

Rescuing Downed Aircrews

The Value of Time

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Preface

Recovering downed airmen is a critical task for the U.S. Air Force, which devotes considerable resources—including personnel, equipment, and training—to ensure that it can carry out this task. In light of the impending drawdown of forces and the pressure to reduce defense budgets, the Air Force has been reassessing its personnel recovery (PR) force structure, along with other organizational aspects. It asked RAND Project AIR FORCE to assist in this reassessment with an examination of the operational risk associated with Air Force PR. Specifically, the Air Force sought “to refine the metric used to assess PR’s operational risk, [which] is the degree of likelihood of mission success.”

To this end, the research described here quantifies the “rescuability window” of downed aircrews. The current research quantifies the relationship between rescuability and time so that the most cost-effective options for increasing the rescuability of downed personnel can be pursued. The implications of the findings are also summarized in this report.

The research reported here was sponsored by Maj Gen Scott Zobrist, Director of Plans, Programs, and Requirements, Headquarters Air Combat Command, and Brig Gen Jeffrey Taliaferro, Deputy Director, Plans and Programs, Directorate of Plans, Programs and Requirements, Headquarters Air Combat Command, and conducted within the Force Modernization and Employment program of RAND Project AIR FORCE as part of a fiscal year 2014 project called “Measuring Personnel Recovery Operational Risk.”

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Summary

Background, Purpose, and Approach

U.S. air power has been a major contributor to the success of military operations. Yet that success has not come without losses of aircraft and personnel. An important aspect of U.S. Air Force (USAF) operations is its ability to rescue pilots, crews, and passengers whose aircraft have been brought down by enemy action, weather, or mechanical failure. Operations to rescue downed aircrews and passengers are often joint operations involving military, diplomatic and civilian organizations. The USAF has dedicated units specially trained and equipped for such missions. Given the drawdown in military operations, declining defense budgets, and the aging of key pieces of equipment, it would be useful if the Air Force had a robust metric by which it could assess the cost-effectiveness of various components of the personnel recovery (PR) process.

While it is obvious that getting to downed aircrews faster or improving their survivability is good, the degree to which these improve the “rescuability” of downed personnel has not been previously quantified. We define a downed aircrew as *rescuable* if they have not been killed or captured. Absent information relating rescuability and time, it is not possible to quantify the effectiveness of changes to the way PR is currently conducted. Therefore, the current research seeks to quantify the relationship between rescuability and time so that the most cost-effective options for increasing the rescuability of downed personnel can be pursued.

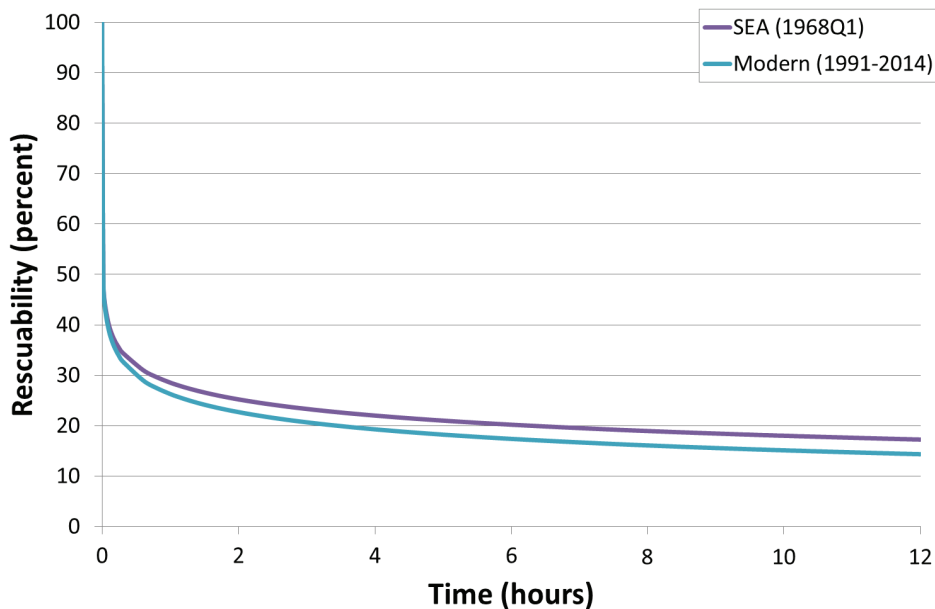
The USAF asked RAND Project AIR FORCE to quantify factors that affect the success of a rescue. Recognizing that a necessary condition for a successful rescue is that the rescue forces arrive before the downed person is killed or captured, the project team focused on deriving the rescuability window of downed personnel. This generated the probability, given the arrival time of rescue forces, that the downed person has not already been killed or captured. To the extent possible, the research takes into account factors that could influence this timeline, such as where downed personnel are located, their condition, how they became isolated, and the environment around them. The analysis draws on historical combat rescue data from the Vietnam to the present.

Results in Brief

Taking the historical data, we analyzed it from two perspectives: First, by conflict, and then by the characteristics that are significantly associated with rescuability. We define the *rescuability window* as the period during which a downed person can be rescued. That is, the rescuability window is the time from the isolating event until, absent a recovery, the person is either captured or succumbs. We analyzed the conflict data to determine whether the rescuability

curves remained consistent from one conflict to another. Knowing this is important, because if the curves change dramatically from conflict to conflict, it limits what conclusions can be drawn from either combined or individual data sets. The results of the analysis by operation appear in Figure S.1. The vertical axis shows the probability of being rescuable (i.e., not killed or captured) and the horizontal axis shows time. In particular, the figure shows Southeast Asia data from the first three months of 1968 and the combined results of all modern conflicts from Operation Desert Storm to present.

Figure S.1. Rescuability Curve of All Operations



The figure shows that the rescuability curves are surprisingly similar between Southwest Asia and recent conflicts. In both curves, approximately 55 percent of downed personnel are either killed or captured immediately. The percentage of personnel rescuable continues to drop significantly during the first few hours. By two hours, only about 25 percent of downed personnel are still rescuable, and this falls to less than 20 percent by 8 hours.

While future conflicts may look different, the data suggests that there may be some invariance in the domain of combat search and rescue (CSAR). This, in turn, suggests that applying the findings from these past conflicts to current decisionmaking can improve the survivability of personnel in future conflicts. Specifically, we believe these results provide a basis on which to make defense planning decisions, even though they may not accurately predict the rescuability of personnel in any particular conflict. In other words, these results represent reasonable planning assumptions without being predictive.

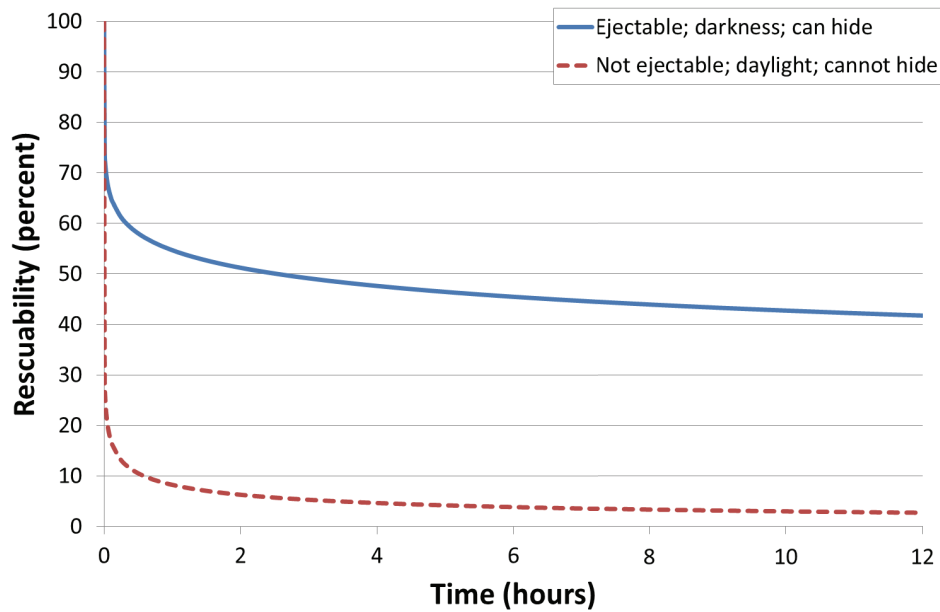
The parametric analysis identified a set of factors that are believed to affect the rescuability timeline in fundamental ways. That analysis enabled us to develop rescuability curves based on

different predictors.¹ Due to various statistical reasons and data limitations, we winnowed a much broader set of factors down to four for statistical analysis:

- whether the aircraft had ejection seats
- whether the event took place in daylight or after nightfall
- whether the terrain provided cover and concealment opportunities
- whether the downing took place over water or land.

The latter of these factors had to be excluded from the analysis because the data was not sufficient to support statistically valid results. The key results—presenting the best and worst case scenarios—of the analysis appear in Figure S.2. Being able to eject and being downed in darkness had the greatest positive impact on rescuability, while the ability to hide had a small positive impact on rescuability.

Figure S.2. Most and Least Hazardous Predictors



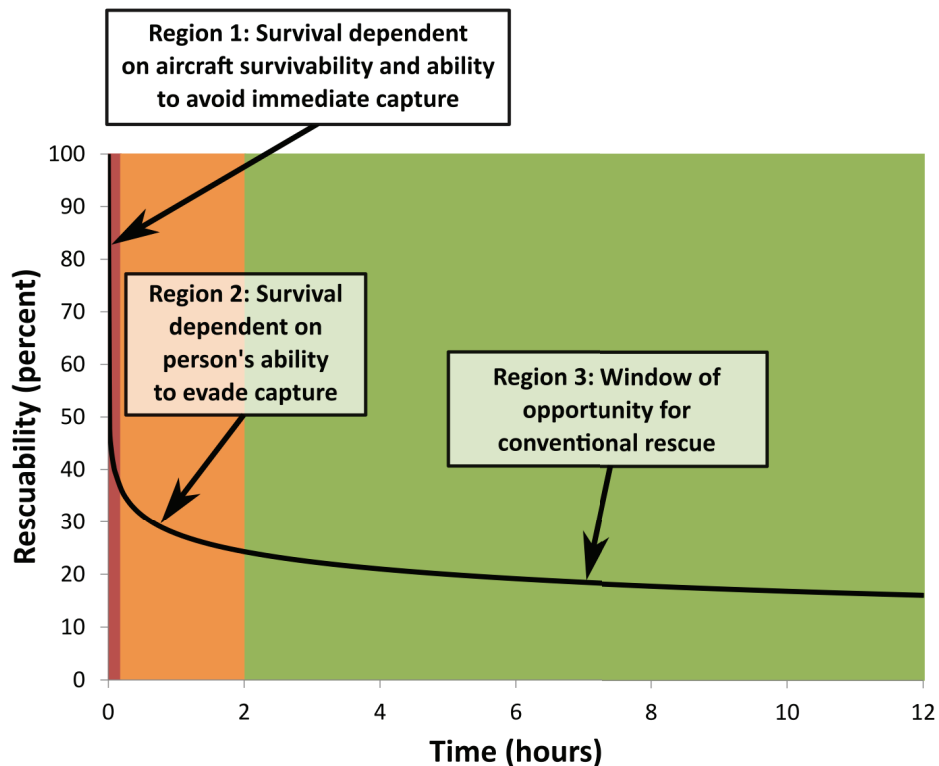
Again, the vertical axis shows rescuability and the horizontal axis shows time. The upper curve indicates that if a shutdown occurs in the dark, the aircraft has an ejection seat, and the terrain features good cover and concealment, the survival of the aircrew is considerably better than if those conditions do not exist. For example, at two hours, rescuability is over 40 percent

¹ Throughout this document, the terms *rescuability* and *survival curve* are both used. This is because the mathematical set of tools used in this analysis is part of a field known as survival analysis and generate what are generally known as *survivability curves*. However, we use the term *rescuability* to emphasize that the ultimate parameter we are trying to assess is the likelihood of successfully rescuing a person, which requires that they not be killed or captured before rescue forces arrive.

for the ejectable, darkness, can hide case, but less than 10 percent for the not ejectable, daylight, cannot hide case.

Aggregating the Southeast Asia data and modern conflict data produces the result shown in Figure S.3. This result can be broken into three distinct regions of the rescuability curve, each roughly defined by a time interval. These regions are highlighted in Figure S.3, with red indicating region one (first few moments), orange indicating region two (first two hours), and green region three (two hours onwards).

Figure S.3. Rescuability by Temporal Region



Obviously, the chart indicates that, as time goes on, the chances of the aircrew surviving decrease. However, the rate of decrease in the various regions is interesting. In the first region, over 60 percent of the downed personnel are either killed or captured. Given that it is unlikely that rescue forces will be able to arrive in the first few moments, the survival of the downed person(s) depends on the survivability of the aircraft, the continued maneuverability and tractability of the aircraft, the ability to successfully and safely exit a damaged aircraft, and the ability to avoid immediate capture. Combat rescue records and anecdotal evidence show that if the pilot were able to control the aircraft even for a short period after being hit, it had a strong positive effect on the outcome. Continued control could enable the pilot, for example, to steer the aircraft closer to friendly forces or farther from the enemy.

The second region is when traditional SERE (survive, evade, resist, escape) training appears to be the most critical. This is the time frame in which the downed person would have survived the initial incident but before rescue forces are likely to arrive. Survival therefore depends on the ability of the individual to evade. The precise time frame of region two is highly dependent on the nature of the conflict and on the rescue tactics, techniques, and procedures. The estimate of 2 hours is based roughly on the time for rescue forces to be alerted, a launch to be approved, and the helicopter to fly to the downed person's location. In Southeast Asia, rescues often happened much faster because of the dispersal of rescue assets and the fact that rescue helicopters were often on airborne alert. Air Force CSAR assets no longer generally plan to be on airborne alert in a major contingency operation. In Afghanistan, rescues were often made shortly after the incident, but often not by dedicated rescue forces. Rescues such as those seen in Afghanistan would likely not be possible in a major contingency operation.

The final region is when rescue forces are likely to arrive, and the downed person is much less likely, as a function of time, to be killed or captured.

Recommendations

The results provided in Figure S.3 form a basis on which to make defense planning decisions as they relate to PR. The rescuability timeline, as summarized in Table S.1, indicates that it is important to consider solutions for improving PR across the spectrum of options. In particular, the rescuability curve provides a way of quantifying the benefit—in terms of increasing the chance of rescuing downed personnel—both in terms of shifting the curve up (e.g., improved aircraft survivability) and moving the rescue time to the left (e.g., faster rescue platform). This means that the cost-effectiveness of all options, applicable across the different time windows, needs to be considered. Forthcoming RAND research uses the rescuability timeline to compare the cost-effectiveness of incorporating V-22s into the CSAR fleet. Specifically, for an equal-cost fleet, the research weighs the improvement in reaching downed personnel faster against the risk of not having sufficient assets available, given the higher cost of a V-22 compared to an HH-60. Such an analysis is possible only because the relationship between rescuability and time is now quantified.

Table S.1. Summary of Rescuability Regions

Region	Time Criticality	Possible Improvement Areas
1	Extreme	Aircraft survivability design Ejection seat capabilities Secure beacons
2	Great	Evasion training, tactics, and procedures Survival and evasion equipment
3	Significant	Combat rescue equipment Survivor communications equipment Command and control capabilities

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Finally, we are thankful for those that provided formal reviews of this document: Beth Ann Griffin, Lewis (Punch) Jamison, and Lt Gen (Ret) Ted Kresge. Their comments and suggestions gave us the ability to more clearly and more precisely present our work.

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Abbreviations

AAA	antiaircraft artillery
ACC	Air Combat Command
AFHRA	Air Force Historical Research Agency
ARRS	air recovery and rescue squadron
AWACS	Airborne Warning and Control System
C2	command and control
CAS	close air support
CDF	cumulative density function
CSAR	combat search and rescue
FROG	free rocket over ground
IP	isolated personnel
ISR	intelligence, surveillance, and reconnaissance
JPAC	Joint POW/MIA Accounting Command
MANPADS	man-portable air defense system
MIA	missing in action
NATO	North Atlantic Treaty Organization
OAF	Operation Allied Force
ODF	Operation Deny Flight
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
POW	prisoner of war
PR	personnel recovery
PSDA	Probability of Survival Decision Aid
RAF	Royal Air Force
RCC	Rescue Coordination Center
SAM	surface-to-air missile

SEA	Southeast Asia
SERE	survive, evade, resist, escape
UKNIIS	UK National Immersion Incident Survey
USAF	U.S. Air Force
USARIEM	U.S. Army Research Institute of Environmental Medicine
USMC	U.S. Marine Corps
USN	U.S. Navy
WMD	weapons of mass destruction
WSO	weapon systems officer

1. Introduction

Background

Personnel recovery (PR) is “the sum of military, diplomatic, and civil efforts to prepare for and execute the recovery and reintegration of isolated personnel (IP).”² The primary means by which the U.S. Air Force (USAF) conducts PR in combat is combat search and rescue (CSAR). *CSAR* is defined as “the tactics, techniques, and procedures performed by forces and to recover isolated personnel during combat.”³ CSAR missions can be complex and can require integrated operations consisting of various force elements. Specifically, these force elements may include a ground recovery force; helicopters; fixed-wing transports; tankers; electronic warfare aircraft; close air support (CAS) aircraft; intelligence, surveillance, and reconnaissance (ISR) assets; and command and control (C2).

Although all services contribute to the joint PR mission, the Air Force is the only one with dedicated units specially trained and equipped for such missions. The Air Force operates 37 (Active, Guard, and Reserve) HC-130 aircraft dedicated to PR. HC-130P/N aircraft were procured in the 1960s and are reaching the end of their service lives. A new variant of the HC-130, based on the C-130J, is currently replacing these aircraft. The Air Force operates 97 HH-60 Pave Hawk aircraft (a variant of the Black Hawk helicopter) dedicated to PR and is recapitalizing these aircraft with the Combat Rescue Helicopter. Furthermore, the Guardian Angel weapon system is growing to 42 deployable unit type codes (UTCs) of combat rescue officers and pararescue specialists.

Given the drawdown of forces in the current contingency operations and the need to reduce overall defense spending, a reassessment of the PR force structure and organizational aspects has been ongoing. Such an assessment requires robust metrics to measure the cost and the effectiveness of the force. Past work looking at PR has focused on the availability of PR assets. However, such a focus is only a partial requirement for successful PR. The likelihood of successfully recovering IP depends on their ability to survive and evade capture until PR assets reach them. In addition, the condition of the IP will depend on how they became isolated, their location, and how long they have been isolated. While PR includes the full set of personnel needing to be recovered, such as members of other services or civilian personnel, this work focuses primarily on rescuing downed aircrew and passengers.

² Joint Publication 3-50, *Personnel Recovery*, Washington, D.C.: Office of the Joint Chiefs of Staff, January 5, 2007, p. ix.

³ Joint Publication 3-50, 2007, p. GL-9.

Purpose

The motivation for this project, entitled “Measuring Personnel Recovery Operational Risk,” was articulated in the project description:

Given, the drawdown of forces in the current contingency operations and the need to reduce overall defense spending, a reassessment of PR force structure and organizational aspects have been ongoing. Such an assessment requires a robust metric by which the cost and the effectiveness of the force can be measured. Past work has focused on the availability of assets. However, this is only a partial requirement for successful PR. The likelihood of successfully recovering IP depends on the ability of the IP to survive and evade capture until PR assets reach them, given the physical and military environments of the mission.

The purpose of this document is to provide the information necessary to inform decisionmaking as it relates to the rescue of downed aircrews. Generally speaking, downed aircrews will ultimately be killed, captured, or rescued. The goal of PR is to increase the percentage of people that fall in the latter of these three categories. Many factors go into a successful rescue, but, at a basic level, the percentage of people rescued can be increased by either reaching them faster or by increasing their survivability while isolated. Of course, there are many enablers for each of these factors: faster rescue platforms, improved rescue radios, improved C2, and more rescue assets can all decrease the time it takes to reach a downed aircraft. Improved survive, evade, resist, escape (SERE) training; advanced ejection seats; and new evasion tools can all increase the time an isolated person is able to survive.

While it is obvious that getting to downed aircrews faster or improving their survivability is good, the degree to which these improve the “rescuability” of downed personnel has not been previously quantified. We define a downed personnel as *rescuable* if they have not been killed or captured. Absent information relating rescuability and time, it is not possible to quantify the effectiveness of changes to the way PR is currently conducted. Therefore, the current research seeks to quantify the relationship between rescuability and time so that the most cost-effective options for increasing the rescuability of downed personnel can be pursued.

Specifically, this analysis recognizes that a necessary condition for a successful rescue is that the rescue forces arrive before a downed person is killed or captured. To the extent possible, the research takes into account factors that could influence this timeline, such as where downed personnel are located, their condition, how they became isolated, and the surrounding environment. The analysis draws on historical data about rescue operations gathered from conflicts; in particular, recent conflicts from Operation Desert Storm to present, as well as data from the Vietnam War. However, given the evolution of warfare since Vietnam, the research team also analyzed and compared data across conflicts to understand whether and how data from past conflicts may be used to estimate rescue success in future conflicts.

Past Personnel Recovery Analyses

The need to understand the factors that affect the rescue of downed personnel has been around for many years, and a number of studies have tried to answer this need.

The *Air Force Joint Personnel Recovery Requirements Analysis Report*, prepared by Air Combat Command (ACC) in 2009, suggests a notional relationship between the probability of rescue and the time that an IP is on the ground, where the longer the IP is on the ground, the less likely the recovery becomes as the enemy density increases in search of the IP.⁴ Although certainly a sensible hypothesis, neither a quantitative analysis using modeling nor historical data were provided in the report to support this argument.

One report by the Air Force Historical Research Agency examined manned aircraft combat losses between 1990 and 2002 and, based on the causes of the losses, suggests certain countermeasures to reduce future losses, such as employing superior fighters and destroying enemy airfields to suppress enemy air defenses; employing stealth technology; “flying high, fast and at night”; and employing flares and chaff to ensure protection against enemy actions.⁵

Because of the large number of PR opportunities in SEA,⁶ the most extensive analyses have been done on data obtained from this conflict. A study done by the 7602 Air Intelligence Group, under the auspices of the Headquarters USAF Analysis Program for the Southeast Asia Prisoner of War Experience, was published in 1976.⁷ The report examined USAF, U.S. Navy (USN), and U.S. Marine Corps (USMC) aircrews who were captured between 1964 and 1972 in Vietnam, where data were obtained primarily from USAF intelligence debriefing reports. The events were then analyzed one by one, where the analyst made a judgment as to what factors caused the failure of rescue. These data were then compiled to show that the percentage of people captured depended on various factors, such as injuries and the population density of the crash location.⁸ These quantitative data were augmented by qualitative discussions from the debriefing reports. The report concludes that the main reason for capture was because they were captured immediately after landing or were very close to the enemy—a result that is supported by the current research.

A more recent study on PR operations in Vietnam as well as more recent conflicts up to Operation Allied Force was done in 2001, in support of the Combat Rescue Future Recovery

⁴ See ACC, *Air Force Joint Personnel Recovery Requirements Analysis Report*, August 24, 2009, p. 24.

⁵ Daniel L. Haulman, *USAF Manned Aircraft Combat Losses 1990–2002*, Air Force Historical Research Agency, December 9, 2002.

⁶ One source counts 3,322 fixed-wing aircraft losses; see Christopher Hobson, *Vietnam Air Losses: USAF, Navy, and Marine Corps Fixed-Wing Aircraft Losses in SE Asia 1961–1973*, Specialty Press, 2002.

⁷ See USAF, *Factors Relating to the Search and Rescue (SAR) and Evasion Experiences of US Prisoners of War (POWs) in Southeast Asia*, Series: 700/FO-1, September 1976.

⁸ USAF, 1976, p. 23.

Vehicle Analysis of Alternatives.⁹ The study included analysis on the types of weapons that led to crashes, such as antiaircraft artillery (AAA) and small arms, and crashed aircraft type, as well as the fraction of all IPs that were awaiting rescue, rescued, and captured as a function of time elapsed since crashing.¹⁰ This study concludes that there is a direct correlation between the time an IP is stranded and the probability of rescue. Furthermore, the study identified additional factors for PR success, such as C2 relationships, the threat environment, and accurate location identification of the IP and communication.

Current Analysis Approach

Much can be learned through past studies such as those just described. However, our analysis expands on past studies and adds further statistical rigor. In particular, we apply rigorous survival analysis to historical PR data. The technique itself is described in more detail in a later chapter. Applying this technique leads to two major advances of our analysis over past studies.

The first major advance is that we are able to determine—with quantitative and statistical rigor through regression analysis—which factors (e.g., proximity to enemy, weather, terrain) are most strongly associated with the *time to end state*. This means that, as one approach to the statistical analysis, we can include all of the factors that we have recorded and then, without knowing *a priori* which factors may be most important, the technique quantitatively indicates which factors most strongly contribute to a longer time window to rescue the IP.

The second major advance is that, to establish a baseline for determining and improving the ability to rescue personnel, it is necessary to know how long it would take for an IP to be captured by the enemy in the absence of any rescue forces. However, just because an isolated person was rescued at a certain time does not mean that if they were not rescued at that time, they would have been captured just a few moments later. In fact, they may have evaded capture for much longer had they not been rescued—an undesirable but true realization. Therefore, any rigorous statistical analysis must take into account the fact that some of the down personnel were rescued, but could have survived for a longer time without being captured. In the language of survival analysis, these rescued personnel represent *censored* data. Previous studies do not make this distinction—leading to radically altered results—but we properly account for this in our analysis. The impact of not properly censoring the data is discussed in Chapter Three and shown in Figure 3.4.

⁹ Marc DiPaolo, *Combat Rescue Operational Review: A Summary of Combat Rescue Operations from Vietnam to Kosovo*, Las Vegas, Nev.: Pioneer Technologies, 2001.

¹⁰ DiPaolo, 2001.

How the Report Is Organized

The next chapter describes the historical data gathered to support the analysis. These data include information from conflicts dating from 1968 through 2013. Chapter Three then explains the methodologies used to examine these data and explores the factor of time in rescue operations and explains the determination of what we call the *rescuability window*, the period in which a rescue may be successful. The methodology then leads us to two sets of findings. The first, discussed in Chapter Four, show rescuability results by operation, which provides information about how the rescue curve has or has not changed over time. Chapter Five then examines how certain variables affect the rescue process. Drawing upon Chapters Four and Five, the final chapter presents our conclusions. The report also has two appendixes.

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2. Personnel Recovery Data from Past and Present Conflicts

As a first step in determining the best investment decisions to increase the likelihood of a successful PR operation in combat in the future, we examined PR operations from the following conflicts:

- Vietnam War (1961–1975; focus on January–March 1968)
- Operation Desert Storm (1991)
- Operation Deny Flight (1993–1995) (NATO no-fly zone over Bosnia)
- Operation Allied Force (1999)
- Operation Enduring Freedom (2001–present, as of August 21, 2014)
- Operation Iraqi Freedom (2003–2010)
- Operation Odyssey Dawn (2011) (American role in the international military operation in Libya to enforce UN Security Council Resolution 1973).

We obtained data on fixed-wing aircraft crashes from these conflicts from official reports, books, and news reports. For the purposes of our study, we specifically excluded helicopters. This was because both the isolation of helicopters crews and their rescue are fundamentally different from those of fixed-wing aircraft. Helicopter crashes often benefit from the helicopters' ability to autorotate, which significantly softens an unpowered landing. In addition, helicopter forces often fly in formation, giving them the ability to self-rescue. Finally, helicopter forces tend to operate in closer proximity to friendly ground forces. Beyond these differences, the Air Force primarily operates fixed-wing aircraft; with its helicopter fleet devoted primarily to missions in the continental United States and, of course, CSAR. We also exclude unmanned aircraft crashes, since these do not require PR operations. We define *downed personnel/aircraft* as any person or aircraft that is downed (because of either enemy action or mechanical failure) over contested territory or over water.

The data gathered included a range of factors, from quantitative to qualitative. Note that even for qualitative data, we were able to perform a regression analysis and obtain meaningful quantitative results. The data parameters recorded—not all of which was used directly in the current analysis—are listed in Table 2.1. The definition of each variable is included in Appendix B. While this list represents all of the items one might like to know, they were generally not well documented. It tended to be easier to reconstruct some of these, such as weather, for recent conflicts. However, in general, sufficient data was not available on many of these parameters to provide a basis for analysis.

Table 2.1. Factors Recorded for Downed Personnel

Aircraft	Country	End Daylight	Proximity to Friendlies	Supporting Witness Nearby
Alone on Ground	Date	End Sun	Proximity to Enemies	Terrain
Begin Daylight	Disposition of Population	Injury	Rescue Force	Time to End State
CAS Mission	Ejectable	Latitude	Rescue Training	Time to Initiate Rescue
Cause	Ejected	Life Sustaining Resources	Service	Weather
Communications	End Date	Longitude	Single Seat	
Conflict	End Local Time	Nearest City	Start Local Time	

Although we recorded 33 parameters for each downed person, we ultimately performed regression analysis with a subset of the 33 because we were not able to obtain the same quality of data for all parameters for all events, and some presented analytic challenges. Some of these are well defined, such as aircraft type and location. Others, while still perhaps critical, are less well defined, such as proximity of friendlies.¹¹ A subsequent chapter describes in more detail the regression analysis that enabled us to determine the most relevant independent parameters. The most important parameter to note here is the time until the downed personnel reached an *end state*, which could be rescued, captured by the enemy, or killed. In mathematical terms, this time is referred to as the *time to event of interest*. Our analysis determines the factors that are most strongly associated with the time, absent rescue, until the person was killed or captured. In the cases where the person was rescued, this represents, in mathematical terms, *censored* data and will be discussed more in later sections.

The Vietnam War

The conflict in Southeast Asia, including Vietnam, Laos, and Cambodia, saw numerous U.S. aircraft losses. The United States began putting forces in South Vietnam in 1962, most of which were withdrawn by 1973.¹²

Christopher Hobson's seminal *Vietnam Air Losses*¹³ catalogues 3,322 fixed-wing aircraft losses. Each record includes the names of downed personnel, type of aircraft, date of event, end

¹¹ While there are numerous examples of friendly forces providing air cover to support and lengthen the time an isolated person could survive, the Rescue at Ban Phanop (Boxer 22) illustrates this better than most. See Robert L. LaPointe, "Boxer 22 SAR: 5–7 December 1969," web page, *PJs in Vietnam*, updated December 11, 2014.

¹² DiPaolo, 2001, p. 2-2.

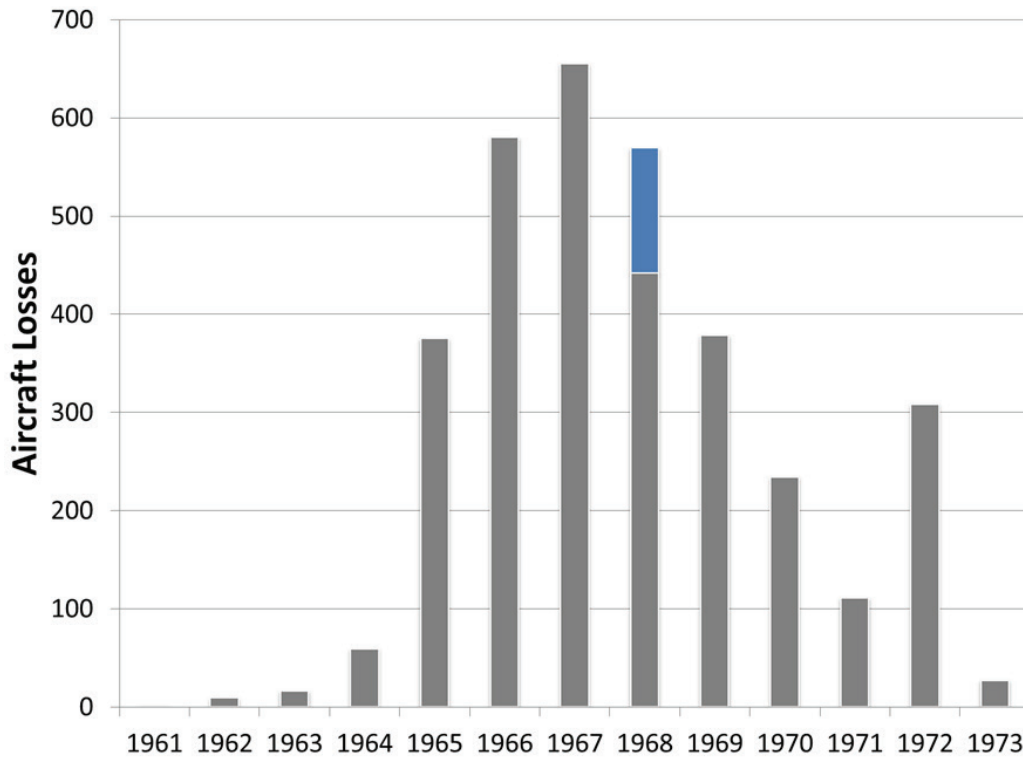
¹³ Hobson, 2002.

state of the downed personnel (killed, survived, captured), and tail number. We used this book as the index of aircraft losses in Southeast Asia. However, because the book did not focus on rescue missions, many of the details necessary for the PR analysis were missing—in particular, the information necessary to determine the *time to end state*, so we had to turn to other data sources. Here, we relied on rescue mission narratives, air recovery and rescue squadron (ARRS) history summaries, and other record sources available from the Air Force Historical Research Agency (AFHRA). Another source was the Rescue Coordination Center (RCC) logbooks maintained at the Joint Prisoners of War (POWs)/Missing in Action (MIA) Accounting Command (JPAC). The mission narratives and the ARRS history summaries were typewritten reports. Unfortunately, digital text searches were not effective on these reports. Moreover, all of the RCC logbooks were handwritten records and hence not searchable digitally and often difficult to read. Because of the extensive manpower and time needed to work through the entirety of the Southeast Asia (SEA) data, the research team decided to focus on one slice of time in the conflict that would provide at least a hundred records of events for a robust, illustrative analysis. As Figure 2.1 illustrates, the top three years for fixed-wing aircraft losses were 1966, 1967, and 1968. Whereas there were some AFHRA records of the events for all the years of the SEA conflict, the RCC logbooks only contained events from January 1968 to April 1973. For this reason, the RAND team selected the period of January to March 1968 to analyze.

During this period (shown as the blue portion in Figure 2.1), over 200 events with sufficient data for analysis were found. Admittedly, these three months do not represent the operational environment and capabilities of the entire SEA conflict¹⁴—no such short time segment could, especially giving the evolving and varying nature of the conflict. However, while the conclusions and insights derived from an analysis of these three months may not be representative of the entire conflict, we believe that this data can still be extremely useful in understanding the rescuability timeline. A brief synopsis of each event used in the analysis is presented in Appendix C.

¹⁴ Air refueling of the rescue helicopters began just before the three-month period chosen. As a result, the rescue helicopters flew established orbits and were able to launch rescue missions more quickly than if they were launched from home airbases. During these months, it was not uncommon for rescue helicopters to arrive at the scene of the downed aircraft within 15 minutes.

Figure 2.1. Fixed-Wing Aircraft Losses During SEA Conflict



SOURCES: Hobson, 2002; RCC logbooks; and AFHRA records.

NOTES: Blue area indicates data from January to March 1968, which exhibited a relatively high number of aircraft losses and is the period focus for this study.

The rescue mission narratives are first-hand accounts of the rescue mission by the rescuers (for an example, see Figure 2.2). They were the most complete accounts and provided great details on the start and end times of rescue missions, description of the events that led up to the downing of the aircraft, and details of the search and rescue event. They also provided the name(s) of the downed personnel and the aircraft type.

Figure 2.2. Example of Rescue Mission Narrative in Southeast Asia

FROM: Det 1, 37 Aerospace Rescue and Recovery Sq, APO SF 96310 5 JAN 1968

SUBJECT: Mission Narrative, 2 - 3 Jan 68, Men #1
Downgraded to CONFIDENTIAL

TO: 3ARRGP (C) 25 MAR 1971 [Date] [Signature]

1. (U) This report is submitted in accordance with ARRS, 55-2/24140p Sup 1, dated 15 June 67.

2. (S)(GP-4) At 1900L, 2 Jan 68, the alert crews were notified of a downed a/c, 090/31 Ch 89. The alert crews proceeded to TUOC and received a detailed briefing on the area of the downed aircrew member. Sandies 7 and 8 (ALB's), Jolly Green 20 and 15 launched at 1928L and proceeded to the scene. Mail 50 was in the area and had an approximate fix of the survivor. Sandy 7 started a low level search and was able to establish voice contact with Zorro 11, the survivor. Jolly Green 20 and 15 arrived in orbit 5 miles from Zorro 11 at 1947L. While in orbit, 4 large air bursts were observed within a 2 mile radius of our orbit track. Sandy 7 drew light ground fire on his low level search. Zorro 11 stated that his condition was good, but he was in a tree. He further stated that he heard people on the ground near his position. Due to darkness, hostile forces and terrain in addition to the possibility of giving away the survivors position if the attempt failed, Sandy 7 recommended the SAR effort be terminated until first light. Zorro concurred and the SAR forces were withdrawn.

3. (S)(GP-4) At 0415L, 3 Jan 68, the SAR forces were again briefed at TUOC. Take off time for Jolly Green 20 and 15 was 0530L. Crown 1 arrived on scene at 0515L. Sandies 5 and 6 arrived on scene at 0530L and Jolly Green 20 and 15 with Sandies 7 and 8 arrived on scene at 0545L. Mail 55 was FAC for Hobos 11, 12, 13, and 14 (ALB's). Boxer flight (F-4's) was Rescate. The survivors chute was spotted and voice contact was reestablished at 0605L. Sandy 5 decided that an attempt could be made and Jolly Green 20 descended from orbit and proceeded to the survivor with Sandy 5 escorting. When Jolly Green 20 was approximately 1 mile from Zorro 11, Sandy 5 requested Zorro 11 to light a smoke flare which he did. The flare was sighted and Jolly Green 20 came to a hover over Zorro 11 at 0621L. Zorro 11 was able to board the tree penetrator without assistance and was hoisted aboard Jolly Green 20 at 0624L. Egress was made from the area and no hostile action was encountered. Jolly Green 20 terminated at Ch 89 at 0640L. The survivors condition was good. All participants carried out their assignment to perfection. Radio discipline was good. Weather was not a factor.

4. (U) The survivors name was John Patten, Major, USAF, 606AGSq.

Handwritten notes:
1-22-74
9 and 11-7-68

The ARRS history summaries were published by the rescue squadron that performed the rescue and provided short descriptions of the event (an example is shown in Figure 2.3). These short summaries provided the date, aircraft type, start and end times of rescue, and name(s) of downed personnel. These summaries provided little description of the downed event or the rescue mission. The names of the downed personnel were used to match the events of ARRS summaries and mission narratives with the records of Hobson's book.

Figure 2.3. Example of an ARRS History Summary from SEA Conflict

(2)(U) 1-3-3, 7 Jan 1968. At 0605Z, Jolly Green 04 was scrambled from DaNang to recover the pilot of a USAF F-100 who had bailed out eighteen (18) miles east of DaNang. Crown 05 made contact, spotted and marked the survivor's position in the water. Jolly Green 04 made a water landing and picked up the survivor, Major Dwayne P. Wright, FR31198, 37 TFW, APO 96368. The survivor was uninjured and Jolly Green 04 returned him to DaNang terminating the mission at 0630Z.

The AFHRA records also provided some handwritten records of rescue missions. These were likely the first recordings of the event that were intended to be typewritten at a later time. In some cases, the preservation of these handwritten records was poor and made deciphering the writing challenging (e.g., Figure 2.4a). Other records included lined recordings that were recorded near real-time as the event unfolded (e.g., Figure 2.4b).

Figure 2.4. Examples of AFHRA Records from SEA Conflict

2.4a
→

THE RESCUE MISSION WAS INITIATED BY THE PILOT WHO PARACHUTED
OUT OF HIS F-100 SEVEN MILES EAST OF DANANG. HE WAS IN GOOD
CONDITION AND WAS LOCATED BY THE SEARCH PARTY. THE SEARCH PARTY
ARRIVED AT THE PARACHUTE SITE AT 0630Z. THE PILOT WAS PICKED UP
BY JOLLY GREEN 04 AND RETURNED TO DANANG. THE MISSION WAS
TERMINATED AT 0630Z.

2.4b
→

10. 02 JAN 68
10. (B) NOT A FAKTOR
13. SANDY 05, 02/2310Z/1715N 10512E
14 FORREST PENETRATOR, 02/2324Z
15. (A) 1/1/1/1/0/0
16. TAKEF TOSNAYON PHAFOM
17. 4/4;10/HH3E/DET 1 57ARRS; 6/2;10/AYE/502 F100;
1/3;15/HC130P/33ARRS
18. SS/E
19. JG 20 FERRELL J.B. CAPT DET 1 SICHTERUAN E. J. 1/LT
GRAU B.W. S/SGT TAYLOR R.A A1C
(B) RATTEE, JOHN R MAJOR, 56 ACW NAKHON QYANOM RTAFB
20. (A) 1715N 10512E. HILLYSZERRAIN(B) POB RECOVERED
AS (H) THIS US A COMBAT SAVE. EFFORT WAS CALLED BECAUSE OF DARKNESS
THE EVENING OF 2 JAN 68. PREPARATIONS WERE MADE OVERNIGHT AND A
FIRST LIGHT ATTEMPT SET UP. VOICE CONTACT WAS ESTABLISHED WITH
PILOT WHO REMAINED IN HARNESS OVERNIGHT. SANDY 5 LOCATED THE
PILOTS CHUTE AND CALLED IN JG 20 WHO MADE PICKUP 15 MINUTES
BEFORE SUNRISE. SURVIVOR IN GOOD CONDITION AND TRANSPORTED TO
NAKHON PHANOM.

These four types of records from AFHRA provided about 50 percent of the events in SEA during January to March 1968. The data for most of these events were retrieved from the mission narratives and the ARRS history summaries.

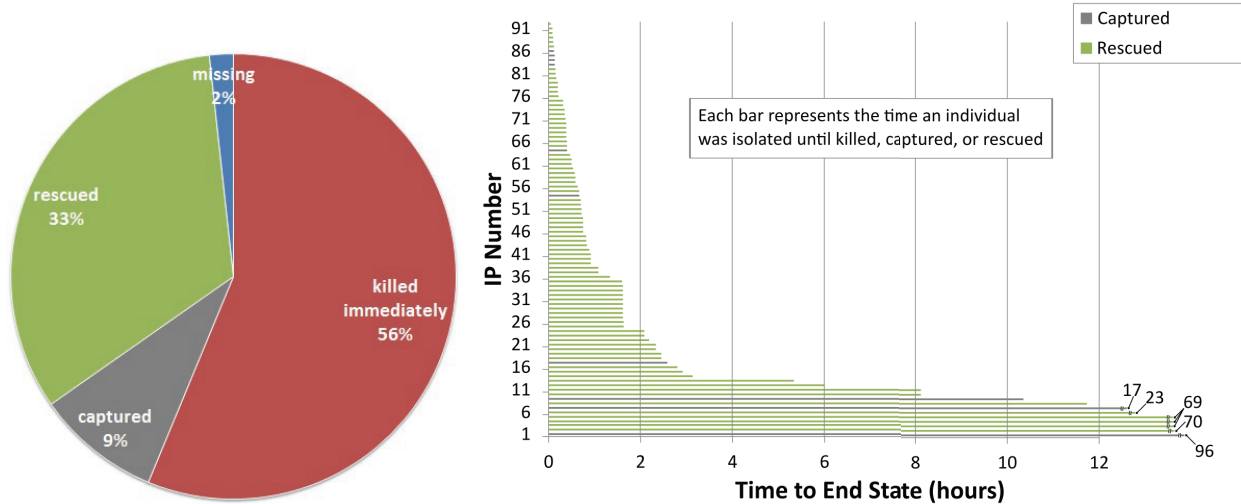
Unlike the records from AFHRA, which were records written by the rescue pilots, the RCC logbooks from JPAC hold the handwritten recording of the RCC operators—in other words, the command center. Hence, they provided a complementary perspective to the AFHRA records of the each event. The RCC logbooks provided data for more than 80 percent of the events, so it was able to fill the gaps of the AFHRA records. With all the records from AFHRA and the RCC logbooks, more than 80 percent of the events from January to March 1968 were analyzed. We were not able to identify a systematic reason to explain why certain downing events did not appear in our dataset; therefore, we do not believe there is bias in our analysis.

The RCC logbooks provided the start and end times of the events, the aircraft type, and some descriptions of the event. They did not provide as complete a description as the mission narratives, but they provided enough data for analysis. Using the date of event and aircraft type, the RCC logbook records were matched to the AFHRA records and Hobson's book. In cases where there was a discrepancy in start time between the AFHRA and RCC logbook records, we deferred to the RCC logbooks because the command centers likely received the first word when the aircraft went down. In cases of differences in end time, the team deferred to the AFHRA records because the rescuers were probably in a better position to know the exact time of rescue. However, there were no significant discrepancies among the different data sources. In most cases, the difference was 5 to 15 minutes.

Until recently, the only record of the RCC logbooks was the original notebooks stored at JPAC. This research provided the impetus for JPAC to ship the logbooks to AFHRA, which had the capability to unbind and scan the thousands of pages of the logbooks. Now, these valuable records have been digitized and stored at AFHRA for wider public access.

Given the vast dataset, we focused on events between January 1 and March 31, 1968. This left us with 127 aircraft losses involving 288 downed personnel. The majority of downed personnel (65 percent) originated from USAF aircraft, with the remaining belonging to the USN and USMC. The aircraft losses included 23 aircraft types (e.g., A-1, A-37, A-4, F-4)—34 types, if subtypes are distinguished (e.g., F-4B, F-4C, F-4D). Of the 288 downed personnel, 162 (56 percent) were killed immediately—either by the crash or by the enemy in the air—and thus had no chance of being captured or rescued. A total of 95 people (33 percent) were eventually rescued, 26 people (9 percent) were captured, and five people (2 percent) were missing. These numbers are shown in the pie chart in Figure 2.5. It shows that, in this conflict, if downed personnel survived the initial crash, it was more likely for them to be rescued than captured. Some of the larger downed aircraft include one P-3B, whose crash led to the deaths of 12 people; three OP-2E aircraft, whose crashes led to the deaths of 20 people; one AC-47D crash, which led to the deaths of eight people; and one EB-66C that involved seven people.

Figure 2.5. Downed Personnel *End State* and *Time to End State* for the Vietnam War



Note: Bar graph on the right includes only those who were not killed immediately.

The bar graph in Figure 2.5 shows the *time to end state* of the IP (excluding downed aircrew who were killed or captured immediately). We see that 7 percent of IP could have been rescued after more than 10 hours, and one could have been rescued for four days, but was captured by the enemy. This person was flying a USMC A-6A during a night strike when it was probably shot down by a surface-to-air missile (SAM). The person that survived longest and was rescued was floating out on open waters for almost three days after his F-8E ran out of fuel, forcing him to eject. The next-longest surviving personnel who were also successfully rescued were three people on an EB-66C electronic warfare aircraft when it was engaged by a MiG-21 and shot down by an air-to-air missile. Of the seven people on board, four were captured and three were rescued, although one died soon after as a result of injuries sustained in the crash.

Operation Desert Storm

As a result of Iraqi President Saddam Hussein’s invasion of Kuwait, the United Nations authorized the use of force by a multinational coalition to repel the Iraqis from Kuwait.¹⁵ Operation Desert Storm lasted from January 17 to February 28, 1991, with an initial air campaign led by USAF, followed by a ground offensive.

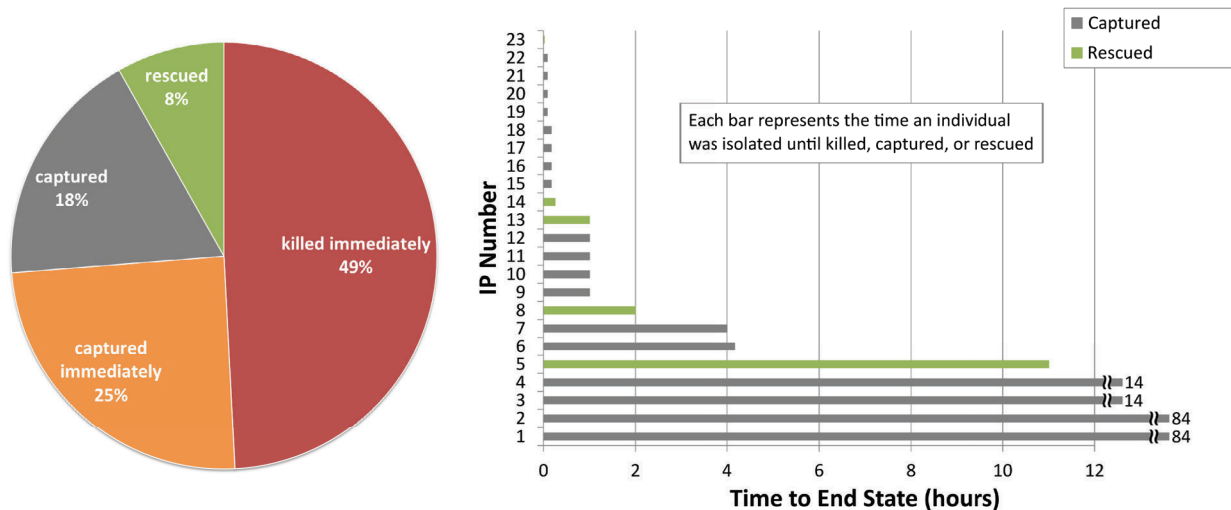
As a primary data source, we used the book *Combat Search and Rescue in Desert Storm* by Darrel D. Whitcomb and the document *Combat Rescue Operational Review*, by Marc DiPaolo,

¹⁵ DiPaolo, 2001, p. 2-60.

as a secondary data source.¹⁶ These two documents provide a comprehensive description of all aircraft crashes in that conflict.

In our analysis, we included 33 fixed-wing aircraft that crashed, involving a total of 61 people. Of those, 30 people (49 percent) were killed immediately—either while in the aircraft or upon impact with the ground—and 15 people (25 percent) were immediately captured. This means 16 people (26 percent) were classified as having a defined rescuability window according to our definitions. Ultimately, 26 people (43 percent) were captured by the enemy and five people (8 percent) were rescued. This means that, of those who could have been rescued, 31 percent were successfully rescued. Of all crashes considered, about one-half had no chance of rescue, even if there were no enemy present on the ground, because they died in the crash. These numbers are depicted in the pie chart in Figure 2.6. Of those immediately killed, 14 people (23 percent) were on a single AC-130 during a night mission to provide CAS to ground forces, destroying Iraqi FROG (free rocket over ground) missile batteries. The aircraft was hit by a missile while engaging enemy forces and crashed into the water off the coast. A brief synopsis of each event used in the analysis is presented in Appendix C.

Figure 2.6. Downed Personnel End State and Time to End State for Operation Desert Storm



Note: Bar graph on the right includes only those who were not killed immediately.

The bar graph in Figure 2.6 shows the *time to end state* of each of the downed personnel who were not killed or captured immediately. We observe that most reached their *end state* in less than four hours. More than 20 percent (five people) of personnel who initially survived remained rescuable after 10 hours. The two people who were captured after three and a half days (84 hours) were originally on an F-15 shot down by an SA-2. They were able to make radio contact

¹⁶ Darrel D. Whitcomb, *Combat Search and Rescue in Desert Storm*, Maxwell Air Force Base, Ala.: Air University Press, 2006; DiPaolo, 2001.

with a passing aircraft about half a day after their shootdown, but because the passing aircraft was unaware of downed airmen in the area, they were unable to mount rescue operations immediately. The downed airmen walked toward Syria to escape but were captured by the enemy before reaching the border.

The personnel who were captured in 14 hours were originally on a Royal Air Force (RAF) Tornado that was shot down by a Roland missile. The pilot and crew both ejected, but one had serious injuries. They tried to make contact with their survival radios using both voice and beacon, but were never heard. Ultimately, they were captured by the enemy.

Seventeen people went down over water, 14 of whom were from the AC-130 crash described previously. Aside from that AC-130 and two OV-10s, the remaining 30 aircraft were all fighters. Most of the aircraft went down in southern Iraq and in Kuwait, where the majority of the sorties were flown.

Operation Deny Flight and Operation Allied Force

For both Operation Deny Flight (ODF) and Operation Allied Force (OAF), our primary data source was the document by DiPaolo, which was written in support of the “Combat Rescue Future Recovery Vehicle Analysis of Alternatives” for Headquarters Air Combat Command/Defense Reutilization and Marketing Region.¹⁷

ODF was an operation initiated by the North Atlantic Treaty Organization (NATO) in response to a UN Security Council request to quell the ethnic conflict taking place in Bosnia and Herzegovina, lasting from April 1993 to December 1995.¹⁸ During that time, over 100,000 aircraft sorties were flown and 3,000 bombs dropped.¹⁹

In this conflict, two aircraft were shot down in enemy territory: one F-16 and one Mirage 2000. A Bosnian Serb SA-6 battery shot down the F-16 during cruise flight. The pilot managed to eject, landed in a relatively uninhabited area, and evaded enemy capture for five and a half days. On the fifth day, he made radio contact and was ultimately recovered during the daytime by CH-53s escorted by AH-1W Cobra gunships. In the case of the Mirage, which belonged to the French Air Force, man-portable air defense systems (MANPADS) engaged the aircraft and the pilot and crew ejected successfully. However, one of the two crewmembers sustained a serious leg injury, and both were captured soon after.

OAF was a NATO operation from March to June 1999 against Serbian forces who were committing atrocities in Kosovo.²⁰ Two aircraft were shot down in enemy territory in this conflict: one F-117 and one F-16. The F-117 was shot down by a SAM while on a night mission

¹⁷ DiPaolo, 2001.

¹⁸ DiPaolo, 2001, p. 2-80.

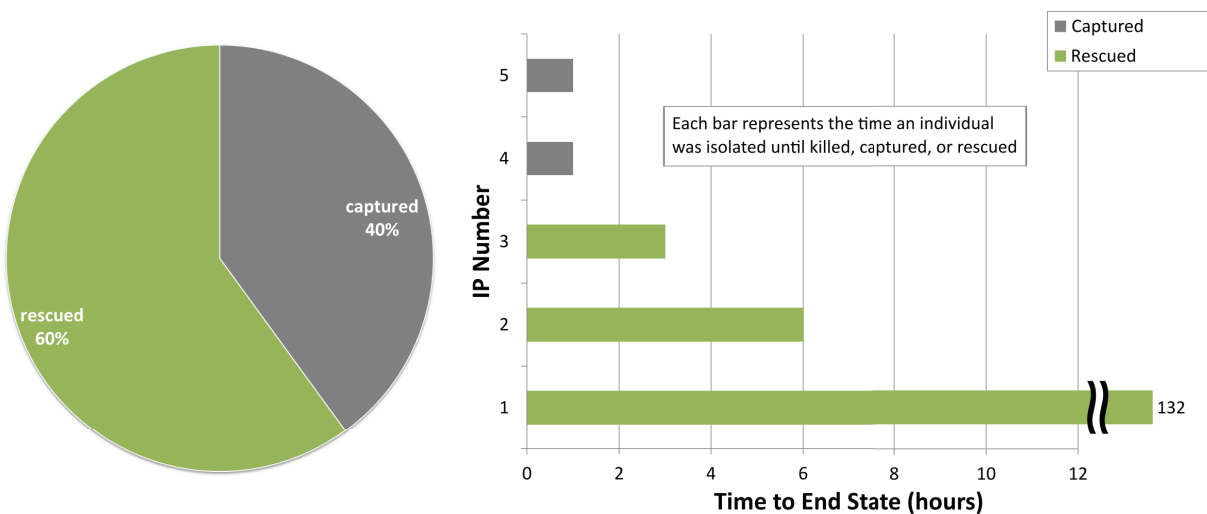
¹⁹ DiPaolo, 2001, p. 2-80.

²⁰ DiPaolo, 2001, p. 2-96.

and the pilot ejected immediately. He landed in a field and was able to make a radio call to an Airborne Warning and Control System (AWACS) of his predicament. He then evaded capture for six hours before being recovered by an MH-60G. The F-16 was shot down by an SA-3 while on a suppression of enemy air defenses night mission. The pilot landed in a field and was in immediate radio contact with his flight lead. He evaded capture and was rescued after three hours by an MH-60G.

The *end states* and *time to end states* of all five people involved in the two conflicts in the Balkans are summarized in Figure 2.7. Of the five people involved, three (60 percent) were rescued and two (40 percent) were captured. Except for one case, where the pilot was rescued after five and a half days, all IP reached their end state in less than six hours. A brief synopsis of these events is presented in Appendix C.

Figure 2.7. Downed Personnel *End State* and *Time to End State* for ODF and OAF



Operation Enduring Freedom

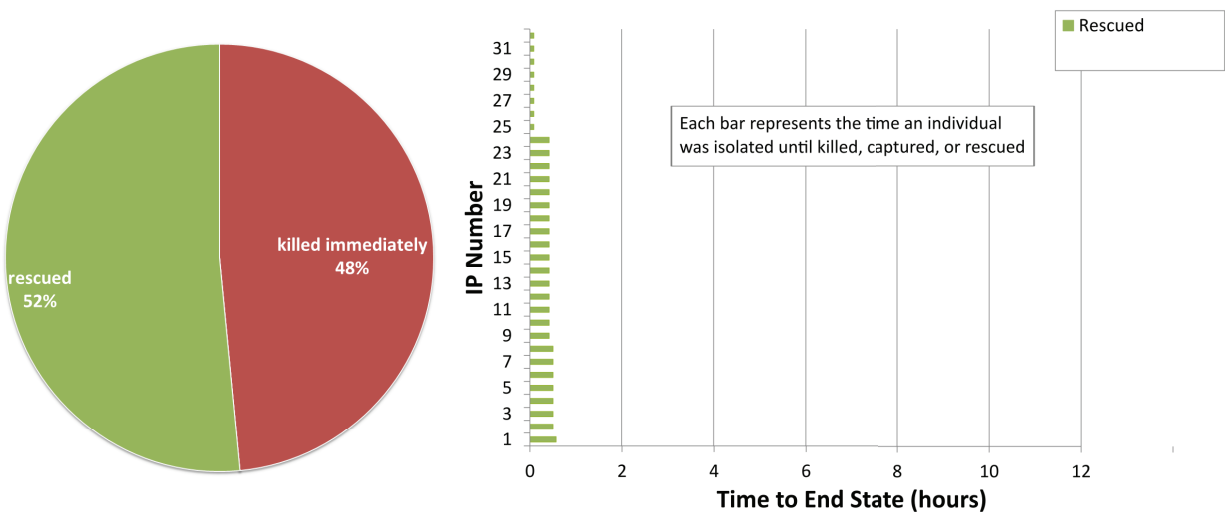
After the September 11, 2001, attack against the World Trade Center in New York City and the Pentagon, the United States was determined to pursue those responsible: Osama bin Laden and his terrorist group al Qaeda, who were harbored by the Taliban regime in Afghanistan.²¹ Operation Enduring Freedom (OEF) was an operation in Afghanistan from October 7, 2001, to the present (as of August 7, 2014) to rid the country of terrorist elements and bring stability to the region. Our analysis included events up until December 31, 2013. As data sources, we used USAF Aircraft Accident Investigation Reports (when available), since these contained detailed

²¹ Benjamin S. Lambeth, *Air Power Against Terror: America's Conduct of Operation Enduring Freedom*, Santa Monica, Calif.: RAND Corporation, MG-166-1-CENTAF, 2006.

information on the crash and the recovery efforts, as well as *The Nimrod Review*, by Charles Haddon, and various news reports.²²

In our analysis, we included ten fixed-wing aircraft crashes, which involved 66 people. Of those, 32 people (48 percent) were killed immediately and 34 people (52 percent) were rescued successfully. No downed personnel were captured by the enemy. Four aircraft accounted for the vast majority of downed personnel. This included one Nimrod MR2 with 14 people (21 percent), one CV-22 with 20 people (30 percent), and two MC-130s with 18 people (27 percent). Aside from those aircraft, the remaining personnel were in fighters with seven people (11 percent), one MC-12 with four people (6 percent), and one C-12 with three people (5 percent). Figure 2.8 shows a pie chart summarizing the end state of all 66 IP, as well as the time to end state for the IP who survived the initial incident and where we had information on time to rescue. In the case of OEF, of those who were not killed immediately, all were rescued within one hour. A brief synopsis of each event used in the analysis is presented in Appendix C.

Figure 2.8. Downed Personnel End State and Time to End State for OEF



Note: Bar graph on the right includes only those who were not killed immediately.

The Nimrod MR2, an RAF asset, was on a routine mission in Helmand province supporting ground forces when it crashed because of an on-board fire, killing all 14 people.²³ The fire is believed to have been caused by ignited fuel that had leaked during air-to-air refueling.

The CV-22 was on a routine night mission to infiltrate a team near Qalat, Afghanistan, in support of ground forces when it crashed.²⁴ Four people were killed, and the remaining 16

²² Charles Haddon, *The Nimrod Review*, London: The Stationery Office, 2009.

²³ Haddon, 2009.

²⁴ United States Air Force Aircraft Accident Investigation Board, *CV-22B Osprey, T/N 06-0031*, 2010.

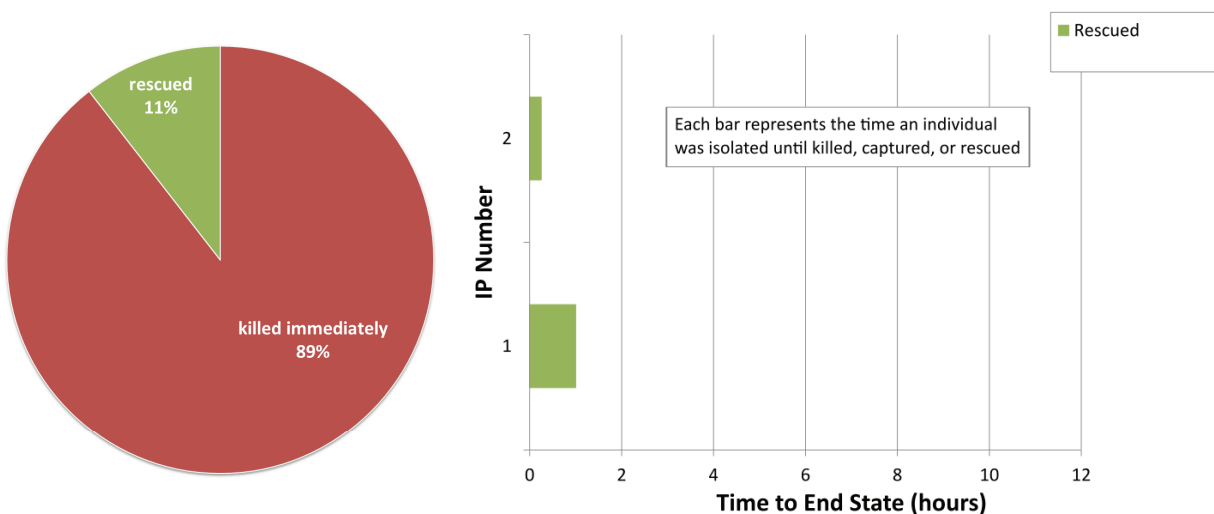
sustained various levels of injuries. Another CV-22 aircraft in the mission saw the crash and was able to request medical evacuation assets immediately. Furthermore, these assets were able to land nearby and provided initial assistance in less than half an hour. The cause of the crash was not conclusively determined, but it was almost certainly not due to enemy action.

Operation Iraqi Freedom

In early 2003, the United States believed that Iraq possessed weapons of mass destruction (WMD) and was determined to stop it from further developing its WMD program. Thus, Operation Iraqi Freedom (OIF) was launched March 20, 2003, and lasted until September 1, 2010, when it was then renamed Operation New Dawn, which lasted until December 15, 2011.²⁵ As a source, we used various USAF Aircraft Accident Investigation Reports (when available), as well as the RAF Board of Inquiry report,²⁶ and various news reports.

Our analysis included 8 aircraft that crashed, involving a total of 19 people. Of those, 17 (89 percent) were killed immediately and 2 (11 percent) were rescued. None of the downed personnel was captured by the enemy. The results are summarized in Figure 2.9. Additionally, brief synopses of each event used in the analysis are presented in Appendix C.

Figure 2.9. Downed Personnel *End State* and *Time to End State* for OIF



NOTE: Bar graph on the right includes only those who were not killed immediately.

One C-130 had ten people (53 percent) on board. The remaining nine people (47 percent) were in fighters. The C-130 was an RAF asset en route from Baghdad to Balad on a routine daytime mission that included transporting passengers and freight when it is believed to have

²⁵ “Operation Iraqi Freedom and Operation New Dawn Fast Facts,” *CNN*, updated April 21, 2015.

²⁶ Royal Air Force Board of Inquiry, *Hercules XV179*, 2005.

been hit by an enemy AAA that severed its right wing, causing the aircraft to crash.²⁷ All ten people were killed in the incident.²⁸

The pilot rescued in less than an hour was in an A-10 near Baghdad when it was struck by a Roland missile.²⁹ The pilot ejected and was recovered by Coalition ground forces soon after.³⁰ The pilot rescued in about an hour was in an F-16 as part of a CAS mission.³¹ The crash occurred after an aerial refueling, when the fuel became trapped and starved the engine, forcing the pilot to eject in an uninhabited area.

Operation Odyssey Dawn

Operation Odyssey Dawn was conducted from March 19 to March 31, 2011, in support of UN Security Council Resolution 1973, to protect the people of Libya from violence by the regime of Muammar Qaddafi and his forces. One F-15E carrying two people crashed in this operation. Our primary source was the USAF Aircraft Accident Investigation Board report.³²

The F-15E aircraft took off from Aviano Air Base in Italy for a night combat mission near Benghazi, Libya. After dropping its bombs, it entered an unrecoverable spin due to exceeding aircraft controllability parameters, partly because of weight imbalance. The pilot and weapon systems officer (WSO) ejected with minor injuries in an uninhabited area. The crew evaded separately for about three hours before being recovered by friendly forces. A brief synopsis of these events is presented in Appendix C.

Summary of Events

Table 2.2 summarizes the number of downed personnel from all of the conflicts we studied, excluding Vietnam.

²⁷ Royal Air Force Board of Inquiry, 2005.

²⁸ “Ten feared dead in Hercules crash,” *BBC News*, February 1, 2005.

²⁹ “U.S. A-10 Warplane Shot Down Near Baghdad,” *Fox News*, April 8, 2003.

³⁰ “Ground Attack Fighter Shot Down Near Baghdad,” *PBS NewsHour*, April 8, 2003.

³¹ United States Air Force Aircraft Accident Investigation Board, *Executive Summary Aircraft Accident Investigation F-16CG, S/N 88-0424*, 2003.

³² United States Air Force Aircraft Accident Investigation Board, *F-15E Strike Eagle, T/N 91-000304*, 2011.

Table 2.2. Number of Downed Fixed-Wing Personnel from Recent Conflicts Considered

Operation	Downed Personnel
Desert Storm	61
Bosnia	3
Kosovo	2
Libya	2
OEF	66
OIF	19
Total	153

Of the 153 downed personnel, we performed survival analysis on 115. We had to remove cases with incomplete information, such as unknown *time to end state* and unknown outcomes. There did not appear to be any systematic difference in the cases with and without sufficient details; therefore, we do not believe the exclusion of these data bias our results.

In the next chapter, we describe in detail how we analyzed this data and performed survival analysis to extract the information that we used as an input in constructing the model to determine the optimum resource allocation for future PR efforts.

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3. Approach and Methods to Assess the Value of Time

This chapter discusses the importance of developing a rescuability window to quantify the value of time in executing a rescue and to better understand the operational risk associated with PR. Specifically, a necessary condition for a successful rescue is that rescue forces arrive before the IP is otherwise killed or captured. This chapter also details the methodology for deriving the rescuability window based on a field of statistics known as survival analysis.

To execute a successful CSAR rescue of downed aircrews, a series of steps need to be completed.³³ These include the following:

- **Confirming that someone may have survived.** While aircraft often fly within sight of others in the formation, the chaos of battle often obscures a loss; therefore, it is not uncommon for a flight to not immediately realize an aircraft is missing. Ideally, the pilot will transmit his intention to eject, followed by a call from his survival radio while descending in his parachute, and call again when on the ground. All of these things seldom happen. Even if the pilot of a stricken aircraft transmits a mayday call, these calls are sometimes lost among the other radio chatter common during the battle. Losses at low altitudes are especially difficult if the pilot must eject immediately. Furthermore, aircraft flying alone sometimes transmit a distress call, but there is no guarantee anyone will hear it. Absent knowledge of survival, if the area is particularly “hot,” rescue forces often will not attempt a rescue; however, in more permissive environments, a search can be conducted absent definitive information.
- **Locating the isolated personnel.** Rescue forces must know at least a rough estimate of the IP’s location to develop a tactical plan for the rescue. Other aircraft seeing the parachute on the ground or communication from a survival radio greatly increase the ability to locate the IP.
- **Authenticating the IP’s identity.** Rescue forces must know with a high degree of certainty that the IP is the one operating the survival radio, and there are established procedures to make a positive identification. There are numerous instances of enemy forces trying to spoof American rescue forces to fly into flak trap ambushes. In particular, the North Vietnamese were experts at this spoofing.
- **Alerting CSAR forces.** Direct communication between strike aircraft and the rescue command centers seldom occurs; therefore, the notification of an aircraft downing and surviving IP must travel through pre-arranged communications channels. If these channels are not efficient, delays may occur. Each relay of information creates the potential for confusion, and contradictory “facts” reaching the RCC is not uncommon.
- **Assessing the threat and formulating a rescue plan.** If the IP is in a heavily defended area, an area unfamiliar to rescue forces, or weather is poor, formulating a rescue plan can be a time-consuming task. Further complicating the problem can be the addition of

³³ We focus on traditional CSAR rescues in this section; however, there are many other means, including nonstandard methods of rescuing IP. Many of these involve a substantially different process.

support forces, aerial refueling tankers, escort aircraft, and threat suppression aircraft. Building such a large “package” takes time.

- **Gaining approval from commanders to attempt the rescue.** While rescue forces are certainly “leaning forward” and looking to save the IP, it falls on senior commanders to make the decision to launch a rescue. The process to make this decision takes time—some brief, some long, but time nonetheless.
- **Commitment of rescue forces.** Dispatching rescue forces involves more than pushing a “go” button. Support forces must be notified, tasked, and committed for the correct rendezvous times and enemy engagement times.
- **En route time to IP’s location.** A direct route to the IP is not always the most effective. Sometimes the best route is indirect and, hence, longer, but gives a better chance of success.
- **Rendezvous with the IP.** After arriving at the IP location, rescue forces must rendezvous with the IP and complete the rescue and begin the reintegration.

While the timeline of a rescue is certainly complicated, we know that, for a rescue to be successful, we must rendezvous with the downed personnel before they are killed or captured. That is, the time to complete all of the steps listed above must take less time than it takes the enemy to capture the downed person or the downed person to otherwise succumb to injuries. Therefore, the operational risk is failing to reach the downed person in what we term their “rescuability window.”

The current research seeks to quantify the rescuability of downed personnel so the timeline of the above series can be converted to a probability of successful rescue. By doing so, the value of improving the timeliness of any one of these steps can be analyzed in terms of both effectiveness and cost-effectiveness. For example, forthcoming RAND research is using the rescuability timeline derived in this analysis to quantify the potential benefit of incorporating V-22s into the CSAR fleet as a potential means of reducing the en route time to IP’s location. While it is obvious that getting to downed aircrews faster is generally good, the degree to which improved timeliness increases the chances of a successful rescue has not been previously quantified.

Absent the underlying information that relates rescuability and time, it is not possible to quantify the effectiveness of changes to the way PR is currently conducted. Therefore, the current research focuses on quantifying the relationship between rescuability and time so that the most cost-effective options for increasing the rescuability of downed personnel can be pursued. The relationship of rescuability and time form the rescuability window.

Rescuability Window

We define the *rescuability window* as the period during which a downed person can be rescued. That is, the rescuability window is the time from the isolating event until, absent a recovery, the IP is either captured or succumbs.³⁴ We know that a necessary condition of a

³⁴ Obviously, rescue or release after capture is possible.

successful rescue is that the rescue forces arrive at the downed person's location within the rescuability window (i.e., they arrive before the IP are killed or captured or die of their injuries). This timeline must be met irrespective of such issues as rescue force location, communications quality, and enemy action. Rescue platform, rescue and communications equipment, and training are therefore enablers of a successful rescue. These items compress the rescue timeline to increase the likelihood of reaching the downed person within their rescuability window. We specifically use the term *rescuability window* to emphasize the ultimate objective; however, since the set of statistical tools on which this analysis is based is known in literature as survival analysis, we at times use the term *survival* for clarity.³⁵

This rescuability window is not a definitive length of time; rather, it depends on a plethora of factors. Some of these factors can be accounted for *a priori*, such as whether the aircraft had an ejection seat, the aircraft's altitude when it was downed, whether it was day or night, whether the downing took place over land or water, and whether the terrain offered opportunities to hide. But many others depend on the precise details of the event.

Take, for example, the downing of Col Dave Eberly and Maj Tom Griffith on January 24, 1991, over western Iraq. Several factors affected their rescuability window, but these are essentially random in nature (i.e., luck or lack thereof). For example, after not being able to establish communications with friendly forces, they decided to start walking toward the Syrian border, where they hoped to cross into sanctuary. Being cold, wet, hungry, and thirsty, the crew tried to seek shelter in what appeared to be an abandoned building a few miles from the border. The building was occupied by Iraqi troops, who captured the two fliers. Conversely, there are cases where pilots, in addition to their experience and training, have benefited from some measure of luck. In Serbia, on March 27, 1999, Lt Col Darrell Zelko was shot down in his F-117. At the time of rescue, rescue forces reported that enemy vehicles and personnel were only 50 yards from Zelko's position. Even the slightest change in Zelko's or the enemy's position could have brought them into contact.

Both examples illustrate that whether and how a person ends up being captured or killed (i.e., the duration of their rescuability window) depends on a set of factors, some of which cannot be known in advance. However, with enough data, we are able to assess these factors in the aggregate and determine how they play out probabilistically.

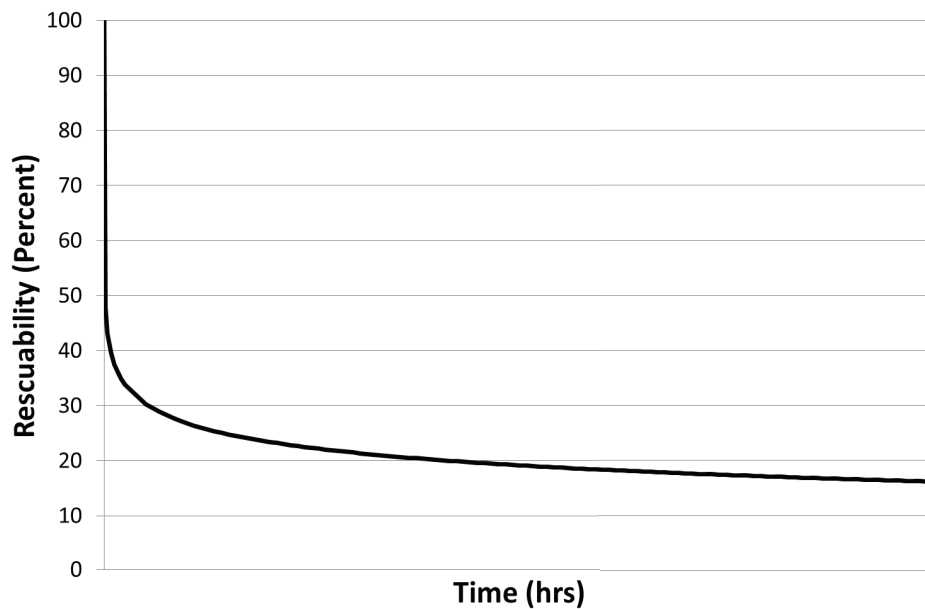
However, a few factors *a priori* can give an indication of the rescuability window, while the rescuability window itself is in fact much more stochastic. That is, while there is no defined closing of the window, there are factors that may in general reduce or extend this window.

Figure 3.1 shows a notional rescuability curve. Here, because of the cumulative risk as time passes, the probability of being rescued decreases. Simply put, the more time on the ground, the

³⁵ *Survival* and *rescuability* can be used as synonyms. To be *rescuable*, the person must survive—that is, not be killed or captured. Therefore, the *survival* or *rescuability window*, is the time from isolation until, absent recovery, the person is otherwise killed or captured.

more likely it is that a downed person will come into contact with the enemy. While this is, of course, an obvious conclusion, what is important is that this rescuability curve quantifies the value of time. Once quantified, the value of time can be used to make defense planning and force structure decisions, which will be discussed in the next section. The method for deriving such a curve is discussed later in this chapter, and the results of the analysis are presented in Chapters Five and Six.

Figure 3.1. A Sample Rescuability Curve



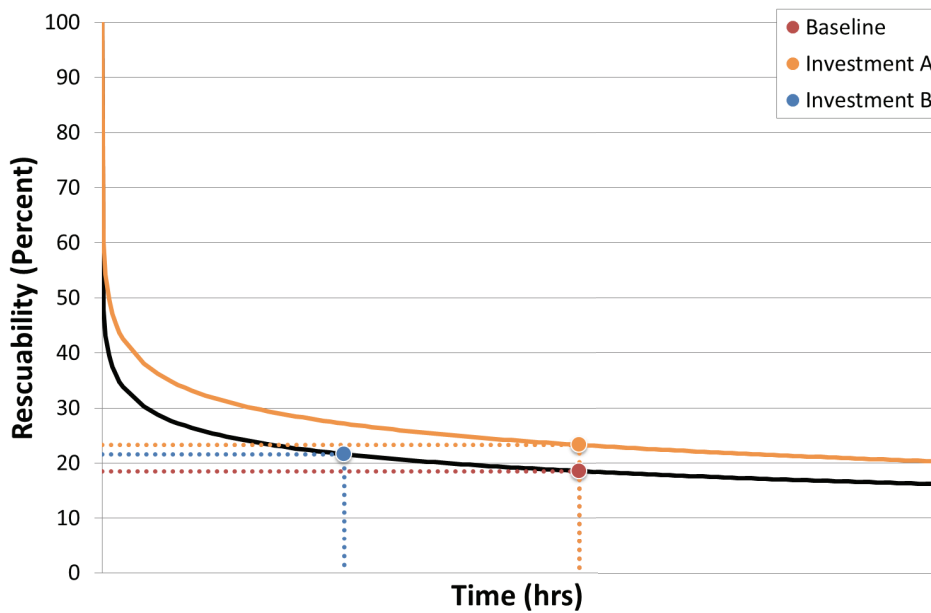
Utilizing the Value of Time

By quantifying the value of time, it is possible to make investment decisions across the spectrum of PR. Investing in a faster rescue platform can be characterized both in terms of the cost of the investment and the benefit of a reduced timeline, and increased likelihood of rescue can be quantified (i.e., the benefit of moving X minutes to the left on the rescuability curve). Similarly, this investment could be compared with other investments, such as improved survival radios that allow the IP location to be determined faster.

Take, for example, the notional curve shown in Figure 3.2. Here we see the baseline timeframe to reach a downed person. This could be improved in a number of ways—e.g., initial survivability, either through aircraft improvements, ejection seat capabilities, or initial evasion tools (Investment A). These types of investments represent an upward shift of the rescuability curve. There could also be an investment in a faster rescue platform, in improved survival radios, or in an improved C2 structure (Investment B). These types of investments represent a leftward shift on the rescuability curve. This chart shows that these types of improvements can be

quantified and compared in terms of the probability of reaching the downed person, or decrease to the operational risk. Pairing this with the cost for each of these investments, it is possible to derive the cost-effectiveness of each option. Imagine that Investment A is the least costly. Then, this would be the most cost-effective investment. However, if Investment A is three times the cost of Investment B, then Investment B may offer the best cost-effectiveness, even though it does not offer the greatest net benefit.

Figure 3.2. Notional Improvements to Improve Rescuability



Forthcoming RAND research uses the rescuability timeline to compare the cost-effectiveness of incorporating V-22s into the CSAR fleet. Specifically, for an equal-cost fleet, the research quantifies the improvement in reaching downed personnel faster against the risk of not having sufficient assets available, given the higher cost of a V-22 compared to an HH-60. This type of analysis is only possible because the relationship between rescuability and time is now quantified. The details of how we constructed this relationship are presented in the next section.

Deriving the Rescuability Window

To derive the rescuability model, we use a set of established mathematical tools known collectively as survival analysis. In survival analysis, the dependent variable of interest is the time to some well-defined event of interest. In a medical setting, the mathematical event of interest could be the onset or relapse of a disease, or the death of a patient. In an industrial reliability application, the event could be the failure of a component. In each case, survival analysis can be used to (1) estimate the expected time to the event and (2) to characterize, via

regression, the effects of different covariates on the time of events—all based on prior observations.

In the present application of CSAR, survival analysis can be used to formally characterize the rescuability—over time—of downed personnel. The mathematical events of interest are capture and fatality, while the ultimate goal is avoiding these outcomes. Mathematically, the two end states of being killed or captured are treated in the same way: both mark the end of the rescuability window.

The present approach is largely empirical. Data for subsequent analysis comes from historical U.S. combat rescue events, cataloged and reconstructed from multiple sources. The details of the combat rescue data can be found in Chapter Two. The critical data fields are the duration of the downed personnel events, as well as covariates that can affect survival and rescue outcome, such as the presence of ejections seats on the aircraft or the amenability of the terrain for hiding and evasion. The details of the covariate selection process and regression analysis are in Chapter Five.

The computational framework draws heavily from validated modules in the Matlab Statistics Toolbox. The rest of this chapter provides a self-contained, if basic, description of the underlying mathematics.³⁶

The Survival Function and Data Censoring

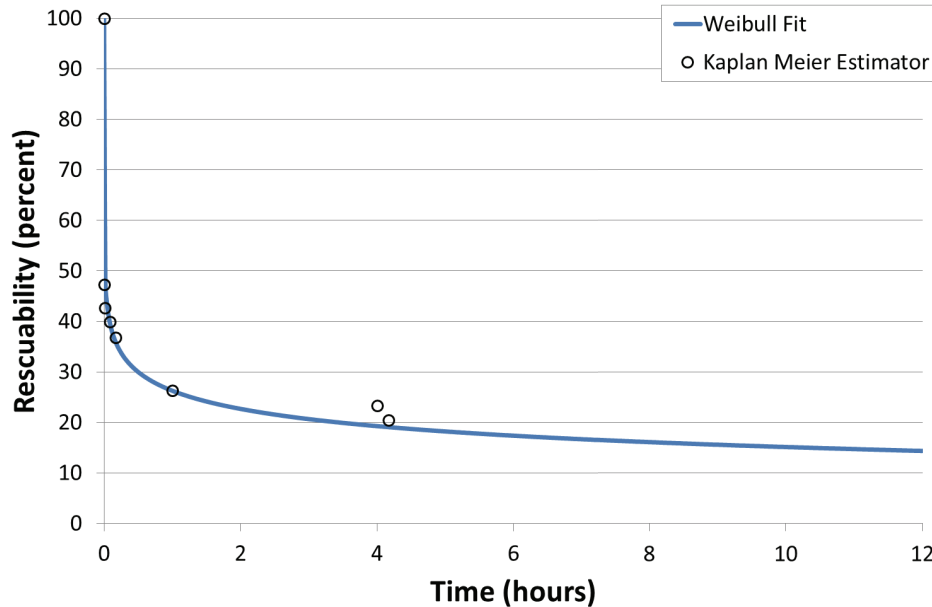
In survival analysis, the random variable is the time of occurrence of an event of interest T . Specifically, the complementary cumulative density function (CDF) of interest, termed the *survival function*, is defined as the probability that an event will happen after time t :

$$S(t) = \Pr\{T \geq t\}$$

The survival function can, as the name suggests, be used to describe patient survival and mortality. It can also be used to describe the probability of failure of manufactured devices. In this context, the same function is sometimes referred to as the *reliability function*. In the present application, where the events of interest are personnel capture and fatality, the function describes the probability of a successful rescue as a function of time, or the *rescuability function*. An example of a parametric rescuability function is shown in Figure 3.3.

³⁶ For more comprehensive discussions of survival analysis, see D. Hosmer, S. Lemeshow, and S. May, *Applied Survival Analysis: Regression Modeling of Time to Event Data*, 2nd ed., New York: John Wiley and Sons Inc., 2008; and David G. Kleibbaum, and Mitchell Klein, *Survival Analysis: A Self-Learning Text*, New York: Springer-Verlag, 1996.

Figure 3.3. Example Parametric Rescuability Function



The survival function can be estimated using empirical population data. Here, an important consideration is the treatment of *censored data*, which arises when the event of interest occurs outside of the predetermined time frame of the study. An example of censored data in the medical domain is if contact with a patient is lost in the course of a drug study. If the event of interest is mortality, then all that is known is that the patient in question survived to the last known observation. As the patient exits the study prematurely, the observation of outcomes is incomplete, and the associated data point becomes “right censored.” While the nature of this example is different than PR—right censoring occurs when a patient exits a study prematurely, as opposed to a downed person being rescued—it does illustrate the mathematical concept of incomplete observations.

The way to deal with censored data is to include the data point for as long as possible and then remove it from the study when the survival data are no longer available. This is illustrated by example in the so-called life table shown in Table 3.1.

Table 3.1. Section of a Life Table to Demonstrate Right Censoring

Time (hrs)	Rescuable	Killed or Captured	Rescued	Survived the Interval	Rescuability (interval)	Rescuability
0:00	150	0	0	150	150/150 (100%)	100%
0:00	150	79	0	71	71/150 (53%)	53%
0:01	71	7	1	64	64/71 (90%)	47%
0:05	63	4	8	59	59/63 (94%)	44%
0:10	51	4	0	47	47/51 (92%)	41%
0:15	47	0	2	47	47/47 (100%)	41%
0:25	45	0	16	45	45/45 (100%)	41%
0:30	29	0	7	29	29/29 (100%)	41%
0:34	22	0	1	22	22/22 (100%)	41%
1:00	21	6	2	15	15/21 (70%)	29%
2:00	13	0	1	13	13/13 (100%)	29%
3:00	12	0	1	12	12/12 (100%)	29%

A life table, such as the one shown in Table 3.1, records statistical information about survival over time. It is the basis of a number of empirical estimators of the survival function. Indeed, given the time of the events, the values in the last column represent the Kaplan Meier estimator of the survival function. In this analysis, we did not directly use the Kaplan Meier estimator or the life table. The life table concept is, however, a convenient way to illustrate the proper treatment of censored data.

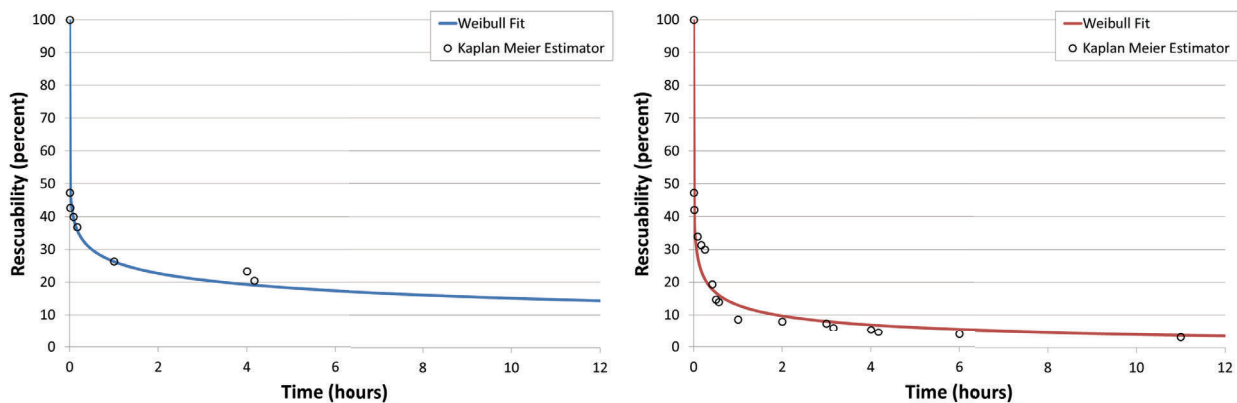
The first column of Table 3.1 records the time interval between recorded downed personnel events, while the second column shows the number of rescuable personnel remaining at the start of a given time interval. The next two columns record the number of personnel killed, captured, and rescued (i.e., censored) over each time interval. The “Survived the Interval” column computes the survival rate at the end of the interval by subtracting the number of IP killed or captured in the interval from the value in the “Rescuable” column. The interval survival rate is the ratio between the “Survived the Interval” and “Rescuable” columns. The last column is the cumulative distribution (product of all previous interval survival rates) and approximates the survival function.

Consider the eight IP rescued at approximately 5 minutes (highlighted in green in Table 3.1). Since the rescued IP survived beyond the interval, they do not impact the interval survival field, highlighted in red. To properly censor the data, the eight IPs are removed from the “Rescuable” field of the next interval, highlighted in blue. The smaller pool of IP is reflected in the smaller denominator for all subsequent interval survival estimates (highlighted in orange). This effectively increases the interval probability of survival, which in turn increases the cumulative survival, highlighted in purple.

The censor mechanism captures the fact that a rescued person may have continued to survive in isolation and may have been rescued at a later time. Not properly treating the right-censored data would lead to an overly pessimistic characterization of the rescuability function.

Figure 3.4 illustrates this idea graphically using two survival curves derived from the same data—one with proper data censoring and the other without. In the incorrect analysis, we simply considered rescue, capture, or being killed as the end state, with no compensation for the censoring mechanism. Specifically, this incorrect construct supposes that a person that is rescued would not have survived longer had the rescue not occurred. Note that this incorrect construct is equivalent to simply taking all of the times people were isolated (until killed, captured, or rescued) and simply fitting a curve through the data. Observe that, at 4 hours, the probability of survival is over 20 percent in the correctly censored data as opposed to only 8 percent in the incorrect formulation. As previously discussed, our research advances previous research done on this topic by properly accounting for censoring.

Figure 3.4. Comparison of Censored (left) and Uncensored (right) Rescuability Functions



The Parametric Rescuability Function

The rescuability function can be defined in parametric and nonparametric terms. Parametric models, as the name suggests, assume an underlying functional form for the probability distribution and fit data to that distribution. A nonparametric function, such as the Kaplan Meier estimator mentioned earlier, makes no assumptions about the underlying probability distribution.

The Weibull distribution is a commonly used parametric distribution to model the survival curve. It is a generalized, two-parameter extension of the exponential distribution:

$$S(x, k, \lambda) = e^{-(x/\lambda)^k}$$

The Weibull model allows for accelerations in the time to event, which add richness to the representation of the survival function. The functional values of the Weibull complementary

CDF start at 1 and approach 0. This property is convenient for survival analysis. We fit empirical survival data using the Weibull distribution to obtain the λ and k coefficients.

An advantage of the Weibull distribution, and parametric survival models in general, is the potential to estimate the survival function with limited data. This makes the Weibull distribution appropriate in situations where the sampling frequency is irregular and time precision limited. Unlike a laboratory experiment on a test specimen, it is difficult to consistently, precisely, and frequently observe the duration of a CSAR event. In recent conflicts, there have also been relatively few combat rescue events. When the data is limited and sampling coarse, an empirical distribution, such as the Kaplan Meier estimator,³⁷ is not likely to converge to the true survival curve. Finally, the Weibull model has the added benefit of being differentiable. This allows us to conveniently examine the rates of the change of rescuability over time.

Regression Analysis

In addition to characterizing the overall survival curves, it is often useful to quantify the effects of different variables on survival. A medical study might measure the relative effects of treatments, age, sex, and other factors on patient outcomes. In the context of CSAR, we want to quantify important factors that can increase or decrease aircrew rescuability. These may include factors such as the cause of the incident, the ground picture, the weather, or terrain features. To this end, we applied multivariate regression to model survival as a function of time and the predictors x :

$$S = f(x, t)$$

In this research, we used the popular Cox Proportional Hazard Model for the regression.³⁸ The basic approach is to divide the risk among different predictors. The *hazard function* is an alternative way of looking at survival statistics. It is defined as the instantaneous rate of occurrence of the event, conditioned on the event having not occurred previously:

$$\lambda(t) = \lim_{dt \rightarrow 0} \frac{\Pr\{t < T \leq t + dt \mid T \geq t\}}{dt}$$

The hazard function is related to the survival function by integration:

$$S(t) = e^{-\int_0^t \lambda(\tau) d\tau} = e^{-\Lambda(t)}$$

³⁷ Hosmer, Lemeshow, and May, 2008.

³⁸ Hosmer, Lemeshow, and May, 2008.

Here, $\Lambda(t)$ is the *cumulative hazard function*, which corresponds to the expected times that the event of interest should have occurred by time t . In other words, the cumulative hazard measures the instantaneous risk to the population.

The regression is based on a proportional hazard model of the following form:

$$\lambda(t | x) = \lambda_0(t)e^{x'\beta}$$

where the baseline hazard $\lambda_0(t)$ is a function of time. The β coefficients terms, which correspond to the hazards, are assumed to be time-invariant. This means that the relative risks posed by different variables (predictors) are in constant ratio with one another over time. Depending on the nature of the predictors, the assumption of constant hazard may be overly simplistic. More investigation is needed to qualify this assumption. Integrating the hazard rate we obtain the proportional hazard survival function:

$$S(t | x) = S_0(t)e^{-x'\beta}$$

If the baseline hazard $\lambda_0(t)$ is left unspecified (i.e. nonparametric), then the model represents the Cox Proportional Hazard Model. The regression resolves the baseline nonparametric survival function S_0 and the parametric β coefficients. Once the coefficients and the baseline function are resolved, we can generate different survival curves as functions of predictor values.

Individual survival curves for different conflicts, as well as combined survival curves produced using the Weibull estimator can be found in Chapter Four. Cox proportional hazard results and comparison of Weibull curves are presented in Chapter Five.

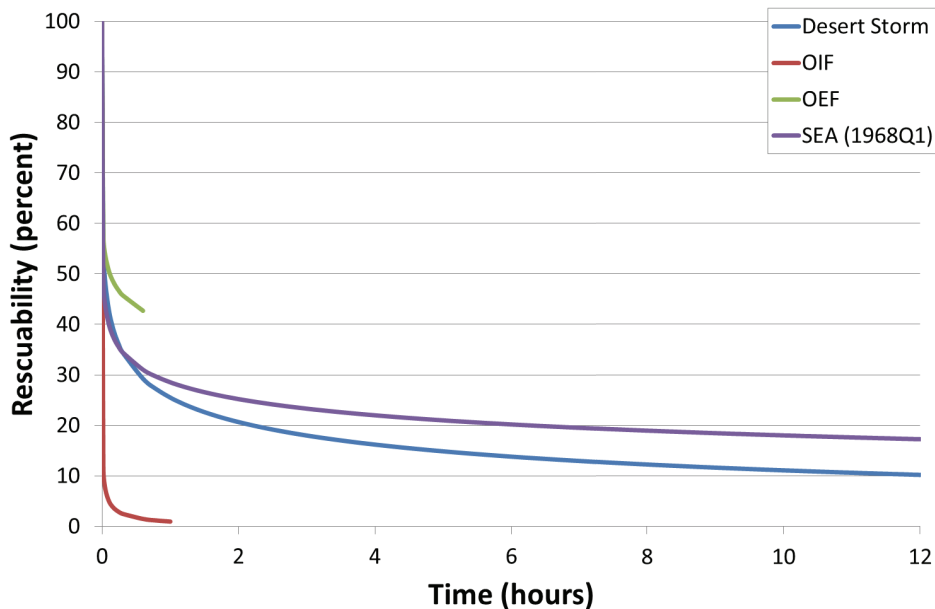
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4. Rescuability Curves by Conflict

We analyzed the data described in Chapter Two from two perspectives. The first was by conflict, while the second was by the characteristics that were significantly associated with rescuability. This chapter explores the rescuability curves by conflict. We conducted this analysis to examine how the rescuability curve has or has not changed over time. This insight is important, because we assumed that any curves derived from historical data are also relevant for future conflicts. While similarities do not guarantee that the past is also a prologue, it does suggest that such continuity over time is at least plausible. To the extent that there are differences between campaigns, it speaks to the complexity and uniqueness of each given campaign, and that no past conflict will accurately reflect future conflict.

We constructed conflict-specific and combined rescuability functions, shown in Figure 4.1, using the Weibull parametric estimator discussed in Chapter Three. Note that both the OIF and OEF data are truncated, since the datasets had no data beyond about one hour.

Figure 4.1. Individual Conflict Rescuability Functions



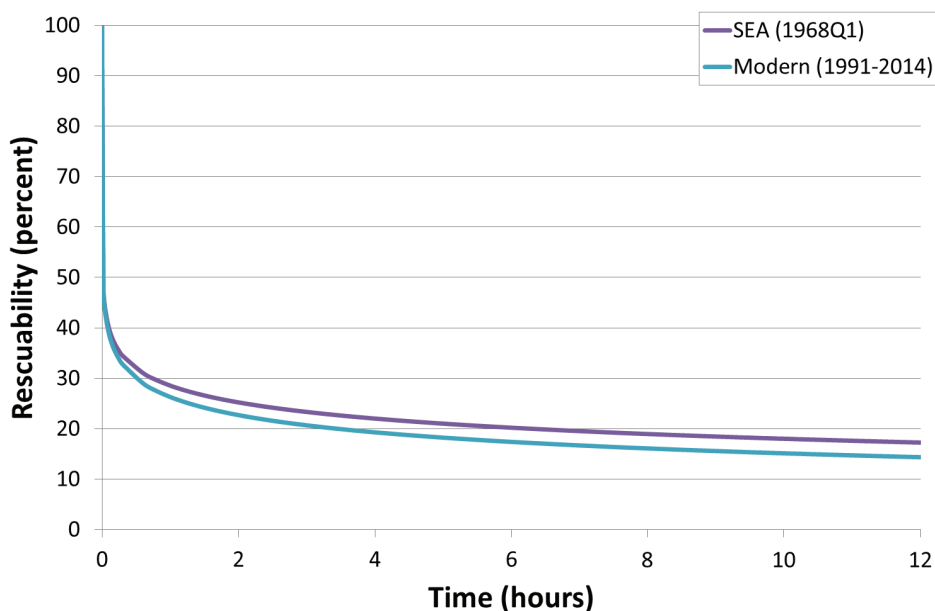
The SEA and Desert Storm survival curves share similar initial characteristics and rescuability over time: 50–60 percent of the downed personnel were immediately killed or captured, followed by a long tail to 12 hours and beyond. The data also suggest that downed personnel had a noticeably higher probability of being rescued in OEF (at least based on the

available SEA data). This could be because of the more localized nature of individual engagements in OEF and/or be a consequence of the limited number of shootdowns.

The OIF survival curve shows a more distinct shape, with a substantially lower initial survival rate of only 5 percent. This occurred because (1) there were very few events and (2) a single British C-130 with the loss of everyone onboard dominated the rescuability statistics. Unsurprisingly, in situations where data were limited, the characters of the rescuability curves are highly sensitive to individual aircraft losses, especially for aircraft with passengers. These sensitivities reinforce our goal of deriving average rescuability curves across conflicts in our data to aid in defense planning, as opposed to predicting the outcome of a particular conflict.

There were too few events in Bosnia, Kosovo, and Libya to generate individually meaningful survival curves. In addition, since the OIF and OEF curves do not extend beyond an hour, we chose to create a single modern-conflict set (composed of Desert Storm, Bosnia, Kosovo, OEF, OIF, and Libya). We then compared the modern and SEA subsets, the results of which are shown in Figure 4.2. We note here that the data on modern conflicts is largely driven by Desert Storm, since most observations come from that conflict.

Figure 4.2. Comparison of Modern Conflicts and Southeast Asia Rescuability Curves



Despite significant differences in the nature of the conflicts and the prevailing technologies, the SEA and modern conflict curves in Figure 4.2 look remarkably similar. Some 60 percent of downings resulted in immediate fatality or capture. Most events cluster in the first hour. The tails of the distributions are also similar.

This similarity may be accidental. The SEA data, as discussed in Chapter Two, represent only a quarterly snapshot of search and rescue activity in 1968, which may not be representative

of the SEA conflict as a whole. The shapes of curves can also be sensitive to individual downing events, particularly if the downed aircraft carried large numbers of passengers. Moreover, the individual modern conflict survival curves in Figure 4.1 show greater diversity across conflicts.

However, both the modern and SEA survival functions are based on significant numbers of data points. The diversity in the shape of the individual modern survival curves in Figure 4.1 could be a function of the paucity of data, and the consequent sensitivity of the statistics to the outcome of even individual aircraft losses. The agreement in the modern and SEA curves could therefore point to possible invariants in search and rescue across different conflicts.

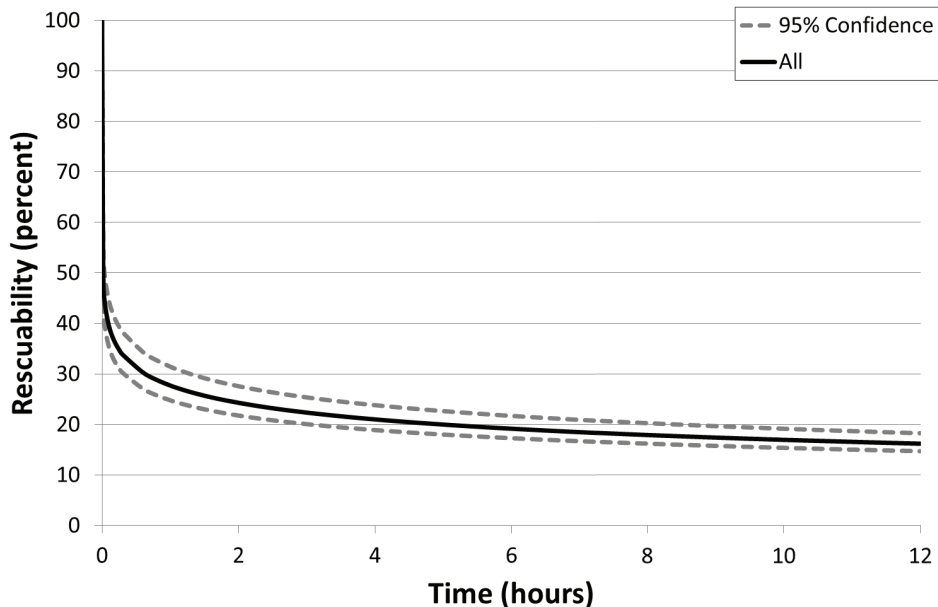
First, although the SEA and modern conflicts are separated by one to two generations of aircraft technology, the basic configuration, material, and energetics of military aircraft—and hence their vulnerabilities and failure mechanisms—remain broadly similar. Moreover, despite changes in technology, physics dictates that an efficient aircraft can only be designed with a finite level of pilot survivability, which is at all times subject to trade-offs against cost, performance, and operational effectiveness. So while U.S. tactics and countermeasures against SAMs and other threats have improved, even disproportionately so against recent adversaries, the underlying aircraft failure mechanisms and pilot vulnerability *after the aircraft is fatally hit* may have remained largely the same. One might argue that special platforms like the A-10 represent exceptions to this norm, as they are designed to maximize battlefield survivability and damage tolerance. But the A-10 is also tasked with arguably riskier close support missions, such that the effective risk to the pilot may well be analogous to more fragile, high-performance fighters.

Second, for the pilot who has made it to ground in the different conflicts, he or she still faces the same basic mechanisms of trying to evade capture. Technologies for pilot camouflage and adversary surveillance have not fundamentally changed between SEA and recent conflicts. The visibility and operation of the parachute is also largely the same. And the maximum speed at which rescue forces can arrive on scene remains—as always—limited by physics, organization, communication, and intelligence.

Physics limits the speed of rescue platforms, especially when it is considering the need for extraction compatibility such as vertical and/or short take-off and landing and disk loading. Organization constraints add to the time it takes for the information to be processed, disseminated, and for a decision to be made, transmuted, and implemented. Part of this is the communication time that is needed to establish one- and two-way communications, specifically considering the likelihood of reduced bandwidth and communication efficiency in combat conditions and under interference and jamming. Finally, intelligence gaps lead to uncertainty in the IP's situation and position as well as the overall ground and air picture.

The similarities in the modern and SEA data suggest that we can potentially pool the data and look at the combined survival curve of all of our combat rescues data. The combined survival function, with uncertainty bounds, is shown in Figure 4.3.

Figure 4.3. Combined Rescuability Curve Based on All Available Data, with Confidence Bounds



It should be emphasized that the utility of any empirically derived survival curves is limited when extrapolating for survival in future conflicts. Past history may not be a good predictor of future performance, especially if the natures of the conflicts differ significantly. That said, the similarity between the SEA data and combined modern conflict survival curves suggest that some measurable invariants may exist. Including additional SEA data to build a more representative SEA survival curve is a logical next step to test the invariance of the survival curve. While still noting that the variance that does exist between conflicts suggests that these results represent reasonable planning assumptions on average, they are not necessarily good predictors for any particular conflict unless future conflicts will closely mirror past ones.

5. Rescuability Curves as Functions of Predictors

This chapter presents the parametric analysis. This analytic approach is important because it allowed us to characterize how certain exogenous variables influence the rescuability timeline. This is important to analyze options for improving the rescue timeline in a context that is most relevant to the problem. For example, looking at night-vision goggles would only make sense in the context of the nighttime survival timeline. Similarly, ejection seat capabilities would only make sense in the context of aircraft that have ejection seats. Finally, terrain and the cover and concealment it affords are key and could indicate that different materiel and non-materiel solutions are needed to deal with isolation in open terrain.

Predictors for Rescuability

The conflict-specific and combined survival curves presented in Chapter Four are useful. A complementary line of inquiry would examine the influence of different variables on downed personnel rescuability. In this chapter, we apply the Cox Proportional Hazard regression discussed in Chapter Three to quantify the effects of different variables on rescuability.

As discussed in Chapter Two, the researchers collected data on 33 different variables for each downed personnel event. The variables include, among other things, the cause of downing, the type of aircraft involved, whether the event occurred during the day or at night, the extent of injury suffered by the downed personnel, and whether the downed personnel established communications with friendly forces.

The first step is to select meaningful predictors from this large pool of variables. One important selection criterion is independence: the predictors should be independent (exogenous) variables whose states are well defined at the start of the event, rather than dependent variables that arise as the event progresses. In the context of combat rescue, the start time is when the aircraft suffers the fatal breakdown or combat damage.

For example, the availability of an ejection seat can affect the initial survival of pilots. It is also an independent variable whose state (aircraft has ejection seat or not) is well defined at the start of the event. Contrast this variable with one such as pilot injury, which is determined by the downing process itself. The injury is dependent on the cause and process of downing, as well as the situation on the ground. Endogenous variables are excluded from the predictor set because their effects ultimately trace their origins to other, independent variables. Specifically, the set of predictors is limited to those items that are knowable prior to the actual downing incident.

Variables that primarily enable rescue rather than survival are also excluded from this analysis to conform to the scope of the research.³⁹ An example is a variable that describes the presence of a reliable means of two-way communication between the IP and friendly forces. This parameter, while important for the rescue process, has less of influence on the survival of the downed personnel on the ground. The effect of communication equipment on rescue performance should be investigated in future research.

After isolating the independent variables, we selected the regression predictors based on the four components of the Department of Defense’s SERE program.⁴⁰ Since this study does not consider events subsequent to capture by enemies, only the variables that relate to survival and evasion are relevant. These identified predictors are listed in Table 5.1.

Table 5.1. Candidate Predictors of Survival and Evasion

	Predictor	Description
Survive	Cause of downing	SAM, AAA, Mechanical etc.
	Ejection capability	Does the aircraft have ejection seat(s)
Evade	Altitude	At which hit or malfunction occurs
	Daylight or night	At the start of the event
	Terrain for hiding	Afghanistan and Iraq assumed not easy to hide in
	Water or land	Where the pilot came down
	Ground picture	The "laydown" of friendly and enemy forces

NOTE: The predictors highlighted in red are difficult to measure and isolate. The predictor highlighted in orange is quantifiable, but not available for the present research.

Many of the predictors listed in Table 5.1 actually fall into multiple SERE categories. The ground picture, altitude, day or night, and water or land variables may affect survival as much as they do evasion. Since the SERE framework is used here as a heuristic to help identify potentially significant predictors, the classification of variables into single SERE categories is not essential.

In the survive category, we included the cause of downing and the ejection capability of the aircraft. Both are independent variables that relate to the survivability of the downed personnel in the first minutes of the event. Ejection capability comes directly from the recorded aircraft type. The causes of downing for each event come from official reports and other sources.

³⁹ Here, the term *survival* is used, to emphasize that the rescuability window is the window of time from isolation to when the person, absent rescue, would otherwise be killed or captured. Many factors, beyond the scope of this research, will affect whether rescue forces can and will arrive within this window or not.

⁴⁰ U.S. Department of the Air Force, *Operations Support: Survival, Evasion, Resistance, and Escape (SERE) Program*, Air Force Instruction 16-1301, September 6, 2006.

We identified five variables in the evade category. First, the altitude of the shutdown or malfunction is a proxy for the energy left to maneuver (particularly in the case of engine failures) and, more important, the time for the pilot to react, make decisions, and control the final flight path. Both have implications for the downed persons' proximity to enemy and friendly forces and his or her ability to evade capture. In addition, a higher-altitude ejection allows crews to transmit their descent, as well as observe and possibly react to the ground situation. Second, whether the aircraft is downed in the day or night affects the downed person's immediate options to go to ground and evade capture. The values for the time of the downing are reconstructed from search and rescue reports.

Third, similar to the time of the day, the terrain also affects the downed personnel's ability to evade. Terrain cover varies widely by location. The first level classification used in the present analysis is *coarse*. We simply assumed that the terrain in Iraq and Afghanistan, on balance, do not provide good places to go to ground and hide. The terrain in Libya, Bosnia, Kosovo, and SEA, on the other hand, were assumed to support hiding. The authors acknowledge that this classification scheme represents a gross oversimplification of the complexities of local terrain. Future work should attempt to reconstruct the terrain features and vegetation on the ground.

Fourth, the over-water variable tracks the risks associated with ditching in water. It is generally recognized that ditching in water is preferred, as it moves the downed personnel away from enemy forces on land. However, recent conflicts (from Desert Storm to present) have few overwater shutdowns. Consequently, the water survival results were based almost exclusively on 30 over-water Vietnam-era events. The research team considered two alternative datasets and models to expand and supplement the water survival data. They are the UK National Immersion Incident Survey (UKNIIS) dataset and the U.S. Coast Guard Probability of Survival Decision Aid (PSDA) thermodynamics model.⁴¹ Neither tool is based on CSAR data. An implicit assumption in using these data is that the key stressor in immersion situations is the marine environment, not the enemy. However, after substantial analysis, particularly with the UKNIIS dataset, a determination was made that these additional datasets are not collected or structured to support our probabilistic description of survival over time. The details of the UKNIIS dataset and Coast Guard outputs are included for completeness in Appendix A.

Finally, the ground picture is a broad category of variables that defines the laydown of opposing and friendly forces close to where the IP are located. If the downed person falls close to enemy territory, we might expect him or her to have a higher chance of being immediately captured. Conversely, friendly ground forces or overhead support, even if they are unable to

⁴¹ Elizabeth McCormack, Chris A. Turner, and Michael J. Tipton, "The Prediction of Survival Time in Water," University of Portsmouth, UK, undated; M. Tipton, E. McCormack, and A. Turner, "The UK National Immersion Incident Survey (UKNIIS) Revisited," 2012; Xiaojiang Xu, Mitesh Amin, and William R. Santee, *Probability of Survival Decision Aid (PSDA)*, Natick, Mass.: Army Research Institute of Environmental Medicine, No. USARIEM Technical Report T08-05, March 2008.

facilitate a rapid rescue, may be able to suppress the enemy's ability to search and locate the downed person.

Of course, not all of the predictors listed in Table 5.1 are quantifiable. Variables that are likely relevant but whose value or effects cannot be quantified are highlighted in red. Quantifiable variables that are not available in the current study are highlighted in orange.

The ground picture variable is complex and difficult to characterize. It would have to capture, among other things, the relative proximity of friendly and opposing forces to the downed personnel; the tactics, doctrine, and morale of the forces engaged; the relative mobility, ISR, and C2 capabilities of friendly and enemy forces; and all of the interactions in between. The research team collected data on some ground picture variables, such as proximity to friendly and enemy forces. But the picture remains far from complete or descriptive. Moreover, even if we were able to formulate a quantitative model of the ground picture, the combat environment is not a controlled experiment; the fog of war occludes the precise knowledge of friendly and enemy laydowns. Hence the ground picture—beyond just being difficult to model—may be fundamentally unknowable. Finally, even if the ground picture can be characterized and learned, the laydown of future conflicts will likely be substantially different, with a multitude of new variables and dynamics. This brings into question the utility of an empirical model of the ground picture in predictive applications. For all of these reasons, the ground picture was excluded from the regression.

The cause of downing variable was excluded for similar reasons. While the immediate causes of aircraft loss are generally known, their effects on pilot and crew survival are highly contextual to the conflict and to the aforementioned unquantifiable ground picture. For example, being hit by AAA or a SAM may have implications for pilot survival, but operational, technical, and tactical parameters of these weapon systems and their employment vary across conflicts. For example, AAA batteries in Desert Storm tended to be low-caliber weapons with a high rate of fire, effective at low altitude. AAAs in Vietnam included higher-caliber weapons with a low rate of fire that could be effective at much higher altitudes. The cause of downing variable lacks granularity when taken out of context and was consequently excluded from the regression.

Finally, while the altitude of the shutdown or failure is important, the research team was not able to obtain accurate data for this predictor. It was originally thought that the cause of downing could serve as a proxy for altitude. This is true in certain cases, where we knew with confidence that the aircraft was brought down by short-range systems: low-caliber AAA, small arms, and MANPADs. However, in many cases the cause of downing was not known with the necessary degree of precision. Little can be said about air defense systems that can operate over a wide range of altitude bands. Future work should attempt to reconstruct this potentially important predictor of the downed personnel's ability to evade. The four final regression variables are summarized in Table 5.2.

Table 5.2. Regression Predictors

	Predictor	Description
Survive	Ejection capability	Does the aircraft have ejection seat(s)
Evade	Daylight or night	At the start of the event
	Terrain for hiding	Afghanistan and Iraq assumed not easy to hide in
	Water or land	Where the pilot came down

Semiparametric Models Assuming Proportional Hazards

We now apply the Cox Proportional Hazard Regression discussed in Chapter Three to fit the four predictors identified in Table 5.2. Note that the regression operates on the combined dataset of all conflict data. The implicit assumption is that the predictors capture invariant dynamics in combat rescue across these very different conflicts. Recall that the goal of the regression analysis is to describe the survival function in terms of time and the vector of predictors x .

$$S = f(x, t)$$

Recall that the proportional hazard model has the following form:

$$S(t | x) = S_0(t)e^{x\beta}$$

The outcomes of interest are the β coefficients discussed in Chapter Three, which relate the effects of different predictors. The relative effects of the variables are more intuitively expressed as hazard ratios (HRs):

$$HR = e^{\beta}$$

A hazard ratio of unity indicates that the variable in question has a neutral effect on rescuability. A hazard ratio greater than 1.0 indicates increased risk. A hazard ratio smaller than 1.0 indicates reduced risk. As described in Chapter Three, the hazard ratios are assumed to be time invariant.

The hazard ratios from the regression using all four variables are shown in Table 5.3. As one might expect, daylight appears to increase risk. The presence of ejection seats and terrain that supports hiding decrease risk. The data also show that the ejection seat has a greater effect on survival than the other variables.

Table 5.3. Predictor Removal Process

Step 1	Condition #	10.5
Predictor	Hazard Ratio	P-value
Under daylight	1.287	0.064
Can eject	0.664	0.001
Over water	1.068	0.699
Can hide	0.864	0.255

Also shown in the table is the condition number of the predictor set. The condition number, computed based on the 2-norm of the matrix of predictors, is an indirect measure of multicollinearity. A high condition number (generally held to be greater than 30 for scaled predictor values) indicates that some of the variables may be strongly co-linear and therefore highly correlated.⁴² This correlation is generally undesirable. If the variables are co-linear then it is not clear which independent variable is responsible for what outcome. Mathematically, this means that the coefficients of the regression tend to be highly sensitive to small changes in the training data. Fortunately, in this case, the predictors in Table 5.3 have a low condition number, which indicates that the predictors are independent.

Table 5.3 also shows the P-value associated with each of the predictors. The P-value is a commonly used estimate of statistical significance.⁴³ Small P-values provide evidence against the null hypothesis (predictor has no effect), which in turn means that the predictor is likely to be significant. By convention, we accept that a small P-value (less than 0.10) implies that a predictor is significant. It should be noted that this commonly used significance threshold is evidentiary, not definitive. The limit is arguably an arbitrary one. Hence the P-test should not be accepted as a conclusive measure of significance. Rather, it is a heuristic to highlight interesting parameters. For this research, we used the conventional value of 0.10 to define significance. However, since the test is not definitive, intermediate P-values may be retained on a case-by-case basis.

A common approach in multivariate regression is to build models successively to test the statistical significance of the predictors, and remove insignificant ones from the regression. The goal is to build the simplest model described by statistically significant predictors. A simple model can reduce over-fitting and the sensitivity of the data to uncertainty and noise. When data fields are missing, using fewer predictors also enables us to retain more data points.

Based on the P-value criterion, we removed the over-water predictor, which (as shown in Table 5.3) has the largest P-value: nearly 0.7. To continue the stepwise regression, we refit the

⁴² Hosmer, Lemeshow, and May, 2008.

⁴³ Hosmer, Lemeshow and May, 2008.

model using the remaining three predictors. The new model hazard ratios and statistics are shown in Table 5.4.

Table 5.4. Results of a Semiparametric Cox Model Following the Predictor Removal Process

Step 2	Condition # 6.9		
Predictor	Hazard Ratio	P-value	Δ Hazard
Under daylight	1.287	0.064	0%
Can eject	0.664	0.001	0%
Can hide	0.864	0.255	0%

The P-values of the daylight and ejection capability show that both variables remain significant. The ability to hide in the terrain is less significant, with an intermediate P-value of 0.255. This reduced statistical significance could reflect the previously discussed lack of granularity in the ability to hide field.⁴⁴ The variable itself may still be important. The terrain cover variable is retained for this reason.

The last column in Table 5.4 shows the relative change of the hazard ratio from one model to the next. In this case, removing the insignificant predictor (over water) had essentially no effect on the hazard ratios. A commonly used heuristic in survival analysis is that the removal of an insignificant predictor should not drastically change the model; the common metric is that the removal of a predictor should not change any hazard ratio by more than 10 percent.⁴⁵ This criterion was met, giving us more confidence that the over-water predictor can be removed.

Semiparametric Models Allowing for Nonproportional Hazards

The previous section presented the estimated hazard associated with three key predictors, and assumed that these hazards are proportional in the sense that the hazard ratios are constant over time. The proportional hazard model is useful for two reasons. First, it is easy to interpret. Second, because our data is sparse at later times, it avoids the problem of over-fitting. However, we know intuitively that some of these variables have effects that change over time. For example, daytime or nighttime is a transient state, so the benefit of being downed in darkness may fade as the sun rises. Similarly, ejection seats likely offer the greatest benefit in the first few minutes, while their impact later would be expected to be null. In contrast, being downed in an environment that supports hiding may have more sustained benefits that are constant over time.

⁴⁴ As will be seen, the ability to hide has slightly more significance when used as part of a time-varying model.

⁴⁵ Hosmer, Lemeshow and May, 2008.

To relax the proportionality assumption, we introduced interactions between the three predictors (daylight, ejection seats, and ability to hide) and functions of time. This approach is also commonly used to test whether the proportionality assumption is correct.⁴⁶ If the hazards are indeed proportional, there should be no interaction effect between the covariates and time, and the coefficients on the interaction terms should not be statistically insignificant. In other words, if an added interaction variable gives a significant coefficient, this should be interpreted as evidence that the proportionality assumption for that covariate may not be valid.

We explored two versions of the interactions with time and found mixed results. First, we estimated a Cox model incorporating interaction effects between the covariates and time (i.e., using linear functions of time). This model produced no evidence of significant time-interaction terms for all three covariates, and therefore supported the proportionality assumption. Second, we estimated a Cox model incorporating interaction effects between the covariates and a logarithmic transformation of time. This model, by contrast, produced coefficients on the $\log(\text{time})$ interactions with daylight and ability to hide that were statistically significant at the 5-percent level, and a coefficient on the $\log(\text{time})$ interaction with ejection seats that was statistically significant at the 10-percent level. It therefore rejected the proportionality assumption and provided evidence to suggest that the effects of the covariates might indeed vary over time. Given our concerns about over-fitting the sparse data available in the tails of the distribution, we were cautious to over-interpret the findings from the second approach, which may give too much weight to the observations in the tails. For example, the model results imply that ejection seats make downing incidents more hazardous over time and not less so, as would be expected. Despite the coefficients appearing significant, the unreasonableness of the findings bring into doubt the validity of this finding.

Given the sparseness of our data, particularly at later times, we were cautious not to read too much into any one model. The peculiar results of the model with $\log(\text{time})$ suggested that the more complicated model was over-fitting the data. Since there are practical reasons and some statistical evidence that the predictors might have time-varying effects, future research may want to consider a time-varying analysis that is well suited to the underlying data, especially if more data becomes available and, in particular, more data at longer durations. However, for this application, proportional hazard models proved as the superior choice—both due to the robustness of their results and to their relative simplicity.

Parametric Models

An alternative approach to the semiparametric Cox model, which left the baseline hazard function unspecified, is to apply a parametric model that assumes a particular shape for the

⁴⁶ John D. Kalbfleisch, Ross L. Prentice, *The Statistical Analysis of Failure Time Data*, New York, NY: Wiley, 1980.

hazard rate. The basic exponential model, for example, assumes a flat hazard rate. In other words, it assumes that the duration variable can be described by an exponential distribution. Other commonly applied distributions include Weibull and Gompertz models, which assume a monotonic hazard rate, and gamma, log-normal, and log-logistic models, which assume a non-monotonic or bell-shaped hazard rate.

There can be advantages to using parametric models. If one chooses the right shape for the hazard rate—if one characterizes the underlying time-dependency accurately—parameter estimates tend to be more precise than estimates from semiparametric models. If one picks the wrong parametric form, however, problems arise and estimates can be badly biased.

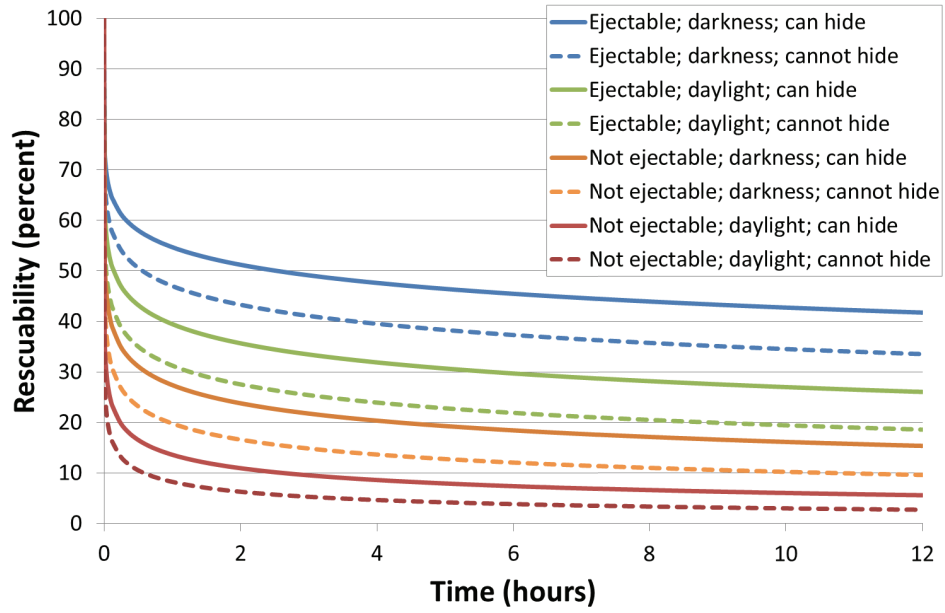
After running a variety of parametric models, we selected the Weibull specification because it exhibited good fit and was relatively simple to interpret. Table 5.5 reports the results of the parametric Weibull model and Figure 5.1 shows rescuability curves for all conflicts for all combinations of predictor values, generated using the Weibull model. Results are similar to those shown for the Cox proportional hazard regression models with time-invariant predictors with P-values that indicate statistically significant results, although the ability to hide is still marginally significant.

Table 5.5 Results from a Parametric Weibull Model

Predictor	Hazard Ratio	P-Value
Under daylight	1.541	0.003
Can eject	0.466	0.000
Can hide	0.799	0.095

The most hazardous rescuability curve in Figure 5.1 corresponds to the combination of daylight, no ejection seats, and terrain that does not support hiding. The least hazardous curve is defined by the opposite predictor values. The blue and red curves define the bounds of the rescuability curves for the predictors we selected.

Figure 5.1. Parametric Weibull Fit for Different Predictor Sets



6. Conclusions

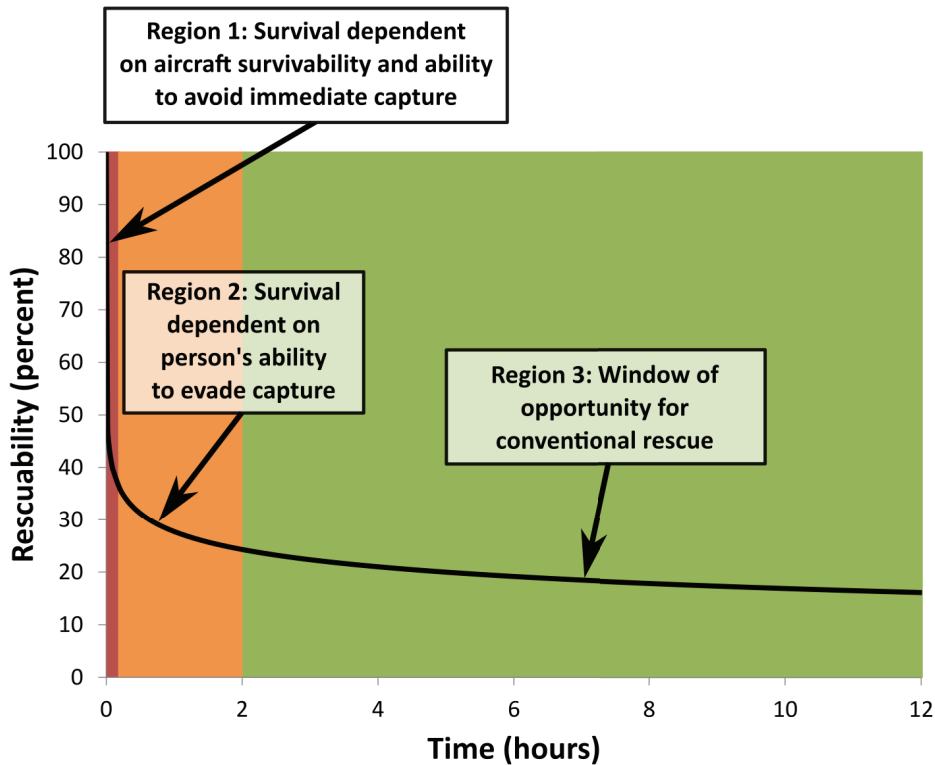
This research described in this report took an empirical approach to determining the timeline for rescuing downed personnel and understanding what parameters are associated with personnel rescuability. Its goal was to quantify the risk by estimating the likelihood of rescuing a downed pilot and passengers as a function of time and other factors. This approach would enable us to help the USAF make decisions about where to make investments in rescue platforms, communications gear, or survivability equipment. A key part of this analysis was to develop a rescuability timeline—that is, determination of the probability that an aircrew can be rescued as a function of time and other factors. We then identified the relevant factors and organized them according to the SERE categorization: survive, evade, resist, and escape. Because our focus was on rescue, we examined only the first two categories, into which we assigned four predictors:

- whether the aircraft had ejection seats
- whether the event took place in daylight or darkness
- whether the terrain provided cover and concealment
- whether the downing took place over water or land.

Findings

Results of the statistical analysis appear in Figure 4.3 and Figure 5.1. When we array the results of all the downings analyzed—from SEA to modern conflicts—we found three distinct temporal “regions.” These are shown in Figure 6.1.

Figure 6.1. Survivability, by Temporal Regions



Region one is very short, comprising just the first few moments. In this region, survival largely depends on the survivability of the aircraft and the aircrew's ability to avoid immediate capture. In this region, personnel have about a 50–50 chance of surviving and avoiding immediate capture.

Region two extends out to two hours. The precise time frame of region two is highly dependent on the nature of the conflict and on the rescue tactics, techniques, and procedures. The estimate of 2 hours is based roughly on the time for rescue forces to be alerted, a launch to be approved, and the helicopter to fly to the IP's location.⁴⁷ In Southeast Asia, rescues often happened much faster than this because of the dispersal of rescue assets and the fact that rescue helicopters were often on airborne alert. Air Force CSAR assets no longer generally plan to be on airborne alert in a major contingency operation. In Afghanistan, rescues were often made shortly after the incident, but often not by dedicated rescue forces. Rescues such as those seen in Afghanistan would likely not be possible in a major contingency operation. During this period of less than two hours, survivability of downed airmen quickly drops by over 10 percentage points.

After two hours, personnel have about one chance out of four of surviving and avoiding capture as they enter region three. The rescuability curve in this region is very flat, with the

⁴⁷ This roughly assumes current tactics, techniques, and procedures, as well as assets. Of course, radical changes in the CSAR force could alter this significantly.

crew's chance of surviving declining slowly to about one in five after twelve hours. This finding contradicts that shown notionally in the *Joint Personnel Recovery Requirements Analysis Report*.⁴⁸ Specifically, the data presented here show that the longer a person has avoided capture, the more likely he or she is to be able to continue to avoid capture.

Recommendations

Recommendations vary by time region. In the first region, the USAF should consider improvements in such areas as aircraft design for survivability and in ejection seat capabilities. In region two, there may exist options to drastically decrease rescue response times; however, if such improvements are unfeasible or cost-prohibitive, the USAF should consider reviewing and revising the tactics, techniques, and procedures in pilot and crew training in evasion and in equipment improvements. Another potential investment area would be improvement in air search and rescue equipment. For the final region, improvements that shortened air search and rescue times and improved communications and C2 could be considered.

While this research does not purport to identify which of these offer the most cost-effective solutions, it does provide a solid basis on which future decisions can be made. In particular, the effectiveness, in terms of the percentage of downed personnel rescued, can be quantified and weighed against the cost of such an investment. By quantifying the value of time, it is now possible to make investment decisions across the spectrum of PR capabilities. For example, a separate RAND project is currently using these results to analyze the cost-effectiveness of incorporating V-22s into the CSAR fleet. One consideration of this analysis is aircraft speed. The V-22 flies significantly faster, but costs significantly more, than HH-60s. However, the traditional CSAR timeline is on the flatter portion of the curve, which indicates the need to not only explore CSAR options but also the need to look for options to increase survivability during the first few hours of isolation, where the chance of a person remaining rescuable drops rapidly with time.

⁴⁸ See ACC, 2009, p. 24.

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A. Immersion Survival Data

To augment the limited overwater shutdown data, the research team attempted to build a separate historical water rescuability model using civilian immersion rescue data. The assumption was that the dominant stressor in water is the environment, rather than enemy action. This assumption allowed us to separate the rescuability function for over-water shutdowns into an initial airborne phase that considers mechanical failure and combat damage, and a subsequent immersed component (after splashdown).

Operational risk for the immersed phase can be very different from shutdowns over land. Much of the risk associated with immersion comes from exposure to cold water. Contemporary literature identifies four principle causes of loss of life under cold water:⁴⁹

1. *Cold shock* refers to the initial nervous system response to cold water: gasp reflex, hyperventilation, reduced lung capacity, and accelerated heart rate. Cold shock tends to occur in the first 3–5 minutes of immersion and could lead to drowning.
2. *Swimming failure* can follow cold shock if the victim becomes too exhausted to maintain efficient swimming posture. Swimming failure can even happen to experienced swimmers in cold water.
3. *Hypothermia* is the thermodynamic limit at which body temperature is too low to maintain basic metabolic functions. Hypothermia in cold water typically occurs after 30 minutes of immersion.
4. *Post-rescue collapse* can occur if the victim's blood pressure collapses when he or she is pulled from the water.

Of course, the availability of fresh water and food becomes relevant over longer periods (beyond 12 hours). For the initial stage of immersion, insulation suits and flotation aid can reduce the onset and intensity of cold shock and swimming failure. Insulation suits also render survival less dependent on sea state (particularly if the suits are not leaky). Air Force crews operating over cold water wear dry suit–equivalent gear to maximize the survival expectancy in the event of water ditching.

In the course of the research, it became clear that the available over-water rescue data were not sufficient to construct an accurate immersed survival function. The key issue was that existing data do not attempt to reconstruct the precise time of survival, but rather tended to focus on estimating the upper bound of survival time. While this may be consistent with the objectives of civilian over-water rescue, it renders the data unsuitable for assessing and balancing operational risk under combat conditions. In the end, the over-water survival function was not

⁴⁹ NATO, *Survival at Sea for Mariners, Aviators and Search and Rescue Personnel*, RTO-AG-HFM-152, February 2008.

included in the results because it tended to inflate the survivability of IP in water. The subsequent discussion of the immersion survival data sources is included for completeness.

Water Survival Data

The same analytical framework discussed in Chapter Three was used to produce the immersed survival curves. We also performed regression analysis on a number of variables related to water survival.

UK National Immersion Incident Survey (UKNIIS)

The immersed survival data source is the UK National Immersion Incident Survey (UKNIIS).⁵⁰ This survey is the largest and most comprehensive cold water survival dataset currently available, and catalogs 2,082 rescue events in the United Kingdom from 1991 to 2009. For each event, the survey records 33 variables. These include the estimated start time of immersion, the time of rescue, and the condition of the immersed persons at the time of rescue. Also recorded are the condition of the marine environment and the health, age, and gender of the immersed persons.

We applied the following filter to the UKNIIS data to focus on a subpopulation that is more representative of a downed USAF aircrew: (1) remove suicide attempts, (2) eliminate cases where the victim has two or more prior medical problems, and (3) eliminate age groups that do not match the typical airman. This left about 1,558 cases for the survival curve. Here, the time of interest is the duration of immersion. The event of interest is fatality and the censor event is rescue. The variables recorded in the UKNIIS allowed us to perform regression analysis using the same Cox Proportional Hazard model discussed in Chapter Six. We performed the same stepwise regression to isolate statistically significant predictors.

After initial analysis, it became clear that the UKNIIS dataset may not be suitable for probabilistic survival analysis. A critical limitation was that the UKNIIS does not attempt to reconstruct the time of fatalities. Instead, only the time of rescue or recovery (in the case of fatality) is recorded. Treating the time of recovery as the time of death is problematic—the body could be recovered long after death. This leads to an overly optimistic estimate of survival.

The UKNIIS also suffers from potential sampling biases. First, in the cases where the victim's body was not recovered, no record of the event was made. This again inflates the survival estimate. Second, reporting was not compulsory for immersion victims and their next of kin. This could lead to an under-reporting of fatalities if the next of kin is less likely to report the event.

In civilian search and rescue situations, where the operational risks do not include enemy action, over-estimating the survival time is less of a problem. Indeed, rescue services are often

⁵⁰ Tipton, McCormack, and Turner, 2012.

interested in determining the *maximum* search time before rescue should be called off. The UKNIIS data can provide such an estimate. In combat situations, where the operational risks are often greater and more uncertain, more-precise data are needed to construct a representative survival curve.

Probability of Survival Decision Aid

A second source of water survival data is the U.S. Army Research Institute of Environmental Medicine’s (USARIEM) Probability of Survival Decision Aid (PSDA).⁵¹ The PSDA includes a calibrated thermodynamic model that aims to predict the time of survival based on physics and physiology. The primary failure mechanisms modeled are hypothermia and dehydration. The model is sensitive to environmental conditions; clothing; floating aids; and the weight, age, and gender of the individual. The PSDA model is now used by the U.S. Coast Guard for rescue planning.⁵² USARIEM kindly executed the PSDA model for RAND with inputs that are representative of downed aircrew. The model inputs are summarized in Table A.1.

Table A.1. PSDA Model Input Values

Environment	Value	Notes
Air temperature	18 °C	
Water temperature	0 °C to 25 °C	
Humidity	75% relative humidity	
Wind speed	Calm day oceanic conditions	
Sea state	4 on the Douglas scale	
Immersion state	Default	head out, rest part of body in water
Physical Attributes		
Height	69"	
Body Weight	185 lbs	
Body fat percentage	Average male values	
Clothing Ensembles	Flight anti-exposure suit	CWU-74 type two layer aircrew dry suit (NOMEX, thermal liner and foam insert, neck seal)

The model outputs are summarized in Table A.2. The primary output of interest is the predicted survival time in hours as a function of the water temperature and the clothing

⁵¹ Xu, Amin, and Santee, 2008.

⁵² Xiaojiang Xu, Chris A. Turner, and William R. Santee, “Survival Time Prediction in Marine Environments,” *Journal of Thermal Biology*, Vol. 36, No. 6, August 2011.

insulation value (in units of clo). Typical flight anti-exposure suits are expected to have clo values of 0.69 to 1.0. The corresponding columns in Table A.2 are highlighted in blue.

Table A.2. PSDA Model Output Values

Water Temperature (°C)	Survival Time (hours)			
	0.0 clo	0.39 clo	0.69 clo	0.95 clo
0	3.6	8.3	13.4	17.6
2.5	6.1	9.6	15.7	20.4
5	7.4	11.3	18.6	22.7
7.5	8.9	13.6	21.4	26.6
10	10.9	16.7	24.8	32.9
12.5	13.9	20.5	31.2	43.5
14	16.5	22.5	37.2	54.2
15	18.6	24.6	43.1	71.7
16	21.1	27.4	53	120
17	23	31.5	120	
18	26	38.7		
19	40.5	120		
20	120			

Unfortunately, the deterministic outputs of the PSDA model are not compatible with the probabilistic survival analysis formulation. Moreover, the PSDA model, like the UKNIIS data, is also geared at informing the upper bound of immersed personnel survival. This again is incompatible with our need to produce an unbiased estimate of the survival function.

B. Definition of Factors Recorded for Isolation Events

In this appendix, we list and define each of the 33 factors recorded for isolation events.

Aircraft. The type of aircraft involved in the crash. Some examples are F-16, F-18, AC-130, etc.

Alone on Ground. Whether the downed personnel is alone or with somebody else on the ground. Downed personnel originating from a single-seat aircraft typically will be alone. If the aircraft can hold multiple people, and more than one successfully landed on the ground, they may not be alone. If multiple people eject from the same aircraft but are not able to meet up on the ground, they are considered to be alone on the ground.

Begin Sun. The state of the sun the moment the aircraft crashed. It can be either daylight or darkness.

CAS Mission. Indicates whether the aircraft was involved in a close air support mission or not.

Cause. Cause of the aircraft crash. Some examples are AAA, SAM, infrared, munition failure, pilot error, etc.

Communications. The degree of the ability of the downed personnel to communicate with rescue forces through electronic means. This can range from none, if there is no communication attempted; minimal, if the downed personnel can communicate only one way; and significant, if two-way communication between the downed personnel and rescue forces was established.

Conflict. The name of the conflict the downed personnel was involved in. Examples are Operation Desert Storm, Operation Enduring Freedom, etc.

Country. The country where the downed personnel was isolated. Examples are Iraq, Afghanistan, Libya, etc.

Date. The date the downed personnel became isolated.

Disposition of Population. The disposition of the general population in the area of conflict to U.S. forces and allies. U.S. military action in a nation does not necessarily mean that the host population is hostile to U.S. forces and allies. This can range from friendly, to neutral, to hostile.

Ejectable. Whether the aircraft had ejection seats.

Ejected. Whether the person ejected from the aircraft or not.

End Date. The date the downed personnel was rescued, captured, or killed.

End Local Time. The time the downed personnel was rescued, captured, or killed.

End State. The end state of the downed personnel. Examples are rescued, captured, or killed.

End Sun. The state of the sun when the downed personnel reached an end state. It can be either daylight or darkness.

Injury. The degree of injury sustained by the downed personnel. None indicates no injury, minimal indicates some injury but downed personnel is still mobile, and significant indicates impaired mobility, such as a broken leg.

Latitude. The latitude where the aircraft crashed.

Life Sustaining Resources. Whether the downed personnel had water or shelter to aid in survival or not.

Longitude. The longitude where the aircraft crashed.

Nearest City. The name of the city nearest to the crash location.

Proximity to Enemies. The distance from the downed personnel to enemy forces immediately after becoming isolated.

Proximity to Friendlies. The distance from the downed personnel to friendly forces immediately after becoming isolated.

Rescue Force. The aircraft involved in the rescue operation, if one were carried out. Examples are MH-53, HH-60, UH-60, etc.

Rescue Training. The level of rescue training of the downed personnel. Significant indicates that the downed personnel was able to successfully execute tactics to aid his or her rescue.

Minimal indicates that the downed personnel executed some tactics but not proficiently. None indicates that the downed personnel could not execute any rescue tactics.

Service. The service the downed personnel belonged to. Examples are USAF, USN, RAF, etc.

Single Seat. Whether the aircraft had only a single seat or not.

Start Local Time. The time the aircraft crashed.

Supporting Witness Nearby. Whether there were friendly forces or not, either in the air or on the ground, that witnessed the aircraft go down.

Terrain. The type of terrain, including vegetation, where the aircraft crashed. Examples include desert, mountain, water, etc.

Time to End State. The amount of time that elapsed between the beginning of isolation and reaching the end state.

Time to Initiate Rescue. The time it took from the moment the aircraft crashed to rescue assets taking off.

Weather. The weather at the time and location the crash occurred.

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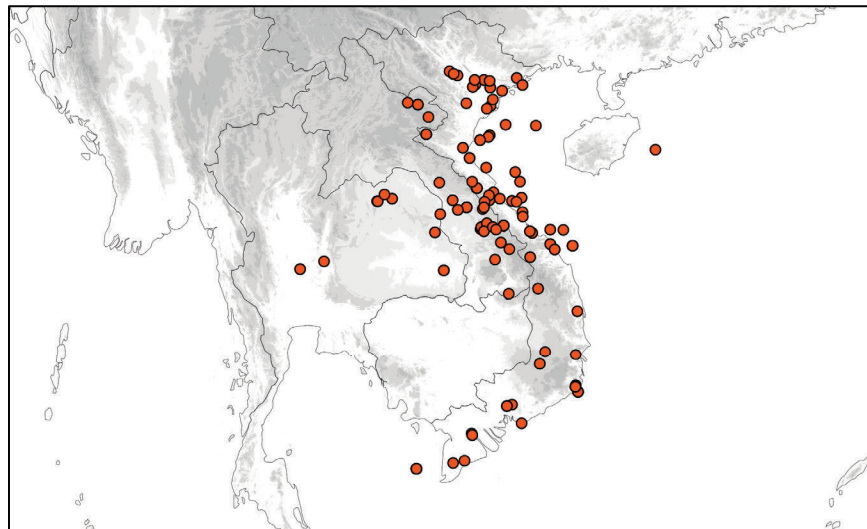
C. Short Description of Each Recorded Event

In this appendix, we provide a list of all events included in our analysis, a map indicating where the crashes occurred, and a short description for each crash.

Vietnam War

The primary source for events in the war in Southeast Asia was Christopher Hobson's book *Vietnam Air Losses*.⁵³ This was augmented by Air Rescue Reports compiled by the AFHRA and RCC logbooks maintained at JPAC.

Figure C.1. Map of the Locations of Fixed-Wing Aircraft Crashes in Southeast Asia, January–March 1968



1. January 1, 1968, USN A-4E: The aircraft was on an armed reconnaissance when an electrical failure made the aircraft uncontrollable and forced the pilot to eject over sea. The pilot was rescued successfully.
2. January 2, 1968, USN RA-3B: The aircraft was on a night reconnaissance mission over North Vietnam when the aircraft was hit by ground fire. The aircraft escaped out to sea, but crashed and killed all three crew members onboard.
3. January 2, 1968, USN F-8C: The aircraft was escorting a reconnaissance plane over North Vietnam when it lost engine and electrical power, most likely due to enemy

⁵³ Hobson, 2002.

- antiaircraft artillery. The pilot successfully steered the plane out to water and ejected. The pilot was then rescued by a Navy helicopter.
4. January 2, 1968, USAF T-28D: The aircraft was on a night reconnaissance mission when an engine failure brought the plane down. The pilot managed to escape and was rescued by a USAF helicopter.
 5. January 2, 1968, USAF F-105D: The aircraft was on a strike mission when it ran out of fuel and ejected. The pilot was rescued.
 6. January 3, 1968, Navy A-4C: The aircraft was on a mission to destroy a SAM site, when it was itself hit by an SA-2 SAM. The pilot ejected and was captured by the enemy.
 7. January 3, 1968, USAF F-105D: The aircraft was on a mission to bomb a railway yard when it was intercepted by several MiG-21s and shot down by an air-to-air missile. The pilot ejected, but was captured.
 8. January 4, 1968, USN F-8E: The aircraft was on a target combat air patrol mission when it was hit by a SAM. There was no indication of an ejection, and the pilot was killed.
 9. January 4, 1968, USAF F-100D: The aircraft was attacking a gun site when it was struck by ground fire. The pilot ejected and was rescued by a USAF helicopter.
 10. January 5, 1968, USAF F-105D: The aircraft was raiding a railway bridge when it was engaged by MiGs. Cannon fire caused the aircraft to roll out of control and the two crew members ejected. However, both were killed.
 11. January 5, 1968, USAF RF-4C: The aircraft was on a photographic reconnaissance mission when antiaircraft fire damaged it. They flew back from North Vietnam to Thailand and the two crew members ejected. Both were rescued.
 12. January 5, 1968, USN A-4E: The aircraft was leading a formation against a SAM site when it was hit by a 37mm flak. The pilot ejected and was captured.
 13. January 5, 1968, USAF F-105D: The aircraft was striking an airfield when it was hit by an 85mm antiaircraft shell. The pilot was seen to eject and his emergency beeper was activated but no voice contact was ever made. He was killed in the crash and his remains were returned in 1985.
 14. January 5, 1968, USN A-4E: The aircraft was on an armed reconnaissance mission when the leader in the attack failed to contact this aircraft. It is believed to have been either shot down or flown into the ground in the dark. The pilot's remains were returned in 1988.
 15. January 6, 1968, USAF F-105D: The aircraft was on a strike mission when it suffered an engine failure. The two crew members survived and were rescued.
 16. January 7, 1968, USAF F-100D: The aircraft was performing a CAS mission when it was damaged by ground fire. The pilot managed to get over the sea and ejected. He was subsequently rescued.
 17. January 8, 1968, USAF RF-4C: The aircraft was on a night photographic mission when it went missing. It is believed to have been shot down and the two crew members killed.
 18. January 9, 1968, USMC F-8E: The aircraft was bombing a road in Laos when it was hit by automatic weapons fire. The pilot ejected and was rescued by a USAF helicopter.
 19. January 9, 1968, USAF F-4D: The aircraft was on a night interdiction mission when it was hit by ground fire. The aircraft crashed and the two crew members were believed to have been killed.
 20. January 10, 1968, USAF F-4D: The aircraft was en route to a raid on an airfield when it was hit by an SA-2 SAM. Both crew members ejected, but one was killed and the other was captured.

21. January 10, 1968, USN F-4B: This and the following aircraft were returning from a bombing mission when they mistakenly homed onto the wrong ship rather than returning to the aircraft carrier. Due to lack of fuel, the two crew members ejected and were rescued.
22. January 10, 1968, USN F-4B: Same situation as the above aircraft. The two crew members ejected and were rescued.
23. January 10, 1968, USN F-4B: The aircraft was on a combat air patrol mission when it suffered a loss of hydraulic pressure. The two crew members ejected and were rescued.
24. January 11, 1968, USN OP-2E: The aircraft was on a daylight sensor delivery mission over Laos in poor weather when radio and radar contact was lost. Later, it was found that it had crashed into the ridge of a cliff; all nine crew members were believed to have been killed.
25. January 11, 1968, USN A-4E: The aircraft was attacking a bridge when it was hit by small arms fire. The aircraft managed to escape out to sea and the pilot ejected. He was rescued by a Navy helicopter.
26. January 14, 1968, USAF F-105D: The aircraft was striking an airfield when MiGs intercepted it and hit it with an Atoll missile. The aircraft crashed and the pilot was believed to have been killed.
27. January 14, 1968, USAF O-1G: The aircraft was controlling a CAS mission when it was hit by ground fire. The pilot sustained major injuries in the crash landing, but was rescued by a USAF helicopter.
28. January 14, 1968, USAF EB-66C: The aircraft was listening for enemy radar and jamming when it was intercepted by a MiG-21 and hit by an air-to-air missile. All the crew members survived the crash. However, four were captured, and 3 were rescued.
29. January 14, 1968, USAF F-100D: The aircraft was on a CAS mission when it suffered an engine failure and crashed. The pilot was killed.
30. January 16, 1968, USAF F-4C: The aircraft was on a strike mission when the bomb of either this aircraft or the next (an F-4D) detonated, probably as it was being armed ready for dropping. The two crew members ejected safely and were both rescued.
31. January 16, 1968, USAF F-4D: The aircraft was on the same strike mission as the above aircraft, and was damaged in the same bomb malfunction. The two crew members ejected and one was rescued but the other was captured.
32. January 16, 1968, USMC EF-10B: The aircraft was on a daylight jamming mission when it crashed into the sea, killing the two crew members. It is believed not to have been due to enemy action.
33. January 17, 1968, USAF O-2A: Moments after taking off the runway, the aircraft was hit by small arms fire and crashed. The two crew members were killed.
34. January 17, 1968, USAF A-1H: This aircraft was part of a search and rescue mission for the missing crew on a F-4D that went down on January 16, 1968, when it was hit by automatic weapons fire and crashed. The pilot was killed.
35. January 18, 1968, USAF F-4D: The aircraft was on a strike mission to destroy a power plant when it was engaged by MiG-17s and hit. The two crew members ejected but were both captured.
36. January 18, 1968, USAF F-4D: This aircraft was on the same mission as the preceding aircraft. This aircraft was also shot down by a MiG-17, and the two crew members ejected. Both were captured.

37. January 18, 1968, USN F-4B: The aircraft was on a barrier combat air patrol mission to protect its carrier. It was directed to investigate an unidentified surface target in overcast weather, and reported that it was a cargo vessel. Then, radio and radar contact was lost. It is believed the aircraft accidentally crashed into the water. The two crew members were killed.
38. January 19, 1968, USMC A-6A: The aircraft was on a night attack mission, but did not return. It is believed the aircraft was either shot down or crashed into the ground as it approached its target.
39. January 20, 1968, USAF F-4C: The aircraft was flying an armed reconnaissance mission and, while attacking trucks, it was hit by 37mm anti-aircraft fire. This caused the aircraft to crash and the two crew members were killed. There is some intelligence that suggests one of the crew members was killed in a shootout.
40. January 21, 1968, USMC A-4E: The aircraft was involved in the defense of its base at Khe Sanh, where the North Vietnamese were launching a massive offensive. It was shot down while attacking ground enemy troops and forced the pilot to eject. He was rescued by a Marine helicopter.
41. January 22, 1968, USMC F-4B: The aircraft was tasked to destroy anti-aircraft gun positions around Khe Sanh when it was hit by .50 caliber gunfire. The two crew members ejected and were rescued by a Marine helicopter.
42. January 23, 1968, USMC A-4E: The aircraft was strafing enemy concentration near Khe Sanh when it was hit by small arms fire. The pilot ejected and landed close to the base. He was rescued by Marines.
43. January 23, 1968, USN A-6A: The aircraft was flying low to approach its target in North Vietnam when it hit the sea. One crew member was killed, but the other escaped and was rescued.
44. January 25, 1968, USN A-4E: The aircraft was on a strike mission against coastal defenses when it was hit by a missile. The pilot guided the aircraft out to sea and ejected. A Navy helicopter rescued him.
45. January 26, 1968, USN A-6A: The aircraft was on a night mission to bomb an airfield when all radio and radar contact was lost as it approached its target. It was never determined what the cause of the crash was. Whether the pilot was killed or captured is unknown.
46. January 27, 1968, USAF F-4C: The aircraft was in North Vietnam attacking a target on the coast when it was hit by 37mm AAA. The pilot steered the aircraft over sea and ejected. The two crew members were both rescued by a USAF helicopter.
47. January 28, 1968, USAF T-28D: The aircraft was on an armed reconnaissance mission at night when it lost oil pressure, which caused engine failure. The pilot ejected and was rescued by a USAF helicopter in the morning.
48. January 29, 1968, USMC A-4E: The aircraft was on a CAS mission when it was probably hit by small arms fire. The pilot did not eject and was killed.
49. January 29, 1968, USN A-4E: The aircraft was on a strike mission when it suffered engine failure. The pilot ejected and a Navy helicopter rescued him.
50. February 2, 1968, USN F-8E: The aircraft was escorting a photographic reconnaissance aircraft when its engine failed. The aircraft crashed and the pilot was lost.

51. February 3, 1968, USAF F-102A: The aircraft was on an escort mission when it was attacked by a MiG-21. It was hit by an air-to-air missile and crashed. No parachutes were sighted and the pilot was killed.
52. February 5, 1968, USAF RF-4C: The aircraft was on a reconnaissance mission when the forward air controller saw an explosion on the ground after the aircraft went down through the cloud to start taking pictures. The two crew members were killed.
53. February 5, 1968, USAF F-105D: The aircraft was performing a raid on enemy barracks when a MiG-21 fired an Atoll missile and damaged the aircraft. The pilot ejected but was captured by the enemy.
54. February 6, 1968, USN P-3B: The aircraft was on a nighttime coastal reconnaissance mission when it failed to return to base the following morning. The cause of crash was not conclusively determined, but a faulty autopilot may have been responsible. All 12 crew members died.
55. February 8, 1968, USAF F-4D: The aircraft was on a bombing mission to destroy MiG bases when it was hit by antiaircraft fire. The aircraft managed to escape into Laos and ejected. The two crew members were both rescued.
56. February 8, 1968, USAF A-1H: The aircraft was attacking enemy tanks with napalm when it was hit by antiaircraft fire and crashed. The pilot was not able to eject and was killed.
57. February 12, 1968, USAF A-1H: The aircraft was on an armed reconnaissance mission when it attacked enemy tanks. The aircraft was hit by ground fire, but the aircraft flew another 10 miles before the pilot ejected. He was rescued.
58. February 14, 1968, USN A-1H: The aircraft was originally in the Philippines undergoing repairs. The pilot was flying the aircraft back to the Coral Sea carrier when it veered off track and came close to the Chinese island of Hainan. The aircraft was intercepted and fired on by Chinese MiGs, and was shot down. The other aircraft accompanying it saw the pilot eject and the parachute deploy, but the pilot was never found. For administrative purposes, the pilot was presumed dead.
59. February 14, 1968, USAF F-105D: The aircraft was dealing with SAM batteries while the strike force was attacking the Paul Doumer Bridge, when it was hit by a SAM. Nobody saw a parachute. In 1988, the Vietnamese returned the pilot's remains to the United States, which were not positively identified until 1999.
60. February 14, 1968, USN F-8E: The aircraft was escorting a photographic reconnaissance when it was shot down by a SAM. There was no sign that the pilot had ejected. His remains were returned in 1990.
61. February 14, 1968, USAF AC-47D: The aircraft was on a CAS mission when it was shot down. All eight crew members died.
62. February 15, 1968, USAF F-100D: The aircraft was tasked to attack a Viet Cong gun position at night when it was hit by small arms fire. The pilot ejected and was rescued.
63. February 15, 1968, USAF F-4D: The aircraft was raiding trucks when it was hit by 37mm antiaircraft fire. The two crew members both ejected but were captured.
64. February 17, 1968, USAF F-100F: The aircraft was bombing enemy troops near the Mekong Delta when it was hit by small arms fire and the two crew members were forced to eject. Both were rescued.
65. February 17, 1968, USN OP-2E: The aircraft was on a sensor delivery mission over southern Laos when it was hit by small arms fire. A fighter escort found burning

- wreckage on the wide of the ridge, and all nine crew members were presumed to have died.
66. February 18, 1968, USAF F-105F: The aircraft was strafing a storage and bivouac area in northern Laos when it was hit by AAA. The aircraft flew back to Thailand and ejected. The two crew members were rescued.
 67. February 19, 1968, USAF F-4C: The aircraft was on a strike mission in the Khe Sanh area when it was hit by ground fire. The two crew members ejected and both were rescued.
 68. February 23, 1968, USAF F-4D: The aircraft was on a combat air patrol mission over North Vietnam when it was intercepted by MiG-21s. An air-to-air missile damaged the aircraft severely and the two crew members ejected. Both were captured.
 69. February 23, 1968, USMC A-6A: The aircraft was on a strike mission when it collided with the F-8E listed below. The two crew members ejected and were rescued.
 70. February 23, 1968, USMC F-8E: The aircraft was on a non-combat flight when it collided with the A-6A listed above. The pilot was killed.
 71. February 24, 1968, USMC A-6A: The aircraft was on a night strike near Hanoi when it was probably shot down by a SAM. The two crew members were killed.
 72. February 25, 1968, USN F-8E: The aircraft was on a night barrier combat air patrol mission to protect its carrier when it ran out of fuel. The pilot ejected and was rescued by a Navy helicopter after two and a half days on a life raft.
 73. February 25, 1968, USAF F-100D: The aircraft was on a strike mission in southern Laos when it was hit by 37mm AAA. The pilot ejected and was rescued.
 74. February 25, 1968, USAF O-1E: The aircraft was on a forward air control mission when it was hit by ground fire. The pilot crash landed the aircraft and was rescued by an Army helicopter.
 75. February 25, 1968, USMC A-4E: The aircraft was attacking an enemy village when it was hit by small arms fire. The pilot ejected and was rescued.
 76. February 26, 1968, USAF F-100D: The aircraft was attacking enemy troops in the Mekong Delta region when it was hit by ground fire. The pilot ejected and was rescued.
 77. February 27, 1968, USN OP-2E: The aircraft was on a mission to drop sensors when it was hit by 37mm antiaircraft shell. The shell killed one crew member and caused a fire on the aircraft. CDR Paul Lloyd Milius kept the aircraft airborne while the other seven surviving crew members ejected and were subsequently rescued. CDR Milius is believed to have also ejected moments before the crash but his parachute failed to open; he was killed on impact with the ground. Overall, two crew members were killed and 7 were rescued.
 78. February 27, 1968, USAF RF-4C: The aircraft was on a solo reconnaissance mission over North Vietnam when it failed to return to base. The aircraft was probably shot down over southern Laos. Both crew members were killed, but one may have survived the crash and died in a POW camp.
 79. February 28, 1968, USAF F-105D: The aircraft was attacking a storage site on the Ho Chi Minh Trail when it was hit by ground fire. The pilot ejected and was rescued by a USAF helicopter.
 80. February 28, 1968, USN A-6A: The aircraft was on a night strike in North Vietnam but failed to return to base. Later, wreckage was found off the coast of Thanh Hoa, but the two crew members were never found. They were presumed to have been killed.

81. February 29, 1968, USAF F-4D: The aircraft was attacking a truck park in southern Laos when it was hit by 14.5mm anti-aircraft fire. One of the crew members was killed in the crash, but the other ejected and was rescued, although he was seriously injured because his parachute did not deploy properly.
82. February 29, 1968, USAF F-105F: The aircraft was on a mission to attack a military vehicle depot in Hanoi, but 10 miles out from the city it was hit by a SAM. Although the two crew members were seen to eject and emergency beepers were heard, they were never seen or heard from again. Their remains were returned in 1975 and 1985. The cause of their deaths is not known.
83. March 1, 1968, USN A-6A: The aircraft was tasked to hit enemy barracks but failed to come back. A search was mounted, but nothing was found. It is believed the aircraft was either shot down or crashed into the sea and the two crew members died.
84. March 2, 1968, USMC RF-4B: The aircraft was on a reconnaissance mission in South Vietnam when it was shot down by enemy ground fire. An Army helicopter rescued both crew members.
85. March 3, 1968, USN A-37A: The aircraft was on a CAS mission in South Vietnam when the aircraft crashed, either because of ground fire or pilot error. The pilot was killed.
86. March 5, 1968, USAF O-1F: The aircraft was en route on a visual reconnaissance mission when it was shot down by ground fire. The pilot was rescued with minor injuries.
87. March 5, 1968, USAF EB-66E: The aircraft was on a radar jamming mission when it crashed in Thailand due to an engine failure. All three crew members were rescued.
88. March 6, 1968, USAF F-100D: The aircraft was returning to base from a mission when it was shot. The pilot ejected about one mile from his base and was rescued.
89. March 6, 1968, USAF C-123K: The aircraft was delivering troops and spare parts to Khe Sanh. Because of an aircraft obstructing the runway as it was about to land, the aircraft had to perform a go-around. As it was circling to attempt another landing, it was hit by ground fire. This caused the aircraft to crash, killing all 50 people onboard.
90. March 6, 1968, USAF F-105D: The aircraft was attacking a road that was a part of the Ho Chi Minh Trail when it was hit by ground fire, which damaged the engine. The pilot ejected and was rescued by a USAF helicopter.
91. March 6, 1968, USAF F-100D: The aircraft was attacking enemy troops in South Vietnam when it was hit in the tail by ground fire. The aircraft became uncontrollable and the pilot ejected. He was rescued.
92. March 6, 1968, USN A-6A: The aircraft was on a night mission to strike a railway yard, but did not return. In subsequent days, there were news reports that the aircraft was shot down and the pilot killed. The remains of the pilot were returned in 1984.
93. March 11, 1968, USAF F-4D: The aircraft was on an armed reconnaissance mission when it was shot down by automatic weapons fire. No ejections were seen, and the two crew members were believed to have been killed. Their remains were returned in 1989.
94. March 11, 1968, USAF A-37A: The aircraft was on a CAS mission when it was hit by ground fire and crashed. The pilot was not seen to eject and was killed.
95. March 11, 1968, USAF A-1E: The aircraft was on an armed reconnaissance mission when its engine failed and crashed. The pilot survived and was rescued.
96. March 11, 1968, USAF F-105D: The aircraft was on a strike mission when it lost oil pressure and its engine failed. The pilot ejected and was rescued.

97. March 12, 1968, USN F-8E: The aircraft was on a barrier combat air patrol when bad weather forced it to divert to a land base. As the aircraft descended through the clouds, the pilot realized he was too close to the ground, and the aircraft hit several trees before he ejected. The pilot was subsequently rescued.
98. March 13, 1968, USAF A-1E: The aircraft was on a mission to destroy a USAF radar facility in Laos that had been overrun by the Pathet Lao and search for survivors, when it was shot down by ground fire. The pilot was not seen to eject and was presumed killed.
99. March 13, 1968, USAF A-1E: The aircraft was on a mission to drop sensors when it was shot down. The aircraft was flying so low so fast (200 feet at 220 knots) that the crew never had a chance to eject. The two crew members were killed.
100. March 13, 1968, USN A-4E: The aircraft was attacking a suspected storage site in southern Laos when it was hit by automatic weapons fire. The pilot ejected and was rescued.
101. March 14, 1968, USAF F-4D: The aircraft was flying a diversionary strike for a helicopter evacuation when it was hit by ground fire and crashed. The two crew members ejected and one was rescued. The other is believed to have been shot by the enemy on the ground.
102. March 15, 1968, USAF F-4C: The aircraft was tasked to destroy a truck park in southern Laos when it was hit by ground fire. The two crew members ejected and were rescued by USAF helicopters.
103. March 16, 1968, USMC F-8E: The aircraft was on a CAS mission to the demilitarized zone when it was hit by 0.50 caliber gunfire. The pilot guided the aircraft out to sea and ejected. A Navy helicopter rescued the pilot.
104. March 16, 1968, USAF O-2A: The aircraft was operating as a forward air controller when it crashed. The cause of the crash was undetermined and the pilot was killed.
105. March 16, 1968, USN A-6A: The aircraft was on a night time low-level strike to hit a railway yard when it was hit by a large-caliber antiaircraft shell. The two crew members ejected but were both captured.
106. March 17, 1968, USAF F-4D: The aircraft was on an armed reconnaissance mission off the coast of North Vietnam when it was hit by automatic weapons fire. The aircraft flew out to the sea and the two crew members ejected. Both were rescued.
107. March 17, 1968, USAF F-105D: The aircraft was hitting the Pathet Lao headquarters at Sam Neua when it was hit by AAA. The pilot was not observed to eject, and was killed.
108. March 17, 1968, USN S-2E: The aircraft was on a night surveillance patrol off the coast of North Vietnam when the pilot reported having radar problems, and subsequently disappeared. A few days later, a part of the starboard wing was found, but the cause of the crash was never determined. All four crew members are believed to have been killed.
109. March 18, 1968, USAF F-100F: The aircraft was acting as the forward air controller when it was hit by AAA. The two crew members ejected, but only one was rescued by a USAF helicopter. The other was believed to have been killed.
110. March 18, 1968, USAF O-1G: The aircraft was controlling an air strike close to its base when it was hit by small arms fire. The aircraft crash-landed but the pilot escaped unharmed and was rescued.
111. March 18, 1968 USAF A-1H: The aircraft was on an armed reconnaissance sortie over northern Laos when automatic weapons fire damaged its engine. The pilot had to make a forced landing, but survived and was rescued.

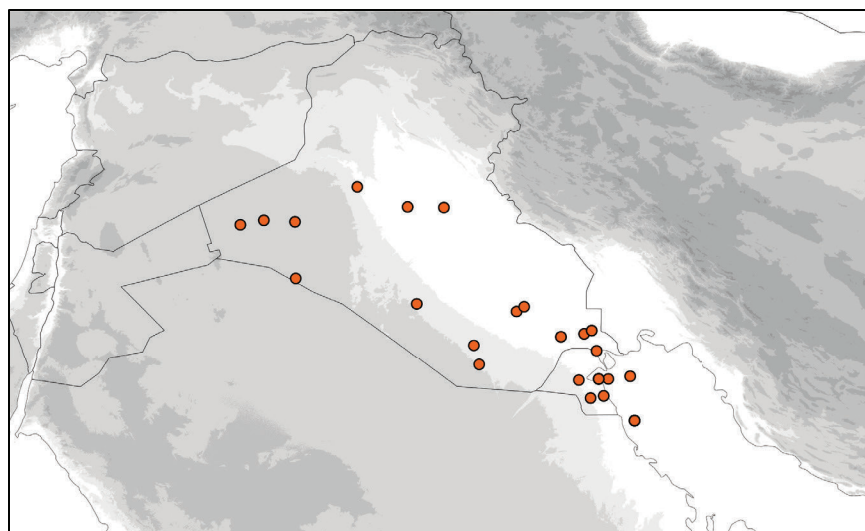
112. March 19, 1968, USAF O-1E: The aircraft was on a visual reconnaissance sortie when it failed to return to base. Later, its wreckage was found on the slopes of a mountain. The cause of the crash is undetermined, and the two crew members were believed to have been killed.
113. March 20, 1968, USAF F-100D: The aircraft was attacking a truck convoy when it was hit by ground fire. The pilot ejected but was captured.
114. March 20, 1968, USAF O-1G: The aircraft was on a visual reconnaissance mission when it was shot down. The two crews were killed.
115. March 20, 1968, USAF O-2A: The aircraft was acting as the forward air controller in southern Laos when all contact was lost. Neither the aircraft nor crew were ever found. The pilot is believed to have been killed.
116. March 21, 1968, USAF F-4D: The aircraft was on a night strike mission in southern Laos when it was hit by a 37mm AAA and crashed into a mountain. No ejections were seen. The two crew members were believed to have been killed.
117. March 21, 1968, USMC A-4E: The aircraft was on a nighttime bombing mission when it was lost. The pilot ejected and was rescued.
118. March 22, 1968, USAF F-4C: The aircraft was on a mission to destroy a gun site in Laos when either a AAA hit it or its own bomb exploded prematurely. The pilot ejected, but the WSO was not seen to eject. The pilot was captured, and the WSO is believed to have been killed.
119. March 23, 1968, USAF F-100D: The aircraft was attacking Viet Cong buildings when it was hit by ground fire and crashed. The pilot was killed.
120. March 23, 1968, USAF O-1F: The aircraft collided with another aircraft during a visual reconnaissance mission and the pilot was killed in the crash.
121. March 27, 1968, USAF F-4D: The aircraft was on a strike mission to attack trucks when it was hit by automatic weapons or small arms fire. The aircraft crashed and neither of the two crew members were seen to eject. It is believed they were both killed.
122. March 28, 1968, USN RF-8G: The aircraft was on a strike mission in southern Laos when the forward air controller saw it go down in a tight spin. It is believed that it tried to perform a roll that was too tight as it was following Skyhawks, which flew at much lower speeds than the RF-8G to perform this maneuver. It was also possibly hit by ground fire. The pilot was killed and the remains were returned to the United States in 1988.
123. March 28, 1968, USAF O-1F: The aircraft was acting as the forward air controller when it was shot down by small arms fire. The two crew members survived the crash and were rescued.
124. March 28, 1968, USAF F-111A: The aircraft was on a low-level night strike on a truck park when all contact was lost. The cause of the crash was never ascertained. The two crew members were believed to have been killed.
125. March 29, 1968, USAF O-2A: The aircraft was on a forward air control mission over the North Vietnamese coast when ground fire damaged its rear engine. The two crew members ejected over Laos and were rescued.
126. March 30, 1968, USAF F-111A: The aircraft was on a night mission in Thai airspace when the crew lost control and had to eject. The two crew members were rescued. The loss of control was due to a solidified sealant, which led to the jamming of the stabilizer actuator.

127. March 31, 1968, USAF C-123K: The aircraft was taking off on a trooping flight when a mechanical failure caused it to crash land. All four crew members survived and were rescued.

Operation Desert Storm

All information for events in Desert Storm was derived from Darrel D. Whitcomb's *Combat Search and Rescue in Desert Storm*.⁵⁴

Figure C.2. Map of the Locations of Aircraft Crashes in Desert Storm, January–February 1991



1. January 17, 1991, USN F-18: The aircraft was deployed aboard the USS *Saratoga* and took off for a strike mission in Iraq. En route, the strike package engaged enemy MiG-25s but in turn was engaged by AAAs. One of the pilots in the package saw an air-to-air engagement and a ground explosion. The pilot was subsequently reported missing.
2. January 17, 1991, RAF GR1 Tornado: The aircraft was part of a four-ship flight attacking an airfield in southern Iraq. As it approached the target to drop its bombs, it was hit by a suspected SA-16 missile. The two crew members ejected and landed safely but, with nowhere to hide, were captured about an hour later by the enemy.
3. January 17, 1991, Kuwaiti Air Force A-4: The aircraft was part of a four-plane package attacking targets in Kuwait. The aircraft was struck by AAA and the pilot ejected. Subsequently, the pilot was recovered by Kuwaiti resistance fighters.
4. January 17, 1991, GR1 Tornado: The aircraft was part of a four-plane package attacking an airfield in southern Iraq. Upon egressing the target, it was engaged by a SAM. Another crew observed an explosion, and no contact was made with the crew. Intelligence determined later that the two crew members were killed.
5. January 17, 1991, USAF F-15E: The aircraft was part of a six-plane package attacking an airfield west of Basra in southern Iraq. Upon egress from the target, another pilot

⁵⁴ Whitcomb, 2006.

- observed a large explosion. No Mayday call was heard, but AAA was heavy in the area. The two crew members were killed in the engagement.
6. January 17, 1991, USN A-6: The aircraft launched from the USS *Saratoga* as part of a large strike package targeting an airfield in western Iraq. As the aircraft was attacking, it was hit by either an SA-6 or Roland missile and crashed north of the airfield. The two crew members ejected, but one of them had a badly wounded shoulder. Within an hour, they were both captured by the enemy.
 7. January 18, 1991, Italian Air Force GR1 Tornado: The aircraft was part of an eight-plane package to attack an airfield in southern Iraq. During the bombing run it was shot down by the enemy and the two crew members were soon captured.
 8. January 18, 1991, USMC OV-10: The aircraft was flying in Kuwait searching for targets, such as Iraqi artillery and FROG sites, when it was hit by a heat-seeking missile. The two crew members ejected, but were both captured by the enemy within 10 minutes.
 9. January 18, 1991, USN A-6: As part of a larger force, this aircraft was dropping aerial-delivered mines to bottle up Iraqi naval units in the northern Gulf area. As it approached the target, the aircraft went down. AAAs were observed in the area. Later, intelligence sources indicated that the two crew members were killed.
 10. January 19, 1991, USAF F-16: The aircraft was leading a flight of four F-16s to attack targets in the Baghdad area. As the aircraft was approaching the target, it was hit by an SA-3 missile. The pilot then ejected but was captured by Bedouin tribesmen as he landed.
 11. January 19, 1991, USAF F-16: This aircraft was in the same flight package as the one in the previous event. As the aircraft was approaching the target, it was hit by an SA-6. The pilot ejected successfully, but was captured soon after landing.
 12. January 19, 1991, RAF GR1 Tornado: The aircraft was part of an eight-plane package to attack an airfield near Basra. As the aircraft was dropping its bombs onto the target, it was engaged by a missile that damaged the aircraft and injured one of the crews severely. The two crew members ejected successfully, but were captured 14 hours later by the enemy.
 13. January 19, 1991, USAF F-15E: The aircraft was part of a package of 24 F-15Es to attack Scud missiles in western Iraq. As the aircraft approached the target, it was hit by (most likely) an SA-2. The two crew members ejected and were initially separated, but met up after 15 minutes. They evaded capture for three and a half days but were ultimately captured by the enemy.
 14. January 20, 1991, USN F-14: The aircraft was escorting an EA-6B supporting a strike package hitting an airfield just west of Baghdad. While holding at the orbit point, the aircraft was hit by an SA-2. The two crew members ejected but were separated. One of the crew was captured by the enemy after about four hours. The other crew was recovered successfully after about 11 hours.
 15. January 22, 1991, RAF GR1 Tornado: The aircraft was part of eight Tornados tasked to attack the Ar Rutbah radar site in northern Iraq. The aircraft was hit while lofting its bombs. There was no contact with the crew, who were determined to have been killed.
 16. January 23, 1991, USAF F-16: The aircraft was the lead in a flight of four tasked to an interdiction target near Kuwait City. After dropping its bombs, the aircraft burst into flames. The pilot glided out over the Persian Gulf before ejecting. The pilot was soon recovered by Navy and Marine Corps assets. Subsequently, it was determined that one of its own bombs had accidentally detonated right under the aircraft.

17. January 24, 1991, RAF GR1 Tornado: The aircraft was part of a large force of Tornados attacking an airfield in Iraq. The two crew members were forced to eject when one of their bombs detonated prematurely. One was captured immediately upon landing. The other was able to hide behind a small ridge, but after the sun came out was captured by the enemy.
18. January 28, 1991, USMC AV-8: The aircraft was the flight lead of two Harriers tasked to attack a FROG missile battery on the Kuwaiti coast. The shootdown was not observed, but the aircraft was reported missing when it failed to rejoin its wingman after the strike. It is believed an AAA shot it down. Subsequent intelligence suggested that the pilot had been captured.
19. January 31, 1991, USAF AC-130: The aircraft was launched at night to support U.S. Marine and Saudi ground forces engaging FROG missile batteries. As dawn approached, an enemy missile hit the aircraft and caused it to crash into the water off the coast. All 14 crew members were killed.
20. February 2, 1991, USN A-6: The aircraft launched from USS *Roosevelt* to fly in an armed surface reconnaissance mission east of Faylaka Island in the northern portion of the Persian Gulf. Soon after, the crew failed to answer radio calls. It is believed the two crew members were shot down by AAA.
21. February 2, 1991, USAF A-10: This aircraft was tasked to hit targets in Kuwait. As it was engaging the enemy it was hit by what is believed to be an SA-16. The pilot ejected, but was captured by the enemy soon after landing.
22. February 9, 1991, USMC AV-8: This aircraft was part of a two AV-8 package attacking an artillery battery in Kuwait when it was hit by a heat-seeking missile. The pilot ejected but was captured soon after landing.
23. February 13, 1991, Royal Saudi Air Force F-5: This aircraft went down just inside Iraq and north of ArAr. Voice contact and authentication with the pilot were never received. The pilot had been captured by the enemy.
24. February 14, 1991, GR1 Tornado: This aircraft was part of a package tasked to attack the Iraqi airfield at Al Taqaddum. As it approached the target, it was hit by a SA-2 and the crew ejected. Contact was never made with either crew member. Subsequent intelligence indicated that the pilot was immediately captured but the navigator was killed in the engagement.
25. February 15, 1991, USAF A-10: This aircraft was part of a flight of two A-10s tasked to attack elements of the Iraqi 17th Armored Division in Kuwait. While orbiting to spot targets, the aircraft was hit by a heat-seeking missile and the pilot ejected. The pilot was captured by the enemy immediately after landing.
26. February 15, 1991, USAF A-10: This aircraft was the lead of the previous aircraft. As it was directing the rescue effort for the previous aircraft, it was also shot down by the enemy, presumably by a heat-seeking missile. Intelligence sources determined that the pilot had been killed in the engagement.
27. February 17, 1991, USAF F-16: This aircraft was part of two F-16s dispatched on a reconnaissance mission along the Euphrates River. As they were returning to base, the engine failed and the pilot was forced to eject and landed safely on the ground. The pilot was subsequently rescued by friendly helicopters.

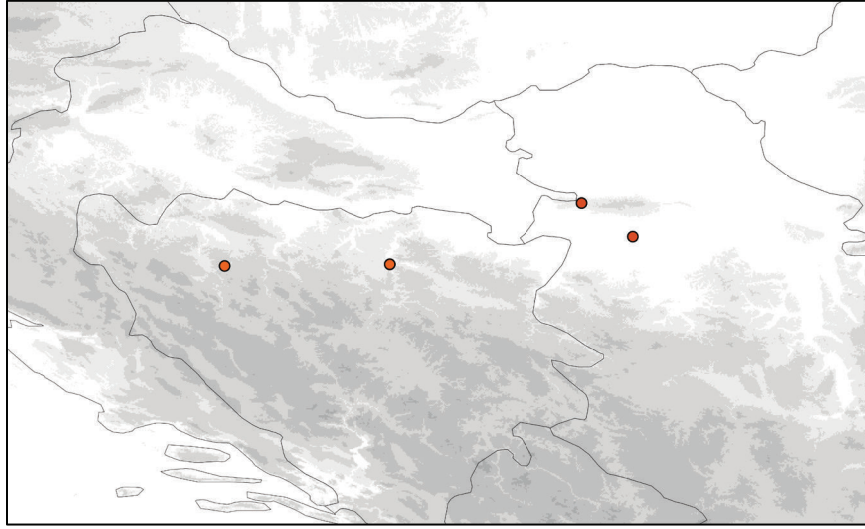
28. February 19, 1991, USAF OA-10: This aircraft was the forward air controller in one of the kill boxes in Iraq. While scanning for targets, it was hit by (most likely) an SA-9. The pilot ejected but was wounded in the process. Soon after, he was captured by the enemy.
29. February 23, 1991, USMC AV-8: This aircraft was on a night sortie to attack targets in Kuwait. As it attacked its target, a nearby aircraft noticed two explosions, and radio contact was lost and the pilot was reported lost. It is possible it was shot down by a SAM.
30. February 25, 1991, USMC AV-8: This aircraft was on a mission to support its fellow Marines on the ground in Kuwait. Once in the target area, it was hit by a heat-seeking missile and the pilot was forced to eject. Soon after landing, he was rescued by a Marine infantry team.
31. February 25, 1991, USMC OV-10: This aircraft was a forward air controller looking for Iraqi forces when it was hit by a heat-seeking missile in Kuwait. One of the crew ejected and was captured immediately by the enemy, but the other was killed in the explosion.
32. February 27, 1991, USMC AV-8: The aircraft was the wingman in a flight of two AV-8s launched from USS *Nassau* in the Persian Gulf tasked to bomb enemy vehicles fleeing Kuwait toward Basra. In attempting to engage the enemy, it was hit by a heat-seeking missile and crashed. The pilot was killed in the engagement.
33. February 27, 1991, USAF F-16: This aircraft was part of a flight of four F-16s tasked to provide CAS for advancing U.S. Army forces. As the aircraft was searching for targets, it was mostly likely hit by AAA. The pilot ejected but broke his right leg upon landing. He was captured soon afterwards.

Operation Deny Flight and Allied Force

All information for events in Operation Deny Flight and Allied Force were derived from Marc DiPaolo's *Combat Rescue Operational Review: A Summary of Combat Rescue Operations from Vietnam to Kosovo*.⁵⁵

⁵⁵ DiPaolo, 2001.

Figure C.3. Map of the Location of Aircraft Crashes in ODF and OAF, June 1995–May 1999



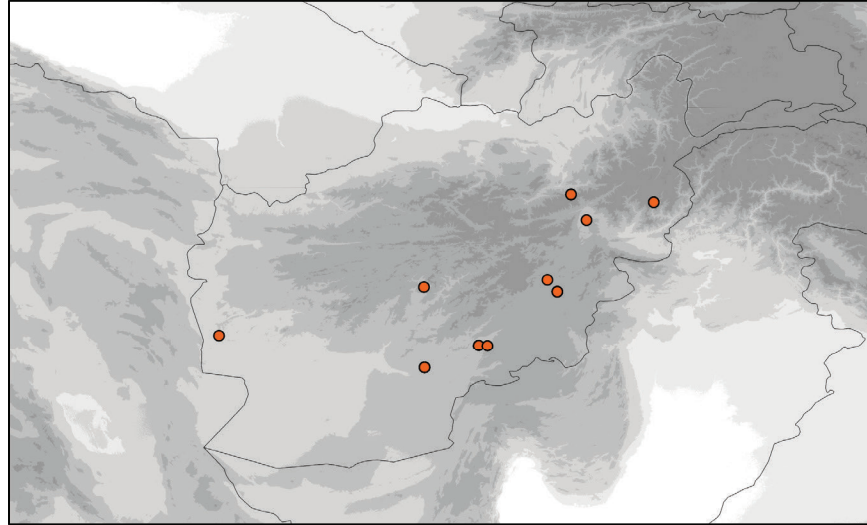
1. June 2, 1995, USAF F-16: The aircraft was shot down by an SA-6 during cruise flight. The pilot ejected safely and evaded capture for five and a half days before being rescued by allied forces.
2. August 30, 1995, French Air Force Mirage 2000: The aircraft was shot down by heat-seeking MANPADS in the target area. The two crew members ejected successfully but were captured by the enemy soon after.
3. March 27, 1999, USAF F-117: The aircraft was on a night mission over Kosovo. It was hit by a radar-guided SAM upon egress from the target area and the pilot ejected. The pilot evaded capture for about six hours in enemy territory, and was successfully rescued by an MH-60G helicopter.
4. May 2, 1999, USAF F-16: The aircraft was on a mission to destroy enemy air defenses in northern Serbia, when SA-3 hit it. The pilot ejected and concealed himself from the enemy for three hours before being rescued by an MH-60G helicopter.

Operation Enduring Freedom

As data sources, we used USAF Aircraft Accident Investigation Reports (when available), since these contained detailed information on the crash as well as the recovery efforts, as well as *The Nimrod Review* by Charles Haddon⁵⁶ and various news reports.

⁵⁶ Haddon, 2009.

Figure C.4. Map of the Location of Aircraft Crashes in OEF, February 2002–April 2013



1. February 13, 2002, USAF MC-130: The aircraft crashed in eastern Afghanistan, where it was on a refueling mission. The crew of eight survived.⁵⁷
2. June 12, 2002, USAF MC-130: The aircraft was participating in a night exfiltration mission to remove U.S. Army Special Forces troops from the area of Band E Sardeh Dam, Afghanistan. Due to excessive cargo weight load, the aircraft crashed. Upon impact three crew members were killed immediately, but seven others survived and were able to escape. The survivors were subsequently rescued.⁵⁸
3. August 31, 2006, Royal Netherlands Air Force F-16: The aircraft was returning from a mission in Helmand province when it crashed near Ghazni, Afghanistan, killing the pilot. The crash was an accident and is not believed to be due to enemy action.⁵⁹
4. September 2, 2006, RAF Nimrod MR2: The aircraft was on a routine mission over Helmand province in southern Afghanistan to support NATO and Afghani ground forces. It caught on fire in mid-air after an in-flight refueling, and subsequently crashed near Kandahar, killing all 14 people onboard.⁶⁰
5. July 18, 2009, USAF F-15E: Upon completion of an evening CAS mission, the two-ship F-15E flight proceeded to practice high angle strafe, but one of the planes impacted the ground due to a misjudgment of target altitude. The pilot and WSO both died.⁶¹
6. October 13, 2009, US Army C-12: The aircraft was on a routine mission in the early morning in Nuristan province when it failed to return to Bagram Airfield. Two weeks

⁵⁷ Aviation Safety Network, “Accident Description: Lockheed MC-130P Hercules, February 13, 2002,” web page, updated October 13, 2014. Information provided by AFSOC Safety.

⁵⁸ United States Air Force Aircraft Accident Investigation Board, *Executive Summary Accident Investigation Board MC-130H, 84-0475*, 2002. Information provided by AFSOC Safety.

⁵⁹ Lieven Dewitte, “Dutch F-16 Crashed in Afghanistan—Pilot Killed,” *F-16 Fighting Falcon News*, August 31, 2006; “Dutch F-16 Crash in Afghanistan,” *BBC News*, August 31, 2006.

⁶⁰ Haddon, 2009.

⁶¹ United States Air Force Aircraft Accident Investigation Board, *Executive Summary Aircraft Accident Investigation F-15E, T/N 90-0231*, 2009.

later, the wreckage and three civilian remains were found. Enemy action was not believed to be the cause of the crash.⁶²

7. April 9, 2010 USAF CV-22: The aircraft was on a mission to infiltrate a team near Qalat, Afghanistan. For an unknown reason it crashed into the ground. 4 people were killed and 16 people were injured. Cause is unknown, but likely not enemy action. Initial rescue were performed by the two wingmen.⁶³
8. May 24, 2011 France Mirage 2000D: The French fighter jet crashed 100km west of Farah, Afghanistan. The two crew members survived and were recovered. The cause of the crash is believed not to be due to enemy action.⁶⁴
9. March 28, 2012 USAF F-15E: Upon completion of a large force exercise, the plane was returning to base. Due to pilot disorientation, the plane became inverted and the crew had to eject. Weapon Systems Officer (WSO) and pilot both eject, but the pilot was fatally injured when he hit a radio tower upon ejection. The WSO ejected safely and was recovered.⁶⁵
10. April 27, 2013 USAF MC-12: The aircraft was on an intelligence, surveillance and reconnaissance (ISR) mission. Due to an aggressive climb to avoid clouds, the plane stalled and entered a spin, causing it to crash. All 4 crews were killed upon impact.⁶⁶

Operation Iraqi Freedom

As data sources, we used various USAF Aircraft Accident Investigation Reports (when available), as well as an RAF Board of Inquiry report and various news reports.

⁶² NATO, "Missing Crew and Aircraft Recovered," press release, October 27, 2009; "3 Civilian Bodies Found from Afghan Crash," *CBS News*, October 27, 2009; "Americans' Bodies Recovered After Plane Crash in Afghanistan," *CNN*, October 27, 2009.

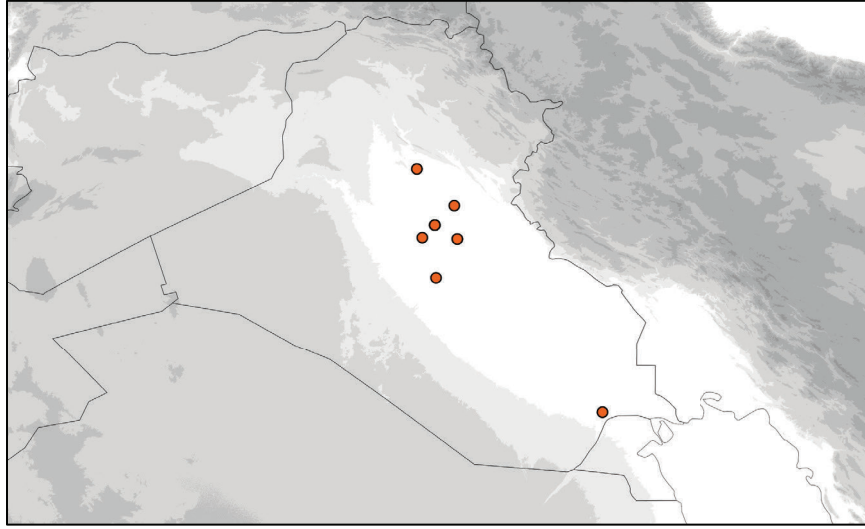
⁶³ United States Air Force Aircraft Accident Investigation Board, 2010.

⁶⁴ "French Fighter Jet Crashes in Afghanistan," *Defense News*, May 24, 2011.

⁶⁵ United States Air Force Aircraft Accident Investigation Board, *F-15E, T/N 90-0235*, 2012.

⁶⁶ United States Air Force Aircraft Accident Investigation Board, *MC-12W, T/N 09-0676*, 2013.

Figure C.5. Map of the Locations of Fixed-Wing Aircraft Crashes in OIF, March 2003–June 2007



1. March 22, 2003, RAF GR4 Tornado: After a successful operational mission in the evening and while returning to base, the aircraft was mistakenly engaged by a Patriot missile battery and was destroyed near the Kuwaiti border. The two crew members were killed.⁶⁷
2. April 2, 2003, USN F/A-18C: As the aircraft was returning from a mission, it was mistakenly engaged by a Patriot missile battery and was destroyed. The pilot was killed.⁶⁸
3. April 7, 2003, USAF F-15E: The aircraft crashed while on a bombing mission near Tikrit, Iraq. Both the pilot and WSO were killed.⁶⁹
4. April 8, 2003, USAF A-10A: The aircraft was shot down near Baghdad by a SAM while on a close air support mission. The pilot ejected and was recovered safely.⁷⁰
5. June 12, 2003, USAF F-16: The aircraft was part of a CAS mission near Baghdad when the fuel system malfunctioned and forced the pilot to eject. The pilot was rescued.⁷¹
6. January 30, 2005, RAF C-130: The aircraft took off from Baghdad International Airport on a routine mission that included transporting passenger and freight to Balad Southeast. En route, the aircraft was hit by AAA and crashed. All 10 people on board were killed.⁷²

⁶⁷ Canadian Pugwash Group, “Open Letter to Canadian Ministers,” April 26, 2004; Neil Tweedie, “U.S. Fighter Shot Down by Patriot Missile,” *The Telegraph*, April 4, 2003; “RAF Tornado Downed by US Missile,” *BBC News*, March 23, 2003.

⁶⁸ Pamela Hess, “Feature: The Patriot’s Fratricide Record,” *UPI*, April 24, 2003; Thomas E. Ricks, “Investigation Finds U.S. Missiles Downed Navy Jet,” *Washington Post*, December 11, 2004.

⁶⁹ Ashley Conner, “Widow Returns to Air Force with Help from 90th FS Family,” *Air Force Print News Today*, June 2, 2013; United States Department of Defense, “DoD Identifies Air Force Casualty,” Washington, D.C., DoD News Release No. 267-03, April 23, 2003.

⁷⁰ “U.S. A-10 Warplane Shot Down Near Baghdad,” *Fox News*, April 8, 2003; “Ground Attack Fighter Shot Down Near Baghdad,” *PBS Newshour*, April 8, 2003.

⁷¹ United States Air Force Aircraft Accident Investigation Board, 2003.

⁷² Royal Air Force Board of Inquiry, 2005.

7. November 27, 2006, USAF F-16: The aircraft was supporting friendly forces under enemy attack 20 miles northwest of Baghdad. While engaging the enemy, pilot fixation on maintaining visual identification of the target caused the aircraft to accidentally impact the ground, leading to the destruction of the aircraft and death of the pilot.⁷³
8. June 15, 2007, USAF F-16: The aircraft was on a CAS mission at night. Soon after takeoff from Balad Air Base, the pilot became disoriented and crashed into the ground. The pilot was killed.⁷⁴

Operation Odyssey Dawn

All information for the event in Operation Odyssey Dawn was derived from the USAF Aircraft Accident Investigation Board report.⁷⁵

1. March 31, 2011, USAF F-15E: The aircraft was on a night combat mission near Benghazi, Libya. After dropping its bombs, it entered an unrecoverable spin. The pilot and WSO ejected with minor injuries. The crew evaded for about three hours before being recovered by friendly forces.

⁷³ United States Air Force Aircraft Accident Investigation Board, *Executive Summary Aircraft Accident Investigation F-16CG, S/N 90-0776*, 2006.

⁷⁴ United States Air Force Aircraft Accident Investigation Board, *Executive Summary Aircraft Accident Investigation F-16CG, S/N 89-2031*, 2007.

⁷⁵ United States Air Force Aircraft Accident Investigation Board, 2011.

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