1	2
Hard landing	0	1	1	0	0	1	0	0	0	0	2	6	1	3	0	0	0	2	1	1	0	1	1
In flight collision with terrain/water	0	0	3	0	0	0	0	0	0	2	3	1	1	1	0	2	2	4	3	2	1	1	0
Rollover/noseover	0	2	1	0	0	0	0	0	0	0	0	0	2	1	1	3	0	4	1	0	0	0	0
Weather	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Miscellaneous/other	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	2
Propeller/rotor contact to person	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Stall/settling with power	0	1	3	1	0	0	0	0	1	4	1	0	0	0	0	1	1	0	0	0	0	0	0
Midair collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
On ground/water collision with object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Fire/explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Abrupt maneuver	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	2
Gear collapsed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Undershoot/overshoot	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total by year	**0**	**11**	**14**	**2**	**1**	**2**	**0**	**2**	**4**	**24**	**26**	**27**	**18**	**18**	**12**	**20**	**19**	**27**	**21**	**26**	**16**	**14**	**17**
Registered fleet size	327	374	411	532	722	960	1141	798	873	951	1005	1041	1068	1090	1143	1303	1457	1523	1494	1454	1538	1614	1645
Accidents per 1,000 aircraft		29.4	34.1	3.76	1.39	2.08	0	2.51	4.58	25.2	25.9	25.9	16.9	16.5	10.5	15.3	13	17.7	14.1	17.9	10.4	8.67	10.3

TABLE D-17. ALL OTHER ROTORCRAFT TYPES ACCIDENT COUNT BY YEAR AND BY FIRST EVENT CATEGORY (CONCLUDED)

NTSB first event category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Cum
Loss of engine power	3	4	2	3	2	0	5	4	4	4	4	8	**111**
In flight collision with object	2	1	0	1	0	0	2	0	1	0	0	2	**28**
Loss of control	1	9	6	8	10	4	10	8	8	1	5	5	**165**
Airframe/component/system failure/malfunction	1	1	2	2	2	3	1	2	4	0	5	3	**73**
Hard landing	0	0	1	1	1	0	0	0	0	1	0	0	**25**
In flight collision with terrain/water	2	2	2	1	2	1	1	1	1	0	0	1	**40**
Rollover/noseover	1	0	1	0	0	0	0	0	0	2	1	0	**20**
Weather	0	2	1	0	0	0	0	0	0	0	0	0	**5**
Miscellaneous/other	0	0	1	0	0	1	1	0	0	0	0	0	**9**
Propeller/rotor contact to person	0	0	0	0	1	0	0	0	0	0	1	0	**3**
Stall/settling with power	0	0	0	0	0	0	0	0	0	0	0	0	**13**
Midair collision	0	0	0	0	0	0	0	0	1	0	0	0	**1**
On ground/water collision with object	0	0	0	1	0	0	0	0	0	0	0	0	**2**
Fire/explosion	0	0	0	0	0	0	1	0	0	0	0	0	**2**
Abrupt maneuver	1	1	1	0	0	1	1	0	0	0	0	0	**10**
Gear collapsed	0	1	0	0	0	0	0	0	0	0	0	0	**2**
Undershoot/overshoot	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Dragged wing, rotor, pod, float or tail/skid	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	**1**
On ground/water encounter with terrain/water	0	0	0	0	0	1	0	0	0	0	0	0	**2**
Missing	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total By Year	**11**	**21**	**17**	**17**	**19**	**11**	**22**	**15**	**19**	**8**	**16**	**19**	**516**
Registered Fleet Size	1703	1772	1849	1936	2026	1994	2054	2345	2321	2625	2798	2979	
Accidents per 1,000 aircraft	6.5	11.9	9.2	8.8	9.4	5.5	10.7	6.4	8.2	3.0	5.7	6.4	

TABLE D-18. HARD LANDING BY TYPE AND SUBCATEGORY

	Single piston		Single turbine		Twin turbine		All other types		Total	
	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%	Cnt.	%
Practice/demo autorotation	236	48.9	76	54.3	3	37.5	0	0.0	315	48.0
Misjudged altitude/speed/descent rate/distance/flare	54	11.2	18	12.9	0	0.0	11	44.0	83	12.7
Failed to maintain adequate rotor RPM	56	11.6	10	7.1	0	0.0	3	12.0	69	10.5
Emergency/precautionary landing	48	9.9	12	8.6	0	0.0	0	0.0	60	9.1
Adverse/unfavorable weather/wind	32	6.6	11	7.9	2	25.0	2	8.0	47	7.2
Improper operation of flight/throttle/power controls	34	7.0	5	3.6	2	25.0	4	16.0	45	6.9
Other causes	23	4.8	8	5.7	1	12.5	5	20.0	37	5.6
Totals	**483**		**140**		**8**		**25**		**656**	

TABLE D-19. LOSS OF ENGINE POWER STATISTICS

People involved	Single piston	Single turbine	Twin turbine	All other types	Loss of power totals	All accidents totals
Fatal	106	129	16	17	257	2,135
Serious	234	237	26	23	494	1,760
Minor/none	2,281	1,480	99	93	3,879	12,930
Total	**2,621**	**1,846**	**141**	**133**	**4,630**	**16,825**
Aircraft damage						
None	0	10	1	0	11	78
Minor	3	9	4	1	17	85
Substantial	1,286	546	21	82	1,935	5,909
Destroyed	265	139	13	28	445	2,363
Unkown	0	0	0	0	0	1
Total	**1,554**	**704**	**39**	**111**	**2,408**	**8,436**
Flight activity						
Unknown/not reported	2	3	0	0	5	22
Public/military use	27	16	0	0	43	183
Executive/corporate	26	33	3	0	62	203
Flight/maintenance test	30	26	3	9	68	239
Ferry/reposition	80	53	5	1	139	389
Business use	97	71	4	3	175	581
Instructional/training	173	15	0	14	202	1,198
Passenger service	117	215	11	0	343	1,161
Personal use	231	58	1	80	370	1,351
General utility	277	162	11	3	453	1,457
Aerial application	494	52	1	1	548	1,652
Total	**1,554**	**704**	**39**	**111**	**2,408**	**8,436**
Phase of operation (common nomenclature)						
Standing/static	1	2	0	0	3	250
Unknown	3	1	0	1	5	89
Taxi	10	0	0	1	11	238
Other	18	5	0	1	24	108
Climb	35	15	2	4	56	128
Descent	72	24	2	5	103	259
Landing	60	33	2	13	108	1,359
Hover	53	58	8	2	121	757
Approach	87	64	2	14	167	467
Takeoff	280	104	8	26	418	1,405
Maneuvering	328	84	2	8	422	1,519
Cruise	607	314	13	36	970	1,857
Total	**1,554**	**704**	**39**	**111**	**2,408**	**8,436**

TABLE D-20. FAA ROTORCRAFT CENSUS AND HOURS FLOWN PER YEAR (REF. TABLES D-21 A, B, C)

Year end	Census all registered types	Census all active types	Census all registered pistons	Census all active pistons	Census all registered turbines	Census all active turbines	Hours flown per year by active rotorcraft: Total fleet	All piston	All turbine	Reference
1964	2,196	1,325	2,105	1,266	91	59	447,000	??	??	FAA Stat. Handbook of Av.,1965, Table 5.1
1965	2,390	1,525	2,290	1,456	100	69	450,000	??	??	FAA Stat. Handbook of Av.,1966, Table 5.1
1966	2,740	1,652	2,614	1,564	126	88	492,000	??	??	FAA Stat. Handbook of Av.,1967, Table 5.2
1967	3,175	1,925	2,844	1,733	231	192	538,000	??	??	FAA Stat. Handbook of Av.,1968, Table 5.2
1968	3,755	2,373	3,355	2,033	400	340	617,000	??	??	FAA Stat. Handbook of Av.,1969, Table 9.7
1969	4,256	2,584	3,642	2,065	614	519	778,000	??	??	Table 30, 1969
1970	3,476	2,275	2,793	1,669	683	606	844,268	543,062	301,206	GA Activity and Avionics Survey (R. Fox)
1971	3,892	2,375	3,095	1,692	797	683	869,400	516,891	352,509	GA Activity and Avionics Survey (R. Fox)
1972	4,265	2,787	3,373	1,957	892	830	1,018,523	591,138	427,385	GA Activity and Avionics Survey (R. Fox)
1973	4,723	3,143	3,673	2,157	1,050	986	1,169,000	654,000	515,000	Census Table 3.7, 1979
1974	5,395	3,597	4,036	2,315	1,359	1,282	1,426,000	729,000	697,000	Census Table 3.7, 1979
1975	6,011	4,054	4,365	2,498	1,646	1,556	1,482,000	686,000	796,000	Census Table 3.7, 1979
1976	6,391	4,425	4,536	2,701	1,855	1,724	1,703,000	753,000	950,000	Census Table 3.7, 1979
1977	6,855	4,726	4,734	2,658	2,121	2,067	1,868,000	609,000	1,259,000	Census Table 3.7, 1979
1978	7,688	5,315	5,139	2,822	2,549	2,492	2,227,651	806,410	1,421,241	Census Table 3.6, 1979, 1983, 1984, 1991
1979	8,380	5,864	5,474	3,123	2,906	2,740	2,555,000	892,000	1,664,000	Census Table 3.7, 1984 &1991
1980	9,012	6,001	5,640	2,794	3,372	3,207	2,338,000	736,000	1,603,000	Census Table 3.7, 1989
1981	9,522	6,974	5,604	3,250	3,918	3,724	2,685,000	930,000	1,754,000	Census Table 3.7, 1991
1982	9,733	6,169	5,426	2,419	4,307	3,749	2,350,000	579,000	1,771,000	Census Table 3.7, 1991
1983	10,047	6,540	5,572	2,541	4,475	3,998	2,271,000	572,000	1,700,000	Census Table 3.8, 1993
1984	10,416	7,096	5,668	2,936	4,748	4,160	2,495,000	592,000	1,903,000	Census Table 3.8, 1993
1985	10,539	6,000	5,720	2,700	4,809	3,300	1,990,000	521,000	1,468,000	Census Table 3.8, 1993*
1986	10,530	6,500	5,760	2,700	4,770	3,800	2,424,000	742,000	1,682,000	Census Table 3.8, 1993*
1987	10,374	5,900	5,754	2,600	4,620	3,300	2,108,000	602,000	1,506,000	Census Table 3.8, 1993*
1988	10,153	6,000	5,763	2,400	4,390	3,600	2,507,000	533,000	1,974,000	Census Table 3.8, 1993*
1989	10,445	7,000	5,929	3,000	4,516	4,000	2,610,000	692,000	1,918,000	Census Table 3.8, 1993*
1990	10,646	6,900	6,091	3,200	4,555	3,700	2,209,000	716,000	1,493,000	Census Table 3.8, 1993*
1991	10,834	6,292	6,107	2,470	4,727	3,822	2,757,000	585,000	2,172,000	Census Table 3.8, 1993*
1992	10,952	5,753	6,193	2,211	4,759	3,542	2,283,000	416,000	1,866,000	Census Table 3.8, 1993*
1993	11,144	4,510	6,480	1,646	4,664	2,864	1,832,000	370,000	1,462,000	Census Table 3.8, 1994
1994	11,459	4,390	6,510	1,381	4,949	3,009	2,006,000	340,000	1,666,000	Census Table 3.8, 1994
1995	11,785	5,830	6,620	1,863	5,165	3,967	1,961,000	337,000	1,624,000	GA Activity Survey, Table 1.5, 1997
1996	12,354	6,570	6,853	2,507	5,501	4,063	2,122,000	591,000	1,531,000	GA Activity Survey, Table 1.5, 1997
1997	12,911	6,786	7,081	2,259	5,830	4,527	2,083,699	343,841	1,739,858	GA Activity Survey, Table 1.4, 1997

*Earlier data revised [downward] to correct for nonresponsive bias

TABLE D-21A. FAA ROTORCRAFT CENSUS

Year end	All registered types	All active types	All reg. pistons	All active pistons	All reg. turbines	All active turbines	Reference	Hours flown per year by active rotorcraft: Total active fleet	All active piston	All active turbine	Reference
1964	2,196	1,325	2,105	1,266	91	59	Table 1, 1964	447,000	??	??	FAA Stat. Handbook of Aviation,1965, Table 5.1
1965	2,390	1,525	2,290	1,456	100	69	Table 1, 1965	450,000	??	??	FAA Stat. Handbook of Aviation,1966, Table 5.1
1966	2,740	1,652	2,614	1,564	126	88	Table 1, 1966	492,000	??	??	FAA Stat. Handbook of Aviation,1967, Table 5.2
1967	3,175	1,925	2,844	1,733	231	192	Table 1, 1967	538,000	??	??	FAA Stat. Handbook of Aviation,1968, Table 5.2
1968	3,755	2,373	3,355	2,033	400	340	Table 1, 1968	617,000	??	??	FAA Stat. Handbook of Aviation,1969, Table 9.7
1969	4,256	2,584	3,642	2,065	614	519	Table 1, 1969	778,000	573,000	205,000	Table 30, 1969
1970	3,476	2,275	2,793	1,669	683	606	Table 6, 1970, 1971	867,000	552,000	315,000	Table 29, 1971/1970
1971	3,892	2,375	3,095	1,692	797	683	Table 6, 1970, 1971	891,000	527,000	364,000	Table 29A, 1971/1970
1972	4,265	2,787	3,373	1,957	892	830	Table 21, 1972	1,018,523	591,138	427,385	Table 29, 1972
1973	4,723	3,143	3,673	2,157	1,050	986	Table 20,1973	1,169,000	654,000	515,000	Table 3.7, 1979
1974	5,395	3,623	4,036	2,332	1,359	1,291	Table 6,1974	1,426,000	729,000	697,000	Table 3.7, 1979
1975	6,011	4,085	4,365	2,502	1,646	1,583	Table 6,1975	1,482,000	686,000	796,000	Table 3.7, 1979
1976	6,391	4,513	4,536	2,753	1,855	1,760	Table 6,1976	1,703,000	753,000	950,000	Table 3.7, 1979

TABLE D-21B. FAA ROTORCRAFT CENSUS

Year end	All registered types	All active types	All reg. pistons	All active pistons	All reg. turbines	All active turbines	Reference	Hours flown per year by active rotorcraft: Total active fleet	All active piston	All active turbine	Reference
1973	4,723	3,115	3,673	2,122	1,050	993	Table 3.5,1979	1,169,000	654,000	515,000	Table 3.7, 1979
1974	5,395	3,597	4,036	2,315	1,359	1,282	Table 3.5,1979	1,426,000	729,000	697,000	Table 3.7, 1979
1975	6,011	4,054	4,365	2,498	1,646	1,556	Table 3.5,1979	1,482,000	686,000	796,000	Table 3.7, 1979
1976	6,391	4,425	4,536	2,701	1,855	1,724	Table 3.5,1979	1,703,000	753,000	950,000	Table 3.7, 1979
1977	6,855	4,726	4,734	2,658	2,121	2,067	Table 3.5,1979	1,868,000	609,000	1,259,000	Table 3.7, 1979
1978	7,688	5,315	5,139	2,822	2,549	2,492	Table 3.5, 1979, 1983	2,227,651	806,410	1,421,241	Table 3.6, 1979, 1983
1979	8,380	5,864	5,474	3,123	2,906	2,740	Table 3.5, 1983, 1984	2,555,000	892,000	1,664,000	Table 3.7, 1983, 1984, 1989
1980	9,012	6,001	5,640	2,794	3,372	3,207	Table 3.5, 1983, 1984, 1989	2,338,000	736,000	1,603,000	Table 3.7, 1983, 1984, 1989
1981	9,522	6,974	5,604	3,250	3,918	3,724	Table 3.5, 1983, 1984, 1989, 1991	2,685,000	930,000	1,754,000	Table 3.7, 1983, 1984, 1989, 1991
1982	9,733	6,169	5,426	2,419	4,307	3,749	Table 3.5, 1983, 1984, 1989, 1991	2,350,000	579,000	1,771,000	Table 3.7, 1983, 1984, 1989, 1991
1983	10,047	6,540	5,572	2,541	4,475	3,998	Table 3.5, 1984, 1989, 1991	2,271,000	572,000	1,700,000	Table 3.7, 1984, 1989, 1991
1984	10,416	7,096	5,668	2,936	4,748	4,160	Table 3.5, 1989, 1991	2,495,000	592,000	1,903,000	Table 3.7, 1989, 1991
1985	10,539	6,418	5,720	2,877	4,809	3,541	Table 3.5, 1989, 1991	2,155,000	564,000	1,590,000	Table 3.7, 1989, 1991
1986	10,530	6,943	5,760	2,921	4,770	4,022	Table 3.5, 1989, 1991	2,625,000	804,000	1,821,000	Table 3.7, 1989, 1991
1987	10,374	6,333	5,754	2,813	4,620	3,520	Table 3.5, 1989, 1991	2,283,000	652,000	1,631,000	Table 3.7, 1989, 1991
1988	10,153	6,406	5,763	2,584	4,390	3,822	Table 3.5, 1989, 1991	2,707,000	576,000	2,131,000	Table 3.7, 1989, 1991
1989	10,445	7,475	5,929	3,244	4,516	4,232	Table 3.5,1991	2,826,000	749,000	2,077,000	Table 3.7, 1991
1990	10,646	7,397	6,091	3,459	4,555	3,938	Table 3.5,1991	2,392,000	775,000	1,617,000	Table 3.7, 1991

TABLE D-21C. FAA ROTORCRAFT CENSUS

Year end	All registered types	All active types	All reg. pistons	All active pistons	All reg. turbines	All active turbines	Reference
1985	10,539	6,000	5,720	2,700	4,809	3,300	Table 3.5,1993*, Table 1.7 1994
1986	10,530	6,500	5,760	2,700	4,770	3,800	Table 3.5,1993*, Table 1.7 1994
1987	10,374	5,900	5,754	2,600	4,620	3,300	Table 3.5,1993*, Table 1.7 1994
1988	10,153	6,000	5,763	2,400	4,390	3,600	Table 3.5,1993*, Table 1.7 1994
1989	10,445	7,000	5,929	3,000	4,516	4,000	Table 3.5,1993*, Table 1.7 1994
1990	10,646	6,900	6,091	3,200	4,555	3,700	Table 3.5,1993*, Table 1.7 1994
1991	10,834	6,292	6,107	2,470	4,727	3,822	Table 3.5,1993*, Table 1.7 1994
1992	10,952	5,753	6,193	2,211	4,759	3,542	Table 3.5,1993*, Table 1.7 1994
1993	11,144	4,510	6,480	1,646	4,664	2,864	Table 3.5,1993*, Table 1.7 1994
1994	11,459	4,390	6,510	1,381	4,949	3,009	Table 3.5,1993*, Table 1.7 1994
1995	11,785	5,830	6,620	1,863	5,165	3,967	GA Act. Survey, Table 1.2, 1997
1996	12,354	6,570	6,853	2,507	5,501	4,063	GA Act. Survey, Table 1.2, 1997
1997	12,911	6,786	7,081	2,259	5,830	4,527	GA Act. Survey, Table 1.1, 1997

Hours flown per year by active rotorcraft

Year end	Total active fleet	All active piston	All active turbine	Reference
1985	1,990,000	521,000	1,468,000	Table 3.8, 1993*
1986	2,424,000	742,000	1,682,000	Table 3.8, 1993*
1987	2,108,000	602,000	1,506,000	Table 3.8, 1993*
1988	2,507,000	533,000	1,974,000	Table 3.8, 1993*
1989	2,610,000	692,000	1,918,000	Table 3.8, 1993*
1990	2,209,000	716,000	1,493,000	Table 3.8, 1993*
1991	2,757,000	585,000	2,172,000	Table 3.8, 1993*
1992	2,283,000	416,000	1,866,000	Table 3.8, 1993*
1993	1,832,306	370,103	1,462,206	Table 3.7, 1994
1994	2,006,470	340,189	1,666,282	Table 3.7A, 1994
1995	1,961,000	337,000	1,624,000	GA Act. Survey, Table 1.5, 1997
1996	2,122,000	591,000	1,531,000	GA Act. Survey, Table 1.5, 1997
1997	2,083,699	343,841	1,739,858	GA Act. Survey, Table 1.4, 1997

*Earlier data revised [downward] to correct for nonresponse bias

TABLE D-22. GENERAL AVIATION ACTIVITY AND AVIONICS SURVEY SUMMARY FOR SELECTED YEARS

Year end	Rotorcraft type	Census	Approximate population	Sample size	Postmaster returns	Counted responses	Response rate*	Active rotorcraft	Fleet hours	Average hours
1977	**Total rotorcraft**	**6,855**	**6,845**	**1,924**	**na**	**1,548**	**80.5**	**4,725**	**1,867,644**	**396.3**
	Total piston	4,734	4,652	1,486	na	1,189	80.0	2,658	608,603	230.5
	Total turbine	2,121	2,193	438	na	359	82.0	2,067	1,259,041	608.3
	Single	1,976	na	na	na	na	na	na	na	na
	Multi	145	na	na	na	na	na	na	na	na
1987	**Total rotorcraft**	**10,374**	**10,034**	**3,171**	**na**	**1,555**	**49.0**	**6,333**	**2,283,000**	**360.5**
	Total Piston	5,754	5,555	2,360	na	1,185	50.2	2,813	652,000	231.8
	Total Turbine	4,620	4,479	811	na	370	45.6	3,520	1,631,000	463.4
	Single	3,688	na	na	na	na	na	na	na	na
	Multi	932	na	na	na	na	na	na	na	na
1988	**Total rotorcraft**	**10,153**	**9,768**	**2,965**	**na**	**1,417**	**47.8**	**6,406**	**2,706,719**	**423.3**
	Total piston	5,763	5,334	2,078	na	979	47.1	2,584	575,955	227.9
	Total turbine	4,390	4,434	887	na	438	49.4	3,822	2,130,764	576.7
	Single	3,518	na	na	na	na	na	na	na	na
	Multi	872	na	na	na	na	na	na	na	na
1989**	**Total rotorcraft**	**10,445**	**10,469**	**10,469**	**1,874**	**6,725**	**78.2**	**7,488**	**2,828,696**	**377.8**
	Manufacturer built									
	Piston	3,993	3,994	3,994	720	2,488	76.0	2,684	728,125	277.8
	Single turbine	3,574	3,616	3,616	648	2,549	85.9	3,248	1,532,270	480.5
	Multi-turbine	942	1,069	1,069	184	709	80.1	984	546,471	551.8
	Amateur built	1,936	1,790	1,790	322	979	66.7	572	21,830	38.2

* Adjusted for postmaster returns [i. e., 100*counted responses / (sample size – postal returns)]

** One time only Rotorcraft Activity Survey of all registered rotorcraft in the United States (Normal GAAAS not conducted for rotorcraft)

TABLE D-22. GENERAL AVIATION ACTIVITY AND AVIONICS SURVEY SUMMARY FOR SELECTED YEARS (CONTINUED)

Year end	Rotorcraft type	Census	Approximate population	Sample size	Postmaster returns	Counted responses	Response rate*	Active rotorcraft	Fleet hours	Average hours
1990	**Total rotorcraft**	**10,646**	**10,422**	**2,313**	**na**	**1,221**	**52.8**	**7,394**	**2,392,066**	**320.7**
	Total piston	6,091	5,802	1,505	na	783	52.0	3,456	774,774	216.4
	Total turbine	4,555	4,620	808	na	438	54.2	3,938	1,617,292	424.9
	Single	3,590	na	na	na	na	na	na	na	na
	Multi	965	na	na	na	na	na	na	na	na
1991	**Total rotorcraft**	**10,834**	**10,474**	**2,856**	**na**	**1,331**	**46.6**	**6,292**	**2,755,599**	**451.6**
	Total piston	6,107	5,848	1,786	na	814	45.6	2,470	583,688	233.7
	Total turbine	4,727	4,626	1,070	na	517	48.3	3,822	2,171,911	592.2
	Single	3,676	na	na	na	na	na	na	na	na
	Multi	1,051	na	na	na	na	na	na	na	na
1992	**Total Rotorcraft**	**10,952**	**9,599**	**3,101**	**na**	**1,522**	**49.1**	**5,752**	**2,282,701**	**381.7**
	Total piston	6,193	5,209	1,918	na	980	51.1	2,211	416,375	184.6
	Total turbine	4,759	4,390	1,183	na	542	45.8	3,541	1,866,326	491.3
	Single	3,681	na	na	na	na	na	na	na	na
	Multi	1,078	na	na	na	na	na	na	na	na
1993	**Total rotorcraft**	**11,144**	**8,220**	**2,919**	**155**	**1,545**	**52.9**	**4,508**	**1,832,305**	**398.6**
	Total piston	6,480	4,274	1,741	115	952	58.5	1,645	370,099	218.8
	Total turbine	4,664	3,946	1,178	40	593	52.1	2,863	1,462,206	506.0
	Single	3,676	3,040	780	32	381	50.9	2,144	1,072,604	501.8
	Multi	988	906	398	8	212	54.4	719	389,602	525.5

* Adjusted for postmaster returns [i. e., 100*counted responses / (sample size – postal returns)]

TABLE D-22. GENERAL AVIATION ACTIVITY AND AVIONICS SURVEY SUMMARY FOR SELECTED YEARS (CONCLUDED)

Year end	Rotorcraft type	Census	Approximate population	Sample size	Postmaster returns	Counted responses	Response rate*	Active rotorcraft	Fleet hours	Average hours
1994	**Total rotorcraft**	**11,459**	**7,866**	**1,307**	**148**	**683**	**52.3**	**4,388**	**2,006,459**	**458.6**
	Total piston	6,510	3,485	643	85	345	61.8	1,380	340,183	252.7
	Total turbine	4,949	4,381	664	63	338	56.2	3,008	1,666,276	571.4
	Single	3,888	3,528	493	48	242	54.4	2,298	1,197,043	526
	Multi	1,061	853	171	15	96	61.5	710	469,233	762
1995	**Total rotorcraft**	**11,785**	**8,217**	**1,557**	**121**	**737**	**47.3**	**5,117**	**2,332,905**	**439.2**
	Total piston	6,620	3,428	718	62	333	50.8	1,474	341,241	233.7
	Total turbine	5,165	4,789	839	59	404	51.8	3,643	1,991,664	528.1
	Single	4,114	3,760	569	38	279	52.5	2,773	1,450,197	504
	Multi	1,051	1,029	270	21	125	50.2	870	541,467	637
1996	**Total rotorcraft**	**12,354**	**8,279**	**1,397**	**70**	**749**	**56.4**	**6,390**	**2,026,000**	**317.1**
	Total piston	6,853	3,488	644	32	335	54.7	2,415	574,000	237.7
	Total turbine	5,501	4,791	753	38	414	57.9	3,975	1,452,000	365.3
	Single	4,410	3,880	542	30	302	59.0	3,329	1,202,000	361.1
	Multi	1,091	911	211	8	112	55.2	646	250,000	387.0
1997	**Total rotorcraft**	**12,911**	**8,455**	**2,727**	**170**	**1,489**	**58.2**	**6,785**	**2,083,699**	**307.0**
	Total piston	7,081	3,378	1,130	84	545	52.1	2,259	343,841	152.2
	Total turbine	5,830	5,077	1,597	86	944	62.5	4,526	1,739,858	384.3
	Single	4,722	4,061	1,178	66	660	59.4	3,762	1,310,878	348.4
	Multi	1,108	1,016	419	20	284	71.2	764	428,980	561.0

* Adjusted for postmaster returns [i. e., 100*counted responses / (sample size – postal returns)]

TABLE D-23. ACCIDENT AND FATALITY COUNT, HOURS FLOWN AND ACCIDENT RATE BY YEAR AND TYPE AND TYPE

Year end	Accidents per year All types	Accidents All piston Per year	Accidents all turbine Per year	Fatalities Per year All types	100,000 hours flown per year by active rotorcraft Total fleet	All piston	All turbine	Accidents per 100,000 hours flown per year Total fleet	All piston	All Tturbine	Fatalities per 100,000 hrs Total fleet
1963	4	0	4	6	??	??	??	??	??	??	??
1964	260	252	8	27	4.47	??	??	58.17	??	??	6.04
1965	243	237	6	23	4.50	??	??	54.00	??	??	5.11
1966	300	287	13	46	4.92	??	??	60.98	??	??	9.35
1967	239	222	17	42	5.38	??	??	44.42	??	??	7.81
1968	230	202	28	80	6.17	??	??	37.28	??	??	12.97
1969	264	217	47	49	7.78	5.73	2.05	33.93	37.87	22.93	6.30
1970	244	196	48	25	8.44	5.43	3.01	28.90	36.09	15.94	2.96
1971	220	187	33	24	8.69	5.17	3.53	25.30	36.18	9.36	2.76
1972	248	181	67	64	10.19	5.91	4.27	24.35	30.62	15.68	6.28
1973	287	221	66	47	11.69	6.54	5.15	24.55	33.79	12.82	4.02
1974	287	231	56	67	14.26	7.29	6.97	20.13	31.69	8.03	4.70
1975	315	238	77	50	14.82	6.86	7.96	21.26	34.69	9.67	3.37
1976	277	214	63	64	17.03	7.53	9.50	16.27	28.42	6.63	3.76
1977	282	199	83	57	18.68	6.09	12.59	15.10	32.68	6.59	3.05
1978	328	236	92	78	22.28	8.06	14.21	14.72	29.27	6.47	3.50
1979	296	200	96	91	25.55	8.92	16.64	11.59	22.42	5.77	3.56
1980	327	198	129	102	23.38	7.36	16.03	13.99	26.90	8.05	4.36
1981	319	189	130	71	26.85	9.30	17.54	11.88	20.32	7.41	2.64
1982	303	174	129	88	23.50	5.79	17.71	12.89	30.05	7.28	3.74
1983	273	150	123	65	22.71	5.72	17.00	12.02	26.22	7.24	2.86
1984	280	141	139	80	24.95	5.92	19.03	11.22	23.82	7.30	3.21
1985	238	127	111	67	19.90	5.21	14.68	11.96	24.38	7.56	3.37
1986	222	123	99	101	24.24	7.42	16.82	9.16	16.58	5.89	4.17
1987	196	122	74	69	21.08	6.02	15.06	9.30	20.27	4.91	3.27
1988	207	125	82	44	25.07	5.33	19.74	8.26	23.45	4.15	1.76
1989	213	123	90	64	26.10	6.92	19.18	8.16	17.77	4.69	2.45
1990	226	142	84	49	22.09	7.16	14.93	10.23	19.83	5.63	2.22
1991	192	131	61	70	27.57	5.85	21.72	6.96	22.39	2.81	2.54
1992	199	128	71	83	22.83	4.16	18.66	8.72	30.77	3.80	3.64
1993	181	109	72	73	18.32	3.70	14.62	9.88	29.46	4.92	3.98
1994	211	116	95	85	20.06	3.40	16.66	10.52	34.12	5.70	4.24
1995	165	91	74	46	19.61	3.37	16.24	8.41	27.00	4.56	2.35
1996	185	86	99	66	21.22	5.91	15.31	8.72	14.55	6.47	3.11
1997	175	92	83	72	20.84	3.44	17.40	8.40	26.76	4.77	3.46

TABLE D-24. MANUFACTURER SINGLE-PISTON ACCIDENT SUMMARY

NTSB accident first event category	People involved	Fatalities	Serious	Minor/none	Aircraft involved	Destroyed	Substantial	Minor	None	Unknown
Loss of engine power	2,621	106	234	2,281	1,554	265	1,286	3	0	0
In flight collision with object	1,417	166	205	1,046	953	327	620	4	2	0
Loss of control	1,048	92	105	851	625	194	428	3	0	0
Airframe/component/system failure/malfunction	1,051	153	109	789	639	212	422	3	2	0
Hard landing	915	4	35	876	483	51	430	2	0	0
In flight collision with terrain/water	708	47	61	600	443	119	323	1	0	0
Rollover/noseover	519	8	17	494	290	53	237	0	0	0
Weather	97	21	7	69	57	23	34	0	0	0
Miscellaneous/other	133	13	8	112	74	20	49	1	4	0
Stall/settling with power	120	6	15	99	67	21	46	0	0	0
Propeller/rotor contact to person	57	14	9	34	33	2	12	7	12	0
Midair collision	43	22	3	18	17	13	3	1	0	0
On ground/water collision with object	43	1	2	40	26	0	26	0	0	0
Fire/explosion	38	2	5	31	28	22	6	0	0	0
Abrupt maneuver	19	5	1	13	12	4	8	0	0	0
Undetermined	21	18	1	2	12	11	1	0	0	0
Gear collapsed	29	0	0	29	16	4	12	0	0	0
Dragged wing, rotor, pod, float or tail/skid	29	2	1	26	20	6	14	0	0	0
Undershoot/overshoot	33	2	0	31	16	6	10	0	0	0
On ground/water encounter with terrain/water	7	0	0	7	5	1	4	0	0	0
Missing	1	1	0	0	1	0	0	0	0	1
Total	**8,949**	**683**	**818**	**7,448**	**5,371**	**1,354**	**3,971**	**25**	**20**	**1**

TABLE D-25. MANUFACTURER SINGLE-TURBINE ACCIDENT SUMMARY

NTSB accident first event category	People involved	Fatalities	Serious	Minor/none	Aircraft involved	Destroyed	Substantial	Minor	None	Unknown
Loss of engine power	1,846	129	237	1,480	704	139	546	9	10	0
In flight collision with object	688	140	106	442	298	114	182	0	2	0
Loss of control	754	155	123	476	284	125	159	0	0	0
Airframe/component/system failure/malfunction	705	157	110	438	282	111	163	4	4	0
In flight collision with terrain/water	389	104	52	233	143	68	75	0	0	0
Hard landing	359	3	14	342	140	11	128	0	1	0
Rollover/noseover	275	13	9	253	119	22	96	1	0	0
Weather	246	107	32	107	85	54	30	0	1	0
Miscellaneous/other	186	9	15	162	42	7	20	1	14	0
Midair collision	195	66	17	112	37	21	9	5	2	0
Propeller/rotor contact to person	108	12	13	83	35	0	14	15	6	0
On ground/water collision with object	58	0	4	54	18	1	16	1	0	0
Fire/explosion	37	5	0	32	15	10	4	1	0	0
Undetermined	39	34	4	1	13	11	2	0	0	0
On ground/water encounter with terrain/water	23	0	0	23	12	1	11	0	0	0
Abrupt maneuver	30	7	7	16	8	3	5	0	0	0
Undershoot/overshoot	18	2	0	16	4	3	1	0	0	0
Gear collapsed	5	0	0	5	3	0	3	0	0	0
Stall/settling with power	6	5	0	1	2	0	2	0	0	0
Dragged wing, rotor, pod, float or tail/skid	5	0	0	5	2	0	2	0	0	0
Missing	3	3	0	0	1	1	0	0	0	0
Total	**5,975**	**951**	**743**	**4,281**	**2,247**	**702**	**1,468**	**37**	**40**	**0**

TABLE D-26. MANUFACTURER TWIN-TURBINE ACCIDENT SUMMARY

NTSB accident first event category	People involved	Fatalities	Serious	Minor/none	Aircraft involved	Destroyed	Substantial	Minor	None	Unknown
Airframe/component/system failure/malfunction	452	148	37	267	89	34	40	8	7	0
In flight collision with object	175	35	29	111	43	16	25	2	0	0
Loss of control	135	38	14	83	40	17	22	1	0	0
Loss of engine power	141	16	26	99	39	13	21	4	1	0
In flight collision with terrain/water	52	18	4	30	16	10	6	0	0	0
Weather	29	16	3	10	12	9	2	1	0	0
On ground/water collision with object	80	18	2	60	10	2	8	0	0	0
Miscellaneous/other	30	6	1	23	9	2	4	0	3	0
Hard landing	23	0	2	21	8	1	6	1	0	0
Propeller/rotor contact to person	48	3	2	43	8	0	1	1	6	0
Midair collision	32	13	3	16	6	3	3	0	0	0
Gear collapsed	54	4	1	49	6	0	4	2	0	0
Fire/explosion	27	0	0	27	5	1	3	1	0	0
Rollover/noseover	18	0	0	18	4	1	3	0	0	0
Abrupt maneuver	6	2	0	4	2	1	1	0	0	0
Undetermined	5	1	0	4	2	1	1	0	0	0
Stall/settling with power	1	0	0	1	1	0	1	0	0	0
Dragged wing, rotor, pod, float or tail/skid	2	0	0	2	1	0	1	0	0	0
Undershoot/overshoot	6	3	0	3	1	1	0	0	0	0
On ground/water encounter with terrain/water	0	0	0	0	0	0	0	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0
Total	**1,316**	**321**	**124**	**871**	**302**	**112**	**152**	**21**	**17**	**0**

TABLE D-27. ALL OTHER ROTORCRAFT TYPES ACCIDENT SUMMARY

NTSB accident first event category	People involved	Fatalities	Serious	Minor/none	Aircraft involved	Destroyed	Substantial	Minor	None	Unknown
Loss of control	175	77	21	77	165	78	87	0	0	0
Loss of engine power	133	17	23	93	111	28	82	1	0	0
Airframe/component/system failure/malfunction	78	43	6	29	73	40	33	0	0	0
In flight collision with terrain/water	45	13	7	25	40	13	27	0	0	0
In flight collision with object	35	11	6	18	28	13	15	0	0	0
Hard landing	29	0	1	28	25	3	22	0	0	0
Rollover/noseover	25	4	2	19	20	3	17	0	0	0
Stall/settling with power	13	0	3	10	13	3	10	0	0	0
Abrupt maneuver	11	8	1	2	10	8	2	0	0	0
Miscellaneous/other	9	1	1	7	9	1	8	0	0	0
Weather	7	0	1	6	5	1	4	0	0	0
Propeller/rotor contact to person	6	1	1	4	3	0	1	1	1	0
Undershoot/overshoot	3	1	0	2	3	0	3	0	0	0
On ground/water collision with object	2	0	0	2	2	1	1	0	0	0
Fire/explosion	5	0	0	5	2	1	1	0	0	0
Gear collapsed	2	0	2	0	2	0	2	0	0	0
On ground/water encounter with terrain/water	3	2	0	1	2	1	1	0	0	0
Midair collision	2	1	0	1	1	0	1	0	0	0
Undetermined	1	1	0	0	1	1	0	0	0	0
Dragged wing, rotor, pod, float or tail/skid	1	0	0	1	1	0	1	0	0	0
Missing	0	0	0	0	0	0	0	0	0	0
Totals	**585**	**180**	**75**	**330**	**516**	**195**	**318**	**2**	**1**	**0**

TABLE D-28. ACCIDENT SUMMARY BY TYPE OF ACTIVITY AND PHASE OF OPERATION

Activity	Single piston	Single turbine	Twin turbine	All other types	Totals
Aerial application	1,494	150	4	4	1,652
General utility	875	520	49	13	1,457
Personal use	787	200	6	358	1,351
Instructional/training	976	127	13	82	1,198
Passenger service	421	642	97	1	1,161
Business use	338	209	23	11	581
Ferry/reposition	205	135	46	3	389
Flight/maintenance test	113	67	16	43	239
Executive/corporate	75	97	31	0	203
Public/military use	78	93	12	0	183
Unknown/not reported	9	7	5	1	22
Total	**5,371**	**2,247**	**302**	**516**	**8,436**

Phase of operation	Single piston	Single turbine	Twin turbine	All other types	Totals
Cruise	1,047	633	84	93	1,857
Maneuvering	1,149	270	30	70	1,519
Takeoff	889	353	36	127	1,405
Landing	949	301	35	74	1,359
Hover	450	247	32	28	757
Approach	241	146	26	54	467
Descent	168	73	6	12	259
Standing/static	126	97	22	5	250
Taxi	164	40	15	19	238
Climb	64	40	14	10	128
Other	76	24	0	8	108
Unknown	48	23	2	16	89
Totals	**5,371**	**2,247**	**302**	**516**	**8,436**

TABLE D-29. COLLECTED ACCIDENT SUMMARY BY NUMERICAL COUNT

	Commercially manufactured helicopters				All other rotorcraft types				All
NTSB accident first event category	**Single piston**	**Single turbine**	**Twin turbine**	**Commercial helicopter total**	**Commercial piston autogyro**	**Amateur piston helicopter**	**Amateur piston autogyro**	**Amateur unknown type**	**other type total**
Loss of engine power	1,554	704	39	**2,297**	6	40	52	13	**111**
In flight collision with object	953	298	43	**1,294**	3	4	16	5	**28**
Loss of control	625	284	40	**949**	14	44	88	19	**165**
Airframe/component/system failure/malfunction	639	282	89	**1,010**	7	19	36	11	**73**
Hard landing	483	140	8	**631**	5	4	12	4	**25**
In flight collision with terrain/water	443	143	16	**602**	5	8	23	4	**40**
Rollover/noseover	290	119	4	**413**	1	11	6	2	**20**
Weather	57	85	12	**154**	2	1	2	0	**5**
Miscellaneous/other	74	42	9	**125**	1	2	5	1	**9**
Stall/settling with power	67	2	1	**70**	2	1	8	2	**13**
Propeller/rotor contact to person	33	35	8	**76**	1	0	2	0	**3**
Midair collision	17	37	6	**60**	0	0	0	1	**1**
On ground/water collision with object	26	18	10	**54**	0	0	1	1	**2**
Fire/explosion	28	15	5	**48**	0	1	0	1	**2**
Abrupt maneuver	12	8	2	**22**	1	1	6	2	**10**
Undetermined	12	13	2	**27**	0	0	1	0	**1**
Gear collapsed	16	3	6	**25**	1	0	1	0	**2**
Dragged wing, rotor, pod, float or tail/skid	20	2	1	**23**	0	1	0	0	**1**
Undershoot/overshoot	16	4	1	**21**	1	0	1	1	**3**
On ground/water encounter with terrain/water	5	12	0	**17**	0	0	1	1	**2**
Missing	1	1	0	**2**	0	0	0	0	**0**
Total	**5,371**	**2,247**	**302**	**7,920**	**50**	**137**	**261**	**68**	**516**

TABLE D-30. COLLECTED ACCIDENT SUMMARY BY PERCENTAGE

NTSB accident first event category	Commercially manufactured helicopters: Single piston	Single turbine	Twin turbine	Commercial helicopter total	All other rotorcraft types: Commercial piston autogyro	Amateur piston helicopter	Amateur piston autogyro	Amateur unknown type	All other type total
Loss of engine power	28.93	31.33	12.91	**29.00**	12.00	29.20	19.92	19.12	**21.51**
In flight collision with object	17.74	13.26	14.24	**16.34**	6.00	2.92	6.13	7.35	**5.43**
Loss of control	11.64	12.64	13.25	**11.98**	28.00	32.12	33.72	27.94	**31.98**
Airframe/component/system failure/malfunction	11.90	12.55	29.47	**12.75**	14.00	13.87	13.79	16.18	**14.15**
Hard landing	8.99	6.23	2.65	**7.97**	10.00	2.92	4.60	5.88	**4.84**
In flight collision with terrain/water	8.25	6.36	5.30	**7.60**	10.00	5.84	8.81	5.88	**7.75**
Rollover/noseover	5.40	5.30	1.32	**5.21**	2.00	8.03	2.30	2.94	**3.88**
Weather	1.06	3.78	3.97	**1.94**	4.00	0.73	0.77	0.00	**0.97**
Miscellaneous/other	1.38	1.87	2.98	**1.58**	2.00	1.46	1.92	1.47	**1.74**
Stall/settling with power	1.25	0.09	0.33	**0.88**	4.00	0.73	3.07	2.94	**2.52**
Propeller/rotor contact to person	0.61	1.56	2.65	**0.96**	2.00	0.00	0.77	0.00	**0.58**
Midair collision	0.32	1.65	1.99	**0.76**	0.00	0.00	0.00	1.47	**0.19**
On ground/water collision with object	0.48	0.80	3.31	**0.68**	0.00	0.00	0.38	1.47	**0.39**
Fire/explosion	0.52	0.67	1.66	**0.61**	0.00	0.73	0.00	1.47	**0.39**
Abrupt maneuver	0.22	0.36	0.66	**0.28**	2.00	0.73	2.30	2.94	**1.94**
Undetermined	0.22	0.58	0.66	**0.34**	0.00	0.00	0.38	0.00	**0.19**
Gear collapsed	0.30	0.13	1.99	**0.32**	2.00	0.00	0.38	0.00	**0.39**
Dragged wing, rotor, pod, float or tail/skid	0.37	0.09	0.33	**0.29**	0.00	0.73	0.00	0.00	**0.19**
Undershoot/overshoot	0.30	0.18	0.33	**0.27**	2.00	0.00	0.38	1.47	**0.58**
On ground/water encounter with terrain/water	0.09	0.53	0.00	**0.21**	0.00	0.00	0.38	1.47	**0.39**
Missing	0.02	0.04	0.00	**0.03**	0.00	0.00	0.00	0.00	**0.00**
Total Accident Count For % Basis	**5,371**	**2,247**	**302**	**7,920**	**50**	**137**	**261**	**68**	**516**

TABLE D-31. ALL ROTORCRAFT ACCIDENT SUMMARY

NTSB accident first event category	People involved	Fatalities	Serious	Minor/none	Aircraft involved	Destroyed	Substantial	Minor	None	Unknown
Loss of engine power	4,741	268	520	3,953	2,408	445	1,935	17	11	0
In flight collision with object	2,315	352	346	1,617	1,322	470	842	6	4	0
Loss of control	2,112	362	263	1,487	1,114	414	696	4	0	0
Airframe/component/system failure/malfunction	2,286	501	262	1,523	1,083	397	658	15	13	0
Hard landing	1,326	7	52	1,267	656	66	586	3	1	0
In flight collision with terrain/water	1,194	182	124	888	642	210	431	1	0	0
Rollover/noseover	837	25	28	784	433	79	353	1	0	0
Weather	379	144	43	192	159	87	70	1	1	0
Miscellaneous/other	358	29	25	304	134	30	81	2	21	0
Stall/settling with power	140	11	18	111	83	24	59	0	0	0
Propeller/rotor contact to person	219	30	25	164	79	2	28	24	25	0
Midair collision	272	102	23	147	61	37	16	6	2	0
On ground/water collision with object	183	19	8	156	56	4	51	1	0	0
Fire/explosion	107	7	5	95	50	34	14	2	0	0
Abrupt maneuver	66	22	9	35	32	16	16	0	0	0
Undetermined	66	54	5	7	28	24	4	0	0	0
Gear collapsed	90	4	3	83	27	4	21	2	0	0
Undershoot/overshoot	60	8	0	52	24	10	14	0	0	0
Dragged wing, rotor, pod, float or tail/skid	37	2	1	34	24	6	18	0	0	0
On ground/water encounter with terrain/water	33	2	0	31	19	3	16	0	0	0
Missing	4	4	0	0	2	1	0	0	0	1
Total	**16,825**	**2,135**	**1,760**	**12,930**	**8,436**	**2,363**	**5,909**	**85**	**78**	**1**