Factors Associated with Delayed Ejection in Mishaps Between 1993 and 2013

John E. Miles

INTRODUCTION: The purpose of this investigation was to identify factors associated with Air Force aviators delaying ejection during in-flight emergencies.

METHODS: The investigator reviewed all reports within the Air Force Safety Automated System describing mishaps that resulted in the destruction of Air Force ejection-seat equipped aircraft between 1993 and 2013. Crewmembers were classified as either timely or delayed ejectors based on altitude at onset of emergency, altitude at ejection, and a determination regarding whether or not the aircraft was controlled during the mishap sequence. Univariate analysis and multivariate logistic regression were used to explore the association between delayed ejection and multiple potential risk factors.

RESULTS: In total, 366 crewmembers were involved in in-flight emergencies in ejection-seat-equipped aircraft that resulted in the loss of the aircraft; 201 (54.9%) of these crewmembers delayed ejection until their aircraft had descended below recommended minimum ejection altitudes. Multivariate analysis indicated that independent risk factors for delayed ejection included increased crewmember flight hours and a mechanical or human-factors related cause of the emergency versus bird strike or midair collision.

DISCUSSION: This investigation provided quantitative assessments of factors associated with aviators delaying ejection during in-flight emergencies. Increased odds of delay among crewmembers with greater than 1500 total flight hours suggests that complacency and overconfidence may adversely influence the ejection decision to at least as great a degree as inexperience. Increased odds of delay during mechanical and human factors mishaps confirms previously reported hypotheses and reaffirms the importance of targeting these areas to reduce aviator injuries and fatalities.

KEYWORDS: aviation, aircraft, human factors, in-flight emergency.

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Since the invention of the airplane, aviators have sought ways to safely exit unrecoverable aircraft before they impact the ground. At first, airborne egress simply involved opening the aircraft canopy (if one existed), unbuckling restraints, climbing out of the cockpit, jumping clear of the aircraft, and manually deploying a parachute to slow one's descent. As aircraft evolved, faster speeds made such simple exits unsafe or impossible. To address these new challenges, ejection seats were developed to propel an aviator away from a doomed aircraft, and additional systems evolved to automatically deploy a parachute effectively even at low altitudes.

Ejection seats are now required for safe egress from today's high-performance aircraft during in-flight emergencies. Since the first successful ejection in 1942, ejection seats have saved thousands of lives. Over 5000 U.S. Air Force (USAF) aviators have ejected since 1949.[7] Multiple studies have confirmed the effectiveness of ejection seats, which, in recent years, have demonstrated survival rates that exceed 80%.[13,17]

Injuries and fatalities nevertheless do continue to occur in aircraft equipped with ejection seats. Nearly all studies that have examined injuries and fatalities related to aircraft ejections have concluded that the single most important factor increasing the risk of serious injury or death is a delay in the decision to eject.[1,4,7] This finding has been consistent across the air forces of multiple nations and has persisted since the first studies of aircraft ejections in the 1950s.

From the U.S. Air Force School of Aerospace Medicine, Wright-Patterson AFB, OH.

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Address correspondence to: John E. Miles, 4355 Longmeadow Lane, Beavercreek, OH 45430; jem48@georgetown.edu.

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As early as 1957, Zeller found that over a third of fatally injured aircrew members experienced their emergencies above 2000 ft (609.6 m) and should have been able to successfully eject.[20] He was among the first to emphasize that "the rapidity with which a decision can be made to eject"[20] is a key factor in determining the altitude at which ejection is initiated. In 1968, Collins et al. found that the majority of deaths in attempted ejections "were due to insufficient time for parachute canopy deployment to produce effective deceleration."[4] In their 1992 study of injuries associated with aircraft ejections by Finnish pilots, Visuri and Aho noted that ejection is a very safe procedure, with the most difficult moment for pilots being "decision-making and timing the ejection."[17] As recently as 2007, Nakamura found in a review of Japanese ejections that 37.5% of fatalities resulted from a delay in the decision to eject.[11]

Several papers have suggested factors likely to contribute to a delay in the decision to eject. In a paper presented at an aviation safety symposium in 1999, Goodman argued that "delaying the ejection decision is responsible for more unsuccessful ejections than any other cause," and he highlighted aerodynamics, response time, excessive motivation to succeed, mission requirements, situational awareness, crew coordination, stigma, ego, overzealous praise for those who save aircraft, overcoming the problem, fear of being restricted from flying, command emphasis, avoiding populated areas, complacency, behavioral inaction, spatial disorientation, and temporal distortion as factors affecting the decision to eject.[6] In a review of USAF ejections from 1977 through 1989, Jenkins suggested that the decision to eject may be delayed due to a wide variety of reasons, including pilot incapacitation, inattention, or distraction.[7] Moreno Vázquez et al. attributed delayed ejections by Spanish aviators to their trust in the aircraft and lack of parachute training.[10] Callaghan and Irwin listed perceived properties of the ejection seat, "height" (altitude) at onset of the emergency, the nature of the emergency, and the consequences of the decision as factors confronting a pilot facing the decision to eject.[2] Of the studies reviewed for this project, none examined a large number of historical ejections specifically to identify factors associated with delayed ejection.

However, prior studies of injuries and fatalities associated with aircraft ejections do provide insight into factors likely to be related to delayed ejection. Various studies have identified age, experience, branch of service, mishap location, number of crewmembers in the aircraft, nature of the mishap, aircraft type, and altitude at onset of the mishap among factors associated with an increased risk of serious injury or fatality following aircraft ejections. Each of these factors is briefly discussed below.

Age has been considered one potential risk factor. In his study of Bulgarian aircrew ejections, Milanov found that more major injuries, but no fatalities, occurred among older ejectees.[9] The author attributed the lack of fatalities among this group to their "long flying experience and training… to act correctly in unusual situations."[9]

Experience has been considered another potential risk factor. In 1957, Zeller included a pilot's total flying experience among his list of factors associated with ejection. Although he did not link inexperience directly to a delay in the ejection decision, he did claim that "less experienced pilots are involved in a disproportionately large number of ejections due in a large part to their general lack of experience."[20] In their simulator-based study, Callaghan and Irwin classified pilots according to total flight hours in the study aircraft and found no relationship between experience and the ejection decision height.[2]

Branch of service has also been considered a potential risk factor. Chubb et al. suggested that Navy pilots may be more prone to eject at lower altitude than Air Force pilots.[3]

The location of a mishap has been considered an additional potential risk factor. As mentioned above, Goodman included "avoiding populated areas" among his list of factors affecting the decision to eject.[6] In his review of Swedish Air Force ejections between 1967 and 1987, Sandstedt found that many pilots took time to aim their aircraft away from populated areas prior to ejecting.[15] Chubb et al. also acknowledged that some aviators delay ejection "while steering the aircraft away from people or houses."[3] One might, therefore, conclude that crewmembers would be more likely to delay ejection when flying over potentially populated land compared to open water. In the same article, however, Chubb et al. also note that about equal numbers of U.S. Navy low-altitude ejections took place over land and over water, with success rates for low-altitude ejections between 65% and 70% over both types of terrain. They actually found that "a higher percentage of ejections over water may be below 500 feet."[3]

The number of crewmembers in an aircraft has been considered yet another potential risk factor. In 1957, Zeller briefly discussed the importance of communication between crewmembers in multiplace aircraft when contemplating the decision to eject. He suggested that ejection may be delayed when crewmembers do not have adequate knowledge of the action being taken by the pilot.[20] McCarthy confirmed the importance of crew coordination in multiplace aircraft, which he noted is especially critical in emergencies occurring at low altitude as in takeoff and landing.[8] Callaghan suggested that the decision to eject may be easier in a multiplace aircraft than a single-place one "partly because the evidence of two people will be more likely to withstand future criticism."[2]

Previous researchers have noted that the decision to eject is influenced by the nature of the emergency. Callaghan and Irwin hypothesized that "sudden emergencies cause quicker decisions and consequently higher ejection heights than more slowly developing emergencies."[1] Nakamura found that most pilots who delayed ejection did so while trying to recover from a mechanical failure.[11] Of the 12 cases he reviewed, 10 were associated with mechanical failure, whereas only 1 was associated with human error.[11] Similarly, Moreno Vázquez et al. found that ejection was delayed longer in accidents due to mechanical failure than in accidents due to human error.[10] On the other hand, after questioning 20 Indian Air Force ejectors, Taneja et al. concluded that the decision to eject may actually be easier when an aircraft is rendered uncontrollable by a mechanical fault rather than precipitated by the aviator's own actions.[16] Likewise, Callaghan and Irwin noted that a pilot may well make

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a greater effort to recover an aircraft "if the difficulty is of the pilot's own making (either an error or even an action which might have been performed better)."[2]

Type of aircraft has been considered a potential risk factor as well. Collins et al. noted that injuries were considerably more common during ejections from bombers than from fighters and trainers.[4] They attributed this difference to the fact that emergencies requiring ejection occur much less frequently in multiengine bombers than in single-engine aircraft, so bomber crews are less prepared when such emergencies do happen.

Finally, the altitude at the onset of the mishap has been considered a potential risk factor. Callaghan and Irwin suggested that mishaps that begin at a low altitude are more likely to lead to delayed ejection as a crewmember takes time to weigh the survival advantages of an attempt to land against those of ejection near the ground.[2] In his review of German Air Force ejections, Werner found no significant correlation between altitude and serious injuries, but a higher rate of minor injuries in mishaps occurring between 500 (152.4 m) and 5000 ft (1524 m).[18]

The studies described above were primarily concerned with ejection-related injuries and fatalities and only tangentially addressed delays in the ejection decision. Additionally, the studies of foreign air force experiences were limited due to the small number of ejections available for review. This study examined a larger sample of ejections to focus specifically on those factors associated with the timing of an aviator's decision to eject. The goal was to more accurately describe the delayed ejector in the hopes that such information may be used to educate aircrews, encourage more timely ejection decisions, and ultimately prevent injuries and save lives.

METHODS

Data Collection

Following any mishap that results in the destruction of an aircraft, the USAF convenes a board of investigators whose task is to identify factors that caused or contributed to the mishap with the goal that such information may then be used to prevent future mishaps. For each mishap, investigators produce a report summarizing mishap events and detailing the findings of their investigation. Since 1993, reports from all mishaps have been compiled in the Air Force Safety Automated System (AFSAS) online database, which is maintained by the Air Force Safety Center. Data for this project were extracted from the mishap reports contained in this database.

AFSAS was queried to identify all flight mishaps in which an ejection-seat equipped aircraft was destroyed. Mishaps that occurred on the ground were not included for analysis if aircrew had not demonstrated a clear intent to fly. Specific data fields recording the age, grade, Air Force Specialty Code, crew position, total flight hours, and altitude at ejection for each mishap crewmember were reviewed. Further review of the narrative and findings sections of each mishap report allowed extraction of additional data as necessary. Some data that were missing after this review were provided by Air Force Safety Center personnel who had access to additional sections within the AFSAS mishap reports. The study protocol was approved by the Office of Research of the Uniformed Services University of Health Sciences, Bethesda, MD.

Study Design

This was a case-control study. Cases consisted of aviators determined to have delayed ejection below recommended minimum altitudes. Controls consisted of aviators determined to have ejected at or above recommended minimum altitudes.

Review of mishap reports was begun with the intention of using a very simple algorithm for classifying crewmembers as delayed (case) or timely (control) ejectors. In accordance with aircrew guidance, a delayed ejector was to be defined as a crewmember who failed to initiate ejection, initiated ejection below 2000 ft (609.6 m) above ground level (AGL) under controlled flight conditions, or initiated ejection below 10,000 ft (3048 m) AGL under uncontrolled flight conditions. Crewmembers who initiated ejection at or above 2000 ft AGL under controlled flight conditions and at or above 10,000 ft AGL under uncontrolled flight conditions were to be classified as timely ejectors. This algorithm is outlined in **Fig. 1**.

It soon became apparent that this algorithm did not accurately identify all aviators who had ejected in a timely manner. The algorithm did not account for emergencies that began below 2000 ft (609.6 m) AGL and did not consider at what point during an emergency an aircraft became uncontrolled. For example, an aviator involved in an emergency that begins immediately on takeoff may take time to ascend prior to ejecting. If this aviator ejects below 2000 ft AGL, he or she has not necessarily delayed ejection. Likewise, a mishap aircraft may be controlled above 10,000 ft (3048 m) AGL, but become uncontrolled as it descends between 2000 and 10,000 ft. If the aviator ejects immediately on loss of control, he or she has not necessarily delayed ejection. To address such concerns, the more complex algorithm outlined in **Fig. 2** was developed.

Based on the literature review, 11 exposure variables were identified as possibly associated with delayed ejection. The Introduction provides details on these variables. Access to the narrative and findings sections of U.S. Navy mishap reports was not granted, so Navy crewmembers could not be accurately classified as timely or delayed ejectors. As a result, data on Naval aviator ejections were not included in the data analyzed for this project. Because all data analyzed were provided by the USAF, crewmember military branch was not further explored as a potential risk factor for delayed ejection. Additionally, data regarding whether an emergency occurred over a populated or unpopulated area were available for very few mishaps. This potential risk factor was likewise not explored, although data regarding whether an emergency occurred over land or over water were considered likely to provide related information. The exact altitudes at which emergencies began were not clearly identified with precision in many mishap reports, so this potential risk factor was also excluded from analysis. Ultimately, the

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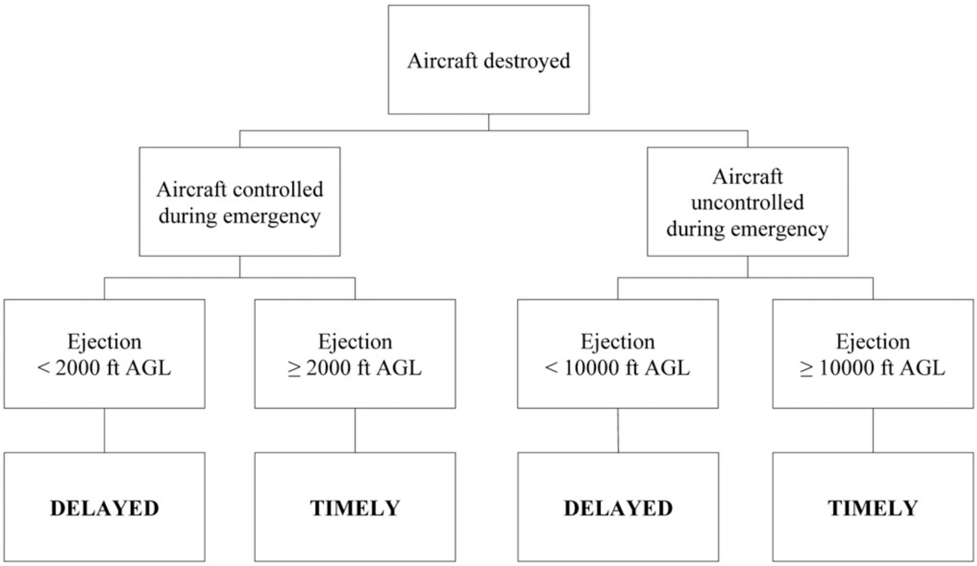

Fig. 1. Original algorithm for classifying cases and controls.

following eight exposure variables selected from those identified in the literature review were considered possible risk factors for delayed ejection: age (<35 or ≥35), military rank (enlisted, junior officer, senior officer, or foreign military/civilian/unknown), total flight hours (<500, 500–1500, or >1500), location of mishap (over land or over water), number of crewmembers in mishap aircraft (single crewmember or multiple crewmembers), crew position (pilot or nonpilot), nature of emergency (collision, mechanical, or human factors), and type of aircraft (fighter/attack, trainer, or bomber/other). Collisions included any in-flight collision with other aircraft or wildlife. Human factors included gravity-induced loss of consciousness, spatial disorientation, controlled flight into terrain, and other unknown or unspecified acts of commission or omission by crewmembers aboard the aircraft.

Statistical Analysis

SPSS 20.0 (IBM, Armonk, NY) was used for all analyses. Descriptive statistics were calculated for all proposed exposure variables. Means and standard deviations were calculated for age and flight hours. These two continuous variables were then converted to categorical variables for further analysis. A Chi-squared test was used to assess the univariate association between each exposure variable and the odds of delayed ejection. Odds ratios (OR) and 95% confidence intervals (95% CI) were calculated for each level of the exposure variables. A baseline level that was presumed to have the lowest odds of delayed ejection was selected for each variable. This level was then compared to the odds of delayed ejection at other levels. All variables were entered into a multivariate logistic regression with the odds of delayed ejection as the dependent variable. Variables were then removed in a stepwise fashion to find the most parsimonious set of predicting variables. Covariates that were significantly ($P < 0.10$) associated with the odds of delayed ejection were included in the final model.

RESULTS

In total, 366 aviators were crewmembers in ejection-seat equipped USAF aircraft destroyed during flight mishaps between 1993 and 2013. Of these aviators, 201 (54.9%) were determined to have delayed ejection below recommended minimum ejection altitudes. Overall, crewmembers were an average of 33.2 ± 6.2 yr old and had flown an average of 1797.7 ± 1142.9 total flight hours. Mean ages and flight hours were similar between cases (33.4 ± 6.6 yr, 1845.0 ± 1194.0 h) and controls (33.0 ± 5.8 yr, 1742.9 ± 1139.9 h).

Table I shows the univariate associations between the odds of delaying ejection and the eight covariates. Increased odds of delaying ejection were associated with crewmember flight hours below 500 or above 1500 and a mechanical or human factors (compared to collision-related) nature of the in-flight emergency. Decreased odds of delaying ejection were associated with fighter and attack aircraft compared to bombers and reconnaissance aircraft. The following variables were not associated with the odds of delaying ejection: age, military rank, number of crew in aircraft, crew position, and location of mishap.

Table II shows the results of the backward stepwise multivariate logistic regression analysis. There were 335 crewmembers (91.5%) who had complete data and could be included in the analysis. Independent risk factors for delayed ejection included crewmember flight hours exceeding 1500 and a mechanical or human factors related nature of the in-flight emergency.

DISCUSSION

This study found that 54.9% of USAF aviators involved in in-flight emergencies resulting in the destruction of an ejection-seat equipped aircraft between 1993 and 2013 delayed ejection. Delayed ejection has been associated with increased risk of injury and fatality in multiple studies, but all recent studies have examined relatively few (i.e., less than 150) ejections and none have investigated factors specifically associated with a delay in the decision to eject. Although the last study to consider a large number of ejections was published 45 yr ago, its conclusions were essentially the same as the smaller studies published since that time. In 1968, Collins et al. reviewed all USAF accident reports involving escape or attempted escape from ejection-seat equipped aircraft between 1962 and 1966. Of the 835 ejections reviewed, 135 resulted in fatal injury, with 59% of the deaths "due to insufficient time for parachute canopy deployment to

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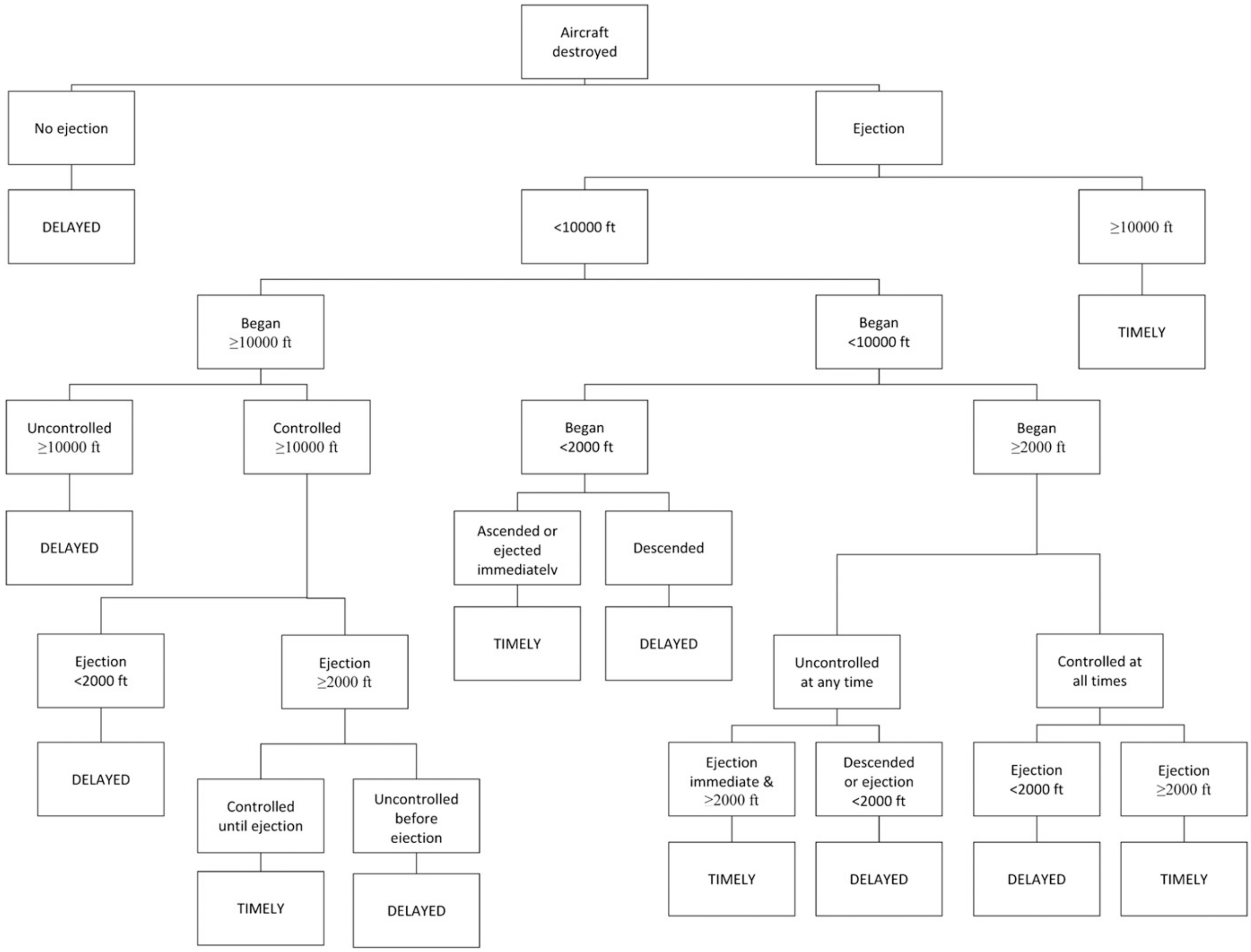

Fig. 2. Final algorithm for classifying cases and controls.

produce effective deceleration; in other words, outside the envelope."[4] The authors concluded that efforts should be exerted toward "extending the performance envelope of the current egress systems and… putting more ejections within this envelope through training to reduce delayed ejections."[4]

Since that time, the performance envelope of egress systems has been dramatically improved. Today, many USAF high-performance aircraft are equipped with ejection seats capable of "zero-zero" performance, requiring no forward velocity or altitude above the ground to initiate a successful ejection. Although all aircrew receive training on the importance of ejecting above recommended minimum altitudes, when faced with an actual emergency, over half delay ejection.

The current study examined a large number ($N = 366$) of crewmembers who ejected or should have ejected over a 20-yr period. Of the multiple potential risk factors considered, only aircraft category, crewmember flight hours, and the nature of the emergency showed any significant association with a crewmember's odds of delaying ejection. This study showed no significant association between a crewmember's age and odds of delaying ejection. This finding contrasts with the conclusions of a 1996 study of 60 Bulgarian aircrew ejections in which Milanov found no fatalities among the seven ejectees in his oldest age category (40-49 yr old).[9] Although the small number of subjects in each age group limited Milanov's ability to detect significant differences, he attributed the lack of fatalities among the oldest aviators to their flying experience and training.[9] In the current study, although age was not significantly associated with delayed ejection, the relationship of experience and delayed ejection was more complex.

Several previous studies explored the relationship between experience and the risk of adverse outcomes in ejection. As early as 1957, Zeller included a pilot's total flying experience among his list of factors associated with ejection.[20] In their 2001 study of 30 pilots flying 600 simulator sorties, Callaghan and Irwin classified pilots according to total flight hours in the study aircraft and found no relationship between experience and ejection decision height.[2] This study also defined low experience as less than 500 h (8 pilots), medium experience as 500 to 1500 h (14 pilots), and high experience as greater than 1500 h (8 pilots), but the ability of the study to detect significant differences was limited by the small numbers in each group. The

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Table I. Univariate Association Between Delayed Ejection and Proposed Risk Factors.

VARIABLE	LEVEL	*N*	% DELAYED	OR* (95% CI)	CHI-SQUARED *P*-VALUE
Age	> 35	133	58.6	1	0.248
	≤ 35	231	52.4	0.78 (0.50-1.19)	
Military Rank	Senior Officer (≥ O4)	141	55.3	1	0.191
	Junior Officer (O1-O3)	205	53.7	0.94 (0.61-1.44)	
	Enlisted	2	0.0	—-	
	Civilian or Unknown	18	72.2	2.10 (0.71-6.21)	
Flight Hours	500-1500 h	94	39.4	1	**0.004**
	> 1500 h	190	**59.5**	**2.26 (1.36-3.75)**	
	< 500 h	51	**58.8**	**2.20 (1.10-4.41)**	
Nature of Emergency	Midair Collision	71	29.6	1	**0.000**
	Mechanical	166	**44.6**	**1.92 (1.06-3.47)**	
	Human Factors	129	**82.2**	**10.97 (5.56-21.67)**	
Aircraft Category	Bomber/Other	33	72.7	1	**0.023**
	Fighter/Attack	278	**51.1**	**0.39 (0.18-0.87)**	
	Trainer	55	63.6	0.66 (0.26-1.69)	
Number of Crew	Single Crewmember	221	53.8	1	0.611
	Multiple Crewmembers	145	56.6	1.12 (0.73-1.70)	
Crew Position	Pilot	332	54.8	1	0.906
	Non-Pilot	34	55.9	1.04 (0.51-2.13)	
Location of Mishap	Over Water	61	47.5	1	0.205
	Over Land	305	56.4	1.43 (0.82-2.48)	

* Bold ORs indicate significant results. $P < 0.05$.

current study assessed both military rank and crewmember flight hours as surrogates for experience. Although no association was noted between a crewmember's rank and odds of delaying ejection, a crewmember's flight hours were significantly related to the timeliness of the ejection decision. Univariate analysis demonstrated increased odds of delaying ejection among both crewmembers with fewer than 500 flight hours and crewmembers with greater than 1500 flight hours. Multivariate analysis confirmed that crewmembers with more than 1500 flight hours were over twice as likely to delay ejection as crewmembers with 500 to 1500 flight hours.

While many human factors undoubtedly influence the timing of an aviator's decision to eject, two in particular are commonly associated with an excess, rather than a lack, of experience. Although both novice and experienced aviators may be subject to overconfidence and complacency, these are among the only human factors frequently considered to increase with experience. The FAA defines complacency as "overconfidence from repeated experience on a specific activity."[5] In "Complacency: The Grim Reaper of Aviation," Rieger notes that "It's spooky, but the more experienced and skillful a pilot is, the more likely he or she might fall victim to complacency."[14] In "Complacency: Is the term useful for air safety," Wiener notes that "factors like experience, training and knowledge contribute to complacency."[19] If complacency and overconfidence do in fact increase with experience, then the findings of this study suggest that these two human factors may be among those that are most likely to exert an adverse effect on the timing of ejection.

Table II. Multivariate Logistic Regression with Delayed Ejection as Dependent Variable.

VARIABLE	LEVEL	*N*	OR* (95% CI)	*P*-VALUE
Flight Hours	500-1500 h	94	1	
	> 1500 h	51	**2.26 (1.30-3.94)**	**0.00**
	< 500 h	190	2.08 (0.96-4.49)	0.06
Nature of Emergency	Midair Collision	71	1	
	Mechanical	166	**1.99 (1.05-3.77)**	**0.04**
	Human Factors	**129**	**11.04 (5.35-22.80)**	**0.00**

* Bold ORs indicate significant results. $P < 0.05$.

Multiple mishap reports reviewed for this study described aviators consciously delaying ejection to avoid crashing into populated areas. This reason for delay has also been reported in several previous studies of aircraft ejections.[3,10,15] Although it seems reasonable to assume that crewmembers would be more likely to delay ejection when flying over populated land versus open water, no such association was found in the current study. In this study, ejectors were classified as over land or over water based on the terrain that their aircraft impacted rather than the terrain over which the in-flight emergency began. Mishap narratives described situations in which an emergency began over land but ended in water due to the pilot's clearly vocalized decision to avoid crashing in a populated area. At least one mishap narrative also described the opposite scenario, in which an emergency began over cold water but the pilot, who was not wearing an anti-exposure suit, intentionally delayed ejection in an effort to eject over land. The data analyzed may not accurately represent the actual factors associated with these crewmembers delaying their decisions to eject.

Three previous studies suggested that the number of crewmembers in an aircraft may affect the timing of those crewmembers' decisions to eject.[2,8,20] The current study, however, found no association between the number of crewmembers and the odds of delaying ejection. Crew position in multiplace aircraft was also not significantly related to the odds of delaying

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ejection. Although communication and crew coordination may factor into ejection decisions, some multiplace high performance aircraft are now designed to eject all crewmembers if any one crewmember initiates the ejection sequence and, as a result, the ejection decision frequently becomes essentially a single crewmember's decision.

The most significant risk factor for delayed ejection identified by this study was the general nature of the emergency that ultimately led to ejection. When compared to in-flight collisions with other aircraft or wildlife, delayed ejection was almost twice as common in emergencies of a mechanical nature and over 11 times as common in emergencies originating from aircrew human factors. Multiple authors have commented on the relationship between the cause of a mishap and the timing of an aviator's decision to eject.[1,9,16] Nakamura and Moreno Vázquez found that delay was more common in mishaps related to mechanical failure than in those associated with human error.[10,11] Callaghan and Taneja suggested the opposite.[2,16] The disparate data between studies may reflect cultural issues. As noted, my study supports the latter conclusion. Given the design of this study, this finding is expected. For the purpose of this study, human factors mishaps included such physiological events as gravity-induced loss of consciousness in which the aviator was incapacitated, as well as spatial disorientation in which the aviator was unaware that an emergency was even occurring. In such situations, delayed ejections are common if ejection occurs at all.

Univariate analysis suggested that crewmembers in fighter and attack aircraft are less likely to delay ejection than those in bombers and reconnaissance aircraft. This was largely due to the lower proportion of fighter and attack aircraft pilots with over 1500 flight hours and the lower proportion of fighter and attack aircraft mishaps with human factors causes. The proportion of pilots with over 1500 flight hours was 56% for fighter and attack aircraft and 70% for bomber and reconnaissance aircraft. The proportion of mishaps with human factors causes was 34% for fighters and attack aircraft and 58% for bombers and reconnaissance aircraft. Thus, the association between aircraft category and delayed ejection was not found to be significant after analysis using multivariate logistic regression to adjust for potentially confounding covariates, including flight hours and the nature of the emergency. While Collins et al. suggested that increased risk of injury among those who eject from bombers may be due to the fact that emergencies requiring ejection occur much less frequently in multiengine bombers than in single-engine aircraft, this effect may be attenuated by the fact that bombers have spent a larger proportion of their time at higher altitudes since 1995 (when bomber employment tactics moved from a low-level penetrating role to a mid- to high-altitude standoff role); thus, crewmembers are frequently afforded more time to troubleshoot emergencies and decide to eject before descending below recommended minimum ejection altitudes.[4] The limited number of ejectors from bombers and reconnaissance aircraft (33 crewmembers in 12 mishap aircraft) also limits the power of this study to detect significant differences in the odds of ejection delay.

There are several important limitations to this investigation. First, the investigation was retrospective and observational in design and as such may provide evidence of association, but no strong evidence of causation as might be more easily inferred from a randomized intervention trial. Second, a single investigator classified subjects as cases or controls and designated whether or not each subject had been exposed to each potential risk factor. As noted in the Methods section of this report, classification of case and control status (and occasionally exposure status) was not always a straightforward process given the available data and current aircrew guidance on minimum ejection altitudes. Attempts were made to mitigate any potential bias by developing and adhering to an algorithm outlining my case selection process. This algorithm became increasingly complex and required information on the altitude at which three key mishap events occurred – the onset of the emergency that led to ejection, the loss of aircraft control, and each crewmember's ejection. The altitude at which control was lost, or whether control was lost at all, was the most difficult to clearly identify. The interrater reliability of the classification algorithm was assessed by an independent review of 37 randomly selected subjects that showed 95% concordance, suggesting that the algorithm was a reasonably reliable but imperfect tool. Intrarater reliability was not assessed. The data required to confidently classify each subject were readily available in some mishap reports, but required more inference from related data in other reports. Third, previous reports on aircrew ejections had focused on ejection-related injuries and fatalities, which were more clearly defined and readily available outcome measures. While injury and death occur more frequently when ejection is delayed, some delayed ejectors survive unscathed while some timely ejectors are injured or killed. Thus, the findings of this study may not be directly comparable to those of the other investigations referenced.

Nevertheless, this study offers results based on a large number of ejections over a 20-yr period and the findings may be readily translated into evidence-based interventions to change aircrew behaviors and save aircrew lives. An approach using the Health Belief Model may be most appropriate for addressing the problem of delayed ejection. The Health Belief Model aims to change an unhealthy behavior by influencing an individual's perceptions of his or her susceptibility to a bad outcome, the severity of the resulting condition, and barriers to change.[12] The severity of delaying ejection has been demonstrated by multiple earlier studies – delayed ejection is the most important factor contributing to severe injury or death during ejection attempts. An aviator's susceptibility to delaying ejection has been suggested by previous reports and refined by the current investigation – over half of crewmembers delay ejection during an unrecoverable in-flight emergency, but those with fewer than 500 flight hours or greater than 1500 flight hours are particularly likely to do so. Future aircrew training should be tailored to highlight these findings. This study identified two important barriers to a timely decision to eject. First, human factors that incapacitate or disorient an individual delay ejection and must be addressed. Second, guidance on minimum ejection altitudes

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must be simple, clear, straightforward, and unambiguous if it is to be effective in the time-compressed, task-saturated, life-or-death moments comprising an unrecoverable in-flight emergency. Elimination of these obstacles can contribute to successful ejection.

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Author and affiliation: John E. Miles, M.D., M.P.H., U.S. Air Force School of Aerospace Medicine, Wright-Patterson AFB, OH.

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