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Accident Rates in Glass Cockpit Model U.S. Army Rotary-Wing Aircraft

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Following the lead set by commercial aviation, the U.S. Army has developed and fielded crewstation designs for four aircraft types that replace traditional instruments with multifunction displays (MFDs). These MFD-based crewstations are known as "glass cockpits." In addition, the U.S. Army fields two aircraft models using a hybrid design which has a mix of dedicated instruments and MFDs. The U.S. Army Safety Center accident database was investigated to compare accident rates for the traditional and glass cockpit models for the OH-58 Kiowa, the UH-60 Black Hawk, CH-47 Chinook, and AH-64 Apache. The accident rates were combined across classes and calculated for the overlapping years for which both the traditional and glass cockpit models were flown. For the OH-58, the glass cockpit accident rate of 20.30 (expressed in accidents per 100,000 flight hours) exceeded the 4.37 rate of the traditional cockpit. For the UH-60, the glass cockpit accident rate of 17.06 exceeded the 8.81 rate of the traditional cockpit. For the CH-47, the 3.94 accident rate of the glass cockpit was less than the 6.97 rate of the traditional cockpit. For the AH-64, the glass cockpit accident rate of 23.00 exceeded the 18.36 rate of the traditional cockpit.

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These data suggest that the accident rate for the glass cockpit is greater than the traditional crewstation design for three of the four aircraft types.

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Introduction

Increasingly, there has been a trend in aviation to introduce digital technology into the cockpit. One aspect of this trend has been the conversion of the crewstation instrument panel from one of a cluster of dedicated instruments to one comprised of one or more multifunction displays (MFDs) (Figure 1). The use of software and hierarchical paging of information can configure MFDs into any desired instrument, or set of instruments. The MFD integrates the information previously provided by electro-mechanical instruments with the speed and processing power of microprocessors and the adaptability of cathode ray tubes (CRTs) and/or flat panel technology displays. MFDs provide the aircrew access to a variety of data and information, in a near endless array of formats, on a single display (although multiple MFDs may be employed in any given cockpit), and controlled by a single controller interface (Leard, 1999). A single MFD can be configured to provide some or all of the information needed for navigation, communication, system management, and aircraft control. Combined with the background automated monitoring capability of microprocessors, the MFD cockpit offers many advantages. The cockpit design based on MFDs has given rise to the phrase "glass cockpit."

While commercial aviation initiated the movement towards glass cockpits military aviation has been quick in adopting the new technologies to include the use of MFDs in the cockpit. Army aircraft have integrated the glass cockpit scheme into four rotary-wing aircraft series: the AH-64 Apache, the UH/MH-60 Black Hawk, the CH/MH-47 Chinook, and the OH-58 Kiowa. The glass cockpit models of these aircraft are designated as the AH-64D, MH-60K, MH-47E, and OH-58D, respectively. In addition, there are two hybrid crewstation configurations that mix MFDs and dedicated instruments, the MH-47D and MH-60L. Note: While glass cockpit models still employ several dedicated instruments, hybrid cockpits (as defined by the aircraft manufacturer) have multiple dedicated instruments and MFDs in a mixed configuration.

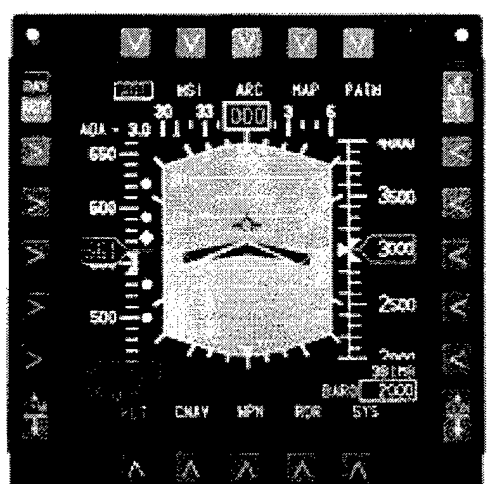


Figure 1. Multifunction display (Honeywell, Inc.).

The Army's first use of MFDs in a fielded glass cockpit design was in the OH-58D introduced in 1987. The MH-60K entered service in 1994, followed by the MH-47E also in 1994 and the AH-64D in 1997. The U.S. Army clearly supports the use of glass cockpits; its next generation aircraft, the RAH-66 Comanche, will be heavily dependent on the glass cockpit configuration and advanced digital technology. This is part of a growing focus on the "digital battlefield," where the glass crewstation approach will be utilized in a variety of systems both within and outside the aviation community.

Each military aircraft has specific functions and general mission requirements. The transition into a glass cockpit crewstation design should aid the crew in accomplishing their mission. The motivation for transitioning into glass cockpits was that mission effectiveness was being degraded by the cramped and cluttered crewstation designs. A more streamlined design was envisioned to allow the crew to successfully complete mission requirements.

Of the many advantages the glass cockpit crewstation design approach provides, one of the most attractive is that of automated monitoring. In fully automated cockpits, such monitoring provides for behind the scenes real-time processing of moment-to-moment status. However, humans, while highly adaptive and flexible, and having vast cognitive skills, are not very good at monitoring tasks (Wiener and Curry, 1980). They are very likely to miss critical signals and commit forced errors.

In addition, there has been considerable discussion on perceived human factors problems with MFD use, especially in the areas of attention and crew coordination. MFDs can offer all the data and information pilots could possibly need, but only a limited amount of information can be displayed at any given time. If certain information is required, the aviator must interact with the MFD to retrieve it. In various situations, this could cause problems. For example, the "search and find" operations normally employed with personal computers does not survive well in the time constrained, dynamic environment of the aviation cockpit (Leard, 1999). The previously developed schemes for monitoring aircraft status information may be upset by the use of MFDs (Wiener and Curry, 1980). In addition, a number of questions have surfaced regarding the premise of reduced workload in an automated cockpit under less than ideal conditions (Hughes, 1989; Phillips, 1992; Foreman, 1996). Within Army aviation, other questions of safety associated with the first high technology glass cockpit in the OH-58D have been raised (Ramsey and Altman, 1998).

This paper attempts to take a first step in looking at how successful the introduction of the glass cockpit into Army aircraft has been. Perhaps the greatest concern about modifying a cockpit design is its impact on flight safety. Every new device in the cockpit presents new possibilities for inducing or contributing to an accident. Therefore, this first step appropriately consists of comparing the accident rates of "glass cockpit" models to traditionally instrumented cockpit models for four Army aircraft: OH-58 Kiowa, CH/MH-47 Chinook, UH/MH-60 Black Hawk, and AH-64 Apache.

Accident data

The data analyzed herein were obtained from a search of the U.S. Army Safety Management Information System (ASMIS) maintained by the U.S. Army Safety Center (USASC), Fort Rucker, Alabama. The USASC tracks three types of aviation accidents: flight, flight-related and ground. A flight accident is one in which intent for flight exists and there is reportable damage to the aircraft itself. Intent for flight begins when aircraft power is applied, or brakes released, to move the aircraft under its own power with an authorized crew. Intent for flight ends when the aircraft is at full stop and power is completely reduced. Flight-related and ground accidents are not used by the USASC in calculations of accident rates. The rates reported herein adopt this criteria and include flight accidents only.

Accidents are classified as Class A, Class B, or Class C (Table 1). Accident rates are based on the number of occurrences per 100,000 flight hours and provided per fiscal year (FY) (1 October through 30 September).

Accident frequencies and rates used in this paper cover the period FY72-FY00, based on data entries made by 31 December 2000. The USASC accident database was not created until 1972.

Table 1.
Descriptions of accident classes.
(Department of the Army, 1999)

Class A	Class B	Class C
$1,000,000 or more and/or	$200,000 - $1,000,000 and/or	$10,000 - $200,000 and/or
Destruction of an Army aircraft, missile or spacecraft and/or	Results in permanent partial disability and/or	Non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or
Fatality or permanent total disability	Hospitalization of five or more people as inpatients	Non-fatal illness/disability causes loss of time from work

Note: Accident class criteria have been revised twice since 1972.

Data analysis

The analysis consisted of the determination of accident frequencies and rates for the four Army rotary-wing aircraft that have fielded glass cockpit models. The data are presented as a comparison between the glass cockpit model and those model(s) having the traditional dedicated instrument cockpit configuration. The term "lifetime" accident rate has been used to denote the accident rate for the time period for which flight hours and accident frequency for a given aircraft model were available since the 1972 creation of the accident database. Such lifetime accident rates have been calculated based on the definition of the total number of accidents (totaled over all years of service) divided by the total number of flight hours for the same period and expressed in number of accidents per 100,000 flight hours.

Since 1972, the criteria of the accident classes have been redefined twice to adjust for inflation. In 1981 the threshold for classification as Class A was raised from $200,000 to $500,000; the threshold for Class B was raised from $50,000 to $100,000; and the threshold for Class C was raised from $300 to $10,000. This change in criteria was not implemented until FY84. In addition, FY84 was the first year of a new emphasis on safety in U.S. Army aviation. This emphasis consisted of numerous new activities designed to heighten awareness of aviation safety. As a consequence of these two actions, there was a sudden and significant drop in accident rates during and following FY84.

Again, in FY89, a second accident class inflationary criteria change resulted in changes in threshold values to those currently used and presented in Table 1. The Class A threshold was raised from $500,000 to $1,000,000; the Class B threshold was raised from $100,000 to $200,000 (with upper ceiling increased to $1,000,000); and, the Class C threshold remained $100,000, but the upper ceiling was raised to $200,000. These new criteria were implemented immediately in FY89.

For the purpose of this study, accident rates were calculated over three reporting time periods. The first was for the period of time defined as all years for which the respective model has recorded flight hours and accident frequency since the 1972 creation of the USASC database, up to and including FY00. This rate is referred to as the "Lifetime" rate. The second period encompassed the years for which data were available since (and including) FY84, the implementation of the first accident class criteria change. This rate is referred to as the "FY84-FY00" rate. The third period encompassed only those years for which data were available for both the traditional instrument and glass cockpit models of an aircraft series. This rate was referred to as the "Overlap" rate.

Arguments exist for the importance and value for each of the three rates defined above. For this reason, all three rates were calculated and reported in this study. It can be argued that the overlap rate is the most valid for comparison of accident rates, since comparing the same time period reduces confounds such as changes in training programs, weather, modifications to accident class criteria, changes in doctrine, etc. For this reason, statistical tests were applied to comparisons between traditional, hybrid and glass cockpit model accident rates for only the overlap rates. The change in criteria of accident classes that was implemented in FY84 precluded a comparison of lifetime accident rates. In a similar manner, accident rates for the FY84-FY00 period were not statistically tested based on the confound argument above.

In addition to rate comparisons based on the periods above, a final comparison based on the accident rates for the first few years of fielding for corresponding glass cockpit and traditional cockpit models of the same aircraft seemed worthwhile. However, because the fielding dates of three of the traditional instrument aircraft models preceded the creation of the 1972 database, this comparison was possible only for the AH-64.

OH-58 Kiowa

The OH-58 Kiowa is an observation/reconnaissance helicopter. The crewstation has a side-by-side seating configuration. The first model of the OH-58 Kiowa, the OH-58A, was fielded in 1968, with updated versions as the B, C, and D models. In an effort to improve workload and manageability of the Kiowa, the D-model, fielded in 1985, was designed with a glass cockpit. The most recently fielded OH-58 model, the OH-58D Kiowa Warrior, is an armed reconnaissance aircraft with defensive and offensive air-to-air and air-to-ground capabilities. It incorporates the same previous D-model MFDs but with software upgrades appropriate for its increased capabilities. Figure 2 shows cockpit views for the OH-58C (left) and the glass cockpit model OH-58D (right).

Although the OH-58 was first fielded in 1968, the USASC accident database was not implemented until 1972. Therefore, flight hours, accident frequencies, and rates were available only for FY72 to the present. The flight hour data were combined and presented in Figure 3 for comparison. The total flight hours for the OH-58A/C and the OH-58D models (as of 1 October 2000) were 7,094,272 and 598,673, respectively. Flight hours by fiscal year are provided in the Appendix.

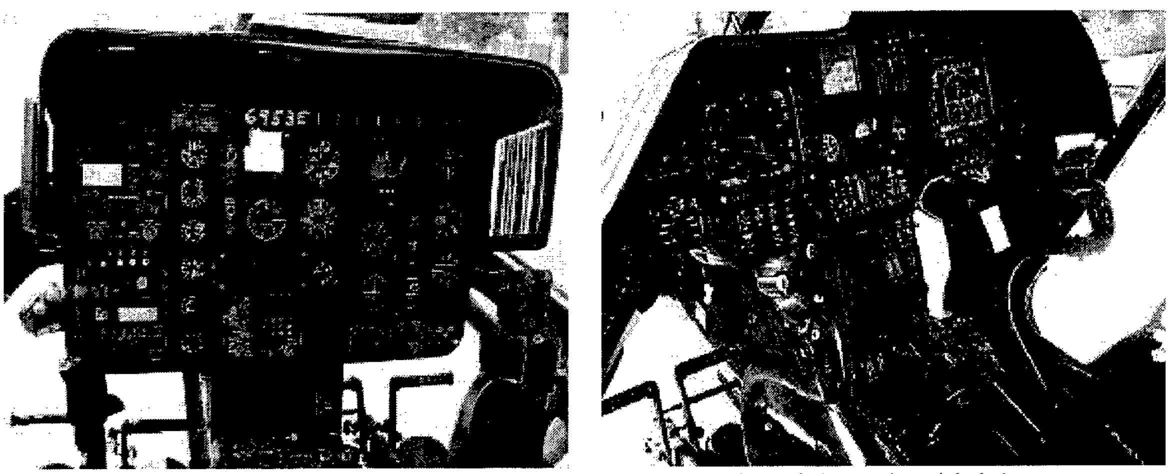


Figure 2. Cockpit views of the OH-58C (left) and OH-58D (right) (reproduced with permission from Mr. Glenn Bloom).

Accident data

Accident frequencies for the OH-58 models are presented in Table 2. These frequencies are presented by accident class and compared as OH-58A/C and OH-58D. As might be expected, Class C accidents, which are lower cost and non-fatal, had the highest frequencies. In a similar manner, accident rates for the OH-58 models are presented in Table 3. The third row from the bottom in Table 3, titled "Lifetime," presents lifetime accident rates for the OH-58 models, where the lifetime rate is defined as the total number of accidents per 100,000 flight hours for a given class, or all classes,

Table 2.
Frequency of OH-58A/C and OH-58D flight accidents.

	OH-58A/C flight accidents				OH-58D flight accidents			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY72	11	3	22	36	-	-	-	-
FY73	21	8	47	76	-	-	-	-
FY74	5	9	37	51	-	-	-	-
FY75	10	6	44	60	-	-	-	-
FY76	11	9	56	76	-	-	-	-
FY77	8	8	46	62	-	-	-	-
FY78	7	15	37	59	-	-	-	-
FY79	9	3	41	53	-	-	-	-
FY80	12	3	46	61	-	-	-	-
FY81	9	3	43	55	-	-	-	-
FY82	13	6	46	65	-	-	-	-
FY83	13	3	68	84	-	-	-	-
FY84	8	0	12	20	-	-	-	-
FY85	12	0	6	18	0	0	0	0
FY86	4	2	10	16	0	0	0	0
FY87	7	1	9	17	0	1	0	1
FY88	6	0	2	8	0	0	0	0
FY89	6	0	6	12	2	2	2	6
FY90	7	0	12	19	4	1	4	9
FY91	10	0	15	25	4	1	4	9
FY92	6	0	10	16	2	0	4	6
FY93	6	0	11	17	1	1	5	7
FY94	8	0	20	28	0	1	3	4
FY95	3	0	5	8	1	3	8	12
FY96	0	0	6	6	1	1	3	5
FY97	1	2	4	7	1	3	9	13
FY98	1	0	1	2	2	1	10	13
FY99	0	1	4	5	3	2	10	15
FY00	2	0	5	7	1	2	18	21
TOTALS	216	82	671	969	22	19	80	121
FY84-00	87	6	138	231	22	19	80	121
Overlap	79	6	126	211	22	19	80	121

Table 3.
Accident rates for OH-58A/C and OH-58D.

	OH-58A/C flight accident rates				OH-58D flight accident rates			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY72	6.16	1.68	12.32	20.15	-	-	-	-
FY73	6.57	2.50	14.70	23.78	-	-	-	-
FY74	1.60	2.88	11.84	16.31	-	-	-	-
FY75	3.15	1.89	13.86	18.90	-	-	-	-
FY76	3.63	2.97	18.46	25.05	-	-	-	-
FY77	2.62	2.62	15.07	20.31	-	-	-	-
FY78	2.41	5.16	12.72	20.28	-	-	-	-
FY79	3.15	1.05	14.36	18.57	-	-	-	-
FY80	4.26	1.06	16.33	21.65	-	-	-	-
FY81	3.06	1.02	14.60	18.67	-	-	-	-
FY82	4.43	2.04	15.66	22.13	-	-	-	-
FY83	4.66	1.08	24.38	30.11	-	-	-	-
FY84	2.88	0.00	4.31	7.19	-	-	-	-
FY85	4.50	0.00	2.25	6.74	0.00	0.00	0.00	0.00
FY86	1.42	0.71	3.54	5.66	0.00	0.00	0.00	0.00
FY87	2.47	0.35	3.18	6.00	0.00	9.93	0.00	9.93
FY88	2.16	0.00	0.72	2.88	0.00	0.00	0.00	0.00
FY89	2.10	0.00	2.10	4.20	8.75	8.75	8.75	26.26
FY90	2.38	0.00	4.08	6.46	15.40	3.85	15.40	34.65
FY91	4.78	0.00	7.17	11.95	21.48	5.37	21.48	48.34
FY92	2.58	0.00	4.29	6.87	9.49	0.00	18.98	28.46
FY93	2.58	0.00	4.74	7.32	4.06	4.06	20.30	28.41
FY94	3.52	0.00	8.81	12.33	0.00	2.36	7.09	9.45
FY95	1.57	0.00	2.61	4.17	2.14	6.43	17.15	25.73
FY96	0.00	0.00	4.54	4.54	1.60	1.60	4.80	8.00
FY97	0.85	1.70	3.41	5.96	1.59	4.76	14.27	20.61
FY98	0.97	0.00	0.97	1.93	2.59	1.30	12.95	16.84
FY99	0.00	0.93	3.71	4.64	3.96	2.64	13.19	19.78
FY00	1.83	0.00	4.57	6.39	1.13	2.27	20.39	23.78
Lifetime	3.04	1.16	9.46	13.60	3.67	3.17	13.36	20.21
FY84-00	2.40	0.17	3.80	6.36	3.67	3.17	13.36	20.21
Overlap	2.36	0.18	3.76	6.29	3.67	3.17	13.36	20.21

across the total flight hours for the associated class or all classes for the total period of time for which the aircraft has been in service (since 1972).

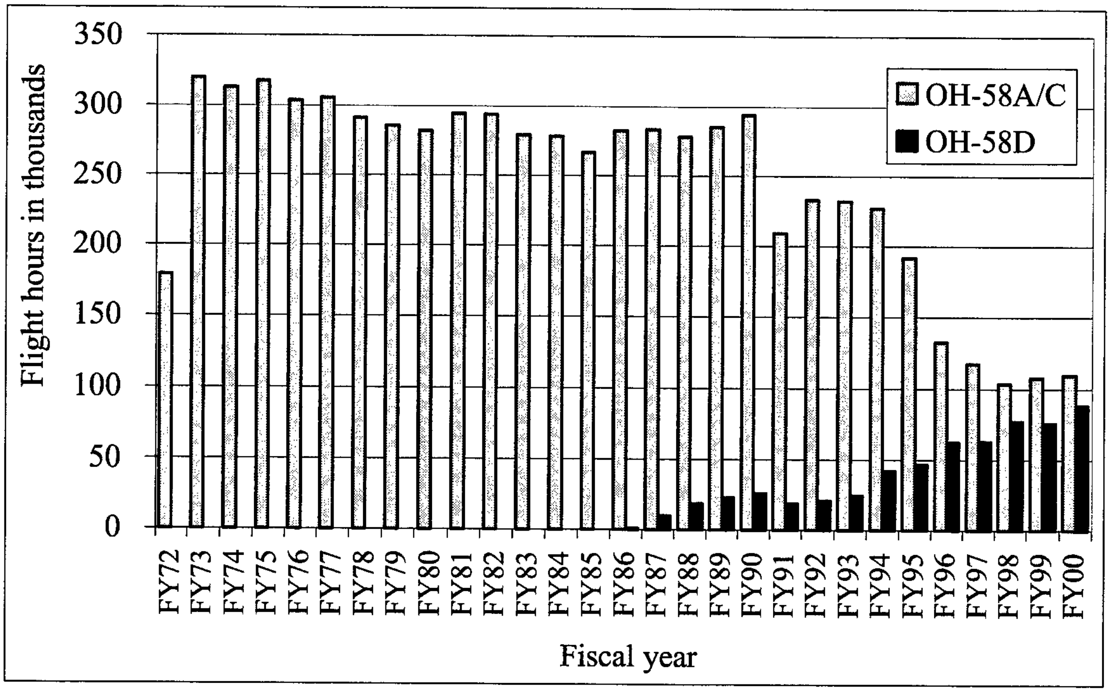


Figure 3. Flight hours for the OH-58A/C and the OH-58D.

For the dedicated instrument models of the OH-58A/C, the accident rates presented in Table 3 are plotted by fiscal year in Figure 4 for individual accident Classes A, B, and C. The lifetime OH-58A/C accident rates for Classes A, B, and C were 3.04, 1.16 and 9.46, respectively. The OH-58A/C lifetime accident rate for all classes combined was 13.60 (accidents per 100,000 flight hours).

For the glass cockpit OH-58D, the accident rates presented in Table 3 are plotted by fiscal year in Figure 5 for individual accident classes A, B, and C. The lifetime OH-58D accident rates for Classes A, B, and C were 3.67, 3.17 and 13.36, respectively. The OH-58D lifetime accident rate for all classes was 20.21.

In Figure 6, accident rates for the dedicated instrument OH-58A/C are compared to those for the glass model OH-58D by fiscal year.

For the reasons stated previously, the implementation of a new emphasis on safety and the FY84 change in criteria of accident classes, it was decided to also investigate accident rates based on the period from FY84 to FY00. Accident frequencies and rates based on this period are presented in the second row from the bottom of Tables 2 and 3. Similar data for the overlap period for the dedicated instrument OH-58A/C and the glass cockpit OH-58D, which includes the years FY85 to FY00, are presented in the bottom row of Tables 2 and 3.

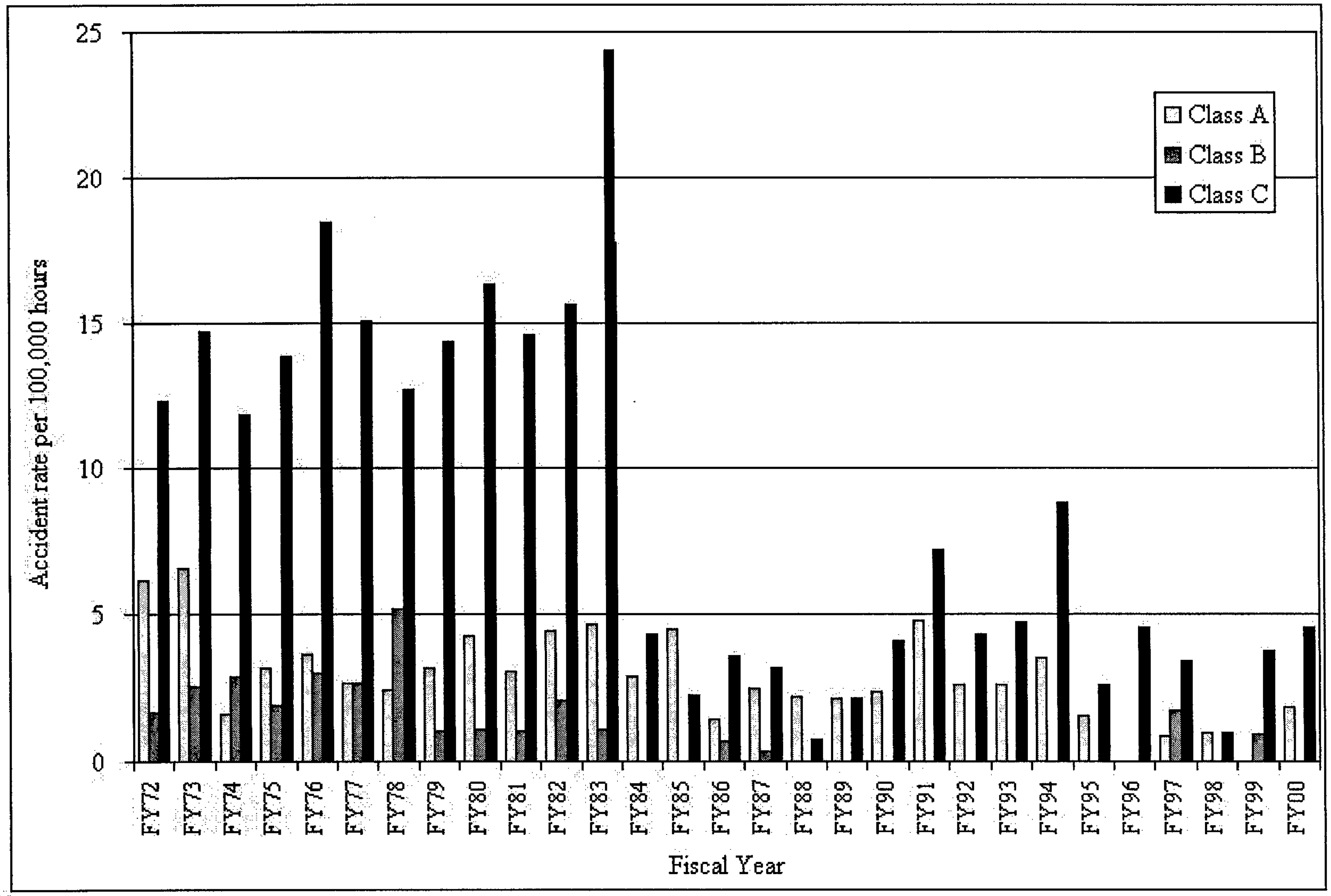


Figure 4. Accident rates OH-58A/C, Classes A, B, C.

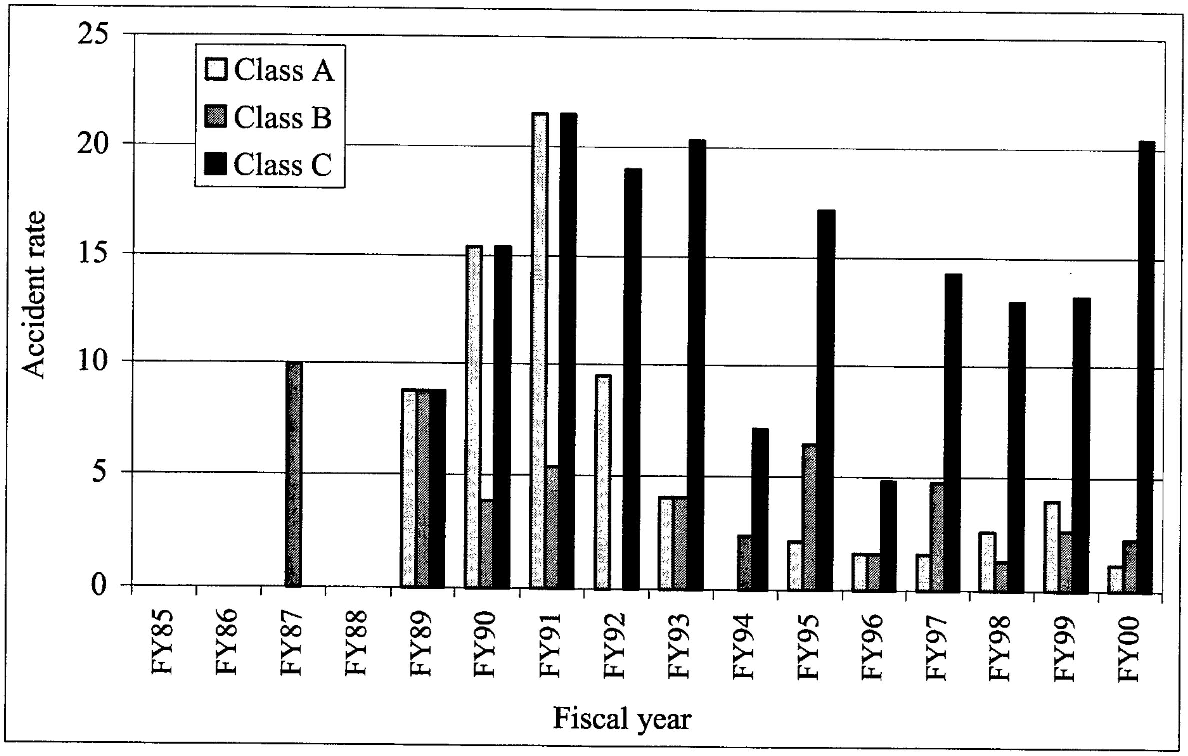


Figure 5. Accident rates for the glass cockpit OH-58D, Classes A, B, C.

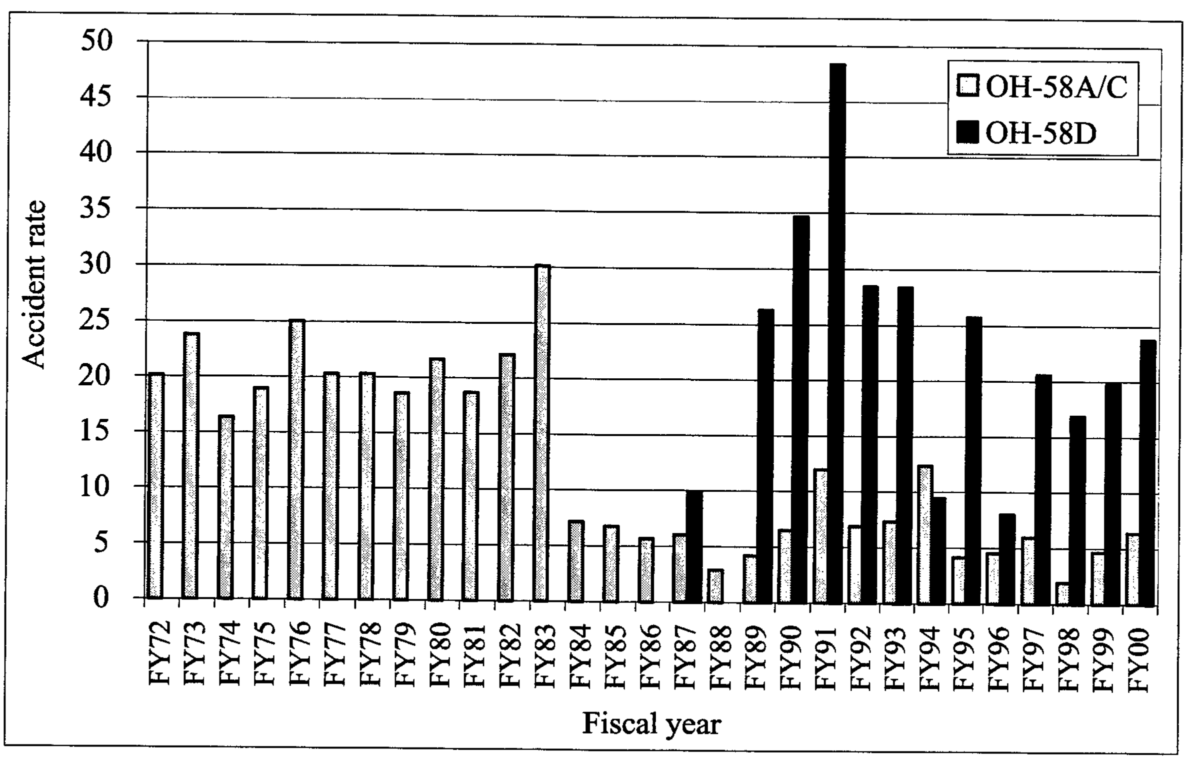


Figure 6. Combined Classes A-C accident rates for the OH-58A/C and OH-58D by fiscal year.

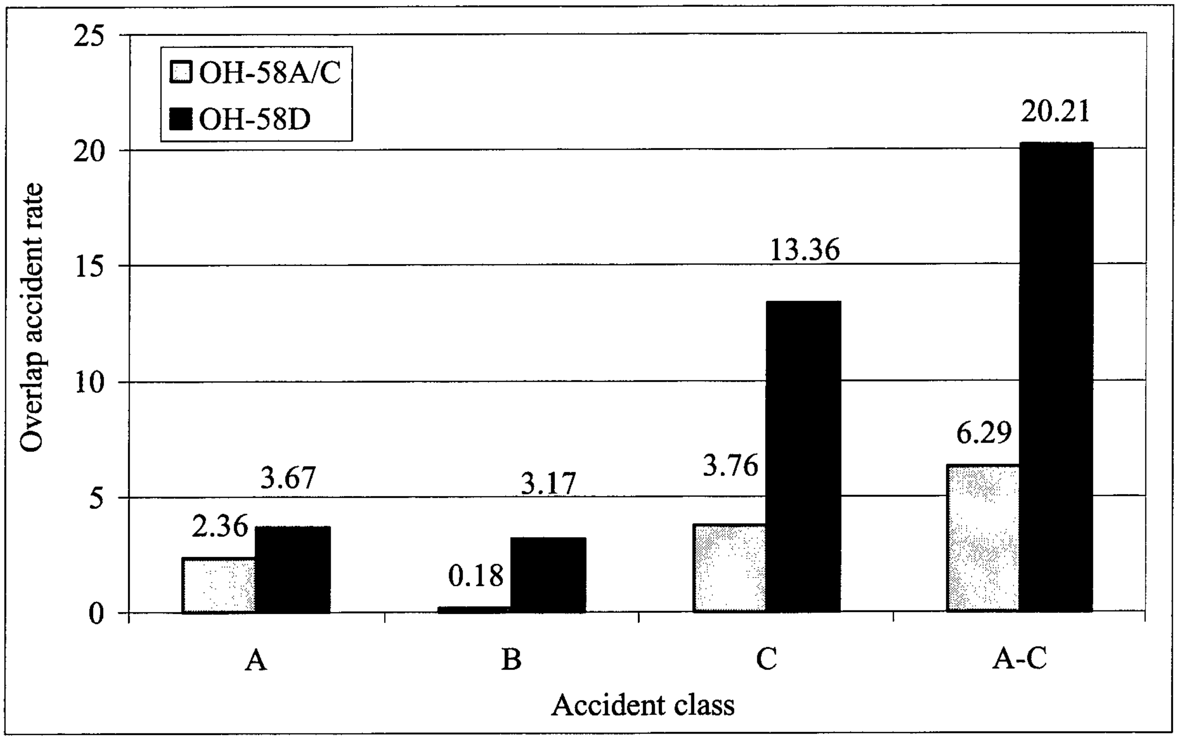


Figure 7. Airframe overlap accident rates for the OH-58A/C and the OH-58D (FY85-FY00).

When accident data were considered only for the period FY84-FY00, the overall OH-58A/C accident rates for Classes A, B, and C were found to be 2.40, 0.17 and 3.80, respectively. The FY84-FY00 OH-58A/C accident rate for all classes combined was 6.36.

When accident data were considered for the overlap period FY85-FY00 only, the overall OH-58A/C accident rates for Classes A, B, and C were found to be 2.36, 0.18 and 3.76, respectively. The overlap OH-58A/C accident rate for all classes combined was 6.29.

For the OH-58D, the lifetime, FY84-FY00 and overlap accident rates for all classes combined were all the same value of 20.21 because all of these rates encompassed the same period of years, except for FY84 for which there was no data.

In Figure 7, accident rates for the OH-58A/C models and the OH-58D glass cockpit model were compared for individual accident classes and for all classes combined for the overlap period FY85-FY00. For all cases, the accident rates for the glass cockpit model were numerically greater than those for the dedicated instrument models.

Discussion

When the overlap FY85-FY00 rates for individual accident classes and all classes combined were tested using an upper-tail two-sample inference for incidence-rate data

(Rosner, 1995), significance values (Table 4) indicated the increased accident rates for the OH-58D glass cockpit model were statistically significant ($p<.05$) for accident Classes A, B and C, and for all classes combined.

Table 4.
OH-58 significance values (Rosner, 1995).

	Accident class			
	A	B	C	A-C
OH-58A/C vs. OH-58D	**.0474**	**.0000**	**.0000**	**.0000**

Note: **Bold** denotes statistical significance ($p<.05$).

These findings add substance to safety concerns in the OH-58D that were raised in 1998. Ramsey and Altman (1998), Army OH-58D pilots, writing in the USASC newsletter, *Flightfax*, reviewed accident frequencies and an upward trend in the accident rate for the OH-58 for the period of FY89 to third-quarter FY98. They speculated on the possible cause and effect of increasing technology in the OH-58, the resulting pilot "task overload" and "loss of situational awareness," and the increasing accident rate.

Since the OH-58A was first flown in FY68, but accident data were available only since FY72, it was not possible to compare accident rates for the first years of fielding for the OH-58A/C and OH-58D models.

UH/MH-60 Black Hawk

The UH-60 Black Hawk is a utility helicopter, primarily used in tactical transport of troops, supplies and equipment. The minimum crew required to fly the Black Hawk is two pilots, but additional crewmembers may be added based on mission requirements. The first model of the UH-60 Black Hawk, the UH-60A, was fielded in 1978. Over the years, a number of UH-60 model variants (e.g., UH-60L, UH-60Q, EH-60A, etc.) have been fielded, all having dedicated instrument cockpits. U.S. Army Special Operations Aviation has fielded two additional Black Hawk models, the MH-60L and the MH-60K. The MH-60L, fielded since 1990, is equipped with upgraded electronics such as color weather radar and Hellfire missile capability. For the purpose of this study, the MH-60L model is considered to be a hybrid cockpit design, having two MFDs, and is considered to be neither a fully dedicated nor a fully glass cockpit design. The MH-60K, which entered partial service in 1994, features a fully integrated glass cockpit. (Note: The next generation Black Hawk is the HH-60L, four of which are currently in operation. It also has a full glass cockpit, but at the time of this study, has been flying for less than two months and is not included in this study.)

For this investigation, the Black Hawk models were considered to be three distinctive groups: dedicated instrument cockpit (all UH-60 models), hybrid cockpit (MH-60L), and glass cockpit (MH-60K). Figure 8 shows cockpit views for the UH-60A (top left), MH-60L (top right), and MH-60K (bottom).

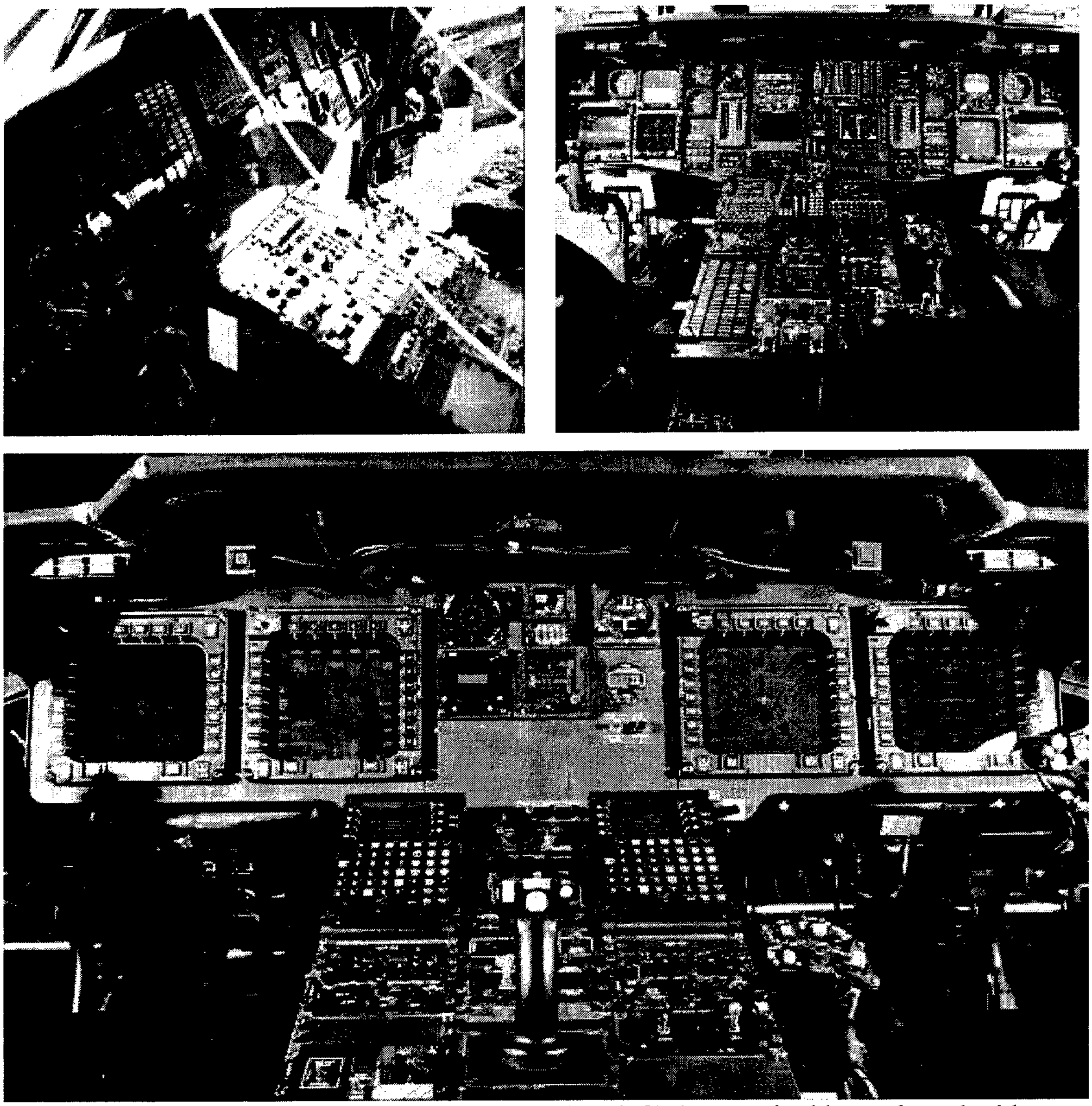


Figure 8. Cockpit views for the UH-60A (top left) (copywrited by and used with permission of Richard Marshall), MH-60L (top right), and MH-60K (bottom).

The total flight hours (as of 1 October 2000) for the dedicated instrument UH-60 models for the period FY79-FY00 was 3,073,475. Due to the covert mission assignments of Special Operations aircraft, the reporting of flight hours for the MH-60L and MH-60K has been incomplete for some fiscal years. While first flown in FY91, flight hours for the MH-60L were not available for FY91, FY92 and FY97. The total MH-60L flight hours used in this study was 64,614. Flight hours by fiscal year are provided in the Appendix.

As with the MH-60L, flight hours for the glass cockpit MH-60K were incomplete for several fiscal years. Flight hours for the MH-60K were not available for FY95-FY96.

The total MH-60K flight hours used in this study was 30,630. Flight hour data for the UH/MH-60 models are combined and presented in Figure 9 for comparison.

Accident data

Accident frequencies for the UH/MH-60 models are presented in Table 5. These frequencies are presented by accident class and compared as UH-60, MH-60L, and MH-60K. As expected, and encountered in the previous OH-58 analysis, Class C accidents were the most frequent. Accident rates for the UH/MH-60 models are presented in Table 6. The next to last row entry in Table 6 presents lifetime accident rates. The lifetime accident rate was defined as the number of accidents per 100,000 flight hours for a given class, or all classes, across the total flight hours for the associated class or all classes for the total period of time for which the aircraft has been in service (since FY79 for the UH-60 models) or for the total period of time for which flight hours were available (FY92-FY00 for the MH-60L; FY94-FY00 for the MH-60K). Special attention should be paid to the accident rates for the MH-60L and MH-60K presented in Table 6. Flight hours were not available for the MH-60L for FY91, FY92, and FY97 or for the MH-60K for FY95 and FY96. Therefore, accident rates could not be calculated for these models for these years.

For the dedicated instrument models of the UH-60, the accident rates presented in Table 6 are plotted in Figure 10 for individual accident Classes A, B and C. The lifetime UH-60 accident rates for Classes A, B, and C were 1.98, 1.17 and 9.27, respectively. The UH-60 lifetime accident rate for all classes combined was 12.43.

Accident frequencies and rates for the dedicated models of the UH-60 for the period FY84-FY00 were added as the bottom rows of Tables 5 and 6. For this time period, the overall UH-60 accident rates for Classes A, B, and C were found to be 1.79, 1.17, and 5.71, respectively. The FY84-FY00 UH-60 accident rate for all classes combined was 8.67.

For the hybrid MH-60L, the accident rates presented in Table 6 are plotted in Figure 11 for individual accident Classes A, B, and C. The lifetime MH-60L accident rates for Classes A, B and C (based on fiscal years of reported flight hours) were 3.10, 3.10, and 23.21, respectively. The MH-60L lifetime accident rate for all classes combined was 29.41. The FY84-FY00 MH-60L accident rates for Classes A, B, and C and all classes combined were identical to the lifetime rates since data were available only since FY91.

For the glass cockpit MH-60K, the accident rates presented in Table 6 are plotted in Figure 12 for individual accident Classes A, B, and C. The lifetime MH-60K accident rates for Classes A, B, and C (based on fiscal years of reported flight hours) were 6.53, 0.00, and 9.79, respectively. The MH-60K lifetime accident rate for all classes combined was 16.32. MH-60K FY84-FY00 accident rates were identical to the lifetime accident rates.

Table 5.
Frequency of UH-60 models, MH-60L, and MH-60K flight accidents.

	UH-60 models flight accidents				MH-60L flight accidents				MH-60K flight accidents			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY79	0	0	1	1	-	-	-	-	-	-	-	-
FY80	0	1	9	10	-	-	-	-	-	-	-	-
FY81	2	0	26	28	-	-	-	-	-	-	-	-
FY82	4	1	47	52	-	-	-	-	-	-	-	-
FY83	3	0	36	39	-	-	-	-	-	-	-	-
FY84	6	2	6	14	-	-	-	-	-	-	-	-
FY85	6	1	3	10	-	-	-	-	-	-	-	-
FY86	2	0	3	5	-	-	-	-	-	-	-	-
FY87	6	2	6	14	-	-	-	-	-	-	-	-
FY88	5	3	3	11	-	-	-	-	-	-	-	-
FY89	4	3	9	16	-	-	-	-	-	-	-	-
FY90	3	2	9	14	-	-	-	-	-	-	-	-
FY91	5	1	12	18	1	1	1	3	-	-	-	-
FY92	0	3	13	16	0	0	2	2	-	-	-	-
FY93	1	6	17	24	0	0	2	2	-	-	-	-
FY94	2	1	11	14	1	0	1	2	0	0	0	0
FY95	2	2	7	11	0	0	3	3	0	0	0	0
FY96	1	2	11	14	0	0	1	1	0	0	4	4
FY97	1	2	10	13	0	0	1	1	1	0	0	1
FY98	5	1	16	22	0	0	1	1	0	0	2	2
FY99	2	3	15	20	0	0	3	3	1	0	1	2
FY00	1	0	15	16	0	1	0	1	0	0	0	0
TOTALS	61	36	285	382	2	2	15	19	2	0	7	9
FY84-00	52	34	166	252	2	2	15	19	2	0	7	9
Overlap	15	17	102	134	1	1	11	13	2	0	3	5

Table 6.
Accident rates for UH-60 models, MH-60L and MH-60K.

	UH-60 models flight accident rates				MH-60L flight accident rates				MH-60K flight accident rates			
	Class A	Class B	Class C	Classes A-C	Class A	Class B	Class C	Classes A-C	Class A	Class B	Class C	Classes A-C
FY79	0.00	0.00	65.36	65.36	-	-	-	-	-	-	-	-
FY80	0.00	5.42	48.82	54.25	-	-	-	-	-	-	-	-
FY81	5.93	0.00	77.04	82.97	-	-	-	-	-	-	-	-
FY82	7.85	1.96	92.19	101.99	-	-	-	-	-	-	-	-
FY83	4.78	0.00	57.34	62.12	-	-	-	-	-	-	-	-
FY84	7.85	2.62	7.85	18.32	-	-	-	-	-	-	-	-
FY85	7.74	1.29	3.87	12.90	-	-	-	-	-	-	-	-
FY86	1.83	0.00	2.74	4.57	-	-	-	-	-	-	-	-
FY87	3.89	1.30	3.89	9.07	-	-	-	-	-	-	-	-
FY88	2.78	1.67	1.67	6.11	-	-	-	-	-	-	-	-
FY89	2.11	1.58	4.74	8.42	-	-	-	-	-	-	-	-
FY90	1.54	1.02	4.61	7.17	-	-	-	-	-	-	-	-
FY91	3.47	0.69	8.32	12.48	*	*	*	*	-	-	-	-
FY92	0.00	1.70	7.38	9.08	0.00	0.00	*	*	-	-	-	-
FY93	0.59	3.56	10.10	14.26	0.00	0.00	49.35	49.35	-	-	-	-
FY94	1.08	0.54	5.96	7.59	10.59	0.00	10.59	21.18	0.00	0.00	0.00	0.00
FY95	1.05	1.05	3.69	5.80	0.00	0.00	30.45	30.45	0.00	0.00	0.00	0.00
FY96	0.50	1.01	5.55	7.07	0.00	0.00	12.11	12.11	0.00	0.00	*	*
FY97	0.49	0.98	4.91	6.39	0.00	0.00	*	*	17.63	0.00	0.00	17.63
FY98	2.43	0.49	7.76	10.68	0.00	0.00	13.07	13.07	0.00	0.00	37.58	37.58
FY99	0.95	1.43	7.13	9.50	0.00	0.00	38.54	38.54	17.89	0.00	17.89	35.78
FY00	0.41	0.00	6.21	6.62	0.00	5.69	0.00	5.69	0.00	0.00	0.00	0.00
Lifetime	1.98	1.17	9.27	12.43	3.10	3.10	23.21	29.41	6.53	0.00	9.79	16.32
FY84-00	1.79	1.17	5.71	8.67	3.10	3.10	23.21	29.41	6.53	0.00	9.79	16.32

Note: Asterisk denotes inability to calculate accident rate due to unreported flight hours.
Lifetime accident rates do not include FYs with unreported flight hours.

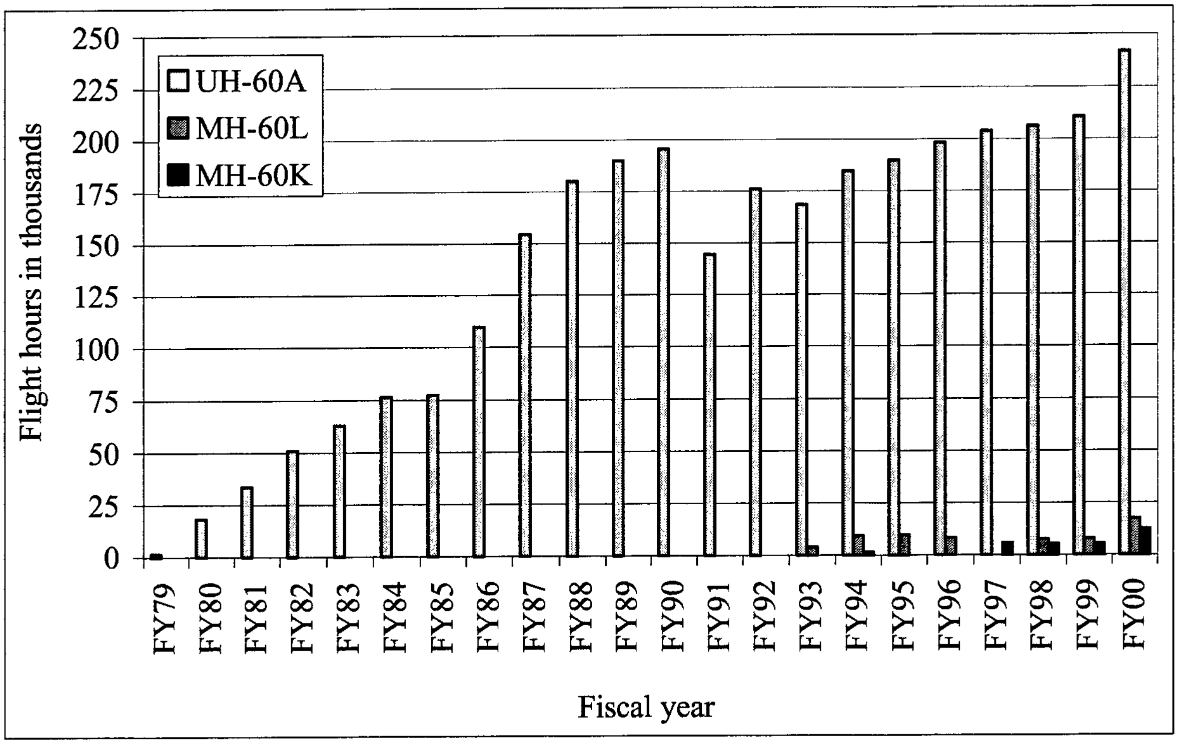


Figure 9. Flight hours for the UH-60 models, the MH-60L, and the MH-60K.

In Figure 13, combined Classes A-C accident rates for the dedicated instrument UH-60 models are compared to those for the hybrid model MH-60L and the glass model MH-60K by fiscal year.

To investigate accident rates for the dedicated, hybrid, and glass cockpit UH/MH-60 models, comparisons were made over differing overlap periods. When comparing the traditional instrument UH-60 models to the hybrid MH-60L, the overlap period covered FY93-FY00, excluding FY97. The overlap period for comparing traditional instrument UH-60 models to the glass cockpit MH-60K covered FY94-FY00, excluding FY95 and FY96. The overlap period for comparing the hybrid MH-60L to the glass cockpit MH-60K covered FY94 to FY00, excluding FY95 - FY97. Note: The excluded fiscal years were due to unreported flight hours.

Overlap accident rates are presented in Table 7 for individual accident classes as well as all classes combined. For the comparison of traditional instrument UH-60 models to the hybrid MH-60L, the hybrid accident rates exceeded those of the traditional instrument UH-60 models for all classes and all classes combined. The all-Classes A-C accident rate for the hybrid MH-60L was 20.12, exceeding the 8.65 accident rate for the traditional instrument UH-60 models. When the glass cockpit MH-60K was compared to the traditional UH-60 models for their overlapping years, the glass cockpit MH-60K accident rates exceeded those of the traditional instrument UH-60 models for Classes A and C, and for all classes combined. For this overlapping period, the glass cockpit MH-60K

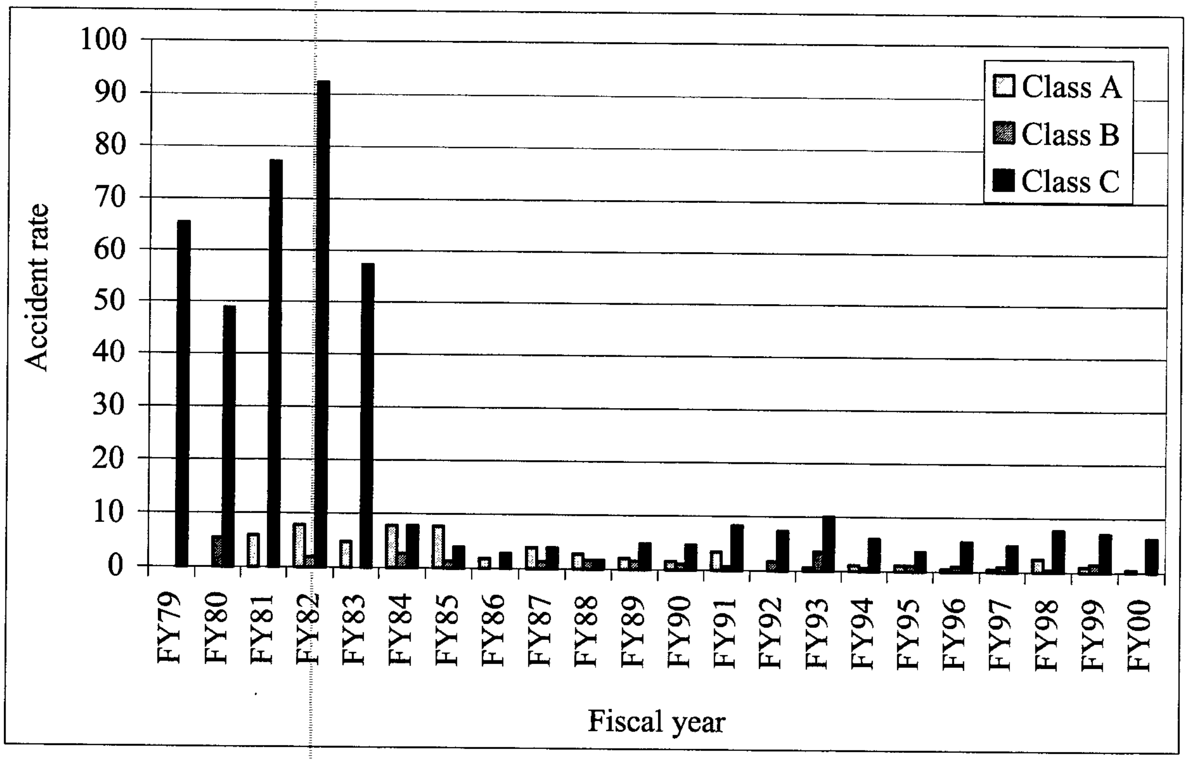


Figure 10. Accident rates for dedicated instrument UH-60 models, Classes A, B, C.

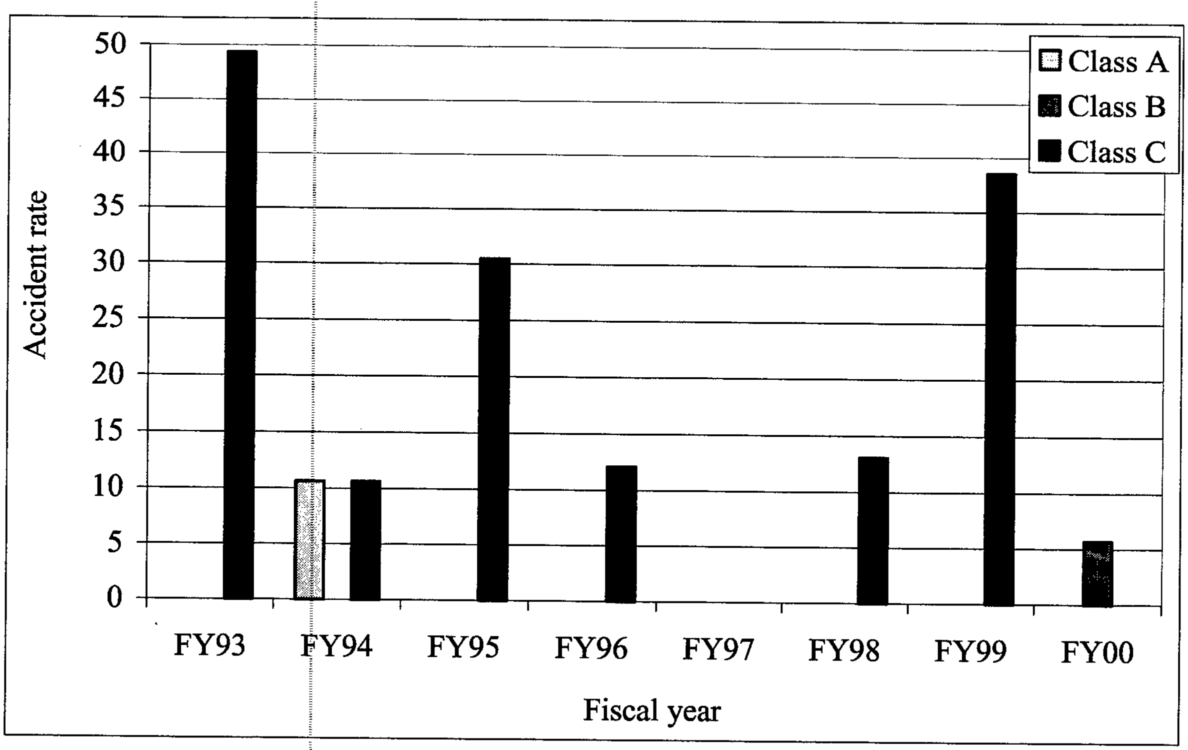


Figure 11. Accident rates for hybrid cockpit MH-60L, Classes A, B, C.

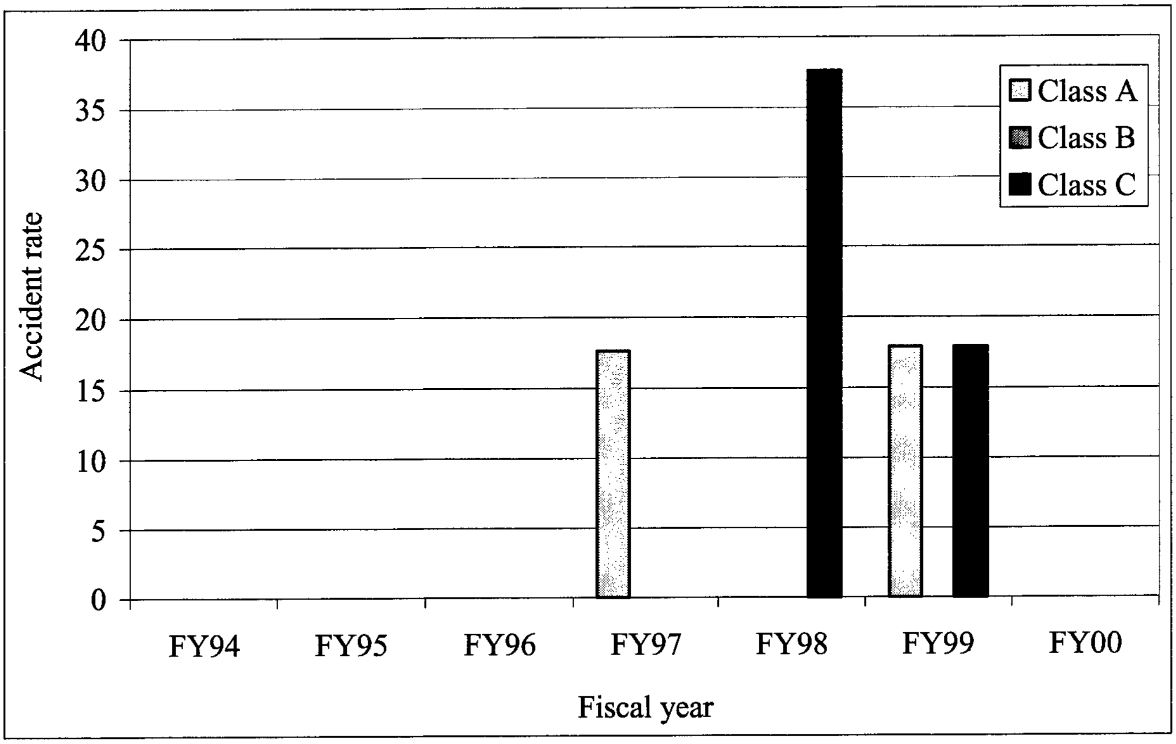


Figure 12. Accident rates for glass cockpit MH-60K, Classes A, B, C.

accident rate for all Classes A-C was 16.32, exceeding the 8.12 rate for the traditional instrument UH-60 models. When the glass cockpit MH-60K was compared to the hybrid MH-60L for their overlapping years, the hybrid MH-60L accident rates exceeded those for the glass cockpit MH-60K for Classes B and C, and for all Classes A-C combined. The all-classes combined hybrid MH-60L accident rate was 25.91, exceeding the 16.02 value for the glass cockpit MH-60K.

Table 7.
Overlap UH/MH-60 accident rates.

	Accident class			
	A	B	C	A-C
FY93-FY00 *				
UH-60 models	1.00	1.07	6.58	8.65
MH-60L	1.55	1.55	17.02	20.12
FY94-FY00 **				
UH-60 models	1.05	0.67	6.40	8.12
MH-60K	6.53	0.00	9.79	16.32
FY94-FY00 ***				
MH-60L	2.36	2.36	21.20	25.91
MH-60K	4.01	0.00	12.02	16.03

*FY97 excluded
**FY95 and FY96 excluded
***FY95, FY96, and FY97 excluded

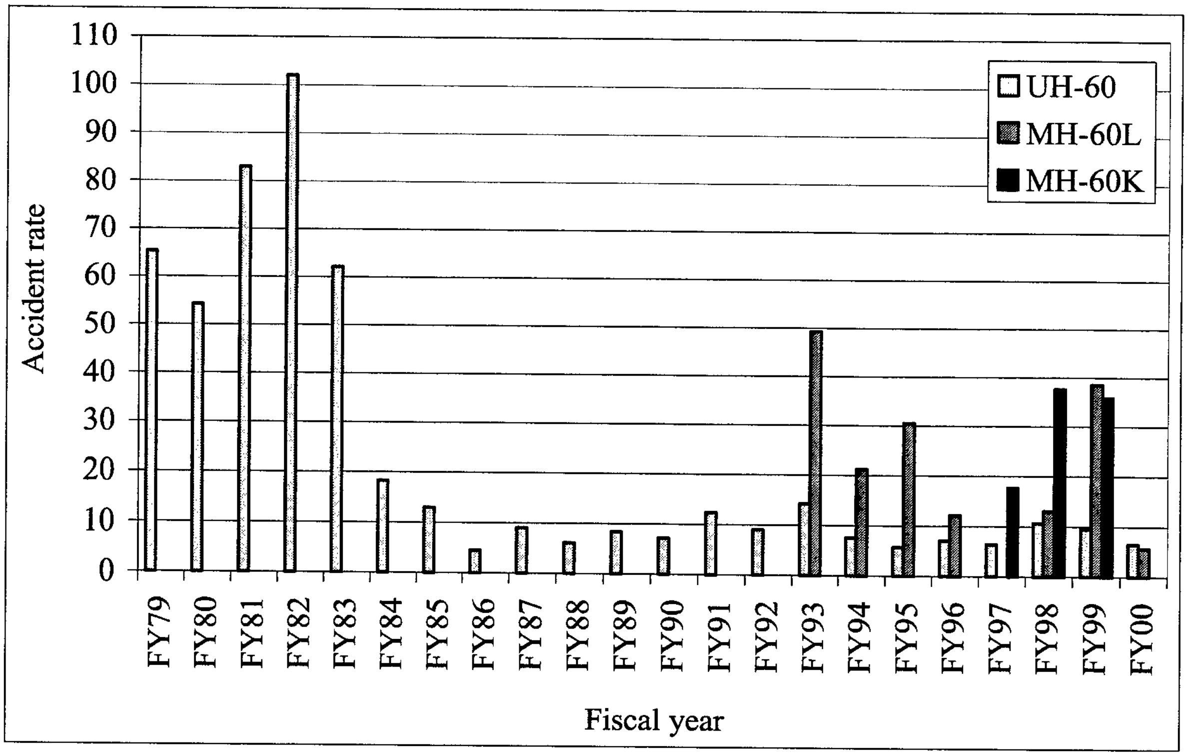


Figure 13. Combined Classes A-C accident rates for the UH-60 models, MH-60L, and MH-60K by fiscal year.

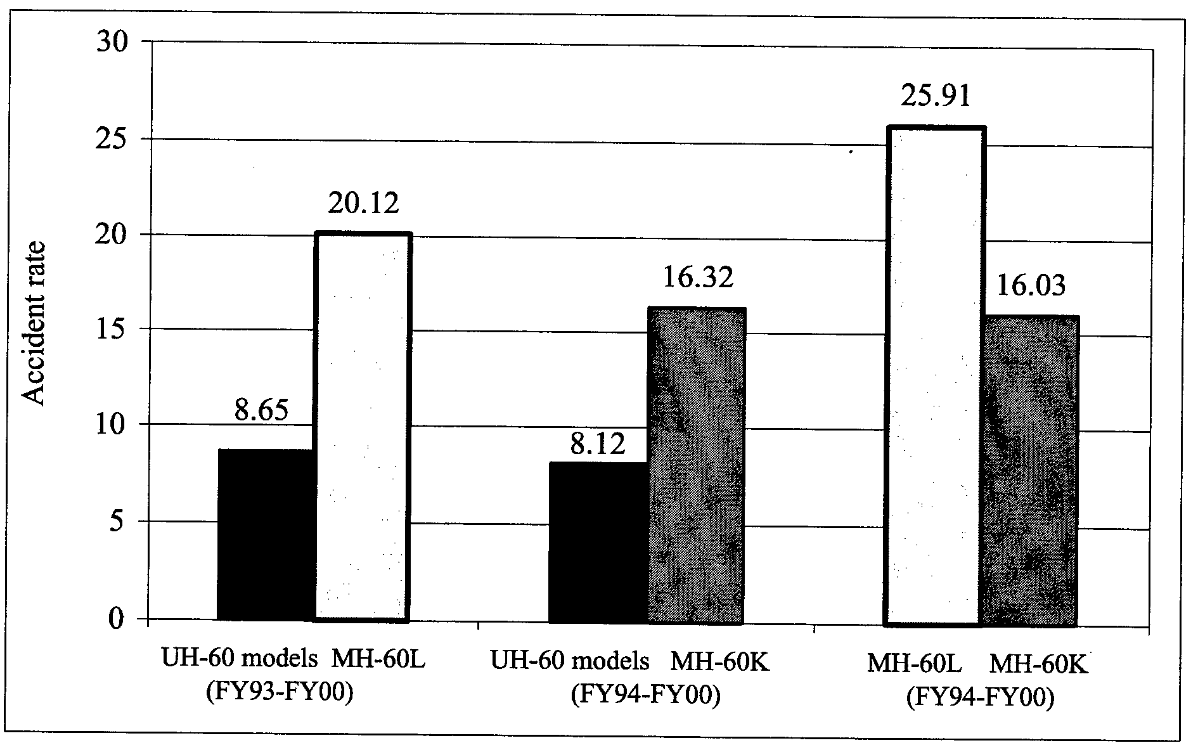


Figure 14. Airframe overlap accident rates for UH-60 models and MH-60L (FY93-FY00), UH-60 models and MH-60K (FY94-FY00), and MH-60L and MH-60K (FY94-FY00).

In Figure 14 overlap accident rates for the UH/MH-60 models are presented in pairs, comparing accident rates for all classes combined between the three UH/MH-60 models.

Discussion

When the overlap rates for individual accident classes and all classes combined were tested using an upper-tail two-sample inference for incidence-rate data (Rosner, 1995), significance values (Table 8) indicated the higher accident rates for the MH-60K glass cockpit model were not statistically significant ($p<.05$) for any of the accident classes or for all classes combined as compared to either the dedicated UH-60 models or the MK-60L hybrid. The only rate differences statistically significant were for the hybrid MH-60L as compared to the dedicated UH-60 models where the rates for the hybrid MH-60L were greater for Class C accidents ($p=.0058$) and for all classes combined ($p=.0065$).

Table 8.
UH/MH-60 significance values (Rosner, 1995).

	Accident class			
	A	B	C	A-C
UH-60 models vs. MH-60L	.4920	.5144	**.0058**	**.0065**
UH-60 models vs. MH-60K	.0512	1.0000	.3207	.1140
MH-60L vs. MH-60K	.6033	1.0000	.8798	.8653

Note: **Bold** denotes statistical significance ($p<.05$).

CH/MH-47 Chinook

The CH-47 Chinook is a transport/cargo helicopter. The standard crewstation design allows for two pilots in a side-by-side seating configuration plus one flight engineer and one crew chief. The CH-47 was developed in 1956. Since then, the Chinook has been continuously upgraded to produce the CH-47A/B/C/D models. The CH-47A was first delivered for use in Vietnam in 1962. The CH-47B began service in May 1967, followed by the CH-47C later that same year. The CH-47D, having twice the load capacity of the CH-47A, was rolled out in March 1979, and the aircraft became operational with the 101st Airborne Division in 1984. The last years of flight for the CH-47A/B/C were FY87, FY88, and FY92, respectively. Currently, the CH-47D is the only CH-47 model still in the field. All CH-47 models have standard dedicated instrument crewstation designs.

Two models, the MH-47D and the MH-47E, are currently designated exclusively as Special Operations Aircraft. The MH-47D, technically fielded in FY90, is a hybrid dedicated instrument/glass cockpit design. The MH-47E, first flown in FY94, has a full glass cockpit crewstation design. Figure 15 shows cockpit views for the CH-47D (top left), MH-47D (top right), and MH-47E (bottom).

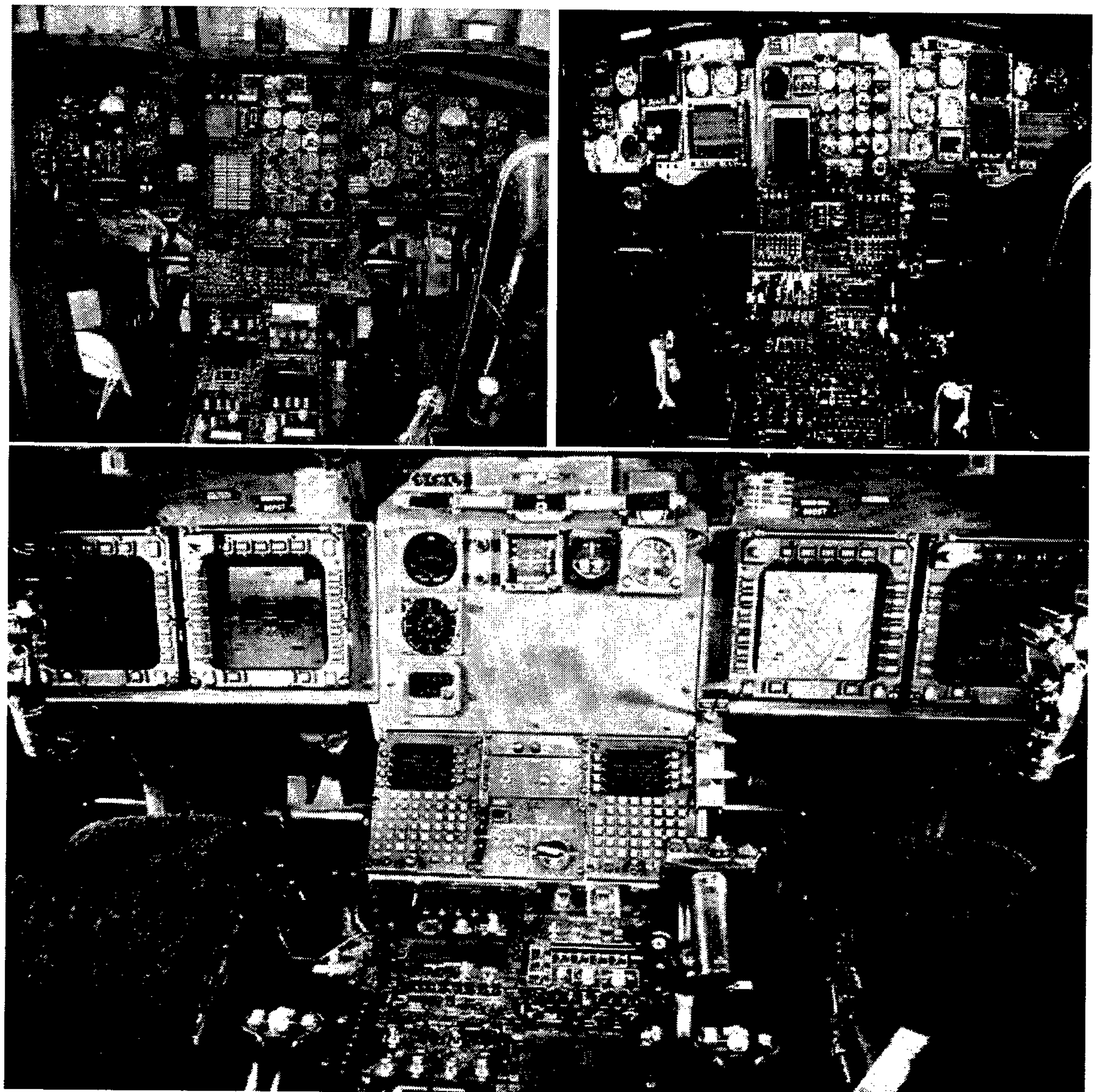


Figure 15. Cockpit views for the CH-47D (top left), MH-47D (top right), and MH-47E (bottom).

Again, since the USASC was not begun until 1972, and the CH-47A was fielded in the early 1960's, flight hours and accident frequencies and rates are available only for FY72 to the present. See the Appendix for flight hours for the dedicated instrument models of the CH-47A/B/C/D, the hybrid MH-47D, and the glass cockpit MH-47E, respectively, by fiscal year. These flight hour data are combined and presented in Figure 16 for comparison. The total flight hours (as of 1 October 2000) for the CH-47A/B/C/D, MH-47D, and MH-47E were 1,539,465, 24,464, and 41,567, respectively. Note: As with other Special Operations Aviation aircraft, some flight hour data were not available. Such was the case for the hybrid cockpit MH-47D, where flight hours were not reported for FY90-FY93.

Accident data

Accident frequencies for the CH/MH-47 are presented in Table 9. These frequencies are presented by accident class and compared as CH-47A/B/C/D, MH-47D, and MH-47E. In a similar manner, accident rates for the CH/MH-47 models are presented in Table 10. The third from the bottom row in Table 10 represents lifetime accident rates for the CH/MH-47 models, where the lifetime rate was defined as the number of accidents per 100,000 flight hours for a given class, or group of classes, across the total flight hours for the associated class or group of classes, for the total period of time for which the aircraft has been in service (since 1972). For the hybrid cockpit MH-47D, lifetime accident rates were calculated based on FY94-FY00, the only years for which flight hours were available. For the glass cockpit MH-47E, lifetime accident rates were calculated based on FY94-FY00.

For the dedicated instrument models of the CH-47A/B/C/D, the accident rates presented in Table 10 are plotted in Figure 17 for individual accident Classes A, B, and C. The lifetime accident rates for Classes A, B, and C were 2.79, 5.46, and 17.28, respectively. The CH-47A/B/C/D lifetime accident rate for all classes combined was 25.53.

Accident frequencies and rates for the dedicated models of the CH-47 for the period FY84-FY00 were added as the second from the bottom row of Tables 9 and 10. For this time period, the overall CH-47 accident rates for Classes A, B, and C were found to be 2.09, 1.15, and 9.50, respectively.

For the hybrid cockpit MH-47D, the accident rates presented in Table 10 are plotted in Figure 18 for individual accident Classes A, B, and C. The lifetime accident rates for Classes A, B, and C were 0.00, 0.00, and 16.35, respectively. The MH-47D lifetime accident rate for all classes combined was 16.35. The FY84-FY00 MH-47D accident rates for Classes A, B, and C and for all classes combined were identical to the lifetime rates since data were available only since FY90.

For the glass cockpit MH-47E, the accident rates presented in Table 10 are plotted in Figure 19. The lifetime accident rates for Classes A, B, and C were 4.81, 2.41, and 4.81, respectively. The MH-47E lifetime accident rate for all classes combined was 12.03. MH-47E FY84-FY00 accident rates were identical to the lifetime accident rates.

Table 9.
Frequency of CH-47A/B/C/D, MH-47D, and MH-47E flight accidents.

	CH-47A/B/C/D flight accidents				MH-47D flight accidents				MH-47E flight accidents			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY72	3	5	10	18	-	-	-	-	-	-	-	-
FY73	0	6	8	14	-	-	-	-	-	-	-	-
FY74	0	7	12	19	-	-	-	-	-	-	-	-
FY75	1	7	7	15	-	-	-	-	-	-	-	-
FY76	1	10	9	20	-	-	-	-	-	-	-	-
FY77	3	11	15	29	-	-	-	-	-	-	-	-
FY78	0	9	11	20	-	-	-	-	-	-	-	-
FY79	5	4	9	18	-	-	-	-	-	-	-	-
FY80	4	4	14	22	-	-	-	-	-	-	-	-
FY81	2	5	21	28	-	-	-	-	-	-	-	-
FY82	2	2	33	37	-	-	-	-	-	-	-	-
FY83	2	3	26	31	-	-	-	-	-	-	-	-
FY84	1	1	6	8	-	-	-	-	-	-	-	-
FY85	3	2	10	15	-	-	-	-	-	-	-	-
FY86	0	0	6	6	-	-	-	-	-	-	-	-
FY87	3	0	5	8	-	-	-	-	-	-	-	-
FY88	2	1	6	9	-	-	-	-	-	-	-	-
FY89	1	1	5	7	-	-	-	-	-	-	-	-
FY90	2	1	6	9	1	0	0	1	-	-	-	-
FY91	2	0	5	7	0	0	0	0	-	-	-	-
FY92	0	1	4	5	0	0	0	0	-	-	-	-
FY93	1	1	7	9	0	0	1	1	-	-	-	-
FY94	2	1	6	9	0	0	0	0	0	0	0	0
FY95	1	0	4	5	0	0	0	0	0	0	0	0
FY96	0	0	8	8	0	0	0	0	2	0	1	3
FY97	1	1	4	6	0	0	2	2	0	1	0	1
FY98	0	1	3	4	0	0	1	1	0	0	0	0
FY99	1	0	2	3	0	0	0	0	0	0	1	1
FY00	0	0	4	4	0	0	1	1	0	0	0	0
TOTALS	43	84	266	393	1	0	5	6	2	1	2	5
FY84-00	20	11	91	122	1	0	5	6	2	1	2	5
Overlap	5	3	31	39	0	0	4	4	2	1	2	5

Table 10.
Accident rates for CH-47A/B/C/D, MH-47D, and MH-47E.

	CH-47A/B/C/D flight accident rates				MH-47D flight accident rates				MH-47E flight accident rates			
	Class A	Class B	Class C	Classes A-C	Class A	Class B	Class C	Classes A-C	Class A	Class B	Class C	Classes A-C
FY72	12.88	21.46	42.92	77.26	-	-	-	-	-	-	-	-
FY73	0.00	13.17	17.56	30.73	-	-	-	-	-	-	-	-
FY74	0.00	15.26	26.16	41.42	-	-	-	-	-	-	-	-
FY75	2.21	15.49	15.49	33.20	-	-	-	-	-	-	-	-
FY76	1.94	19.41	17.47	38.82	-	-	-	-	-	-	-	-
FY77	5.40	19.81	27.02	52.23	-	-	-	-	-	-	-	-
FY78	0.00	16.24	19.85	36.09	-	-	-	-	-	-	-	-
FY79	9.71	7.77	17.48	34.96	-	-	-	-	-	-	-	-
FY80	7.72	7.72	27.03	42.48	-	-	-	-	-	-	-	-
FY81	3.52	8.80	36.97	49.29	-	-	-	-	-	-	-	-
FY82	3.64	3.64	60.11	67.40	-	-	-	-	-	-	-	-
FY83	4.52	6.78	58.80	70.11	-	-	-	-	-	-	-	-
FY84	1.85	1.85	11.09	14.78	-	-	-	-	-	-	-	-
FY85	5.69	3.79	18.96	28.44	-	-	-	-	-	-	-	-
FY86	0.00	0.00	10.92	10.92	-	-	-	-	-	-	-	-
FY87	5.08	0.00	8.47	13.55	-	-	-	-	-	-	-	-
FY88	3.26	1.63	9.78	14.67	-	-	-	-	-	-	-	-
FY89	1.93	1.93	9.65	13.51	-	-	-	-	-	-	-	-
FY90	3.74	1.87	11.21	16.81	*	0.00	0.00	*	-	-	-	-
FY91	3.91	0.00	9.77	13.67	0.00	0.00	0.00	0.00	-	-	-	-
FY92	0.00	1.59	6.36	7.95	0.00	0.00	0.00	0.00	-	-	-	-
FY93	1.66	1.66	11.62	14.95	0.00	0.00	*	*	-	-	-	-
FY94	3.31	1.66	9.93	14.90	0.00	0.00	0.00	31.31	0.00	0.00	0.00	0.00
FY95	1.69	0.00	6.75	8.43	0.00	0.00	0.00	18.07	0.00	0.00	0.00	0.00
FY96	0.00	0.00	13.41	13.41	0.00	0.00	0.00	15.20	32.14	0.00	16.07	48.22
FY97	1.73	1.73	6.91	10.36	0.00	0.00	104.17	26.52	0.00	17.75	0.00	17.75
FY98	0.00	1.97	5.91	7.88	0.00	0.00	49.46	29.23	0.00	0.00	0.00	0.00
FY99	1.87	0.00	3.73	5.60	0.00	0.00	0.00	25.76	0.00	0.00	16.98	16.98
FY00	0.00	0.00	7.35	7.35	0.00	0.00	19.78	24.53	0.00	0.00	0.00	0.00
Lifetime	2.79	5.46	17.28	25.53	0.00	0.00	16.35	16.35	4.81	2.41	4.81	12.03
FY84-00	2.09	1.15	9.50	12.74	0.00	0.00	16.35	16.35	4.81	2.41	4.81	12.03
Overlap	1.26	0.76	7.83	9.85	0.00	0.00	16.35	16.35	4.81	2.41	4.81	12.03

Note: Asterisk denotes inability to calculate accident rate due to unreported flight hours.
Lifetime accident rates do not include FYs with unreported flight hours.

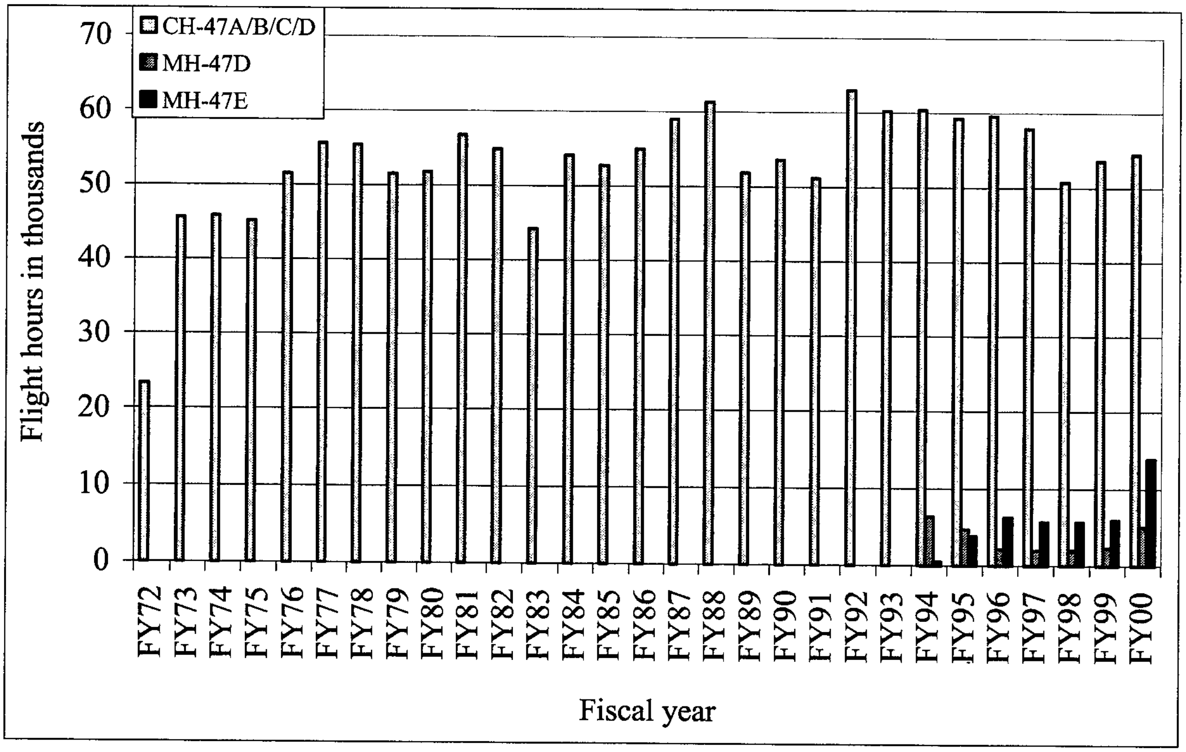


Figure 16. Flight hours for CH-47A/B/C/D, MH-47D, and MH-47E.

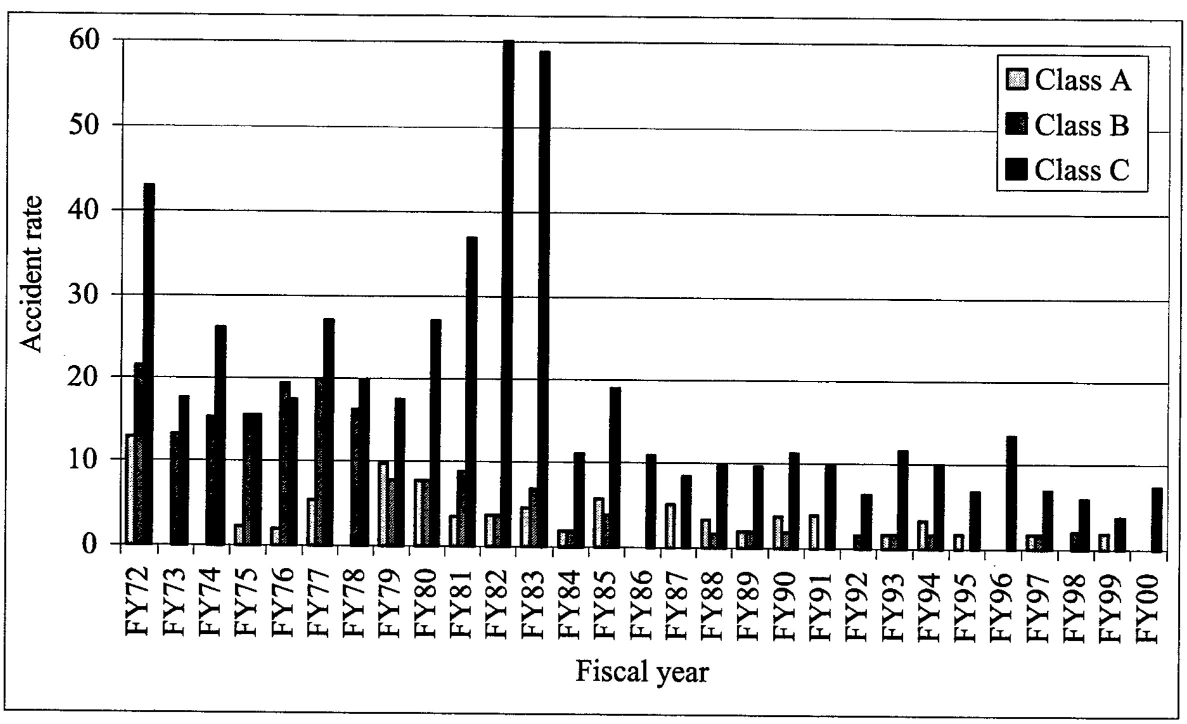


Figure 17. Accident rates for CH-47A/B/C/D, Classes A, B, C.

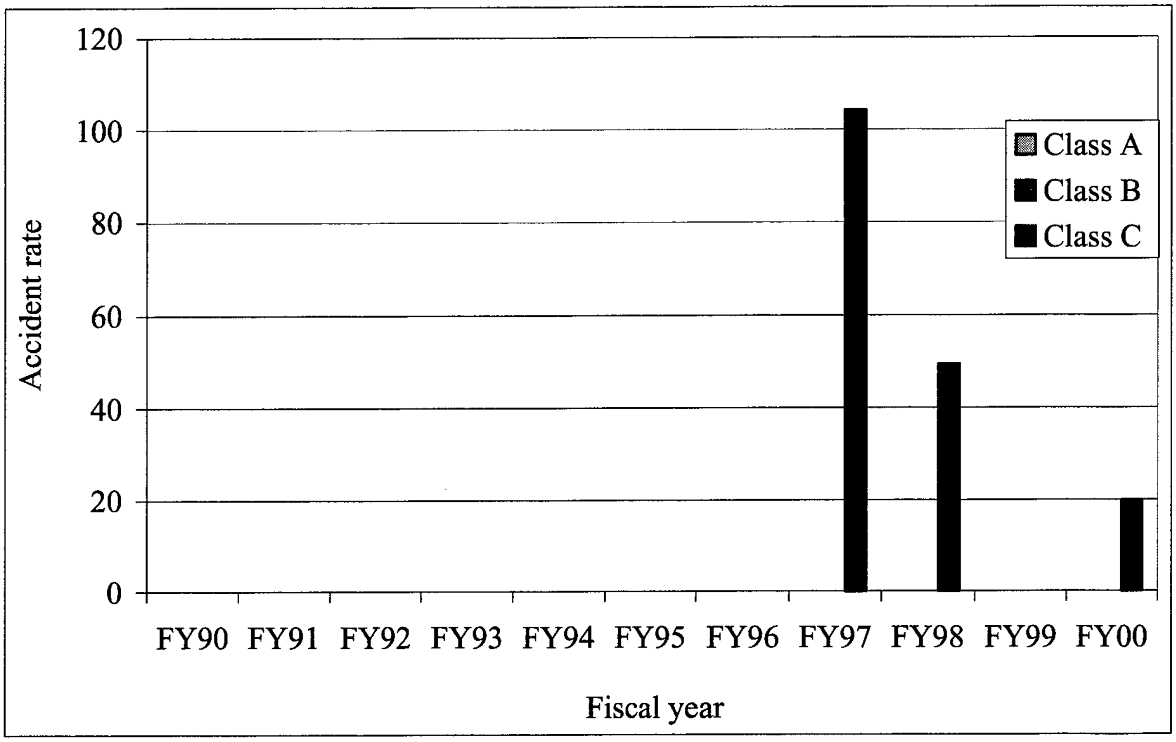


Figure 18. Accident rates for hybrid cockpit MH-47D, Classes A, B, C.

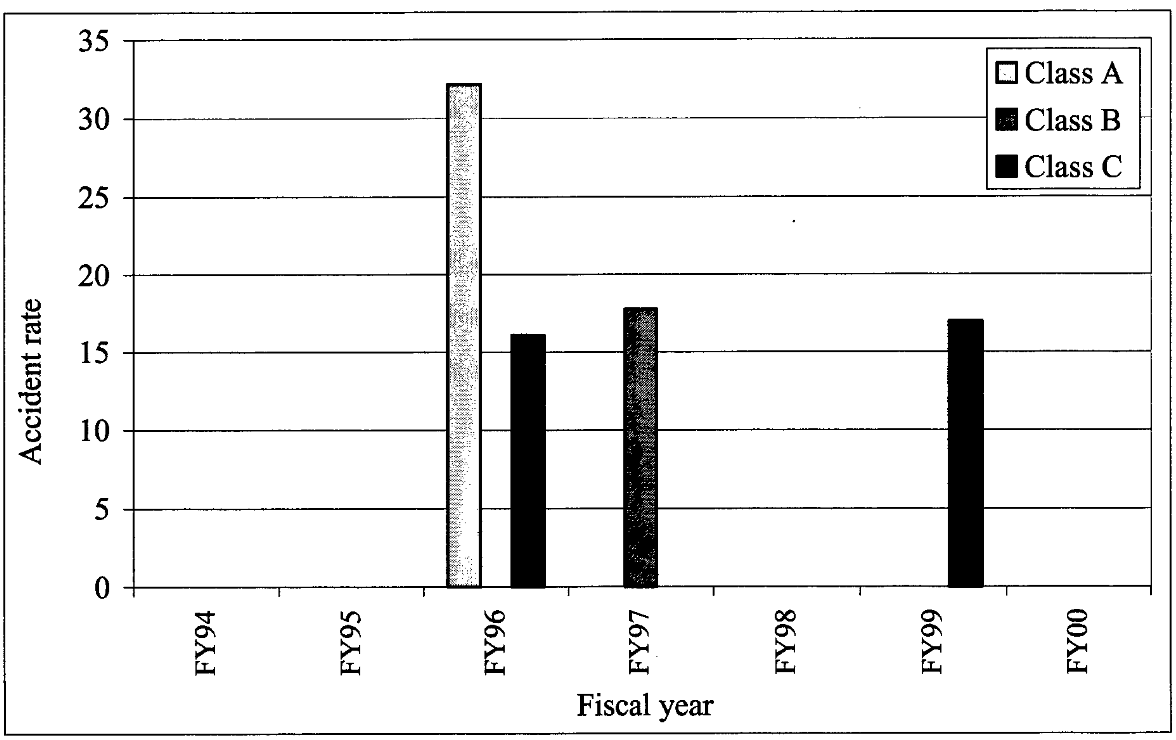


Figure 19. Glass cockpit MH-47E Classes A, B, C

In Figure 20, accident rates for the dedicated instrument CH-47A/B/C/D are presented with those for the hybrid MH-47D and the glass model MH-47E by fiscal year.

To investigate accident rates for the dedicated, hybrid and glass cockpits CH/MH-47 models, comparisons were made over the overlap periods of FY94-FY00 (Figure 21). For all classes combined, the overlap hybrid MH-47D had the numerically greatest rate of 16.35, the glass cockpit MH-47E had 12.03, and the dedicated cockpit CH-47A/B/C/D had 9.85 (Table 10).

Discussion

When the rates for individual accident classes and all classes combined were tested using an upper-tail two-sample inference for incidence-rate data (Rosner, 1995), significance values (Table 11) indicated the accident rates for the MH-47E glass model (which was the lowest rate) were not statistically significant ($p<.05$) for any of the accident classes or for all classes combined as compared to the dedicated CH-47A/B/C/D models. Likewise, the accident rates for the glass cockpit MH-47E were not statistically significant ($p<.05$) as compared to the hybrid MH-47D, and the accident rates for the hybrid cockpit MH-47D were not statistically significant ($p<.05$) as compared to the dedicated cockpit CH-47A/B/C/D.

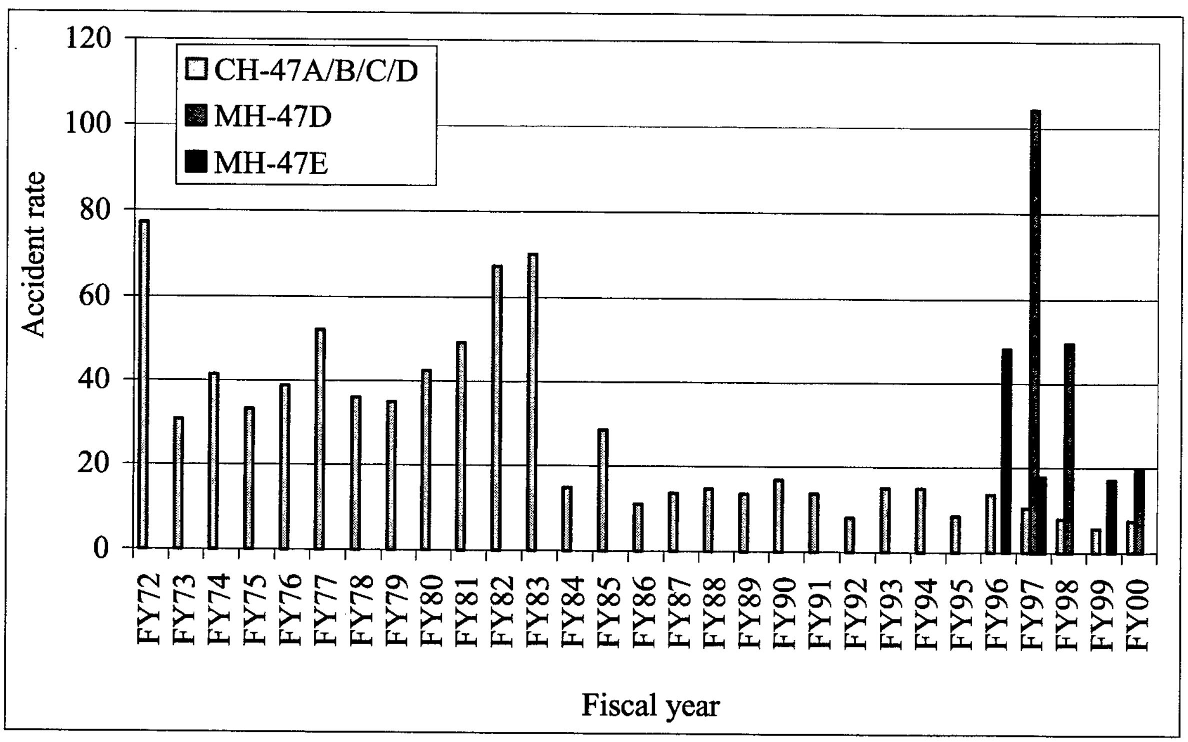


Figure 20. Combined Classes A-C accident rates for the CH-47A/B/C/D, MH-47D, and MH-47E by fiscal year.

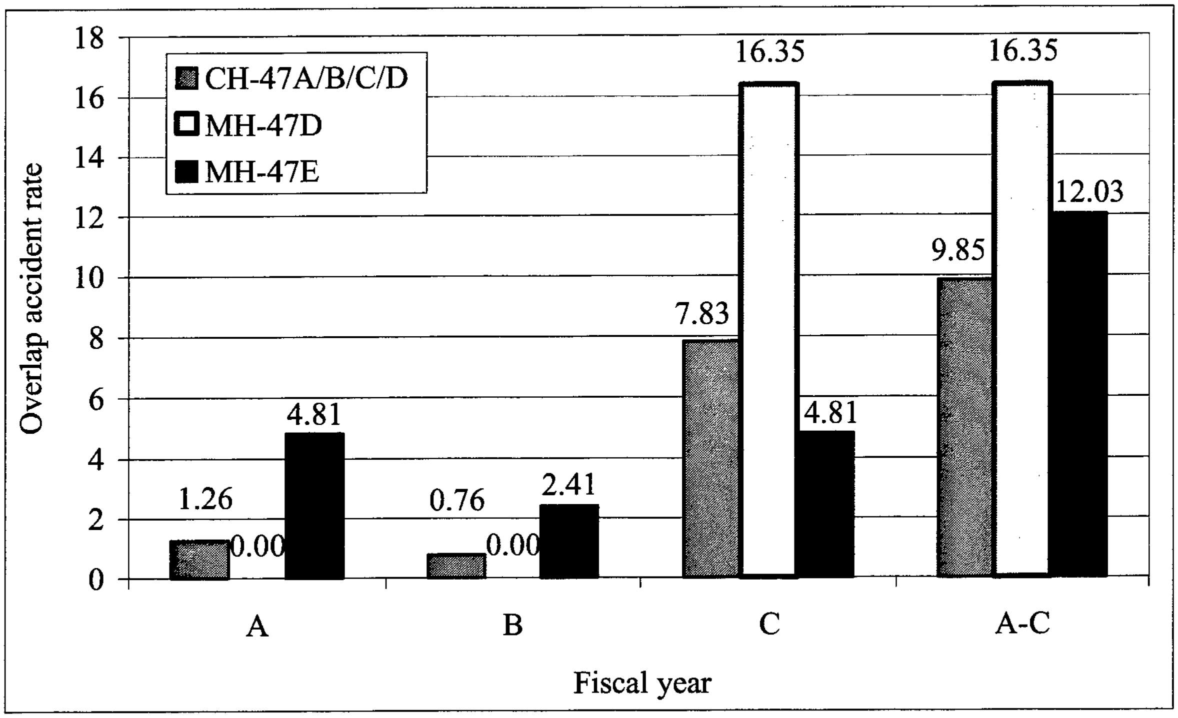


Figure 21. Overlap airframe accident rates for CH-47A/B/C/D, MH-47D, and MH-47E for FY90-FY00.

Table 11.
CH/MH-47 significance values (Rosner, 1995).

	Accident Class			
	A	B	C	A-C
CH-47 vs. MH-47D	1.0000	1.000	.1440	.2394
CH-47 vs. MH-47E	.1374	.3291	.8343	.4078
MH-47D vs. MH-47E	.3962	.6295	.9710	.7918

AH-64 Apache

The AH-64 Apache is the Army's most advanced attack helicopter. It uses a tandem-seating configuration. The dedicated instrument A-model was fielded in 1985. The glass cockpit D-model was introduced in 1997. The two cockpit designs are presented in Figure 22. The total flight hours for the AH-64A and AH-64D models (as of 1 October 2000) were 1,217,398 and 31,192, respectively. The distributions of AH-64 flight hours by fiscal year are presented in Figure 23. Flight hours by fiscal year are provided in the Appendix.

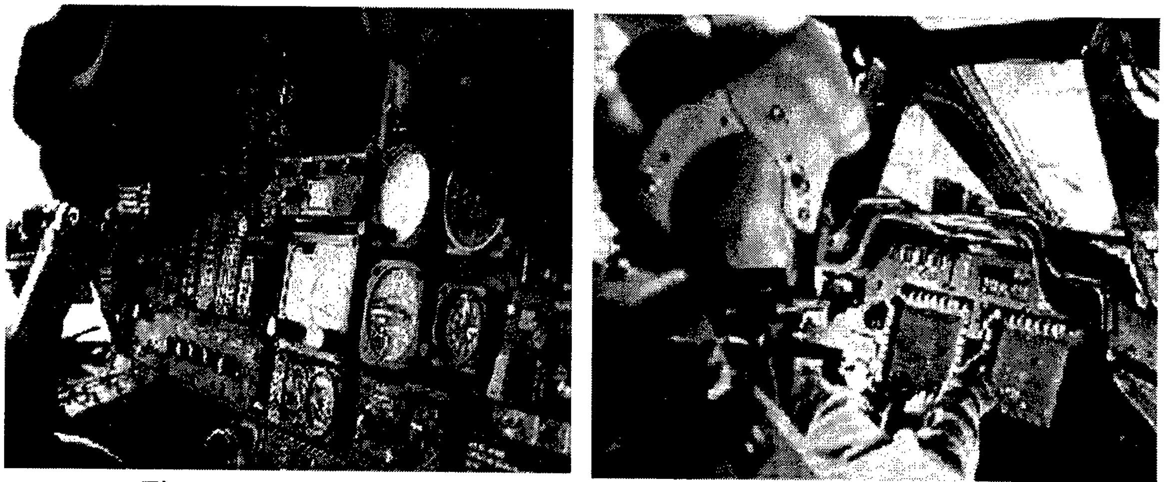


Figure 22. Cockpit views of the AH-64A (left) and AH-64D (right).
(Pictures printed with permission from Boeing)

Accident data

The frequency of accidents for the A- and D- model AH-64 Apache by fiscal year and accident class are represented in Table 12. As has been typical, the highest frequency accident class was Class C. The number of accidents for the AH-64 A- and D- models per 100,000 flight hours are presented in Table 13. The next to last row entry in Table 13 presents lifetime accident rates for the AH-64 models based on the period of FY85-FY00 for the dedicated instrument AH-64A and FY97-FY00 for the glass cockpit AH-64D.

For the dedicated instrument AH-64A, the accident rates presented in Table 13 are plotted in Figure 24 for individual accident Classes A, B, and C. The lifetime AH-64A accident rates for Classes A, B, and C were 4.11, 1.81, and 10.43, respectively. The AH-64A lifetime accident rate for all classes combined was 16.35.

For the glass cockpit AH-64D, the accident rates presented in Table 13 are plotted in Figure 25 for individual accident Classes A, B and C. The lifetime AH-64D accident rates for Classes A, B, and C were 6.41, 6.41, and 9.62, respectively. The AH-64D lifetime accident rate for all classes combined was 22.44.

In Figure 26, accident rates for the dedicated instrument AH-64A are compared with those for the glass model AH-64D by fiscal year.

In Figure 27, accident rates for the dedicated instrument AH-64A and glass cockpit AH-64D are shown for individual accident classes and for all classes combined for the overlap period of FY97-FY00. For accident Classes A and B and for all classes combined, the overlap accident rates for the glass cockpit AH-64D were greater than for the dedicated instrument AH-64A. For Class C accidents, the accident rate for the glass cockpit AH-64D was less than for the dedicated instrument AH-64A.

Table 12.
Frequency of AH-64A and AH-64D flight accidents.

	AH-64A flight accidents				AH-64D flight accidents			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY85	0	1	1	2	-	-	-	-
FY86	3	0	2	5	-	-	-	-
FY87	4	1	4	9	-	-	-	-
FY88	0	0	6	6	-	-	-	-
FY89	4	2	7	13	-	-	-	-
FY90	3	2	3	8	-	-	-	-
FY91	6	4	9	19	-	-	-	-
FY92	5	2	6	13	-	-	-	-
FY93	5	4	8	17	-	-	-	-
FY94	4	1	12	17	-	-	-	-
FY95	2	2	8	12	-	-	-	-
FY96	3	2	8	13	-	-	-	-
FY97	3	0	11	14	0	0	0	0
FY98	3	0	15	18	0	0	0	0
FY99	4	1	16	21	2	2	2	6
FY00	1	0	11	12	0	0	1	1
TOTALS	50	22	127	199	2	2	3	7
Overlap	11	1	53	65	2	2	3	7

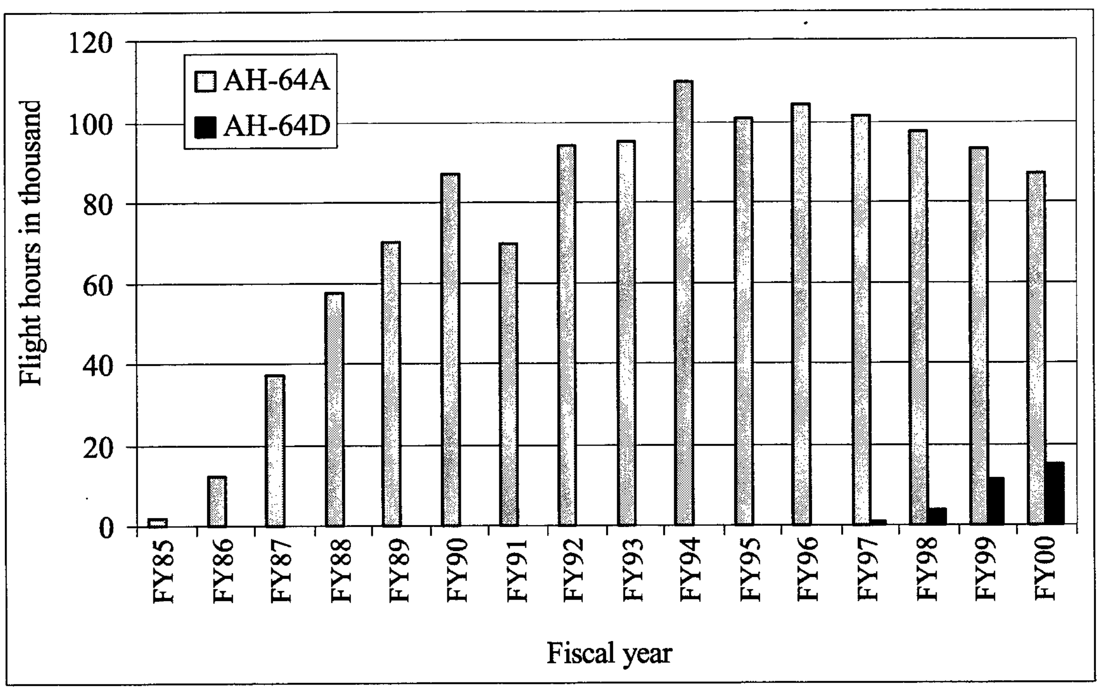


Figure 23. Flight hours for AH-64A and AH-64D.

Table 13.
Accident rates for AH-64A and AH-64D.

	AH-64A flight accident rates				AH-64D flight accident rates			
	Class A	Class B	Class C	Classes A – C	Class A	Class B	Class C	Classes A – C
FY85	0.00	57.05	57.05	114.09	-	-	-	-
FY86	24.45	0.00	16.30	40.75	-	-	-	-
FY87	10.71	2.68	10.71	24.10	-	-	-	-
FY88	0.00	0.00	10.49	10.49	-	-	-	-
FY89	5.72	2.86	10.01	18.59	-	-	-	-
FY90	3.45	2.30	3.45	9.21	-	-	-	-
FY91	8.63	5.75	12.95	27.33	-	-	-	-
FY92	5.32	2.13	6.38	13.83	-	-	-	-
FY93	5.25	4.20	8.40	17.84	-	-	-	-
FY94	3.64	0.91	10.93	15.48	-	-	-	-
FY95	1.99	1.99	7.95	11.92	-	-	-	-
FY96	2.89	1.92	7.70	12.51	-	-	-	-
FY97	2.97	0.00	10.89	13.85	0.00	0.00	0.00	0.00
FY98	3.08	0.00	15.42	18.51	0.00	0.00	0.00	0.00
FY99	4.28	1.07	17.13	22.49	17.39	17.39	17.39	52.16
FY00	1.15	0.00	12.62	13.77	0.00	0.00	6.62	6.62
Lifetime	4.11	1.81	10.43	16.35	6.41	6.41	9.62	22.44
Overlap	2.90	0.26	13.99	17.16	6.41	6.41	9.62	22.44

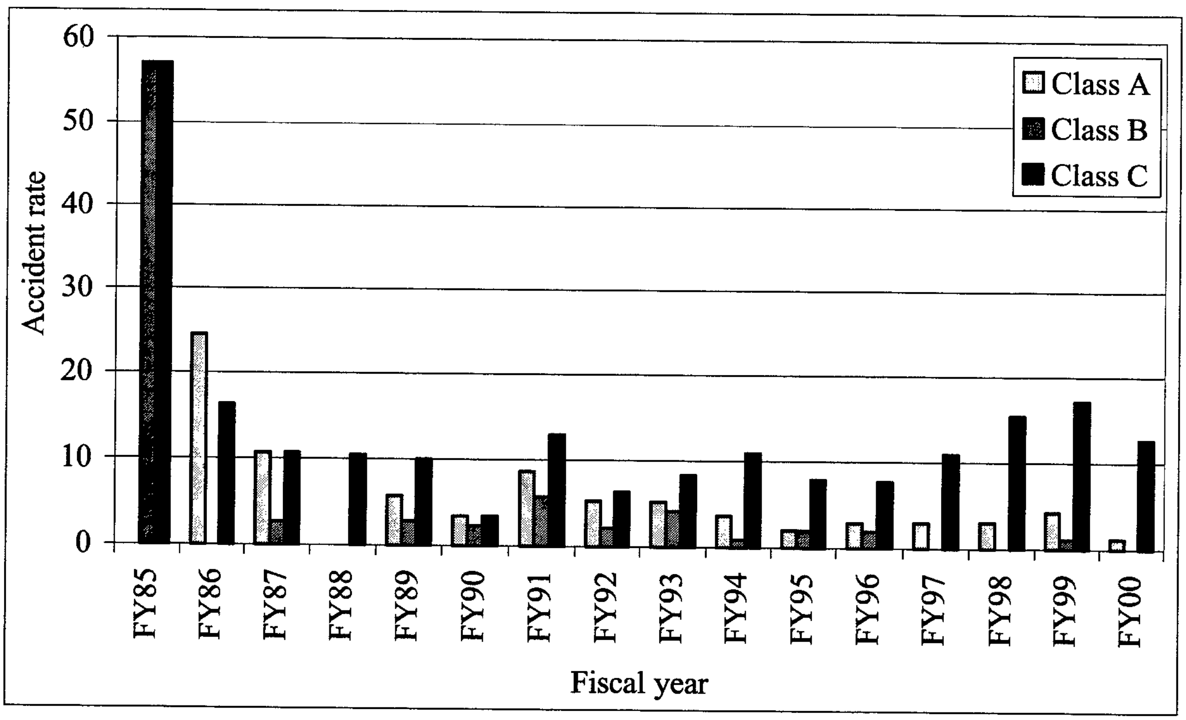


Figure 24. Accident rates for AH-64A Classes A, B, C.

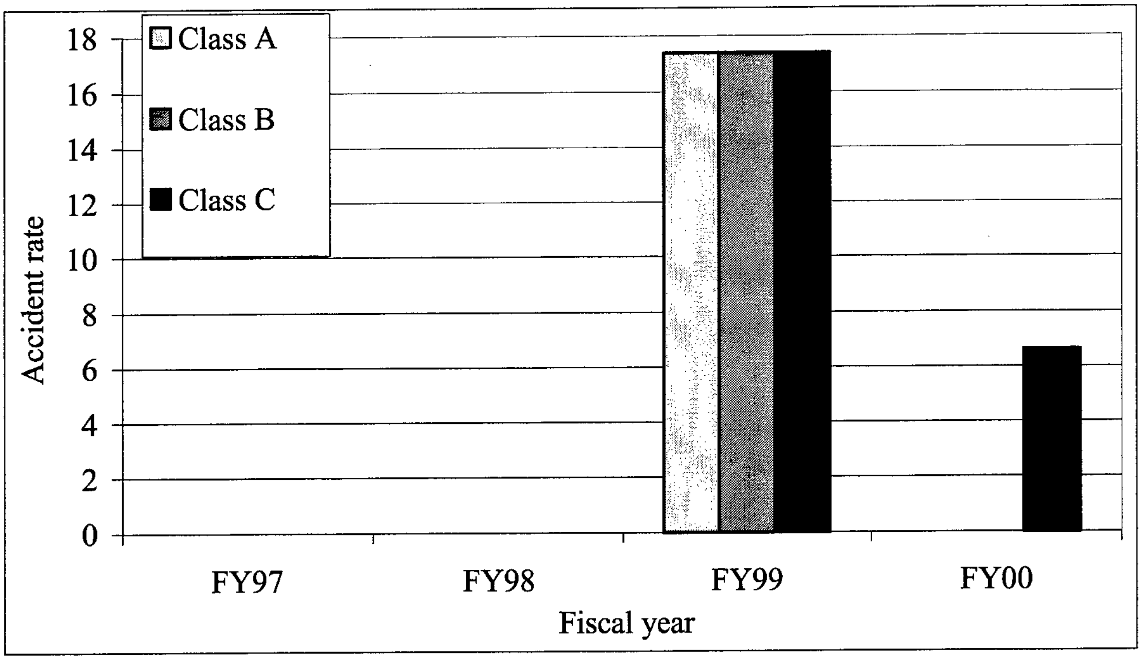


Figure 25. Glass cockpit AH-64D Classes A, B, C

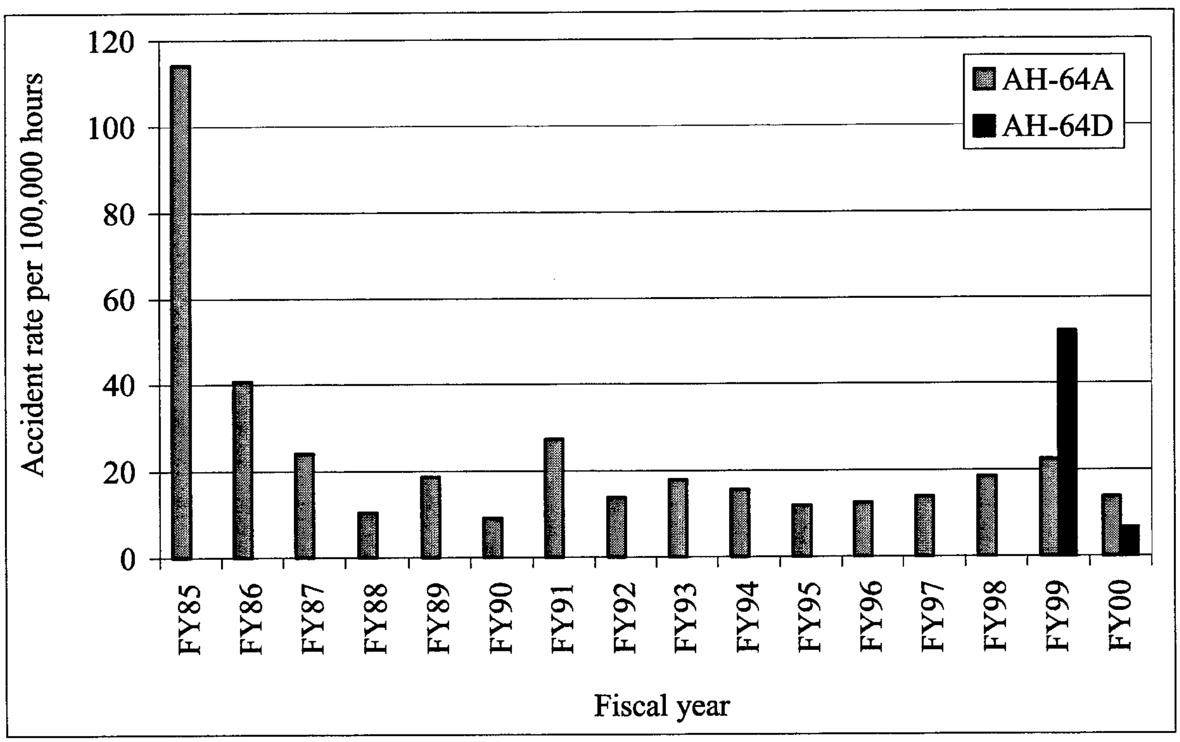


Figure 26. Comparison of combined Classes A-C accident rates for the AH-64A and AH-64D by fiscal year.

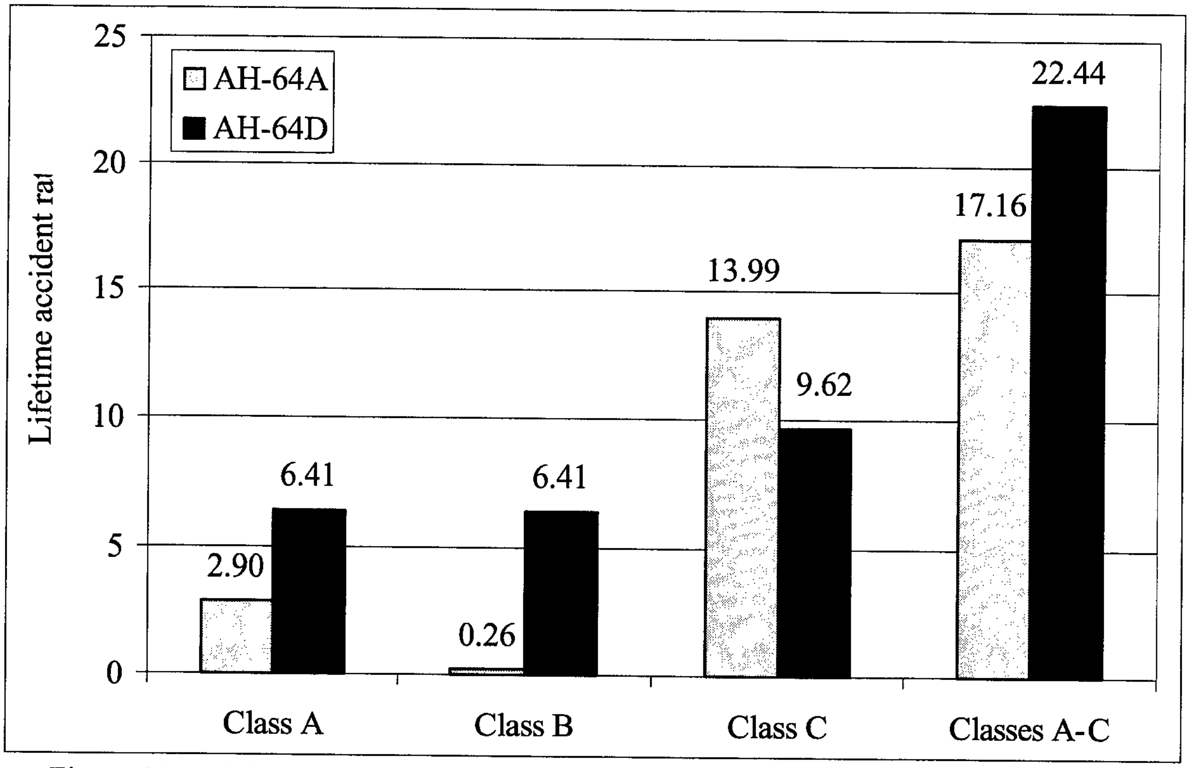


Figure 27. Airframe overlap accident rates for AH-64A and AH-64D (FY97-FY00).

Since there are training issues associated with learning to fly new aircraft models, an argument can be made that a comparison of accident rates should be made for the first few years of fielding of both the dedicated instrument and glass cockpit models of the same aircraft series. This was possible only for the AH-64 Apache where data were available for the first four years of fielding for both models.

Table 14.
AH-64 accident rates for initial four-year fielding periods.

		Year 1	Year 2	Year 3	Year 4	Years 1-4
AH-64A Classes A-C	Accident frequency	2	5	9	6	22
	Flight hours	1,753	12,270	37,341	57,181	108,545
	Accident rate	114.09	40.75	24.10	10.49	20.27
AH-64D Classes A-C	Accident frequency	0	0	6	1	7
	Flight hours	756	3,816	11,503	15,117	31,192
	Accident rate	0.00	0.00	52.16	6.62	22.44

Accident rates for the first four years following the fielding of the dedicated instrument AH-64A and the glass cockpit AH-64D are presented in Table 6 and plotted in Figure 28. This initial fielding period was FY85-FY88 for the A-model and FY97-FY00 for the D-model. The overall four-year accident rate for the dedicated instrument AH-64A (20.27) was numerically less than for the glass cockpit AH-64D (22.44). However, looking at individual fiscal years for this initial fielding period, the accident rate for all classes combined was greater for the glass cockpit AH-64D only for the third year of this period.

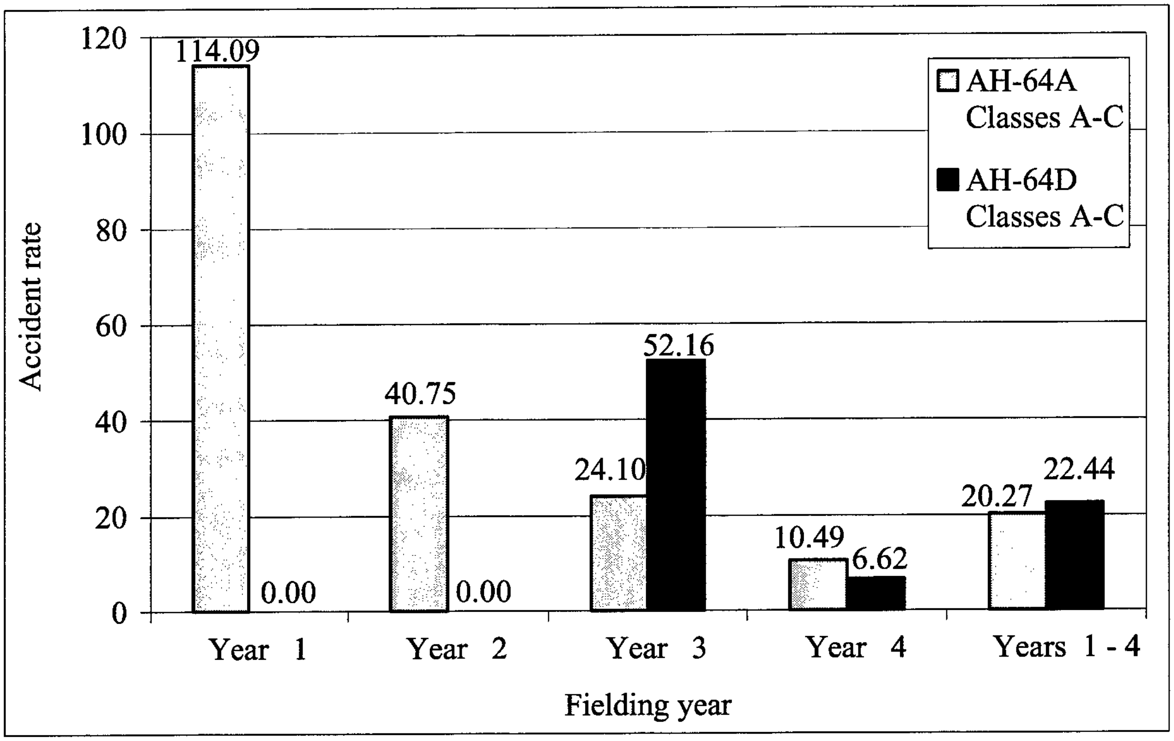


Figure 28. Accident rates for first four years of fielding, AH-64A (FY85-FY88) and AH-64D (FY97-FY00).

Discussion

When the overlap rates for individual accident classes and all classes combined (Table 13) were tested using an upper-tail two-sample inference for incidence-rate data (Rosner, 1995), significance values (Table 15) indicated that the higher accident rates for the glass cockpit AH-64D were not statistically significant ($p<.05$) for any of the accident classes or for all classes combined.

Table 15.
AH-64 overlap significance values (Rosner, 1995).

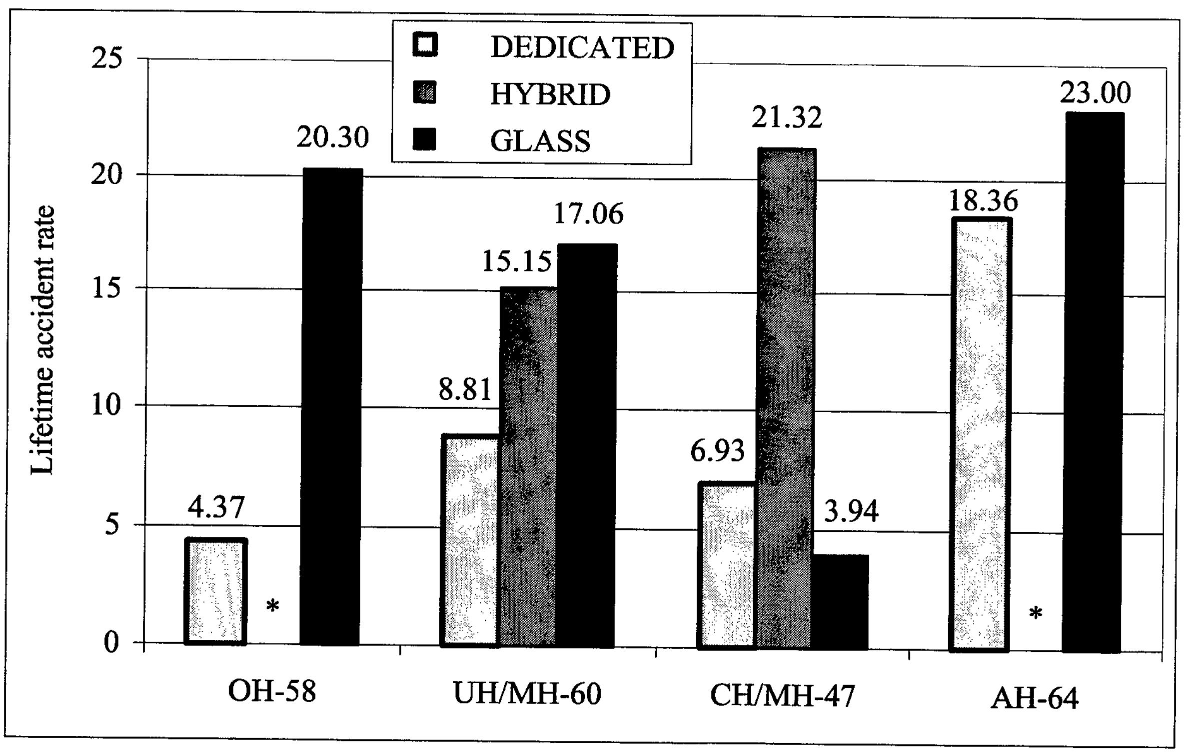
	Accident class			
	A	B	C	A-C
AH-64A vs. AH-64D	.3741	.1200	.6331	.2578

Comparison across all aircraft

In the previous sections, accident rates were compared for the four U.S. Army aircraft series which field glass cockpit models. While within-aircraft comparisons are the most valid, there is some benefit to comparing the dedicated instrument and glass cockpit accident rates across the four aircraft. Using the previous argument that comparisons are best made for periods of overlapping years where accident data and flight hours are available for all models concerned, comparison across all four of these aircraft was based on the period FY98-FY00. Table 16 provides accident frequency, flight hours, and accident rates for this all-aircraft overlap period for all models -- dedicated, hybrid and glass cockpit.

Table 16.
Accident rate data for all aircraft for FY98-FY00.

	Aircraft series									
	OH-58A/C	OH-58D	UH-60 models	MH-60L	MH-60K	CH-47 A/B/C/D	MH-47D	MH-47E	AH-64A	AH-64D
Accident frequency	14	49	58	5	4	11	2	1	51	7
Flight hours	320,587	241,348	658,264	33,009	23,445	158,779	9,383	25,403	277,812	30,436
Accident rate	4.37	20.30	8.81	15.15	17.06	6.93	21.32	3.94	18.36	23.00

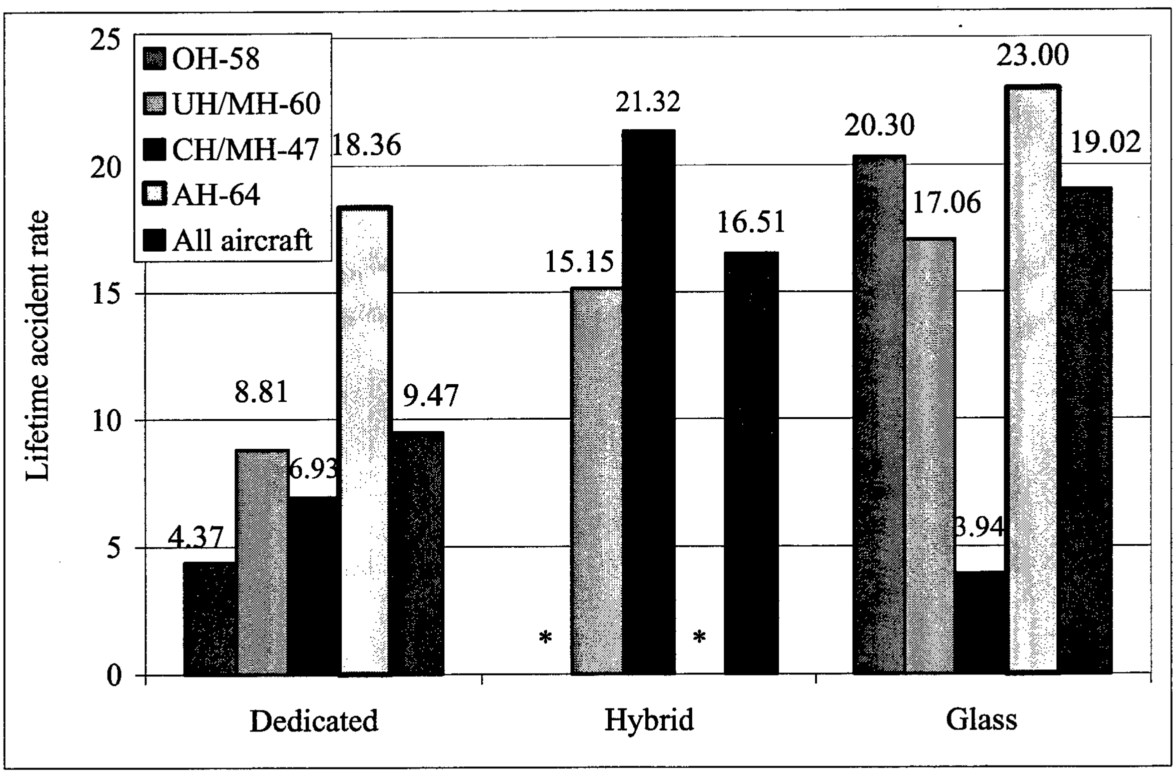


Note: Asterisk denotes no hybrid model exists for this aircraft series.

Figure 29. Accident rates for all accident classes combined by aircraft series for FY98-FY00.

In Figure 29, the accident rates for the overlapping years FY98-FY00 are presented for comparison across aircraft. It can be seen that the glass cockpit models of three of the four aircraft series have accident rates that were numerically greater than for the dedicated instrument cockpit models. The exception was the CH/MH-47, where the glass cockpit MH-47E had the lowest accident rate. For the UH/MH-60 aircraft series, the accident rate for the hybrid MH-60L (15.15) was numerically greater than for the dedicated instrument UH-60 models (8.81), but less than for the glass cockpit MH-60K (17.06). However, for the CH/MH-47 aircraft series, the accident rate for the hybrid MH-47L (21.32) was numerically greater than for the glass cockpit MH-47E (3.94) and for the dedicated instrument CH-47A/B/C/D (6.93). For the period FY98-FY00, looking at all models of the four aircraft series, the greatest accident rate was for the glass cockpit AH-64D (23.00) and the lowest was for the glass cockpit MH-47E (3.94).

In Figure 30, the accident rates across all aircraft for the period FY98-FY00 were re-plotted, grouped by crewstation design. A fifth column was added to each crewstation design group and represented the combined accident rate for that crewstation design. These combined rates for the dedicated instrument, hybrid, and glass cockpits were 9.47, 16.51, and 19.02, respectively.



Note: Asterisk denotes no hybrid model exists for this aircraft series.

Figure 30. Accident rates for all accident classes combined by crewstation design for FY98-FY00.

From Figure 30, it was observed that for the dedicated instrument models, the AH-64A had the greatest accident rate at a value of 18.36. Of the two hybrid models, the MH-47D had the greater accident rate at a value of 21.32. And, for the glass cockpit models, the AH-64D had the greatest accident rate at a value of 23.00.

In summarizing across all four aircraft series, three of the four glass cockpits exhibited accident rates that were numerically greater than dedicated instrument accident rates. In addition, when the accident rates were combined by crewstation design, the glass cockpit models exhibited the greatest accident rate, followed by the hybrid models, and then by the dedicated models. When the incidence-rate statistical test was applied to the combined accident rates by crewstation design, the rate differences were found to be significant only for the dedicated instrument/glass cockpit comparison (Table 17).

Table 17.
Combined FY98-FY00 significance values (Rosner, 1995).

	Classes A-C
Dedicated vs. glass	**.0000**
Dedicated vs. hybrid	.1182
Hybrid vs. glass	.4529

Note: **Bold** denotes statistical significance ($p<.05$).

Conclusions

The purpose of this study was to investigate the possible safety impact of the U.S. Army's trend to replace the traditional crewstation design of clustered dedicated instruments with glass cockpits that include MFDs. Four U.S. Army rotary-wing models have undergone this transition. The resulting glass cockpit models are the OH-58D, MH-60K, MH-47E, and the AH-64D. Two additional models include MFDs in a hybrid cockpit configuration that also includes many dedicated instruments: the MH-60L and the MH-47D.

A comparison of the different cockpit types (traditional, hybrid, and glass cockpit) over the years in which all aircraft had reported flight hours (FY98-00) found that the accident rate for the glass cockpit models was higher than for the traditional models. When broken down into comparisons across cockpit types within individual aircraft, only the OH-58 had a statistically significant difference in accident rates between the traditional and glass cockpit models. The higher rate for the glass cockpit model was found for all accident classes. Two other aircraft, the UH-60 and the AH-64, also had higher accident rates for the glass cockpit model, but the data did not show statistical significance. Comparisons between the traditional and hybrid models (MH-60L and MH-47D) indicated that the hybrid models had higher accident rates than their traditionally equipped counterparts, but the differences did not reach statistical significance.

The failure to reach statistically significant differences for many comparisons may seem surprising given the large numerical differences in accident rates between the traditional and glass cockpit models. However, the failure is largely due to the low number of flight hours available for the hybrid and glass cockpit models. For example, over the period FY98-00, the MH-47D has the second highest accident rate (21.32), but that is based on only two accidents out of 9,383 flight hours. Given such a small number of accidents and flight hours, the accident rate is expected to vary substantially in the future. The same expectation is present for all of the hybrid and glass cockpit models, except for the OH-58D, which has been in service for many years and has several hundred thousand flight hours during the years of analysis.

Taken overall, the findings of this study suggest that there is reason to be concerned that aircraft with hybrid or glass cockpits have higher accident rates than aircraft with traditional cockpits. However, great care needs to be taken in interpreting this statement.

First, there is risk of accidents in every aircraft. While the accident rate for hybrid and glass cockpit aircraft is higher than for traditional aircraft, this does not necessarily mean that the increased accident rate is unacceptable. The hybrid and glass cockpit models also give the aircraft new capabilities for completing missions. It may be that the new abilities offered by the hybrid and glass cockpit designs offset the increased risk of accidents. Whether the risk of accident is acceptable cannot be determined simply by an investigation of accident rates.

Second, it is not at all clear what differences between the traditional, hybrid and glass cockpits are responsible for the different accident rates. There are many possible explanations. For example:

1. Each cockpit upgrade from a traditional to a hybrid or a glass model also included other changes in weapons, surveillance, and equipment. It is possible that it is these changes, rather than the cockpit design *per se*, that are driving the higher accident rates.
2. The MFDs of hybrid and glass cockpit models allow for new information and tasks to be introduced into the cockpit. Pilots may face information overload that prevents them from gaining appropriate situational awareness.
3. The hybrid and glass model cockpits may be more difficult to learn. Perhaps the pilot training programs for the hybrid and glass cockpit models are not as complete and/or effective as the pilot training programs for the traditional models.
4. At any given time, the MFDs in the hybrid and glass cockpits can only display a subset of the available information. Perhaps this is not a good method of information display for military rotary-wing aircraft.
5. Interacting with the MFDs in the hybrid and glass cockpits requires the pilot and co-pilot to focus inside the cockpit. Perhaps this takes time and mental effort that would otherwise be focused outside the cockpit to help fly the aircraft.
6. Designing information hierarchies in MFDs is a difficult task. It may be that the current versions of MFDs in hybrid and glass cockpit models are not optimal.
7. Those aircraft with the enhanced capabilities of the hybrid and glass cockpits may be asked to engage in risky behavior more often because the aircraft are believed to be better equipped to complete the assigned task than the traditional aircraft.

The above list is only intended to be representative; there may be other possibilities. At the moment, there is no mechanism for choosing between these (or other) alternatives.

Third, it is not correct to conclude that hybrid and glass cockpit models are inherently less safe than traditional cockpit models. Indeed, the aircraft with the lowest accident rate across FY98-00 is a glass cockpit model (MH-47E with a rate of 3.94). The aircraft with the highest accident rate across the same years is also a glass cockpit model (AH-64D with a rate of 23.00). The huge variability in accident rates for glass cockpit models reflects the limited amount of data available. The variability may also reflect that the human factors of interacting with an MFD are not as well understood as for traditional instruments, so that the final product depends more on the skill and effort of the designers than on application of fundamental principles. It seems plausible that there can be both good and bad hybrid and glass cockpit models, depending on the details of the design, the mission of the aircraft, and the training of the pilots.

Fourth, the data do not support a hypothesis that hybrid and glass cockpit models are safer than traditional aircraft. This is significant because in fixed-wing commercial aircraft, glass cockpit aircraft have a lower rate of accidents that lead to hull loss than traditional cockpit aircraft (Funk and Lyall, 1997). That the same result is not found in rotary-wing military aircraft indicates that the introduction of a hybrid or glass cockpit will not necessarily make the aircraft safer. Even here though, the situation is complicated because it is possible that any improvements to safety of the aircraft that result from introducing MFDs is offset by other introductions at the same time (e.g., new tasks and duties).

Recommendations

Although, this study cannot pinpoint the precise factors that are involved in the generally higher accident rates for hybrid and glass cockpit models, it does indicate that there is an issue. Moreover, for the OH-58D, there is no question that the accident rate for the glass cockpit design is substantially higher than for the traditional cockpit design. For the other aircraft, there are insufficient flight hours for the observed differences in accident rates to reach statistical significance.

Thus, one recommendation is to repeat the analysis of accident data when more flight hours are available. The required number of flight hours depends on the difference in accident rate that one wants to be able to detect as statistically significant. Table 18 provides an estimate of the necessary number of additional flight hours that will be required to make the differences in accident rates reported in this study statistically significant. Given current and expected future yearly flight hours, the additional required flight hours will probably be reached within 3-5 years. Note that the glass cockpit aircraft MH-47E is not shown in Table 18 because its accident rate was lower than for the traditional cockpit CH-47D.

Table 18.
Required additional flight hours to obtain statistical significance.

Glass model	Required flight hours
MH-60K	50,136
MH-60L	70,300
MH-47D	15,165
AH-64D	272,106

A second recommendation is to begin studies that identify what cockpit characteristics are related to the accident rate in traditional and glass cockpits. These studies will hopefully identify properties of the hybrid and glass cockpits that can be improved in future versions and lead to safer aircraft.

There is no question that glass cockpit designs will be incorporated in future U.S. Army rotary-wing aircraft. A glass cockpit design allows these aircraft to include information and capabilities that are impossible in a traditional dedicated instrument cockpit design. Computer technology is revolutionizing the military cockpit. It is important to understand the impact of this revolution so that the benefits can be maximized and the detriments minimized. For current versions of rotary-wing aircraft, there seems to be at least one detriment: a higher accident rate. Future study must determine how it is to be minimized.

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Appendix .

Flight hours.

<u>OH-58 Kiowa</u>

<u>Table A-1</u>.
OH-58 flight hours.

	OH-58A/C flight hours	OH-58D flight hours
FY72	178,622	
FY73	319,655	
FY74	312,597	
FY75	317,461	
FY76	303,414	
FY77	305,228	
FY78	290,953	
FY79	285,451	
FY80	281,732	
FY81	294,567	
FY82	293,727	
FY83	278,973	
FY84	278,107	
FY85	266,945	68
FY86	282,492	878
FY87	283,376	10,074
FY88	278,185	18,599
FY89	285,379	22,852
FY90	294,108	25,973
FY91	209,279	18,619
FY92	232,964	21,079
FY93	232,154	24,635
FY94	227,082	42,312
FY95	191,685	46,644
FY96	132,195	62,520
FY97	117,354	63,072
FY98	103,365	77,208
FY99	107,713	75,841
FY00	109,509	88,299
TOTALS	**7,094,272**	**598,673**

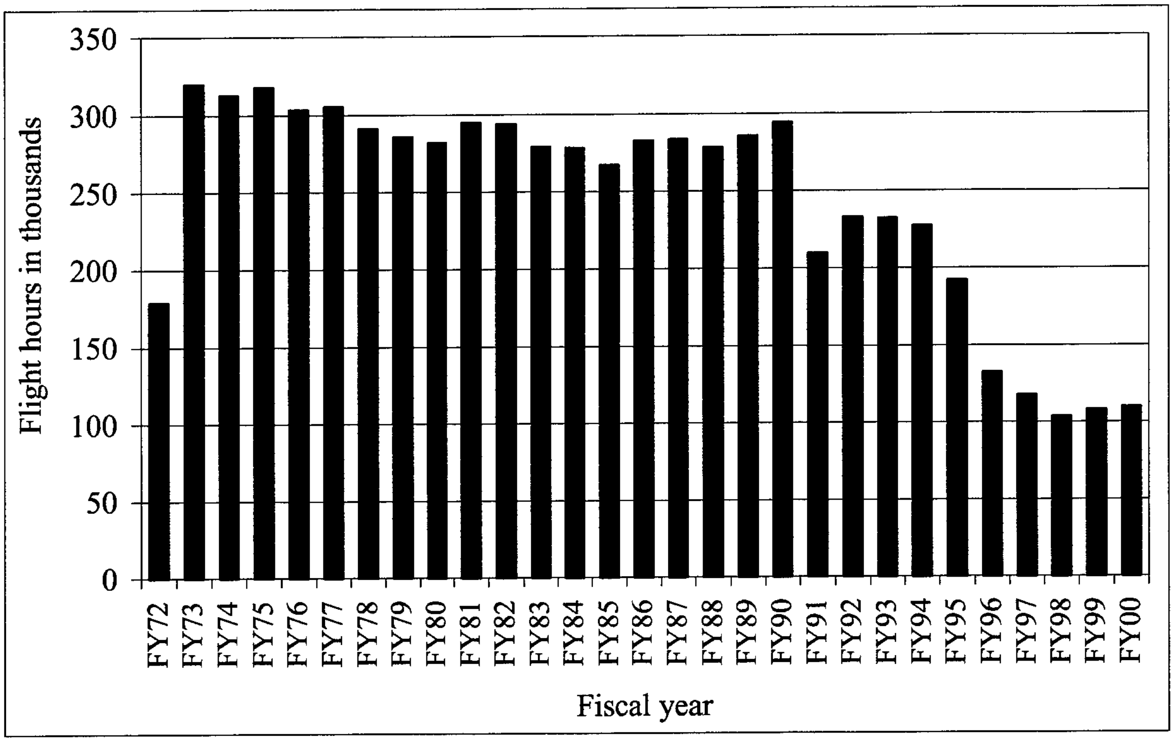


Figure A-1. Dedicated instrument OH-58A/C flight hours.

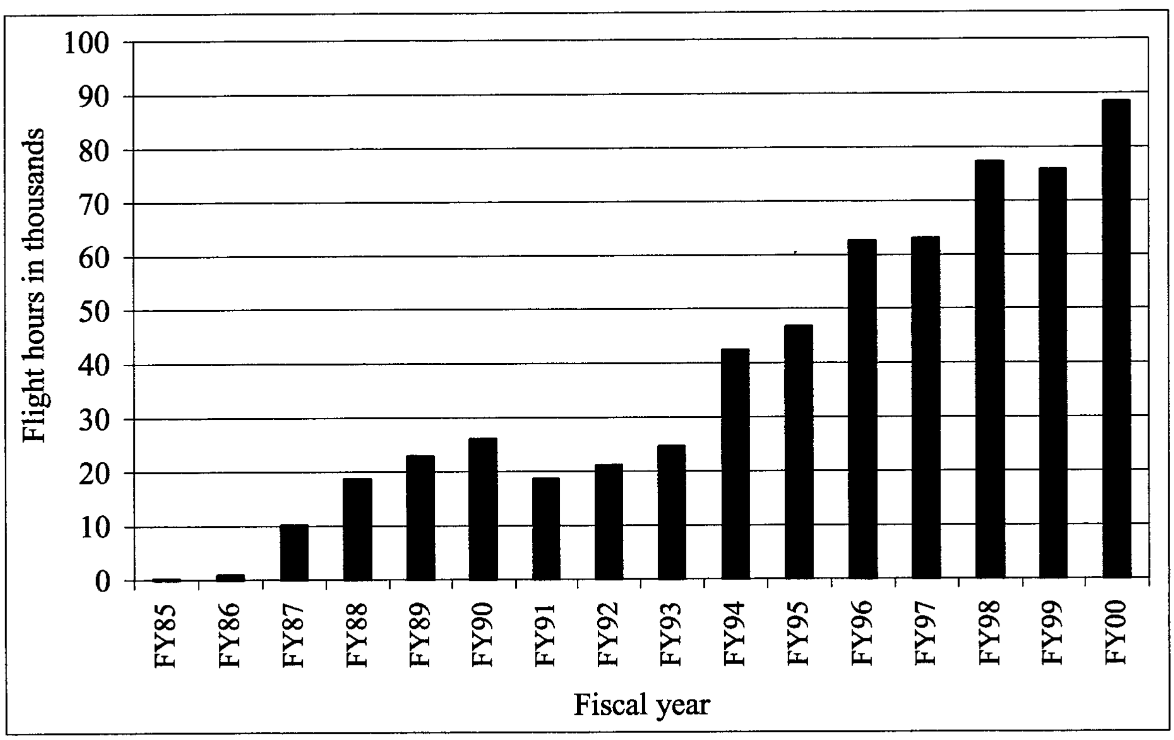


Figure A-2. Glass cockpit OH58-D flight hours.

UH/MH-60 Black Hawk

Table A-2.
UH/MH-60 flight hours.

	UH-60models flight hours	MH-60L flight hours	MH-60K flight hours
FY79	1530		
FY80	18434		
FY81	33748		
FY82	50983		
FY83	62786		
FY84	76435		
FY85	77496		
FY86	109518		
FY87	154354		
FY88	179950		
FY89	189956		
FY90	195317		
FY91	144278	*N.R.	
FY92	176125	*N.R.	
FY93	168324	4053	
FY94	184527	9444	1512
FY95	189717	9852	*N.R.
FY96	198144	8256	*N.R.
FY97	203589	*N.R.	5673
FY98	206064	7650	5322
FY99	210490	7785	5589
FY00	241710	17574	12534
TOTALS	**3073475**	**64614**	**30630**

Note: *N.R. denotes flight hours not reported.

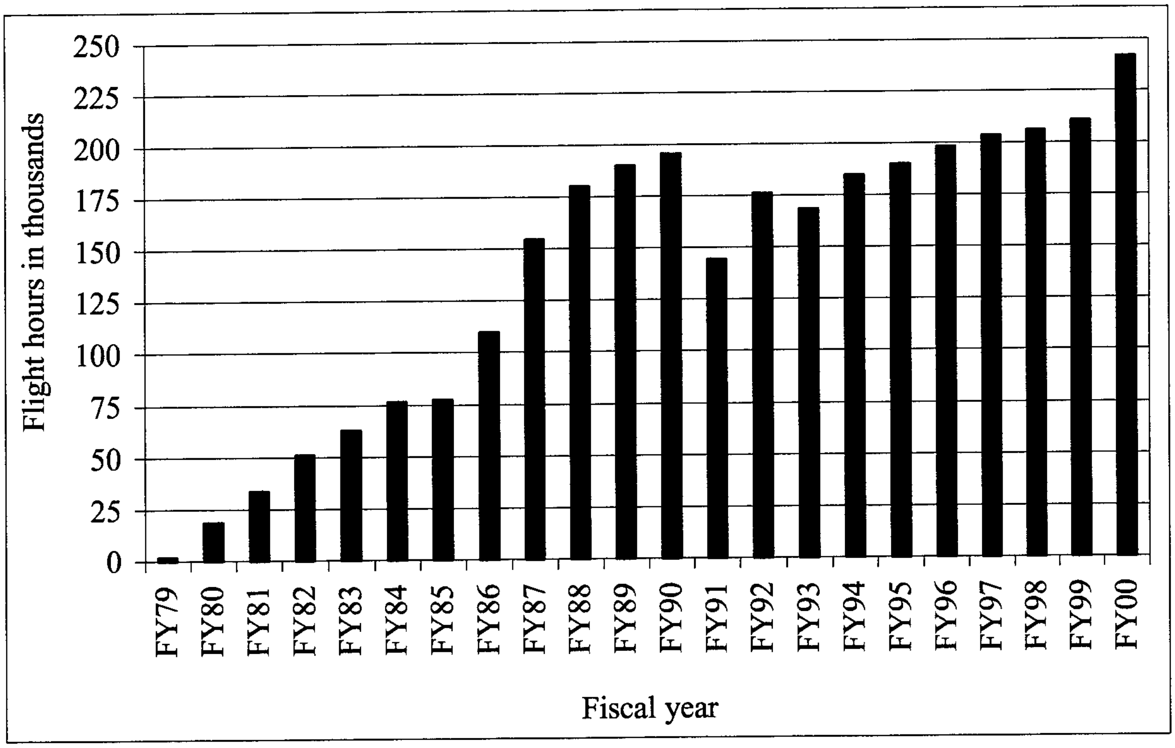
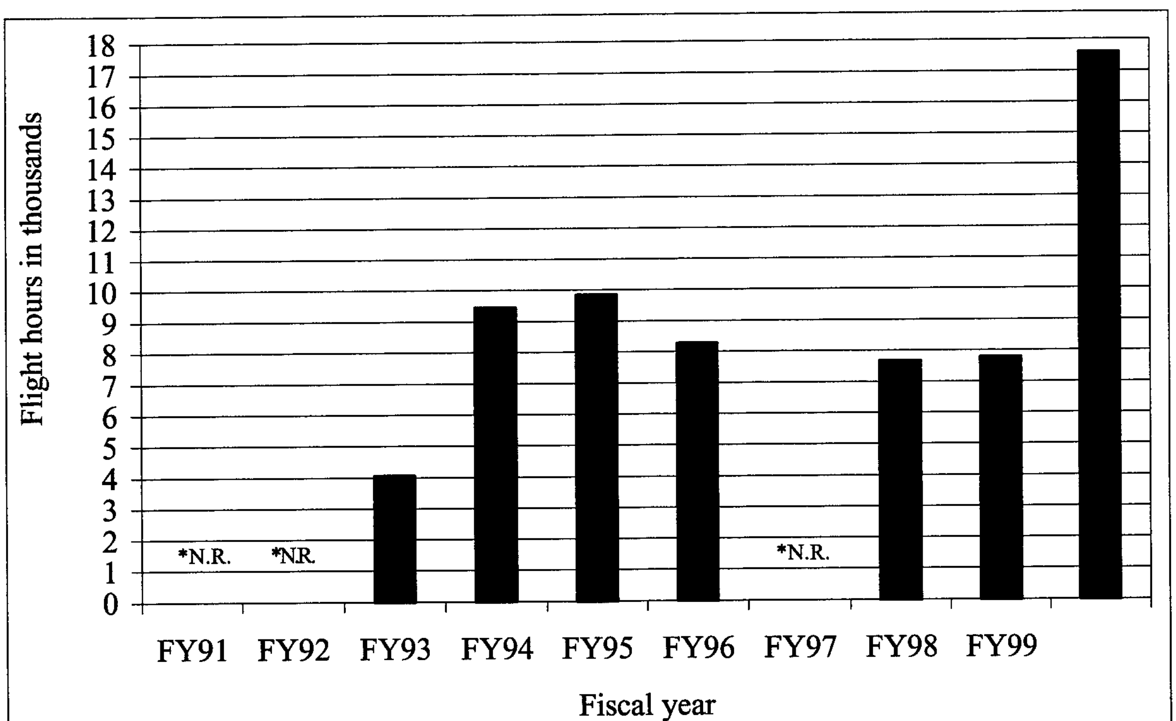
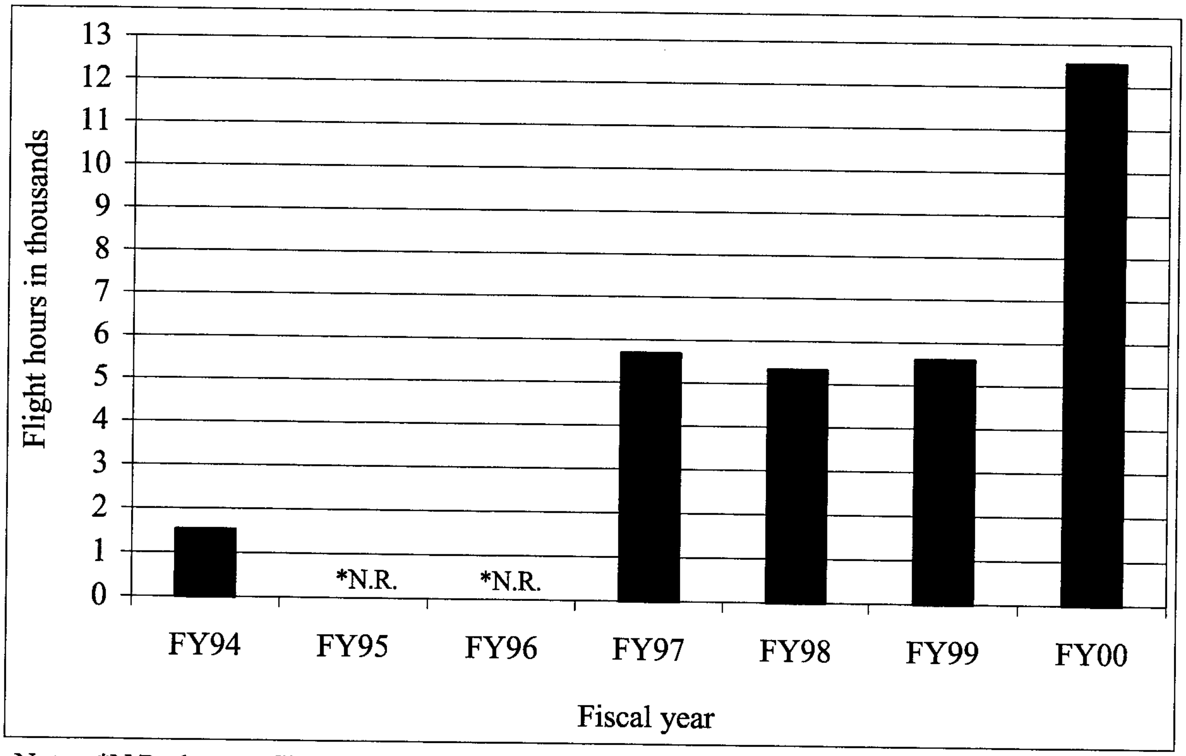


Figure A-3. Dedicated instrument UH-60 models flight hours.



Note: *N.R. denotes flight hours not reported.

Figure A-4. Hybrid cockpit MH-60L flight hours.



Note: *N.R. denotes flight hours not reported.

Figure A-5. Glass cockpit MH-60K flight hours.

CH/MH-47 Chinook

Table A-3.
CH/MH-47 flight hours.

	CH-47A/B/C/D flight hours	MH-47D flight hours	MH-47E flight hours
FY72	23299		
FY73	45552		
FY74	45867		
FY75	45176		
FY76	51514		
FY77	55524		
FY78	55417		
FY79	51492		
FY80	51793		
FY81	56806		
FY82	54900		
FY83	44217		
FY84	54114		
FY85	52746		
FY86	54956		
FY87	59023		
FY88	61331		
FY89	51829		
FY90	53545	*N.R.	
FY91	51198	*N.R.	
FY92	62928	*N.R.	
FY93	60216	*N.R.	
FY94	60399	6387	477
FY95	59280	4680	3831
FY96	59643	2094	6222
FY97	57921	1920	5634
FY98	50775	2022	5643
FY99	53569	2306	5891
FY00	54435	5055	13869
TOTALS	**1539465**	**24464**	**41567**

Note: *N.R. denotes flight hours not reported.

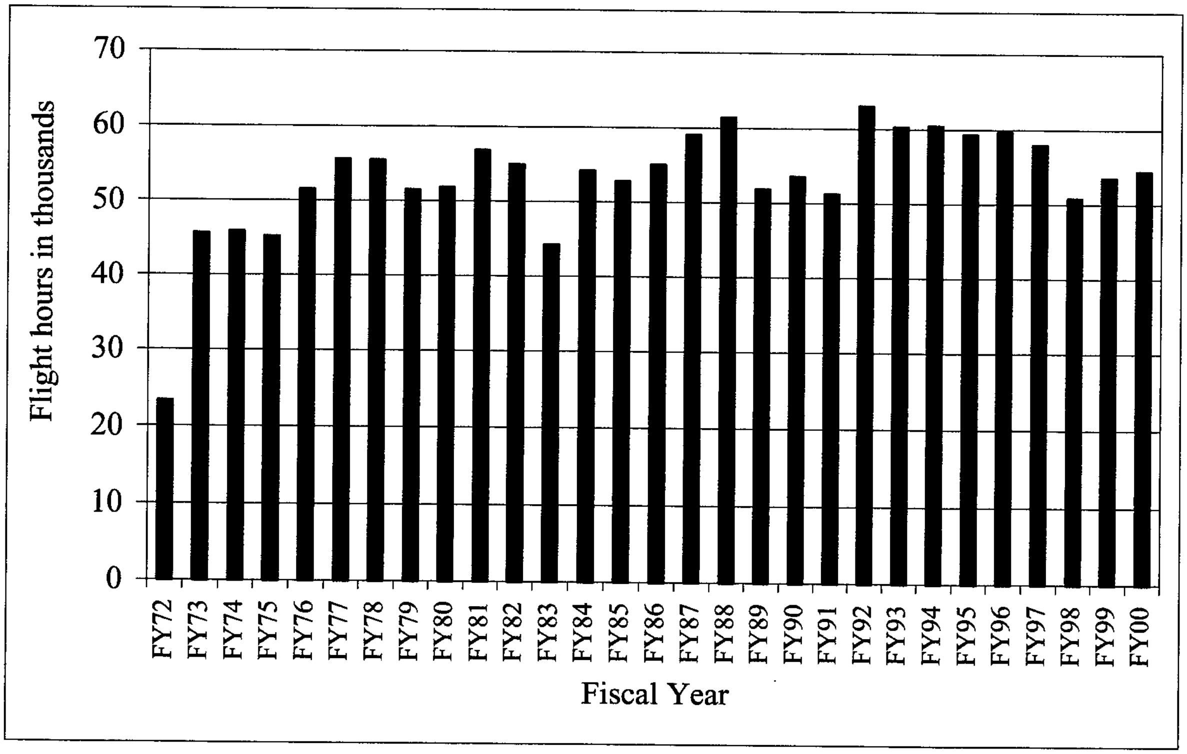
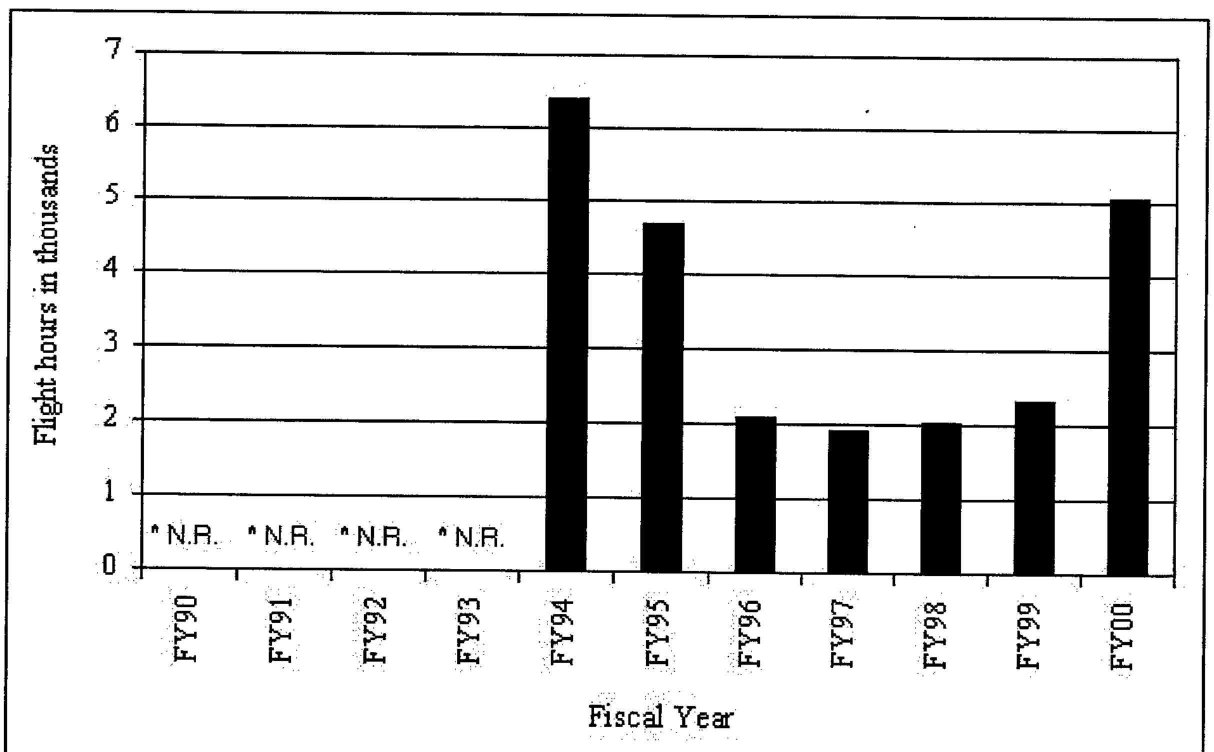


Figure A-6. Dedicated instrument CH-47A/B/C/D flight hours.



Note: *N.R. denotes flight hours not reported.

Figure A-7. Hybrid cockpit MH-47D flight hours.

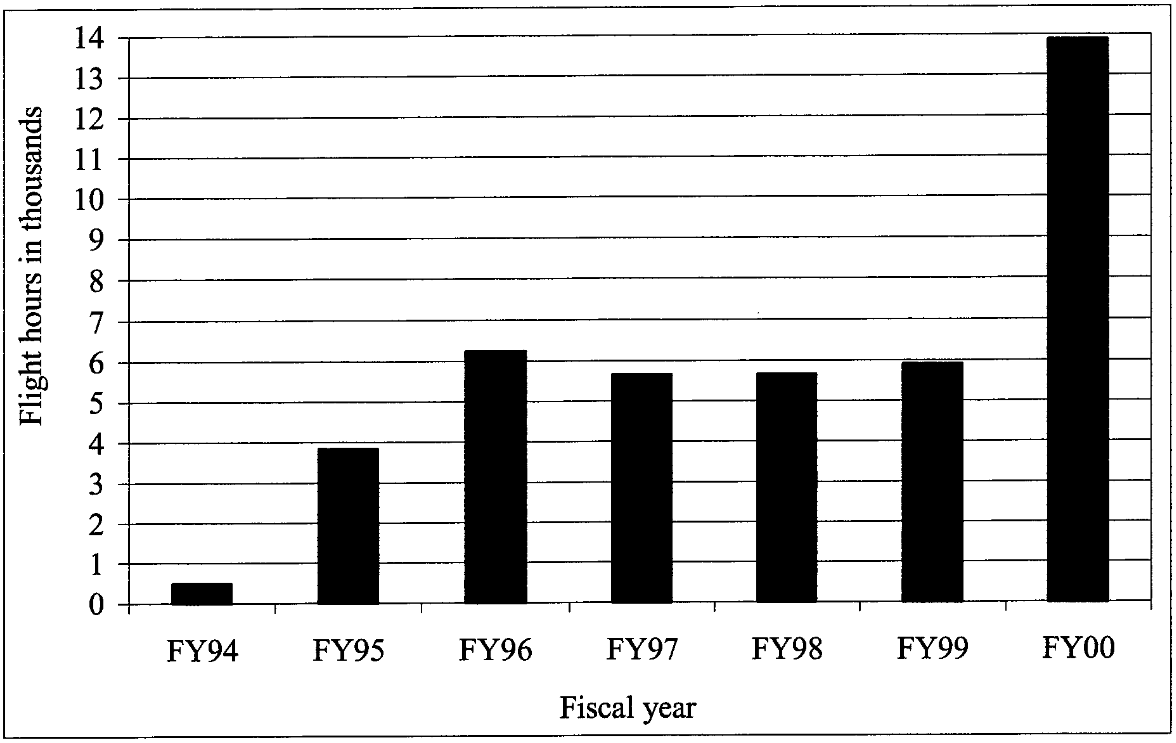


Figure A-8. Glass cockpit MH-47E flight hours.

AH-64 Apache

Table A-4.
AH-64 flight hours.

	AH-64A flight hours	AH-64D flight hours
FY85	1,753	
FY86	12,270	
FY87	37,341	
FY88	57,181	
FY89	69,944	
FY90	86,840	
FY91	69,512	
FY92	94,032	
FY93	95,276	
FY94	109,827	
FY95	100,629	
FY96	103,929	
FY97	101,052	756
FY98	97,266	3,816
FY99	93,378	11,503
FY00	87,168	15,117
TOTALS	**1,217,398**	**31,192**

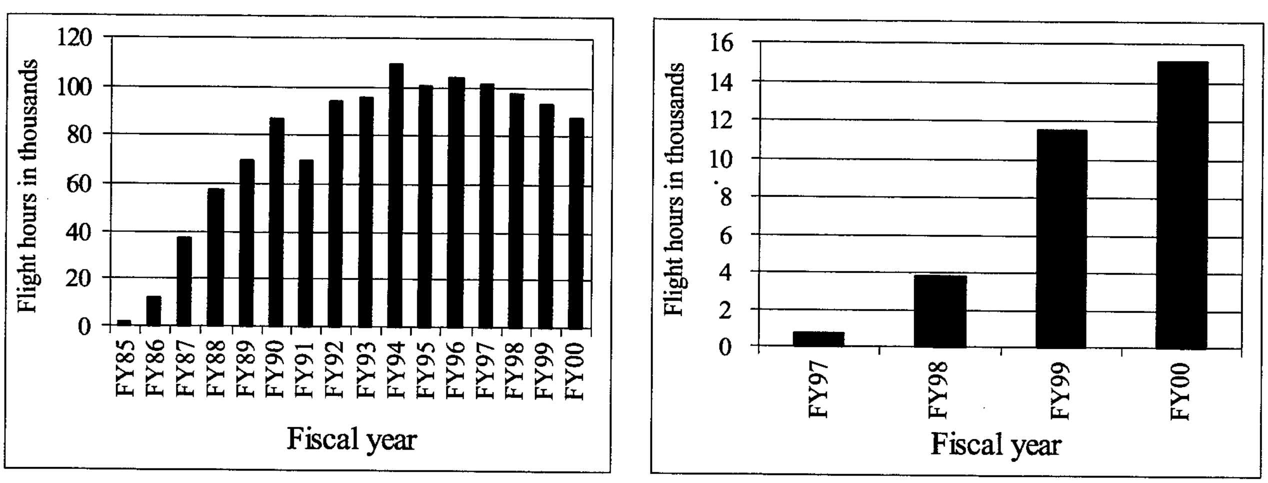


Figure A-9. Dedicated instrument AH-64A (left) and glass cockpit AH-64D (right) flight hours.

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