

# Study on Rotorcraft Safety and Survivability

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## Abstract

During *Operation Enduring Freedom* and *Operation Iraqi Freedom* (OEF/OIF), there were 375 rotorcraft losses with 496 fatalities from October 2001 to September 2009. Mishaps accounted for 81 percent of all losses with combat losses (i.e., aircraft shootdowns) accounting for the remaining 19 percent; 73 percent of the fatalities occurred in a combat theater. The OEF/OIF combat hostile action loss rate is seven times lower than Vietnam. Aircraft vulnerability reduction design and tactics have mitigated the losses. Man-Portable Air Defense Systems (MANPADS) and Rocket Propelled Grenades (RPG)/rockets account for most of the rotorcraft combat hostile action losses in OEF/OIF. The combined mishap loss rate (both combat non-hostile and non-combat) was 2.71 losses per 100,000 flight hours, slightly exceeding the loss rate due to combat hostile action. The in-theater mishap loss rate was ten times worse, and the out-of-theater loss rate was four times worse than the Congressional and SECDEF goal of 0.5 mishaps per 100,000 flight hours. Loss of situational awareness and other human factors accounted for more than 79 percent of the losses of airframe and fatalities. The primary causal factors are controlled flight into terrain and brownout.

## INTRODUCTION

In recent years, there has been an increasing concern regarding Department of Defense (DoD) rotorcraft losses throughout *Operation Enduring Freedom* and *Operation Iraqi Freedom* (OEF/OIF). There is a perception that little progress has been made since the Vietnam conflict, especially when one compares the losses of rotary wing and fixed wing tactical aircraft (TACAIR). Congress, in the National Defense Authorization Act (NDAA) for fiscal year 2009, directed the Secretary of Defense and the Joint Chiefs of Staff to perform a study summarizing the loss rates and causal factors, and provide a prioritized list of candidate solutions for reducing rotorcraft losses.

Under the auspices of the Future Vertical Lift Initiative led by the Office of the Under Secretary of Defense (Acquisition, Technology, and

Logistics), the Joint Aircraft Survivability Program Office and the Director, Operational Test and Evaluation, with support from the Institute for Defense Analyses led a multi-disciplinary team of subject matter experts on rotorcraft safety and survivability to complete the study and report the results to the Joint Chiefs of Staff, Office of the Secretary of Defense, and Congress. The Study on Rotorcraft Survivability [1] was sent to Congress in October 2009, but internal markings restricted widespread public release. This paper provides public releasable information from the study and updates the loss and fatality numbers to include all of Fiscal Year (FY) 2009.

The study team focused on losses and fatalities occurring during the OEF/OIF timeframe to understand the loss causes and to provide solutions relevant to current and near-term DoD vertical lift aircraft. Airframe losses and fatalities were classified in three categories: combat hostile action, combat non-hostile, and non-combat. Combat hostile action losses include events where an airframe loss or fatal injuries to the crew or passengers occurred as a direct result of one or more threat weapons being fired at the aircraft.

This definition of combat hostile action losses includes events where aircraft are lost evading a threat, later destroyed in place, or subsequently deemed non-repairable by the services, and is intended to provide consistency with that of Class A mishaps<sup>1</sup>. Combat non-hostile losses are Class A mishaps occurring within a recognized theater of combat operations (i.e., Vietnam, *Desert Storm*, OEF/OIF, etc.). These events are losses in which the loss of aircraft or fatal injury to the crew or passengers is not a direct result of a threat weapon. Non-combat losses are Class A mishaps occurring outside a recognized theater of combat operations, and thus do not involve combat operations.

This study treats fatalities as distinct from airframe losses to ensure that candidate solutions address both reductions in airframe losses and fatalities. Causal factors for Combat Hostile Action losses/fatalities are identified by threat weapon. Causal factors for mishaps are identified by phase of flight and whether they are human factors or non-human factors mishaps. Recommendations are made for further reducing losses to achieve the goals set forth by Congress in the NDAA.

The analysis was supported by a comprehensive review and in-depth analysis of combat damage reports beginning with Vietnam through the present. The primary sources of combat hostile action loss data came from official DoD reports, databases maintained within DoD, past combat data studies, and open source data (press releases, websites, etc.). Although detailed data from some of the sources is classified, the roll-up of combat data is deemed to be unclassified because there is not a direct link between the aircraft, the event, and the threat causing the damage. The primary sources of mishap data used in this study were Class A mishap reports from 1985-2009 from the Service Safety Centers (Army, Navy/Marine Corps, and Air Force) and previous safety studies. The Service Safety Centers have different standards on how long mishap reports are retained, and these

analyses concentrated on mishaps during the OEF/OIF timeframe with references to data from previous years when needed. Analysis of fixed and rotary wing mishaps during the OEF/OIF timeframe proved consistent with analysis conducted for the Defense Safety Oversight Council [2-4] covering the 1985-2005 timeframe, but the smaller overlapping set of loss data from 2001 through 2009 used in this study allowed for a direct comparison to combat data from OEF/OIF. Information on damage and injuries from combat incidents and mishaps was included when it provided context on the extent of the aircraft losses and fatalities as they related to the overall number of incidents.

## SUMMARY OF FINDINGS

During OEF/OIF, there were 375 rotorcraft losses with 496 fatalities from October 2001 to September 2009. Table 1 summarizes the combat hostile action losses, Class A mishaps, fatalities, and rates by category. Class A mishaps, which include both non-hostile and non-combat events, accounted for 305 losses, or 81 percent of all 375 losses, and combat losses (i.e., aircraft shootdowns) accounted for the remaining 19 percent. Losses in a combat theater, which includes 70 combat hostile action events and 157 non-hostile events, made up 61 percent of all losses and 73 percent of all fatalities. Table 1 also shows that loss and fatality rates in combat theaters were higher and are attributed to increased numbers of passengers on cargo and utility helicopter missions, acceptance of more operational risk on many missions, and routine exposure to combat threats.

Figure 1 shows the losses and mishaps by aircraft type and year. Caution should be used when interpreting data from this figure. While this figure shows the quantity of each rotorcraft lost in each category, comparisons should be made based on loss rates. The purpose of this chart was to show only the aggregate of all the losses across the fiscal years.

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<sup>1</sup> Class A mishaps are defined as events with total damage greater than \$1 Million, loss of a capital asset, any fatality, or permanent total disability.

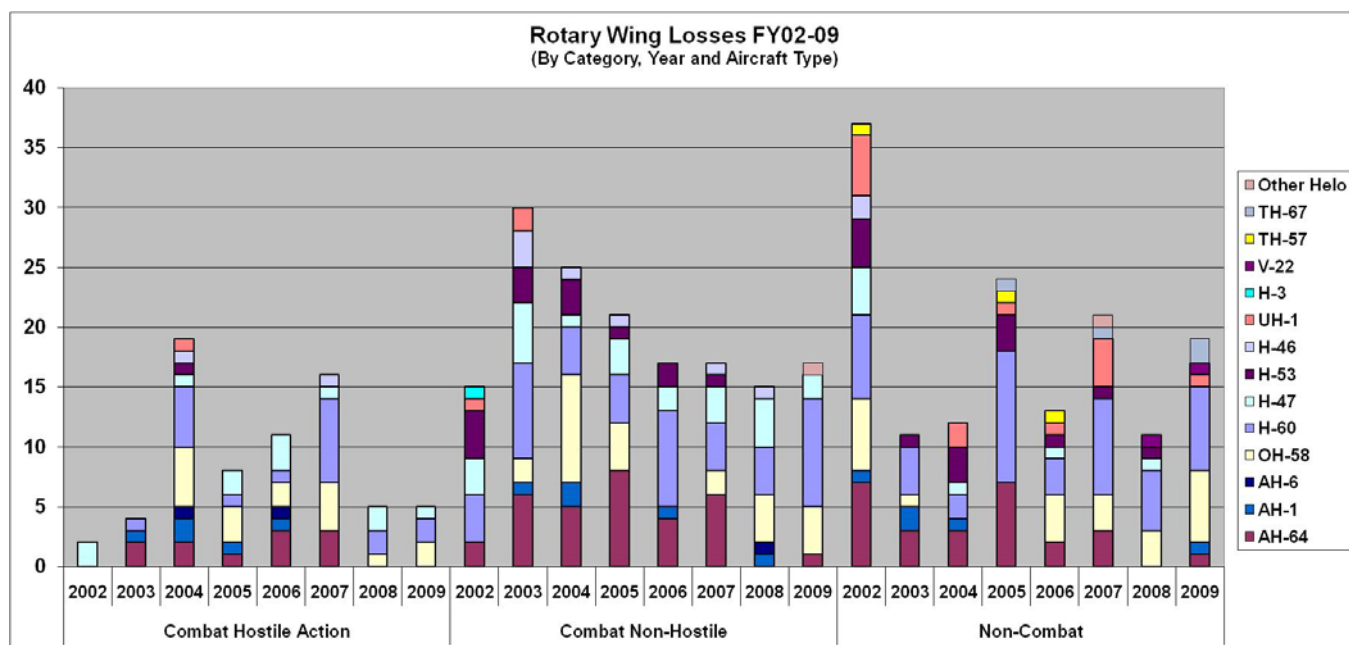
**Table 1. Rotorcraft Losses and Fatalities, October 2001 to September 2009**

	Hostile Action	Non-Hostile	Non-Combat	All Class A Mishaps (Non-Hostile and Non-Combat)	All Combat Losses (Hostile Action and Non-Hostile)
Losses	70	157	148	305	227
Fatalities	145	219	132	351	364
Fatality/Loss	2.07	1.39	0.89	1.15	1.60
Loss Rate <sup>a</sup>	2.31	5.19	1.81	2.72	7.50
Fatality Rate <sup>a</sup>	4.79	7.24	1.61	3.13	12.03
Compared to DoD and Congressional Goal	7x lower <sup>b</sup>	10x higher <sup>c</sup>	4x higher <sup>c</sup>	5x higher <sup>c</sup>	—

<sup>a</sup> Per 100,000 flight hours

<sup>b</sup> Vis-à-vis Vietnam

<sup>c</sup> Vis-à-vis loss rate of 0.5/100K flight hours



**Figure 1. Rotary Wing Combat Losses and Class A Mishaps FY02-09**

### Combat Hostile Action Losses

Helicopter combat hostile action losses in OEF/OIF are significantly less than in Vietnam. Table 2 shows that the total loss rate for all rotorcraft types is seven times lower, and the fatality rate is five times lower than Vietnam. At the beginning of the SEA conflict, helicopters were extremely vulnerable to small caliber weapons. Single engine designs, lack of

redundancy of critical systems, and non-crashworthy fuel systems led to a large number of losses from 1965-1969. Some of these vulnerabilities were reduced by retrofitting aircraft with additional armor to protect against pilot incapacitation, adding redundancy of critical systems such as hydraulics for cargo/utility helicopters, and replacing non-crashworthy fuel

cells with a more crashworthy design to reduce post-impact fires.

As a result of the extensive rotary wing combat hostile action losses in Vietnam, the Army led an effort to significantly reduce the vulnerability of its helicopters to small arms and automatic weapons threats during the acquisition of the Utility Tactical Transport Aircraft System (UTTAS) and the Advanced Attack Helicopter (AAH). The UTTAS program required that the aircraft be capable of safe flight for at least 30 minutes after a single hit by a 7.62mm armor piercing incendiary (API) projectile striking anywhere on the aircraft [5], and the AAH had more stringent requirements. The winning aircraft for the UTTAS program was the UH-60, and for the AAH program, it was the AH-64. Both aircraft had extensive vulnerability reduction programs, and these two aircraft flew 60 percent of all rotary wing combat flight hours in OEF/OIF.

During Vietnam, there was a distinct difference between the loss rates for attack/observation helicopters (pilots and observers only) and cargo/utility helicopters (capable of carrying passengers) with the attack/observation helicopters having a combat hostile action loss rate about twice that of cargo/utility helicopters. Table 3 shows that when only attack and observation helicopters are compared, the OEF/OIF loss rate is nearly ten times lower, and the fatality rate is nine times lower than Vietnam. Table 4 shows that for cargo and utility helicopters the loss rate was only six times lower, and the fatality rate was four times lower. Since the primary threat in Vietnam was small arms and automatic weapons fire, the difference between attack/observation and cargo/utility helicopters was attributed to the different types of missions flown and the level of exposure to the threats by each class of helicopters. Since cargo/utility helicopters normally carry only self-defense weapons and try to avoid direct contact with enemy forces while en route, their losses were noticeably lower.

However in OEF/OIF, the difference in the loss rates between attack/observation and cargo/utility helicopters disappeared. The primary reasons are the reduced vulnerability of the AH-64 and UH-60 and modified tactics that have

mitigated, but not eliminated, the damage effects caused by small arms and automatic weapons. In Vietnam, 94 percent of the combat hostile action losses and 80 percent of the fatalities were caused by small arms and automatic weapons, whereas in OEF/OIF, only 31 percent of the losses and 14 percent of the fatalities were caused by small arms and automatic weapons. In both conflicts, small arms and automatic weapons were the most prevalent threats hitting rotorcraft.

**Table 2. Comparison of All Rotorcraft Combat Hostile Action Losses**

	Vietnam	OEF/OIF
Losses	2,066	70
Fatalities	3,065	145
Fatality/Loss Ratio	1.48	2.07
Flight Hours	12,704,883	3,026,483
Combat Loss Rate <sup>a</sup>	16.26	2.31
Combat Fatality Rate <sup>a</sup>	24.12	4.79

<sup>a</sup> Per 100,000 flight hours

**Table 3. Comparison of Attack/Observation Rotorcraft Combat Hostile Action Losses**

	Vietnam	OEF/OIF
Losses	757	35
Fatalities	644	33
Fatality/Loss Ratio	0.85	0.94
Flight Hours	2,927,130	1,310,619
Combat Loss Rate <sup>a</sup>	25.86	2.67
Combat Fatality Rate <sup>a</sup>	22.00	2.52

<sup>a</sup> Per 100,000 flight hours

**Table 4. Comparison of Cargo/Utility Rotorcraft Combat Hostile Action Losses**

	Vietnam	OEF/OIF
Losses	1,309	35
Fatalities	2,421	112
Fatality/Loss Ratio	1.85	3.20
Flight Hours	9,777,753	1,705,654
Combat Loss Rate <sup>a</sup>	13.39	2.05
Combat Fatality Rate <sup>a</sup>	24.76	6.57

<sup>a</sup> Per 100,000 flight hours

An additional factor influencing the reduction in loss rates from Vietnam to OEF/OIF was the time of day that combat flights were flown. In Vietnam, helicopters were not equipped with night vision devices, and the percentage of night flights

was limited. Thus, nearly all of the Vietnam losses occurred in daylight or twilight hours when the enemy might have had an opportunity to visually acquire the aircraft before firing his weapon. In OEF/OIF, most helicopters were equipped with night vision devices, and night flights were routine. These more frequent night flights limited the enemy's ability to visually acquire the helicopter before engaging it. Validation of this point is seen in the fact that 75 percent of the combat hostile action losses in OEF/OIF occurred during daylight or twilight hours, which shows that visual identification is one of the primary methods for the enemy to acquire low flying rotary wing aircraft.

Fatality rates for both conflicts are higher for cargo/utility helicopters primarily because of the higher number of occupants on each flight. In Vietnam, the fatality to loss ratio for cargo/utility helicopters was 1.85, but in OEF/OIF, the ratio increased to 3.2. Because of the extensive vulnerability reduction programs on helicopters designed since Vietnam, more lethal threats such as Man-Portable Air Defense System (MANPADS), Rocket Propelled Grenade (RPG), and rockets caused far more fatalities per loss.

Lastly, there were no reported rotary wing losses in OEF/OIF due to radar guided weapons. Although this threat was not prevalent in OEF/OIF, it should not be dismissed when designing against future threat projections.

### **Combat Non-Hostile and Non-Combat Losses**

**Mishap Rates.** Table 1 shows that the combat non-hostile mishap rate was ten times higher, and the non-combat loss rate was four times higher than the DoD and Congressional goal of 0.5 mishaps per 100,000 flight hours. When all mishaps are combined (both combat non-hostile and non-combat), the mishap loss rate was 2.71 losses per 100,000 flight hours, slightly exceeding the loss rate due to combat hostile action of 2.31. Figure 2 shows the number by year of rotary wing Class A mishaps, destroyed aircraft, and fatalities using the bars and the left vertical axis. The significant increase in the number of fatalities compared to the number of Class A mishaps is directly related to the higher operational tempo associated with combat operations in Iraq. The

higher operational tempo includes an increased numbers of passengers on cargo and utility helicopter missions and an acceptance of more operational risk on many missions.

To get a better feel for how the rotary wing mishap rates compare to fixed wing and TACAIR, Figure 2 also shows the Class A mishap rates, using the lines and the right vertical axis. The figure shows ratest for all aircraft (orange line), all fixed wing (maroon line), TACAIR (red line), and rotary wing (light blue line) compared to the DoD goal (green line) of 0.5 mishaps per 100,000 flight hours. Although the mishap rates for all fixed wing are lower than all rotary wing, the TACAIR mishap rates are about equal to rotary wing. The reason for this difference is that the TACAIR and rotary wing have about the same number of mishaps and flight hours each year while the larger cargo/bomber aircraft (making up the rest of fixed wing) have much fewer mishaps and about twice the flight hours as both TACAIR and rotary wing.

Comparison of the fiscal year mishap rates between the various aviation communities is a method used by the service safety centers to assess which communities are doing better or worse than others. However, use of the fiscal year reporting method sometimes creates an artificial binning of data that may show a graphical anomaly that is not really a statistically significant difference. For example, in FY05 and FY07 the all rotary wing mishap rates showed a noticeable upward adjustment. Figure 1 shows that there were 10-15 more non-combat mishaps in those years compared to previous years. To statistically compare the FY05 and FY07 rates to the previous years, Fisher's exact test [6] shows that the FY05 mishap data have a p-value of 0.196 and the FY07 data have a p-value of 0.078. P-values of 0.05 or less are normally considered statistically significant. In other words, the likelihood that the difference is due to chance alone must be five percent or less. Therefore, the differences between the FY04 and FY05 all rotary wing mishap rates and the FY06 and FY07 rates are not statistically significance at the 0.05 level.

To smooth out possible anomalies created by the artificial binning across fiscal years, a 3-year running average (dark blue line in Figure 2) for all

rotary wing is also plotted to show that in general from FY04 to FY08 the mishap rate is trending downward. Reasons for the downward trending of the 3-year running average are the maturing of the OIF infrastructure; the maturing of the combat tactics, techniques, and procedures (TTPs); and

the drawdown in combat type of operations in FY08 and FY09 reducing operational risk. However, given the slope of this downward trending, it is unlikely that the all rotary wing mishap rate will meet the DoD goal of 0.5 mishaps per 100,000 flight hours anytime soon.

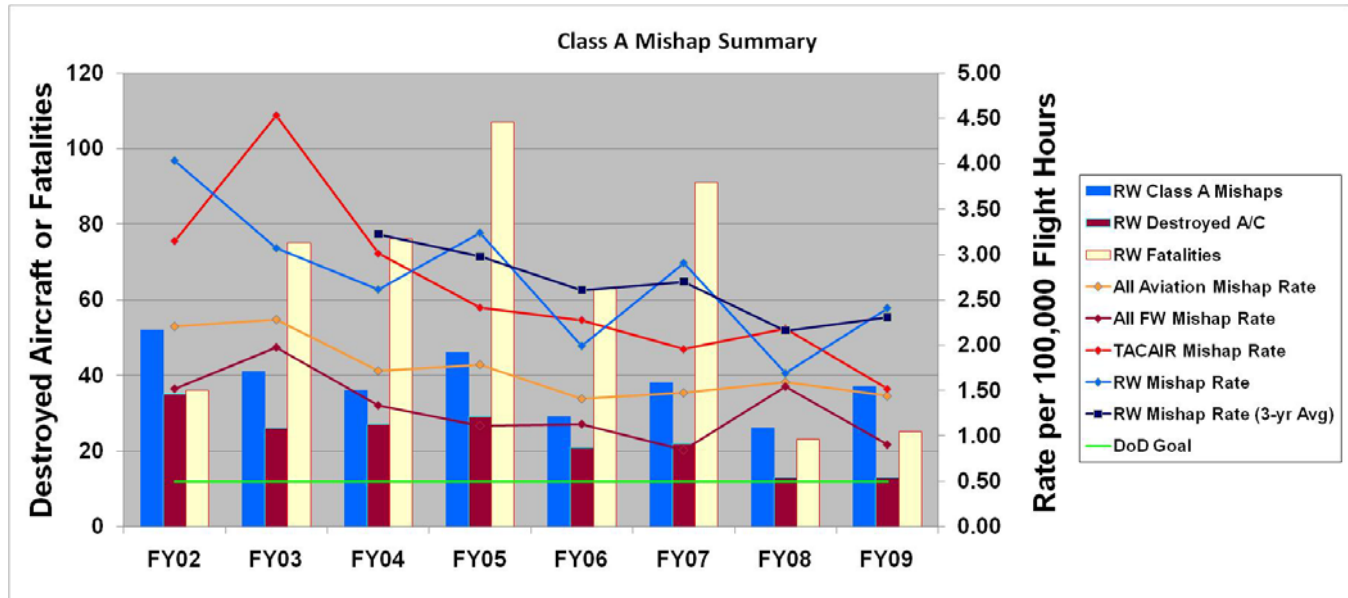


Figure 2. DoD Aircraft Class A Mishaps FY02 – FY09.

**Causal Factors.** Classification of a mishap by its primary causal factor is based on whether the mishap was predominantly caused by human factor issues or non-human factor issues, which include material failures. When the service safety centers investigate a mishap, they will report all causal factors, including both human and non-human factors. In many non-human factor cases, there were secondary human factor causal factors that led to greater damage or injury, but the mishap was still classified as a non-human factor mishap. In this study, we chose to limit the classification to only the primary causal factor to simplify the accounting of mishaps and focus on the first item in the chain of events leading to a mishap. For example, if an aircraft has an engine failure and the pilot crashes the aircraft on landing due to poor landing technique, the mishap will be classified as a non-human factor mishap because the primary cause is an engine failure, regardless of whether the aircraft has one, two, or three engines because it is expected that the pilot is capable of executing appropriate emergency procedure. If the engine failure had not occurred,

it is unlikely that the mishap would have occurred at all, regardless of the pilot's poor landing technique.

In the review of the mishap causal factors, two important trends were identified in mishap fatality data. They are the velocity at which the event occurs and whether it is a human factor or non-human factor mishap. Figure 3 shows the distribution of causal factors for losses and fatalities for both combat non-hostile and non-combat mishaps. The red and yellow slices of the pie charts indicate human factor mishaps. Human factor mishaps are further subcategorized by velocity to account for similar flight profiles. The red slices are human factor mishaps occurring in cruise flight while the yellow slices are human factor mishaps occurring in hover or low speed below effective translational lift (ETL). The blue slices indicate non-human factor mishaps and include mechanical failures such as engine failures, drive train failures, and aircraft fires. The purple slices indicate flight related, improperly forecasted weather, and undetermined mishaps that did not fit well into one of the other

categories. The decision to separate improperly forecasted weather from the human factors category was based upon the traditional classification by the Army and Air Force Safety Centers in which the primary cause was not placed on pilot error; however, for this study, continued visual flight under instrument meteorological conditions (Inadvertent IMC) is classified as a human factor mishap since the pilot's decision to continue visual flight under conditions that do not permit it is a critical part of this causal factor.

Human factor mishaps (red and yellow slices) accounted for 78 percent of all losses and 84 percent of all fatalities. For combat non-hostile mishaps, human factors accounted for 79 percent of the losses and 80 percent of the fatalities, while

for non-combat mishaps human factors comprised 77 percent of the losses and 91 percent of the fatalities. The fact that more than three-quarters of the mishaps are human factor related does not necessarily mean that increased training or better supervision is required to reduce these types of mishaps. Although there are isolated cases where the root cause was a training or supervision failure, in many cases the pilot lost situational awareness of his current flight/mission profile in relation to the surrounding terrain and obstacles. In other words, many mishaps occurred not because the pilots were inadequately trained, but because something kept them from being aware of the chain of events that were leading to the mishap.

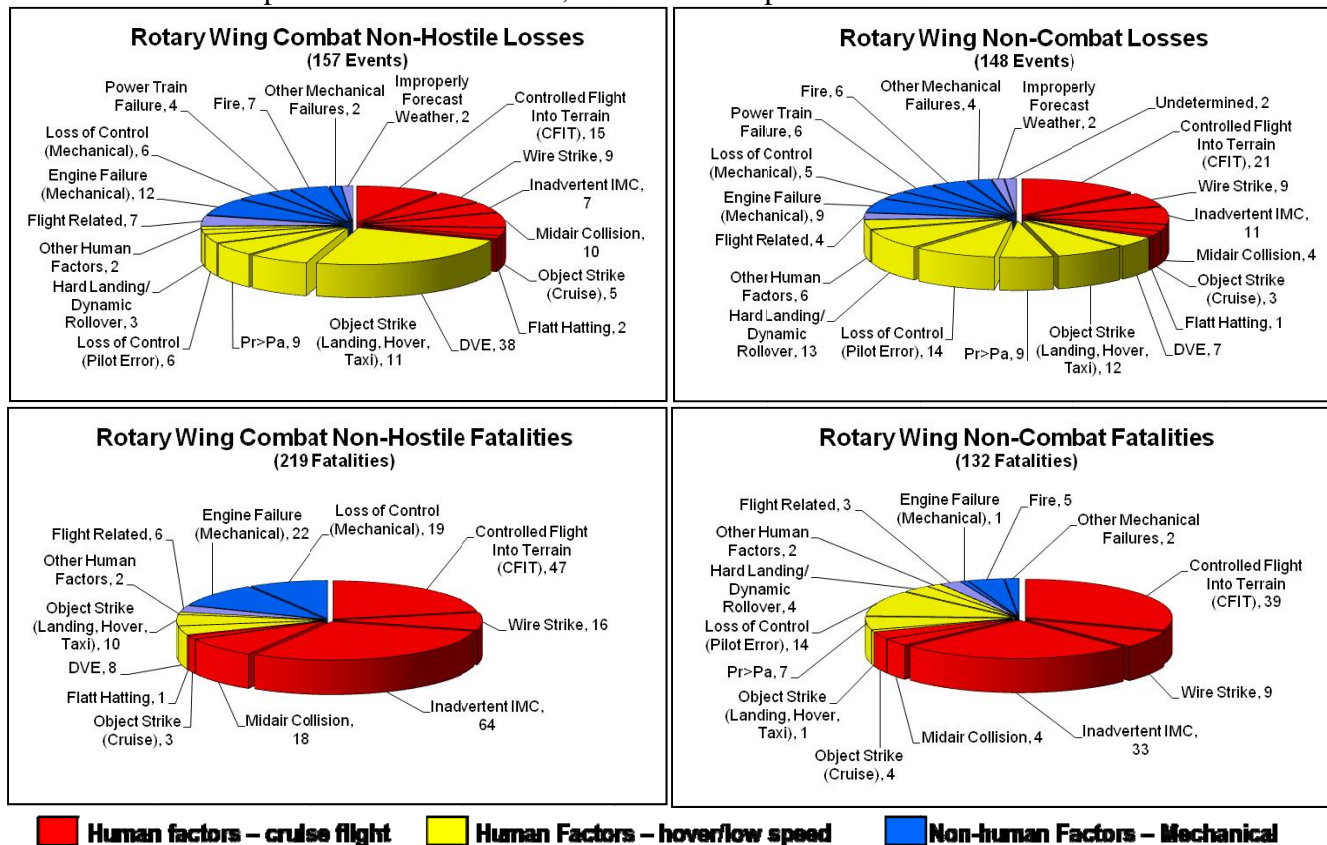


Figure 3. Rotary Wing Mishap Losses by Causal Factor (FY02-09)

The primary causal factors for combat non-hostile and non-combat mishaps were very similar with two exceptions. Mishaps due to degraded visual environment (DVE) were more prevalent in combat non-hostile mishaps. DVE is commonly referred to as brownout or whiteout and occurs below effective translational lift when the helicopter is within ground effect (less than one

rotor diameter above the ground) and particulates are entrapped and circulated in the rotor wash. Brownout/whiteout conditions usually occur during takeoff and landings on non-prepared surfaces which was typical during the beginning of OIF. The second difference was the time of day when the mishap occurred. Although not shown in Figure 3, 60 percent of combat non-

hostile mishaps occurred at night, while only 38 percent of the non-combat mishaps occurred at night. Reasons for this difference are the larger percentage of night hours flown in theater and the willingness to accept greater operational risk associated with night flights in theater.

For human factor mishaps in cruise flight, CFIT, wire strike, object strike (above ETL), inadvertent IMC, mid-air collision, and flat hatting<sup>2</sup> were the leading causal factors. The services normally consider controlled flight into terrain (CFIT) to include actual controlled flight into the ground or water, object/wire strike in cruise flight, and inadvertent instrument meteorological conditions (IMC); however, for this study, the term “CFIT” will only apply to actual controlled flight into the ground or water that is not due to object/wire strike or inadvertent IMC. When referring to the all inclusive list used by the services, the term “all types of CFIT” will be used. The reason this study separates out the different types of CFIT causal factors is that there are different proposed solutions to each of them. All types of CFIT accounted for more fatalities and major injuries than for any other causal factor. This is not surprising since all the CFIT events occurred above ETL. For human factor mishaps at hover or low speed, the leading causal factors were DVE, object strike (below ETL during landing, hover, or taxi), loss of control due to pilot error, dynamic rollover, hard landing, and situations where power required exceeded power available ( $P_r > P_a$ ).

For human factor mishaps, the velocity at which the helicopter hits the ground is the best predictor of the likelihood of fatalities. For combat non-hostile mishaps, only 44 percent of the fatalities occurred below effective translational lift, while only 27 percent of the non-combat fatalities occurred below ETL. ETL is such an important parameter because the statistical probability of fatalities in a mishap decreases significantly when the helicopter is below ETL.

This statistical significance may be attributed to the fact that the G-forces sustained in low-speed collisions are substantially less than those at higher speeds. When helicopter mishaps occur below ETL, they have a greater vertical component of velocity than horizontal component. This helps make them more survivable, since crashworthy features (energy absorbing crew seats, harnesses, energy absorbing landing gear, crashworthy fuel systems, and internal/external airbags) are designed to protect aircrew during crashes when the vertical component of velocity is greater than the horizontal component up to the point where the airframe loses structural integrity. Unfortunately, many crashworthy features are not currently designed to the structural limits. Figure 3 shows the benefit of crashworthiness by the substantial reduction in the proportion of fatalities that are occurring at hover and low airspeed (i.e., the yellow shading on the pie charts) for both combat non-hostile and non-combat mishaps.

Engine failure, fire, power train failure, and other mechanical failures to the flight control system are the leading mechanical and non-human factor mishap causal factors. Fatalities associated with mechanical failures were significantly reduced for non-combat operations primarily because pilots are well trained to execute the appropriate emergency procedures during mechanical failures, and typical flight profiles and environmental conditions in non-combat zones gave pilots opportunity to control the rate of descent in a manner that allowed crashworthy features to better protect the occupants. The reason that this reduction is not seen in combat operations is that the flight profiles and environmental conditions in OEF and OIF produced greater rates of descent after the mechanical failure increasing the likelihood of injuries or fatalities to the occupants. In fact, the mishap reports in six of the twelve engine failures occurring in-theater cited environmental conditions, such as unlevel terrain and high density altitude, as factors that contributed to increased damage to the aircraft and increased injuries to personnel.

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<sup>2</sup> Flat hatting is any maneuver conducted at low altitude and/or a high rate of speed for thrill purposes. These types of maneuvers are prohibited by all the services, except as approved by higher authority for air shows or air demonstrations.

## KEY TECHNICAL FACTORS IMPACTING ROTORCRAFT LOSS RATES

Rotorcraft today are exposed to more lethal combat threats such as MANPADS and RPGs. Technical concerns for combat hostile action losses include a lack of situational awareness during an attack, threat detection and jamming prior to the aircraft being hit, and damage tolerance after a hit. Technical concerns regarding rotorcraft mishaps include positional and situational awareness, warning for flight hazards and terrain, rapid response to hazards once detected, and component reliability. Furthermore, improved crashworthiness is applicable to both combat threats and mishaps. Four concepts must be incorporated into the aircraft crashworthiness design to maximize the survival benefits. The design must maintain survivable living space; occupants must be restrained during the entire crash sequence; the aircraft and occupants must have a gradual deceleration during the crash sequence; and occupants must be able to quickly egress the aircraft after the crash. The problem of adequate occupant restraints was very apparent in many of the human factor mishaps in hover/low speed flight and in the flight related mishaps. While the airframe itself was not destroyed, the fatalities typically occurred only to crewmembers and passengers in the cabin area who were unrestrained or only restrained by a gunner's belt. While operational needs such as fast roping, search and rescue, and special operations may require crew and passengers to be out of their seats during the approach to the objective area, development of improved mobile restraint systems is needed.

Twelve rotorcraft fatalities were directly attributable to immediate threat effects in combat (e.g., hit by a bullet); the other 133 (more than 90 percent) combat hostile action rotorcraft fatalities were most likely the result of crash effects. The implementation of crash protection technology (stroking seats, four-point restraints, airbags, etc.) aboard rotorcraft mitigates death and injury in all rotorcraft losses, whether from combat, non-hostile, or non-combat causes. Nearly the same numbers of people are lost to CFIT (including object/wire strikes and inadvertent IMC) as are lost in combat to all types of threat weapons.

## APPLYING TACAIR LESSONS LEARNED

The prevailing perception is that TACAIR's improved survivability is the result of substantial and sustained research and development (R&D) investment in low observable technology, precision guided standoff weapons and sensors, countermeasures, and electronic warfare. Improvements in TACAIR capability and mission effectiveness since Vietnam center on tactics that limit or eliminate TACAIR exposure to the most lethal threats. However, this perception that TACAIR has reaped the benefits of substantial investment in technology is not fully borne out in the data. A comparison of TACAIR combat hostile action loss rates from Vietnam to *Desert Storm* showed a significant reduction in losses only in the first three days of *Desert Storm* when TACAIR was defeating the Iraqi integrated air defense systems (IADS). After the first three days when TACAIR switched to more close air support missions, the loss rate was the same as Vietnam. Since the Iraqi IADS was never successfully reestablished after *Desert Storm*, the fact that there have been only three combat losses for TACAIR during OEF/OIF does not carry the same impact since the threat to TACAIR in OEF/OIF has been substantially less than it was in Vietnam. The use of precision-guided munitions may have also contributed to reduced TACAIR combat losses, but that evidence is anecdotal.

The primary lesson for rotorcraft is the value of technology which allows tactics to be modified that limit exposure to threats. These technologies include susceptibility reduction features such as lower infrared, visual, and acoustic signatures; precision guided standoff weapons and sensors; threat detection and countermeasures. However, vertical lift missions will continue to require low altitude flight in direct support of the ground forces. Therefore, vulnerability reduction technologies such as damage tolerant components and fire protection/suppression must still provide protection against threats in those profiles.

Figure 2 shows that the TACAIR mishap rate over the past eight years is roughly the same as all rotary wing. The combat non-hostile loss rate for TACAIR is 2.32 Class A mishaps per 100,000 flight hours, and the non-combat loss rate is 2.54 – both exceed the rate of 0.5 or less. The leading

non-materiel causes for TACAIR losses are CFIT and midair collisions, while the leading materiel cause is engine failure, very similar to rotorcraft. The use of fly-by-wire technology in TACAIR makes these aircraft eligible for solutions not currently available to most rotorcraft. Fly-by-wire systems with advanced control laws have allowed TACAIR to expand the flight envelope, enable automatic avoidance of hazards, and increase aircraft survivability. However, TACAIR has been slow to field some of the automatic collision and terrain avoidance systems limiting the impact that these systems could have on the mishap rate.

### **PRIORITIZING ROTORCRAFT SOLUTIONS**

The team considered a wide variety of possible solutions that include leadership and doctrine; operations and training; personnel and facilities; and applications of new and existing materiel. There is little doubt that the applications of non-materiel solutions (e.g., TTPs and training) have and will continue to reduce some rotorcraft losses. Probably the best example of TTP and training impacts is the decline in DVE related mishaps as pilots increased flight time and experience in the OEF/OIF combat theaters. Although the decrease in DVE-related mishaps due to better TTPs and training contributes to the general downward trending of the 3-year rotary wing mishap rate in Figure 2, the cumulative effect of all non-materiel changes since 2002 has not brought the mishap rates down to the DoD goal of 0.5 mishaps per 100,000 flight hours. It is the team's assessment that non-materiel solutions alone cannot reduce the mishap rate to the DoD goal, but rather they should be part of a multi-layered approach, that when combined with materiel solutions, could provide synergism in meeting the DoD goal.

Two mishap causes and two threat weapon categories account for the majority of loss of life and airframes from October 2001 through September 2009. They are all types of CFIT, degraded visual environment (i.e., brownout), guided weapons, and ballistic weapons. Reducing the impact of these four primary causal factors could significantly improve the safety and survivability of the DoD rotary wing fleet. Candidate solutions for reducing rotorcraft losses are listed in Table 5. A focus area that cuts across all loss categories is improved situational awareness. Pilot recognition and understanding of his current flight/mission profile in relation to the surrounding terrain and emerging threats is a key enabler to reducing the human errors associated with all losses. Another key enabler is the development of advanced flight controls systems which includes fly-by-wire technology and modern control laws that affect rotorcraft handling qualities. With the exception of the V-22 Osprey and the proposed CH-53K, the DoD rotorcraft fleet will continue to use legacy hydro-mechanical flight control systems for the foreseeable future. Although TACAIR has not fully realized the benefit of reduced mishap rates with fly-by-wire, application to rotary wing should be considered primarily for the improvement in rotorcraft handling qualities that could benefit combat survivability and operational effectiveness. For combat hostile action losses, improved countermeasures and better fire protection in dry bays will improve the aircraft survivability against the more lethal threats being encountered. Finally, improved crashworthiness will not reduce the number of mishaps or combat losses, but it could reduce the fatalities associated with these losses.

**Table 5. Candidate Solutions for Reducing Rotorcraft Losses**

<b>Loss Category</b>	<b>Focus Areas</b>	<b>Candidate Solutions</b>
Controlled Flight Into Terrain (cruise flight)	<b>Improved Awareness:</b>	Terrain Warning (w/ digital database) Real-time weather updates combined with a Terrain Avoidance Warning System Low-power radar for obstacle detection
	<b>Decreased Pilot Workload:</b>	Advanced Flight Control Systems
Degraded Visual Environment (low speed and hover)	<b>Improved Awareness:</b>	Flight Displays w/ low Speed Flight Symbolology
	<b>Decreased Pilot Workload:</b>	Advanced Flight Control Systems
	<b>Improved Facilities:</b>	Simulator & Training Area Realism & Availability
	<b>Improved Crashworthiness:</b>	Updated Crashworthiness Criteria Improved Occupant Seats and Restraints
Guided Weapons (MANPADS, RF/IR Missiles)	<b>Improved Awareness:</b>	Missile Warning Integrated Aircraft Survivability Equipment
	<b>Improved Countermeasures:</b>	Improved IR Countermeasures and Expendables (New research, more capacity)
	<b>Reduced Vulnerability:</b>	Fire Protection
	<b>Improved Crashworthiness:</b>	Updated Crashworthiness Criteria Improved Occupant Seats and Restraints
Ballistic Projectiles (RPGs, Rockets, & Small Arms/ Automatic Weapons)	<b>Improved Awareness:</b>	Unguided Threat Detection Integrated Aircraft Survivability Equipment
	<b>Improved Countermeasures:</b>	Optical Jamming/Dazzling
	<b>Reduced Vulnerability:</b>	Fire Protection Ballistic Protection
	<b>Improved Crashworthiness:</b>	Updated Crashworthiness Criteria Improved Occupant Seats and Restraints

**CONCLUDING REMARKS**

The DoD and services have successfully reduced rotorcraft loss rates both in combat and non-combat operations since Vietnam, but significant further reductions are needed. Between October 2001 and September 2009, the U.S. military lost 375 rotorcraft with 496 fatalities. Combat hostile action losses only account for 19 percent of all losses with mishaps accounting for the remaining 81 percent. Rotorcraft fatality rates in combat theaters were three to four times higher than non-combat rates in the rest of the world. The higher mishap and fatality rates in combat theaters are attributed to the high operational tempo, increased numbers of passengers on cargo and utility helicopter missions, acceptance of more operational risk, and exposure to combat threats.

Human factors, including loss of situational awareness, account for 78 percent of the losses.

Controlled flight into terrain (CFIT), degraded visual environment (DVE), and object/wire strike are the leading human factors loss causes. Engine failure and power train failure resulting in loss of control are the leading non-human factors loss causes. A high percentage of helicopter losses, including shoot downs, are survivable. Most fatalities result from the crash and passengers make up a majority of those fatalities. Improving rotorcraft crashworthiness, including passenger protection, will reduce injuries and fatalities in all loss categories.

Non-materiel solutions, such as changes in doctrine, improved facilities, and training have reduced and will continue to reduce rotorcraft loss rates. When combined with new materiel capability however, the potential to significantly reduce loss rates is much greater. With additional resources, initial capability of the candidate

solutions listed in Table 5 could be fielded as add-on capability to the current DoD rotorcraft fleet by 2020. Additional capability is achievable as integrated solutions embedded in next generation vertical lift aircraft, given appropriate resources.

Maj. Gen. Jeffrey Schloesser, Commander of the Combined Joint Task Force-101 in Afghanistan, speaking on the need for helicopters in the country by teleconference at the Pentagon on June 2, 2009 [7] said,

*“[T]here’s no doubt that this is the most difficult terrain that I’ve ever seen in 33 years, to actually walk across, operate in or to fight in, or, for that matter, to actually help the people in. Helicopters are just more than part and parcel of what we do each and every day. They are critical to almost every operation that we execute here in Afghanistan.”*

Rotary wing aircraft are and will continue to be critical to the warfighter. Losses and fatalities by any cause will have a substantial impact on operations. Implementation of the following recommendations will reduce the number of rotorcraft losses and fatalities allowing our combat forces to operate effectively in any environment.

1. To further reduce combat losses, increase and sustain the investment to improve rotorcraft situational awareness, threat detection and jamming, and damage tolerance (vulnerability reduction). Effective guided and unguided threat detection and jamming for small and medium size rotorcraft are key technology requirements. Additionally, the incorporation of automatic fire detection and suppression systems in areas that are inaccessible by the crew in flight will reduce the vulnerability of catastrophic fires that have caused some losses.
2. To meet the goal of 0.5 mishaps or less per 100,000 flight hours, increase and sustain the investment in rotorcraft positional and situational awareness; warning for flight hazards, terrain and obstructions; rapid response to hazards once detected; advanced

engine and power train technology and improved component reliability. Advanced flight control systems that use modern control laws, such as fly-by-wire, are key enabling technologies.

3. To reduce personnel injuries and fatalities for combat threat losses and mishaps, improve airframe crashworthiness and crash protection for passengers. DoD crashworthiness standards have not been updated since the 1970s and need to be expanded in scope to cover a wider set of aircraft and environmental conditions.

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