EVALUATING THE EFFECT OF AIRCREW FLIGHT EVENTS ON AMC AIRCRAFT SAFETY INCIDENTS

Graduate Research Paper

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Abstract

Aviation mishaps are complicated events that involve a variety of contributing factors. The Federal Aviation Administration (FAA) and United States Air Force (USAF) determine the propensity for aviation mishaps by comparing total flight hour to mishaps. The USAF uses a mishap per 100,000 flight hour ratio, while the FAA uses a mishap per million flight hours as well as mishaps per million departures. This research aims to determine not only if departures are a better metric for determining possible aviation mishaps, but also other flight events, such as air refueling or assault landings. A variety of statistical tests will be performed to compare mobility aircraft safety data to determine if flight events or departures are more explanatory with respect to mishaps than flight hours. The airframes will also be compared against each other to determine any patterns among mobility aircraft mishaps.

To my family.

Acknowledgments

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Barry V. McKeown

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EVALUATING THE EFFECT OF AIRCREW FLIGHT EVENTS ON AMC AIRCRAFT SAFETY INCIDENTS

I. Introduction

General Issue

In aviation, mishaps are significant events that can cause massive amounts of damage and result in catastrophic losses to both lives and property. Determining the cause of mishap occurrence is the first step in preventing them. Understanding when a mishap is likely to occur will allow decision makers to enact preventative measures to stave off future aircraft mishaps. By analyzing past mishap data, this research hopes to determine the most likely indicator of an aircraft mishap among three factors: flight hours, departures, and flight events.

Flight hours have been widely used as mishap indicators, and are correlated to mishaps (see Figure 1). The more hours an aircraft or fleet of aircraft flies, the greater the chance it will encounter an unsafe situation that leads to a mishap. A dangerous situation could be brought on by any number of factors, such as adverse weather, pilot fatigue, or mechanical failure to list a few. There are also aspects of flights that are more prone to mishap risk than others. For example, departures and landings involve aircraft maneuvering at low speed near the ground and the chance for a mishap is significantly increased. Therefore, the more departures and landings performed by pilots exposes them to greater mishap risk. Several studies have already shown that takeoffs, climbs, approaches, and landings account for the majority of aircraft mishaps. One such study shows the takeoff and the climbing period accounts for approximately 17.5 percent of mishaps involving total aircraft loss (Tiabtiamrat & Wiriyacosol, 2010).

The United States Air Force (USAF) aviation safety program's primary metric utilizes the number of mishaps per 100,000 flight hours. This metric does not account for the varying degrees of risk that different flight events may pose. Air Force pilots perform many different flight events due to the diversity of mission requirements. Thus, it is logical to understand how flight events may be related to aircraft mishaps.

The Federal Aviation Administration (FAA) tracks aircraft mishaps by both flight hours and departures for Federal Aviation Regulation (FAR) Part 121 commercial carriers, which accounts for the majority of aircraft activity for civilian aircraft. Most civilian aircraft only takeoff, climb, cruise, descend, and land. Whereas USAF aircrews are required to perform a wider variety of events, such as assault landings, air-drop, low-level flying, and air-to-air refueling. Therefore, this research investigates if there is also a relationship between flight events and aircraft mishaps for Air Force aircraft.

Problem Statement

The aviation safety community has several measures for determining the likelihood of safety incidents, but little research exists to delineate the differences between these measurements. This research aims to compare the predictive power of flight hours, departures, and flight events on aircraft mishaps.

Research Objectives/Questions/Hypotheses

The primary research question to be answered is which aviation mishap metric provides a stronger explanation of aircraft mishaps? The hypothesis to be tested is if flight events provide more explanative power than flight hours' explanation to aircraft mishaps. Furthermore, this research seeks to determine any possible relationships

between mishap rates among the C-5, C-17, C-130, KC-10, and KC-135 with respect to flight hours, flight events, or departures.

The reason these airframes or Mission Design Series (MDS) may differ by departures or flight events rather than flight hours alone is they all have unique mission sets. The C-5 is a strategic airlifter, performing similar flight profiles to commercial airliners. In contrast, the C-130 is a tactical airlifter that employs using shorter flights and low-level flying, in addition to airdrop to accomplish its mission. Whereas the C-17 performs both the strategic and tactical airlift missions. The KC-10 and KC-135 are both aerial refueling platforms, with some cargo capability. They have additional tactical requirements due to the aerial refueling mission but require monthly flight events between the C-5 and C-17 requirements. The C-5 is the only airframe that does not perform the aeromedical evacuation role, and the KC-10 is rarely used for this purpose in comparison to the other airframes. Table 2 depicts the average Air Force Instruction (AFI) 11-2MDSv1 requirements per month by airframe. This average was built by using the total flight events required per month by airframe and is described in greater detail below.

Research Focus

In addition to flight hours and flight events, various other indicators of aircraft mishaps have been identified, including fatigue, maintenance failure, and weather. Many of these causes can be distilled down into three categories: flight hours, flight events, and human factors. The focus of this research will be to determine a method for explaining aircraft mishaps based on flight hours, flight events, or departures as a particular flight

event, which inherently include human factors, maintenance failure, and weather. The model will incorporate one, two, or all three measures as appropriate to better explain why aircraft mishaps occur and if they occur, more frequently based on the specific mission set for that particular airframe.

Methodology

The methodology employed will be a regression model to determine the best fit for mishaps based on flight hours, departures, or flight events. The data used to develop this model was broken down by governmental Fiscal Year (FY), or the period from 1 October to 30 September. The time period of interest was the last ten years of available data, FY2006 through FY2015. The number of mishaps during this period was obtained from the USAF Safety Center, broken down by airframe, month, and class of mishap (Class A, B, C, or D). These classes are defined in AFI 91-204, Safety Investigations, and Reports, with Class A being the most severe. Table 1 depicts USAF and FAA mishap classification levels (Federal Aviation Administration, 2014; Department of the Air Force, 2009). Note the USAF and FAA categories are similar, but not identical. In order to compare the two sets of data, the class of mishap will not be regarded, but future research could determine if any of the factors of interest (flight hours, flight events, or departures) correlate to a particular mishap severity.

Flight hours and departures were obtained from the Reliability and Maintainability Information System (REMIS). The REMIS system collects data on a variety of Air Force systems, including flight hours and landings. For this study, the

number of landings collected by REMIS will be used as the number of departures, as to record a landing, an aircraft is required to depart.

Table 1: USAF and FAA Mishap Categories

USAF		FAA	
Class A	Direct mishap cost totaling $2,000,000 or more, OR a fatality or permanent total disability, OR destruction of a DoD aircraft	Major	The aircraft was destroyed, OR there were multiple fatalities, OR there was one fatality AND substantial damage to the aircraft
Class B	Direct mishap cost totaling $500,000 or more but less than $2,000,000, OR a permanent partial disability, OR inpatient hospitalization of three or more personnel	Serious	A single fatality without substantial damage to the aircraft, OR at least one serious injury AND the aircraft was substantially damaged
Class C	Direct mishap cost totaling $50,000 or more but less than $500,000, OR any injury or occupational illness that causes loss of one or more days away from work not including the day or shift it occurred OR an occupational injury or illness resulting in permanent change of job	Injury	Non-fatal accident with at least one serious injury but no substantial damage to the aircraft
Class D	Direct mishap cost totaling $20,000 or more but less than $50,000 OR any mishap resulting in a recordable injury or illness not otherwise classified as a Class A, B, or C mishap	Damage	No person was killed or seriously injured, but the aircraft was substantially damaged

This data will be analyzed using a variety of statistical methods to determine relationships between monthly flight hours, departures, flight events, and mishaps. The airframes will also be compared against each other to determine any relationships among them with regard to number of events required, hours flown, and mishaps that occurred over that ten-year period.

Limitations

Due to the limitations of the available data, several assumptions were required to proceed with this research. The data did not have associated pilot experience level tied to the mishap, so pilot experience is unknown. The flight data contained landing data, but not departure data, so departures must be inferred from the data. There were also no specific numbers of flight events available, as that data is only kept on a semi-annual basis and would not cover the entire ten-year period of the data. A number of events required by AFI 11-2MDSv1 may be accomplished in the simulator, so any estimated flight event data may not be accurate with respect to the specific types of events actually accomplished in the aircraft. Finally, the C-5M and C-130J were both introduced during this ten-year period, and their data did not sufficiently represent an established airframe. All of these limitations are addressed below.

Assumptions

Throughout this research, any reference to AFI 11-2MDSv1 flight event requirements were based upon a Flight Level B (FTL B) pilot. The AFI 11-2MDSv1 for all airframes investigated in this research defines FTL B as an "experienced [Mission Ready] crewmember" (Department of the Air Force, 2012a, 2012b, 2012c, 2012d, 2012e, 2016). These requirements are what a moderately-experienced aircraft commander (airline Captain equivalent) or a more highly-experienced instructor pilot would have to accomplish to maintain their flying currency on an annual or semi-annual basis. These comprise the majority of pilots that would be put in charge of an Air Mobility Command (AMC) mission or training flight, so this experience level is appropriate to use as the

flight event requirement baseline. This is because a Flight Level B pilot will more than likely be ultimately held responsible and accountable, either directly or indirectly, for any aircraft mishap that occurs.

Landings, and therefore departures, are known by month per airframe during the timeframe specified. However, actual the number of other flight events per month is unknown (i.e. air refueling events, low-level events, or assault landing events). This makes analyzing flight events more difficult, but it is not necessarily impossible to determine their possible effects. Firstly, since departures and landings account for more mishaps than climb, cruise, and descent, a greater degree of the explanatory power of flight events related to mishaps may be found in departures and landings. Secondly, merely using the estimated flight event data as an aggregate can help determine if there is an effect on aviation mishaps worthy of further investigation.

The absence of actual flight event data, while difficult, is not insurmountable. While REMIS only provides the number of landings, there are other events accomplished in-between. On a typical C-17 airdrop training profile, for example, one takeoff and landing from REMIS would indicate three to five airdrop events, at least one low-level event, three to five formation-related events, some type of approach (tactical or instrument), and possibly air refueling. If this were a C-17 overseas mission, it would include an overseas sortie event, and some type of approach, most likely instrument and possibly air-refueling, although air refueling is decreasingly likely over the past ten years due to the prevalence of C-17s with extended range tanks. Either of these sorties would result in at least three more events in addition to the takeoff and landing.

Since the required number of flight events per pilot and departures (takeoffs) or landings per month are given by AFI 11-2MDSv1, and the number of departures or landings for a given month is known based on REMIS data, the estimated number of events accomplished per month can be calculated. The result becomes a ratio by airframe multiplied by actual departures or landings to yield estimated monthly events. Equation 1 below further explains this process. This equation resulted in the ratios found in Table 2.

Using the C-17 as an example, AFI 11-2C-17v3 requires a total of 75 semi-annual flight events and one annual event for a Flight Level B pilot. Dividing 75 by 6, one by 12, and adding them results in an average of 12.6 required flight events per month. With ten required takeoffs (departures) per month, an average of 1.67 takeoffs are required each month. Dividing 12.58 monthly events by 1.67 monthly departures results in the 7.55 Event-to-Departure ratio listed in Table 2. In April of 2010, REMIS data shows there were 10,388 C-17 landings recorded. This means there were 10,388 takeoffs (departures). Multiplying these 10,388 departures by the 7.55 Event-to-Departure ratio yields an estimated 78,429 total flight events accomplished during that month.

$$E = \frac{D(T)}{TO}$$

Where:
E = estimated monthly events
D = actual monthly departures
T = required monthly 11-2MDSv1 total currency events
TO = required monthly 11-2MDSv1 takeoffs

Table 2: Event / Departure Ratios by Airframe

Airframe	Event / Departure Ratio
C-5	6.40
C-17	7.55
C-130	21.42
KC-10	8.95
KC-135	8.15

Many airframes allow pilots to complete flight currency events in the simulator. For example, C-17 pilots may accomplish 100% of their required takeoffs and landings in the simulator, but they may only accomplish 50% of their assault landings in the simulator (Department of the Air Force, 2012c). This does not mean that pilots do not accomplish any takeoffs or landings in the aircraft, as the cargo and passengers would never get anywhere. Since there is not an accurate way to estimate how many flight events pilots accomplish in the simulator and because the estimated flight event ratio is multiplied by an actual number of landings, the number of estimated flight events accomplished is assumed to be completed in the aircraft.

During the period from FY2006 to FY2015, both the C-5M and C-130J variants were introduced into the USAF inventory. In the case of the C-5M, it is an upgraded version of the C-5B with its chief improvements being new engines and improved avionics. On the other hand, the C-130J is a completely new airframe, not just an upgrade to the older C-130H. These new airframes did not have enough data to

differentiate them as separate entities for the entire time-frame, so the C-5 and C-130 data are assumed to encompass all variants. This means the data for those two airframes has absorbed any variation caused by introducing a new airframe.

The C-17 is not only an airland airframe but is also capable of performing airdrop. For this research, only the airland events required are used, because the hours flown and associated departures in the data cannot accurately be attributed to airland missions or airdrop missions. Since only approximately 30% of the C-17 crew force is airdrop qualified and an even lower percentage of the C-17 missions flown are airdrop in nature, the C-17 data are assumed to be airland data.

Implications

Implications for this research include the ability to explain why mishaps occur. From this information, Air Force leaders can make better decisions on safety and risk management policy by airframe. Currently, AMC has a robust Operational Risk Management (ORM) program for aviation, but this process is generic for all AMC aircraft (Air Mobility Command, 2016). The form accounts for crew fatigue via the length of the FDP and local aircrew show time, and it accounts for pilot experience in terms of total career flight hours. It does try to determine a risk based on "tactical" events during that duty day, but it does not try to determine which particular flight events will be flown in order to allow decision makers to approve mission risk at the appropriate level. This study attempts to differentiate aircraft based on events and to evaluate if flight events are a significant factor in mishap occurrence. Differentiating predictors of aircraft mishaps from airframe to airframe could also stem from the results of this research.

Eventually, after sufficient research and analysis, individual currency events or mission requirements may be correlated to a numerical risk value associated with mishap occurrence and mitigated appropriately via a specific ORM process.

II. Literature Review

Chapter Overview

This chapter will discuss various previous publications related to aviation safety. The primary focus of this chapter will be comparing the USAF and FAA methods for reporting aviation safety metrics to determine if there is a benefit to one over the other. Various causes for aviation mishaps will also be explored, to determine if one or more are more significant than flight hours. The majority of this exploration will focus on flight hours, as that is the current USAF method for determining aviation safety metrics.

USAF Method vs. FAA Method

The USAF safety program measures aircraft mishaps based on a mishap per 100,000 flight hour basis. The FAA measures aircraft mishaps per 1,000,000 flight hours as well as per 1,000,000 departures. The Y-axis values for Figure 1 through Figure 4 indicate the number of mishaps per million flight hours or departures for the FAA data or mishaps per 100,000 flight hours or departures for the USAF data. For example, in 2007, the FAA Part 121 carriers experienced 2.56 mishaps per million departures flown or 1.43 mishaps per million flight hours flown. Note the apparent correlation of the data as shown in Figure 1. For the sake of comparison, selected USAF airframe data is presented in Figure 2 through Figure 4.

The FAA data in Figure 1 shows correlated trends between hours and departures. Every time the mishap rate increases for departures, it increases for flight hours. The USAF data does not always follow this pattern, and it does not always follow it as closely as the FAA data when it does. For example, Figure 2 shows the C-5's mishap rate based

on flight hours declining sharply from FY2009 to FY2012, but from FY2010 to FY2011 the decrease in the mishap rate based on departures was slower than the rate based on flight hours. Additionally, the C-17 mishap rate based on flight hours from FY2008 to FY2009 increases, while the mishap rate based on departures during that period decreases. As a final example, Figure 4 depicts an apparent rise in mishaps per 100,000 departures for the KC-135 from FY2009 to FY2015, while the mishap rate due to flight hours appears to increase much more slowly. Why does one increase more rapidly than the other? Are KC-135s flying more flights over shorter distances or durations? One or two indicators do not adequately explain why the aircraft mishap rates perform the way they do.

These differences illustrate a possible deviation between USAF missions and FAA Part 121 commercial carrier flights. Determining the possible causes for these difference is the aim of this research and will be explored further in subsequent sections.

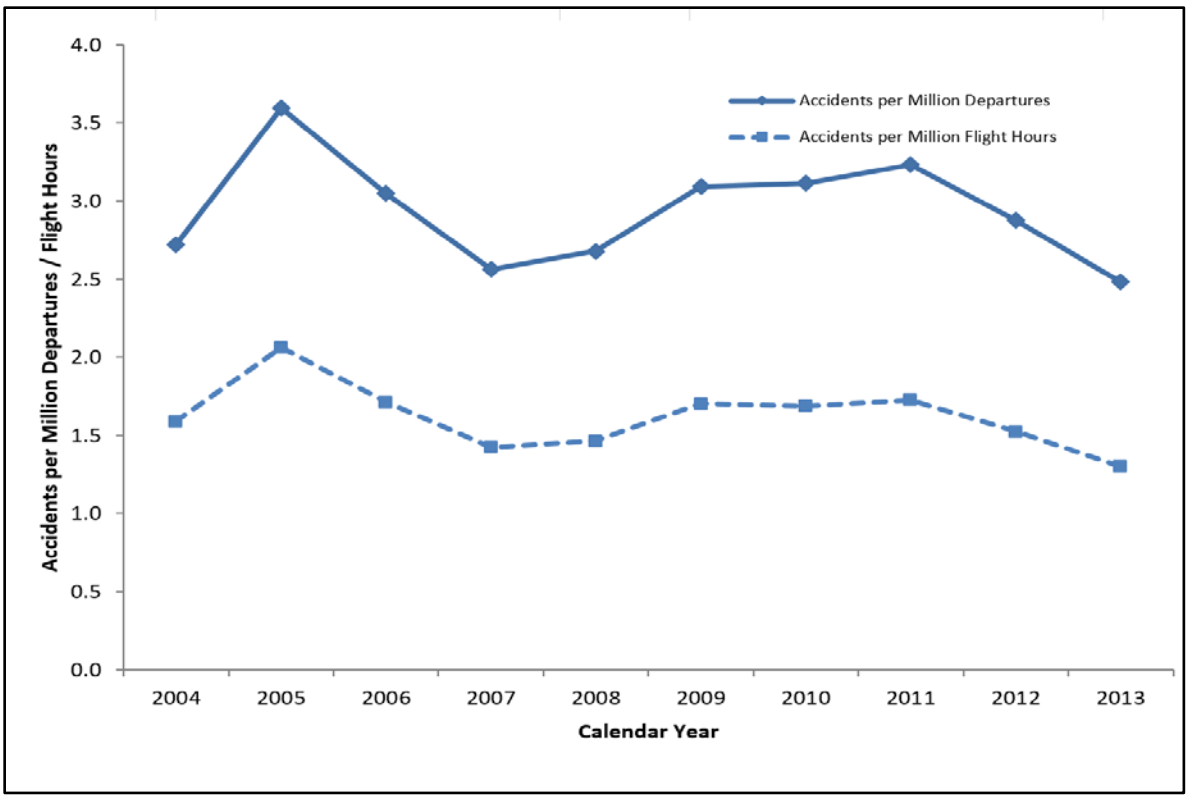

Figure 1: FAA Part 121 Accident Rates, Calendar Year 2004-2013
(Federal Aviation Administration, 2014)

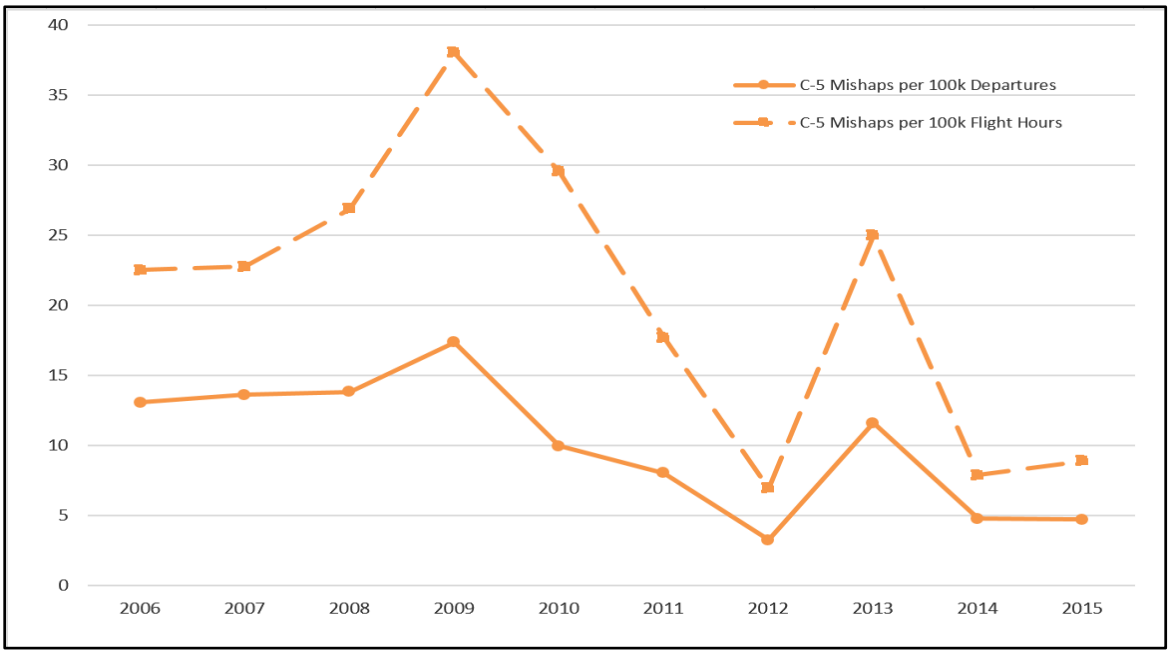

Figure 2: C-5 Mishap Rates, Fiscal Year 2006–2015

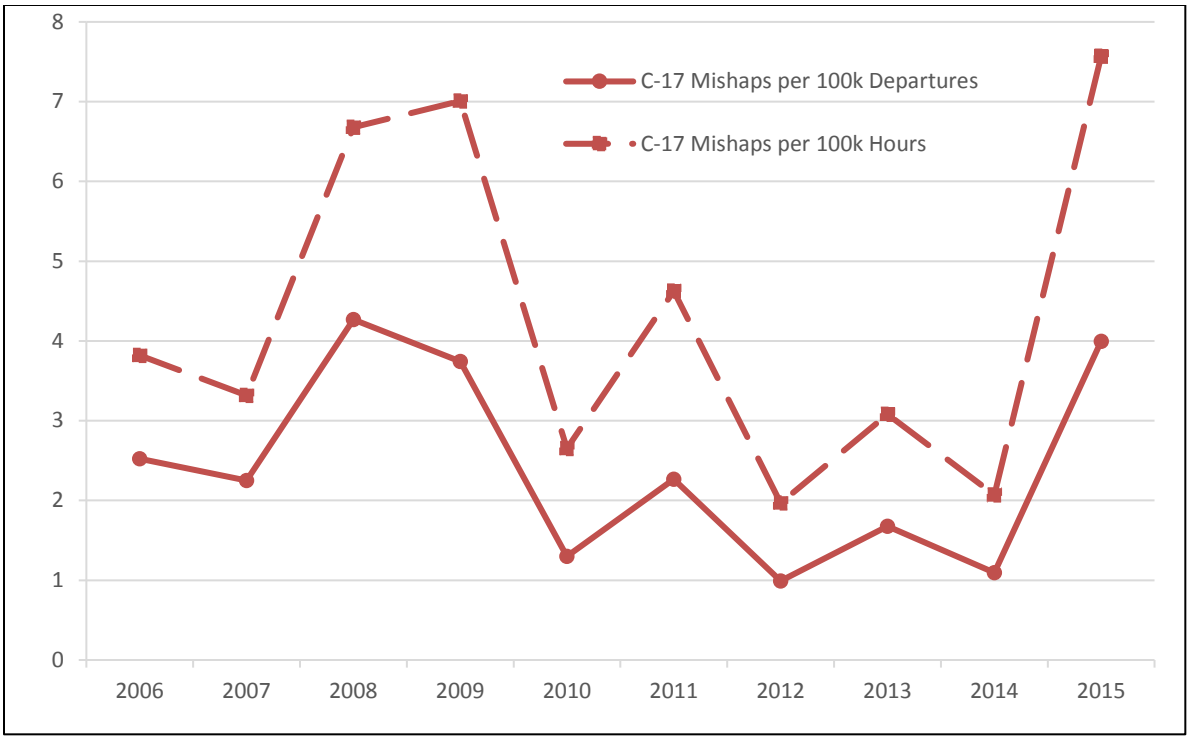

Figure 3: C-17 Mishap Rates, Fiscal Year 2006-2015

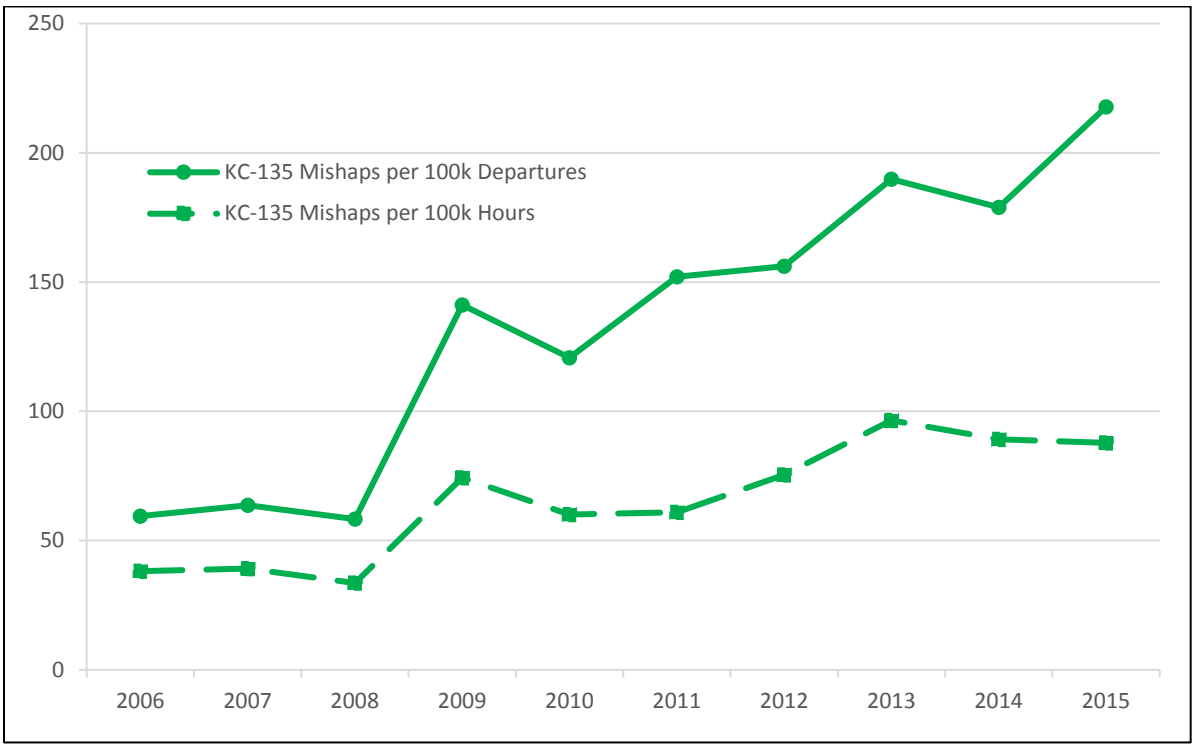

Figure 4: KC-135 Mishap Rates, Fiscal Year 2006-2015

Mishap Causes

There is a variety of possible causes for aviation mishaps. Several studies have been conducted to determine when and why mishaps are likely to occur. As has been previously mentioned, the majority of aviation mishaps occur during takeoff, approach, and landing (Tiabtiamrat & Wiriyacosol, 2010). The primary three to be investigated are flying more hours, performing more departures, and performing more flight events. All three of these expose the aircraft and crew to greater risk of a mishap. Other possible causes include human factors such as fatigue (Rosekind, Gander, Miller, Gregory, Smith, Weldon, Co, McNally, & Lebacqz, 1994), inexperience, or overconfidence (Boss, Depperschmidt, Mwavita, & Bliss, 2013), or organizational factors such as a "just get it done" culture or inconsistencies and unpredictability in scheduling (von Thaden, Wiegmann, & Shappell, 2006). These contributing factors, as well as others, such as weather and maintenance, will be further discussed below.

Hours

While the comparison of FAA and USAF methodologies includes a discussion of flight hours, it does not address a fundamental aspect of flight hours: pilot experience. In the aviation community, flight hours are often used to indicate pilot experience. As such, the USAF places restrictions on its pilots based on recent flight hours flown (Department of the Air Force, 2016) and qualification level (Department of the Air Force, 2015), but pilot experience is more than either of these. It is the combination of recent hours flown, total hours flown, and qualification level. The Air Force measures recent experience in 30-, 60-, and 90-day intervals to determine how much flying a pilot has done over the last three months and to ensure they are not overflying restrictions (Department of the Air

Force, 2016). The type and scope of flight hours are also not standardized, nor is the difference in flight hour quality tracked or measured throughout a pilot's career. This means an instructor pilot with 2,000 hours crossing the ocean has the same "quality" experience level as an instructor pilot with 2,000 hours instructing students in takeoff, landing, low-level flight, and airdrop. While the latter is more demanding, the former is weighed the same when measuring experience. To determine the impact on mishaps by events perceived more dangerous than cruising at altitude, this research will break out flight events as a way to try to measure the "quality," perceived danger, or increased risk of a particular type of flight hour.

Pilot experience is also ostensibly an indicator of the propensity to contribute to or avoid aviation mishaps, as more highly experienced pilots *should* be able to avoid mishaps. Determining what constitutes an experienced pilot can be somewhat subjective, but there are two standards which can be used as a guideline. The first is the legal requirement for Part 121 carriers to increase the pilot experience requirements and more stringent requirements for awarding Airline Transport Pilot (ATP) certificates after the 2009 Colgan Air accident near Buffalo, New York (U. S. National Archives and Records Administration, 2013a, U. S. National Archives and Records Administration, 2013b). This requires pilots to fly a minimum of 1,500 hours before awarding them their ATP certificate. The other standard that may be used is the USAF standard, and more specifically Air Mobility Command's standard. AMC outlines pilot experience requirement to upgrade to aircraft commander in each airframe's AFI 11-2MDSv1. The C-17 requirement is 1,000 total flight hours, including Undergraduate Pilot Training (UPT) student time, and 400 hours of C-17 flight experience (Department of the Air

Force, 2012c). A typical C-17 training sortie is approximately five flight hours, while a typical one-week overseas mission yields approximately 40 flight hours. This means if a pilot flies one training sortie and one overseas mission a month, they will gain 45 flight hours a month, or 540 flight hours a year. Assuming the pilot completes UPT with the typical 250 flight hours, at that rate it will take approximately 1.5 years to reach the 1,000 flight hour minimum experience required to upgrade to aircraft commander. Typically, a pilot will have 1,200 or 1,300 hours before upgrade, requiring an additional six months of experience.

In a study of 50 commercial aviation accidents from 1991 to 2010, 96% of the first officers involved had at least 2,000 flight hours at the time of the accident, with a mean number of hours 6,837 and a median 5,407 hours (Boss et al., 2013). That same study determined the captains involved in these accidents were extremely experienced, with a mean flight time of 11,993 hours and median of 11,500 hours at the time of the accident (Boss et al., 2013). The captains' flight experience ranged from 2,500 flight hours to 25,000 flight hours, while the first officers' flight time range from 1,096 flight hours to 17,734 flight hours, but the study found that pilot performance was not cited as a causal or contributing factor (Boss et al., 2013). Another study from 2001 shows that pilot experience is, in fact, significant to accidents where pilot error is a causal factor, but other external factors such as weather play a larger role than experience (Li, Baker, Grabowski, & Rebok, 2001). Based on the pilots' flight hours in these studies, pilot experience as measured in flight hours is not necessarily indicative of safer operations, and therefore basing aviation mishaps solely on flight hours may also not be significant.

While FAA Part 121 commercial passenger aviation is nearly homogenous, the USAF's variety of Mobility Air Force (MAF) aircraft performs vastly different missions. Like the MAF fleet and mission sets, general aviation also has a large pool of pilots with various experience levels and who do a wide variety of different flying (e.g. recreational, acrobatic, or for personal travel). In a 2012 report to Congress on general aviation safety, the Government Accountability Office (GAO) found that "a singular agency goal – a 10 percent reduction in the general aviation fatal accident rate per 100,000 flight hours …is not the most effective risk-based tool for achieving…safety gains" (USGAO, 2012). While this GAO recommendation is for general aviation, it flies in the face of the USAF safety program's only measure of safety success: a mishap rate based solely on flight hours. The disparate nature of the USAF's mission sets, large pool of pilots, and the vast difference between FAA Part 121 flying and the USAF's mission requirements show a striking similarity to the general aviation community and would indicate that there is more explanatory power to aircraft mishaps than merely flight hours that should be considered.

Departures

As previously noted in Figure 1 and Figure 2, the FAA tracks departure data as well as hourly data on aircraft accidents, while the USAF does not track departure data to determine mishap metrics. Whether or not this data is relevant is an important step in determining if hours are the most effective way of determining mishap causation. Even if mishap data can be explained one percent better utilizing departure data, that is an improvement in predicting and preventing mishaps. As previously noted, takeoff and climb account for 17.5% of all aviation accidents (Tiabtiamrat & Wiriyacosol, 2010). A

different study conducted by the Boeing Corporation showed that 12% of accident occurred during takeoff and climb, while those phases accounted for only two percent of total flight time for a 1.5-hour flight (Boeing Corporation, 2016). This implies that while departures account for a small portion of the flight time, they pose a significant risk for an aviation mishap. If this single flight event (departures) can show a higher propensity for risk of an aviation mishap, perhaps other specific events also show more explanatory power.

Human Factors

The human side of mishap analysis is complex and fluid. Individuals bring a unique set of experiences and talents that may make them more likely than someone else with equivalent flying hours to have a mishap. In order to keep human factors relevant to this discussion, only fatigue will be explored, as it is directly related to flight hours.

Fatigue is an important human factor when analyzing accidents of any type. Studies have been performed regarding both truck drivers and pilots with respect to fatigue. One such study on drivers and hours of service shows that fatigue has many contributing factors (Min, 2009). In this section, the upper left portion of Figure 5 will be discussed, namely work duration. A later section will discuss the bottom left portion regarding organizational factors.

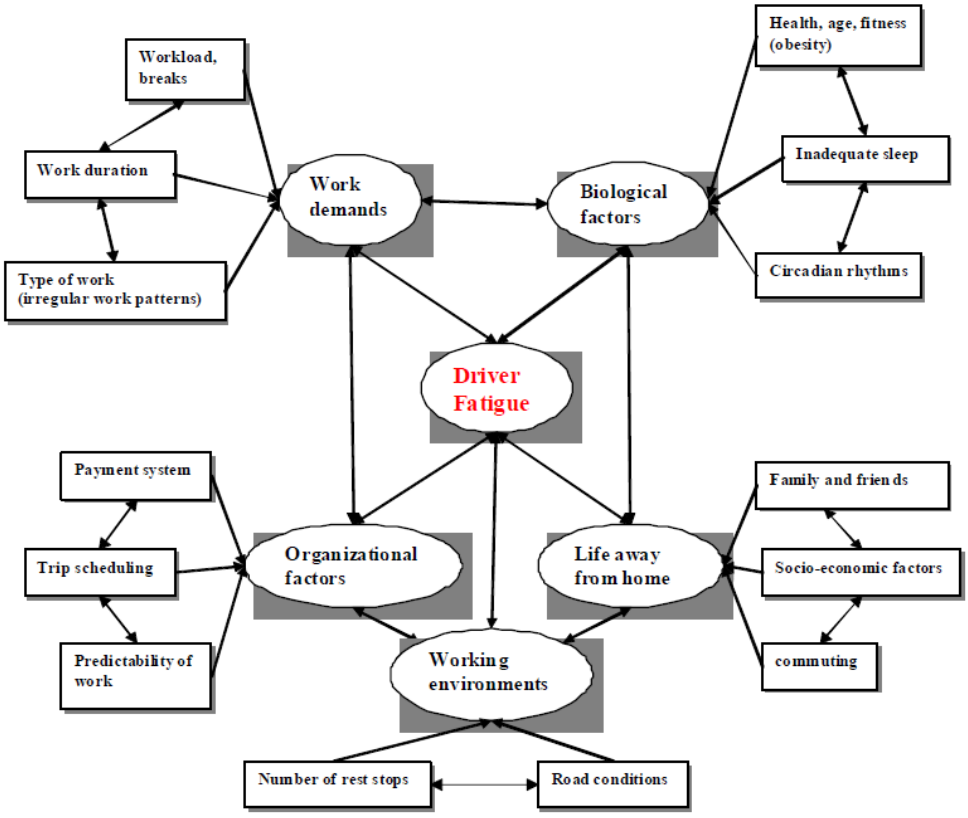

Figure 5: Factors Influencing Driver Fatigue (Min, 2009)

Much like any other transportation industry, the federal government, as well as foreign governments, have regulated the hours of service the operators may be on duty. For example, long-haul truckers are only authorized to drive 11 hours in a 14 hour duty period (U. S. National Archives and Records Administration, 2013d). The FAA has mandated that pilots may only log nine hours of actual flight time per Flight Duty Period (FDP), depending on scheduled report time in the local area. The pilot may be on duty, however anywhere from 9 to 14 hours depending on the scheduled report time and the number of flight segments in that FDP. Also, if the crew is augmented with additional pilots, the FDP may be extended based on how many augmenting pilots and what type of onboard crew rest facilities are available (U. S. National Archives and Records

Administration, 2013). Additionally, pilots may only log 100 hours in a 672 hour (28 day) period, 1,000 hours in 365 day period, 60 FDP hours in a 168 hour (7 day) period, or 190 FDP hours in a 672 hour (28 day) period (U. S. National Archives and Records Administration, 2013).

The USAF also places a flying hour and a duty day limitation on its pilots. AFI 11-202v3 determines the cumulative flight hour limits for USAF pilots. These restrictions are no more than 56 flight hours in seven days, 125 flight hours per 30 days, and 330 flight hours in 90 days. AFI 11-202v3 also outlines generically by aircraft category that pilots may not fly more than 16 hours un-augmented in a tanker/transport aircraft, with augmented operations not applicable (Department of the Air Force, 2016). Each airframe's AFI 11-2MDSv3 operating instruction further outlines pilot duty limits.

AFI 11-2C-17v3 limits basic crews to a 16-hour FDP and 18 hour Crew Duty Time (CDT) but allows augmented crews to fly a 24-hour FDP with a 24 hour and 45 minute CDT (Department of the Air Force, 2015). Much like the FAA, the USAF caveats augmented FDP based on the rest available, but in the C-17 it is limited by leg length of the flight. One flight segment of six hours or two segments of four hours are required to fly the unrestricted augmented CDT and FDP. Absent these requirements, augmented crews must adhere to the basic crew restrictions (Department of the Air Force, 2015).

Overall, flight hours is a powerful tool in determining why aviation mishaps occur, but this research shows that other factors should be considered in order to explain aviation mishaps more fully.

Organizational Factors

Each organization has its culture, and this culture can affect how employees perform. In a study on this subject, von Thaden et al. (2006) cite several examples in which organizational factors influenced safety, such as the Chernobyl meltdown, the *Challenger* and *Columbia* tragedies, and the King's Cross underground fire in London. Additionally, as depicted in the bottom left corner of Figure 5, several organizational factors influence operator performance and could lead to an increased risk for mishaps (Min, 2009). The Air Force also uses the Human Factors Analysis and Categorization System (HFACS) model, which depicts organizational factors that can contribute to accidents (Gibb & Olson, 2008). The top two sections of Figure 6 shows how organizational factors and unsafe supervision can set the stage for mishap conditions. These influences cannot be captured by only measuring mishaps during a certain number of flight hours.

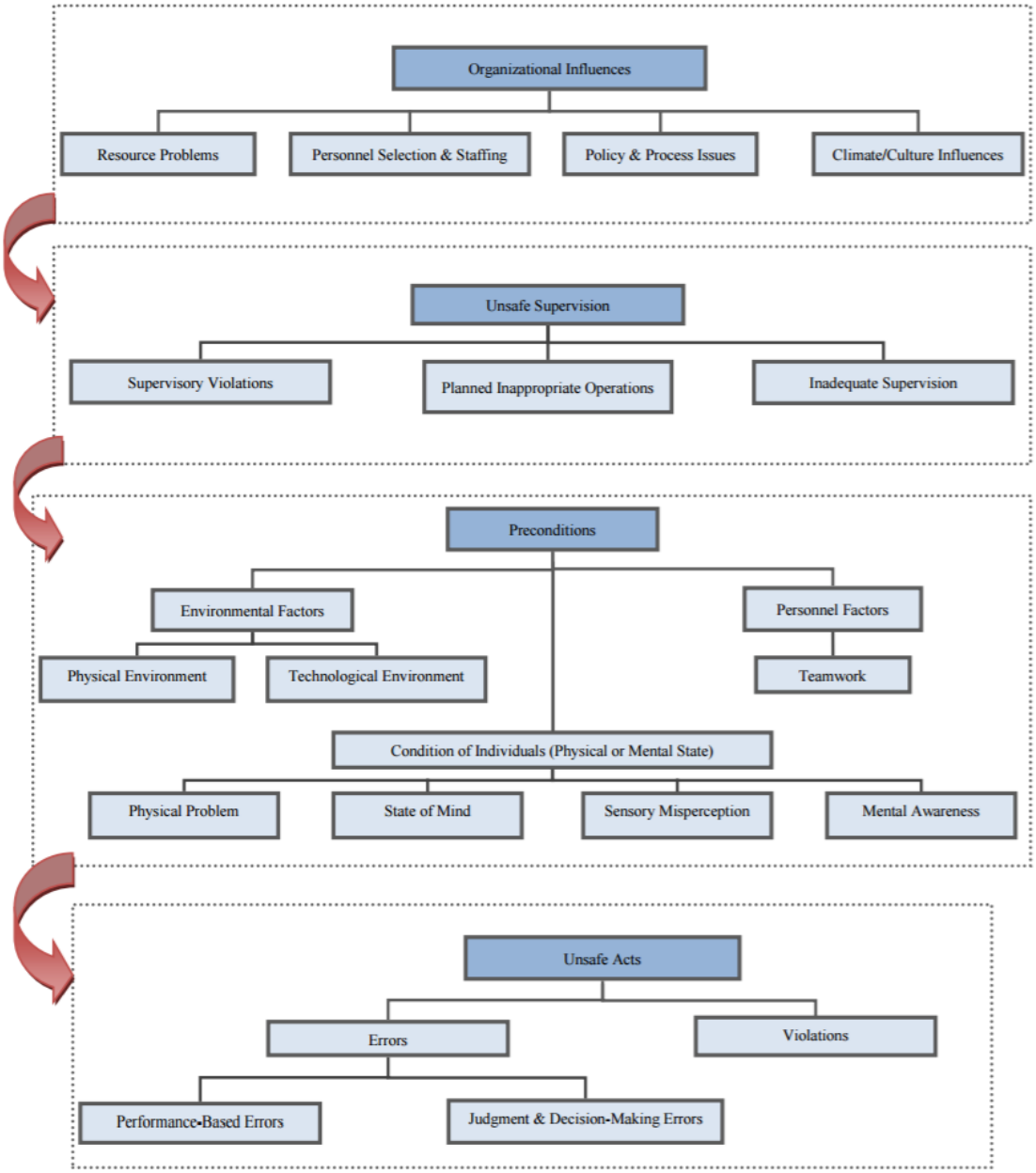

Figure 6: DoD HFACS Model ("DoD HFACS Department of Defense Human Factors Analysis and Classification System," 2015)

Additional Considerations

Other factors contribute to mishap occurrence, and two of the most prevalent are weather and maintenance. Weather contributes to aviation mishaps but is not usually the

only factor that has caused the mishap. A 2014 study of US aviation mishaps from 1987 to 2008 showed that 22.2% of the mishaps were due to system component failures only, 25.9% of the mishaps were solely caused by human error factors, and none of the mishaps were due to environmental conditions only (icing, wind shear, or low visibility) (Ancel, Shih, Jones, Reveley, Luxhoj, & Evans, 2014). The 31.5% of mishaps environmental factors were involved in either included human error or both human error and system component failures (Ancel et al., 2014). This means that while weather contributes to aviation mishaps, it is a compounding or contributing factor, and not usually the cause of the mishap.

Maintenance is another important factor to consider in aviation mishaps. Maintenance encompasses two areas: component failures and human errors in performing maintenance. In one study of maintenance failures leading to safety incidents, 96% of the incidents cited maintenance personnel as a causal or contributing factor (Hobbs & Williamson, 2003). These human factors can be categorized in much the same way as the human factors discussed in aviation accidents with pilot errors have been in various works (Gibb & Olson, 2008; von Thaden et al., 2006; Wiegmann & Shappell, 2001). These errors come from a variety of maintenance activities, including installations, inspections, servicing, modification, or overhaul (Goldman, Fiedler, & King, 2002).

Component failures are also a source of aviation mishaps. In a NASA study of loss of control accidents, approximately 30% of all accidents occurred due to component failure or malfunction (Belcastro & Foster, 2010). These failures are often due to component fatigue, which can result from flying the aircraft more hours. While this

could lead to hours being a better indicator of an impending mishap, there are other sources of fatigue failure. The type of flight, like hard, assault-type landings or low-level flight also contributes to fatigue failure. Materials scientists and engineers familiar with aviation component fatigue have thus advocated for a systems approach to fatigue-related failure (Conor, James, Hollis, & Campbell, 2012). Different types of flying place different stresses on the aircraft, and therefore components may wear out due to fatigue at varying rates. This again relates to how various types of events in may lead to more explanatory power when considering mishaps than flight hours alone.

Summary

Many causes for aviation mishaps link back to flight hours. There is, however, an important distinction to draw: more flying does not fully explain mishap rate. Aviation mishaps occur due to a variety of factors, such as pilot experience, pilot fatigue, type of flying environment, maintenance personnel, and component fatigue. Of these, the most important to investigate are flying hours and flying environment (i.e. the type of flying the crew and aircraft must perform). This research will do that by investigating the effects of flight hours, estimated flight events, and departures on AMC aircraft mishaps.

III. Methodology

Chapter Overview

This chapter reviews the method applied in this research. Each airframe has a variety of different factors influencing the risk involved; therefore, each factor (hours, departures, and estimated events) will be analyzed separately by airframe. To determine the independent airframe factor interactions, the data will be analyzed for normality, and if necessary transformed into a useful distribution. A linear regression analysis will be performed on each factor to determine their influence on aircraft mishaps. The normalized datasets will also be analyzed between airframes using a parametric analysis of variance if the data is normal or a non-parametric method if the data is not normal. This will determine if the airframes share similar characteristics or if the number of events per flight hour is significantly different between airframes. Additionally, if multiple datasets appear to be from the same distribution or none of the datasets are from the same distribution (i.e. well related or completely unrelated), a Mann-Whitney U-test will be performed to determine their relationships if any.

Tests of Normality

The Kolmogorov-Smirnov test of normality was used to determine the normality of the data. This method determines how closely the cumulative frequency distribution of a population matches the cumulative step-function of a random sample of data (Massey, 1951). This test can be applied to a variety of distribution types, including the exponential and normal distributions. While not as powerful all around as Anderson-Darling or Shapiro-Wilks in determining normality, it does perform better when there are

ties in the data (Stephens, 1974). As there are ties in the data with these datasets, the Kolmogorov-Smirnov test statistic was used to determine the distributions.

Not all data sets were normally distributed, but they did appear to be a left skewed normal distribution. Data that is skewed left or right can be logarithmically transformed to fit a normal distribution (Bland & Altman, 1996a, 1996b). By taking the base 10 logarithms of the mishap data, most of the data resembled a normal distribution, allowing the linear regression analysis to yield better results.

Linear Regression

The linear regression is a method to determine the effect of one or more independent variables (typically denoted as X) and a dependent variable (typically denoted as Y). This process attempts to fit a line to a set of data points and determine how well those points fit the line (McClave, Benson, & Sincich, 2014). This fit is given as an R^2 value, which is expressed as a percentage of the fit, or how well the independent variable explains the dependent variable. This method was used in order to determine how much each dependent variable (monthly flight hours, flight events, and departures) explained monthly mishaps.

Kruskal-Wallis H-test

As noted above (Gibb & Olson, 2008), not all datasets showed predicted normality at a 95 percent confidence using the Kolmogorov-Smirnov test of predicted normality. Therefore, to determine if the airframes mishaps per flight hour and mishaps per departure come from a similar distribution, a non-parametric test must be performed. The Kruskal-Wallis test is a similar test to the Analysis of Variance (ANOVA), but it

does not assume normality and is, therefore, useful when analyzing non-normal data (Kruskal & Wallis, 1952).

Mann-Whitney U-test

When comparing a control group to a group that received a treatment, or two groups that have been given the same treatment, the datasets must be compared to see if they are statistically different from each other. The Mann-Whitney U-test accomplishes this by determining if each observation in one sample is equal to the corresponding observation in another sample (Mann & Whitney, 1947). This is accomplished by placing the observations in rank order by sample and comparing them. This will determine whether they are significantly different. This test was applied to monthly flight events per mishap per flight hour and monthly departures per mishap per flight hour

Summary

Linear regression determines each factor's individual effect on the overall outcome. By comparing the R^2 values of each treatment, in this case, hours, departures, and events, it can be determined which factor had the most effect on the number of aircraft mishaps. The Kruskal-Wallis methodology used in this paper analyzes the variance of each data set individually and compares them as a whole. This test does not assume a normal distribution like the ANOVA does, and therefore may be used to analyze non-normal data. In the event no datasets have an equivalent variance or multiple datasets are shown to have similar variance, the Mann-Whitney U-test can determine which datasets have similar variances.

IV. Analysis and Results

Chapter Overview

The results of the normality analysis, linear regression analysis, and Kruskal-Wallis H-test are presented below. Due to the nature of the data, a Mann-Whitney U-test was required for each pair of datasets. This analysis, combined with the linear regression data from the previous section shows the propensity for indicators other than flight hours to explain aircraft mishaps.

Normality Analysis

After evaluating the goodness of fit for the various airframes mishaps to a normal curve, it was determined that only three airframes were normal. After transforming logarithmically, all but the KC-10 were normal. Table 3 below shows the fit each dataset exhibits compared to a normal distribution and a normal distribution after a logarithmic transformation.

Based on the p-values, the KC-10 mishap data does not fit a normal distribution regardless of the form of the data, as the p-value must be greater than the alpha value of 0.05 in order to be significant at the 95% confidence level. The other three airframes all exhibit normality at the 95% significance level when transformed logarithmically. While it is impossible to know why the KC-10 data is so different from the other airframes with this data alone, one possible cause is the KC-10 has a smaller fleet size compared to the other airframes, and so may exhibit differences due to its relative lack of overall hours, departures, and mishaps.

Table 3: Kolmogorov-Smirnov Goodness of Fit Statistics (α=0.05)

Airframe	Normal	Log_{10} Normal
C-5	0.048	0.486
C-17	0.534	0.054
C-130	0.336	0.470
KC-10	0.001	0.017
KC-135	0.106	0.963

Results of Linear Regression Analysis

The results of the linear regression of the logarithmically transformed data are presented in Table 4. The table shows that all five airframes are better explained by some combination of flight hours and departures than by any one factor. It also shows that the C-17 and C-130, aircraft that share similar mission sets, both exhibit a higher sensitivity to flight hours than to departures. The C-5 and KC-135 showed greater sensitivity to departures. Overall, the C-17 mishaps showed the greatest explanation of all the airframes, with 36.2% of all mishaps being explained by a combination of hours and departures. It should also be noted that the KC-10 had the worst fit of any airframe to the data, and the linear regression for the KC-10 shows the lowest R^2 values of all the airframes. This could be due to the difficulties noted above with the population size of the KC-10 data.

The C-5 regression data indicates that the combination of hours and departures do not necessarily interact, as the combination R^2 value is the sum of the hours and departures R^2 values. The combination of the two values explains C-5 mishaps almost

four times better than hours alone. Other specific flight events may be more effective at predicting and explaining aircraft mishaps.

For the C-17, monthly flight hours show greater explanation for monthly mishaps. The combination, however, depicts an explanatory R2 value higher than the sum of flight hours and departures. This indicates an interaction variable between the two with a coefficient other than zero. Compare this to the C-5's combination R^2 value, which is exactly the sum of flight hours and departures R^2 values, indicating the interaction variable's coefficient is zero.

While the C-130's flight hours and departures R^2 values are similar, their combination R^2 value is only slightly higher. The C-130's flight hours and departures show an interaction quite the opposite from the C-17. While the C-17's hours and departures display synergy due to interactions, the C-130's hours and departures seem to show a large amount of negative interaction (i.e. they explain similar portions of the reason for C-130 mishaps).

The KC-10's R^2 values do not show very much explanatory value compared to the other airframes. It is unknown what the differentiating factor or factors may be that determine the KC-10s difference from the other airframes. The only obvious difference between the KC-10 and other airframes is its small fleet size. The remaining statistical tests were still performed on the KC-10 data to try to determine any possible influences.

The KC-135 values show the lowest correlation between monthly flight hours and monthly mishaps. Departures explain 1,100% more of the KC-135's mishaps than flight hours, and the combination explains 1,3450% more. The KC-135 also shows the same synergy of interaction between flight hours and departures as the C-17, with the

combination of flight hours and departures explaining more than just the combination of the two factors. For the KC-135, departures are extremely important in explaining mishaps, and the causal data for these monthly mishaps may yield greater insight as to when KC-135 mishaps occur.

Table 4: Linear Regression of Hours and Departures

Airframe	Hours R^2	Departures R^2	Combination R^2	Combination Percent Increase
C-5	0.076	0.22	0.297	290.8%
C-17	0.155	0.069	0.362	133.5%
C-130	0.175	0.154	0.176	1.1%
KC-10	0.014	0.014	0.017	21.4%
KC-135	0.002	0.221	0.271	13450.0%

The most interesting thing to note in Table 4 is the far-right column. This is a calculation of the improvement of the combination hours and departures R^2 value over only the hour's value. All but the C-130 show a significant improvement in fitting the regression when both hours and departures are analyzed. Additionally, the C-5, C-17, and KC-135 all show significant increases in mishap explanation due to the combination of flight hours and departures.

Results of Kruskal-Wallis and Mann-Whitney Analysis

The airframes analyzed in this research do not fly the same number of hours per month, perform the same number of departures per month, or complete the same number of flight events in a month. This is based on a variety of factors, including fleet size, usage rate, and mission set. In order to compare the airframes to each other and determine which airframes may be similar, the data must be transformed into a ratio. For example, the C-130 flies an average of 13,700 hours per month across this data, while the KC-10 flies an average of 5,200 hours per month. This does not allow for an equitable comparison across the airframes. By calculating a departure per hour and an estimated flight events per hour ratio per airframe and then dividing mishaps by those ratios, we can make a more logical comparison of the airframes. In this context, the C-130 has an average mishap to departure per hour ratio of 0.063, while the KC-10's ratio is 1.516. All airframe mean mishap to event per hour ratios are presented in Table 5.

To compare all five airframes, the Kruskal-Wallis H-test was used in order to determine if they came from the same population. The resulting p-value of less than 0.0001 for both the mishap per departure/hour and mishap per event/hour comparisons indicate that all five airframes data are from entirely different distributions when those respective metrics are compared. In order to determine if there is any relationship between the individual airframes, they must be analyzed in pairs using a two-sample test. In this case, a Mann-Whitney U-test determined all airframes were roughly equivalent with respect to departures, but only a few airframes did have relationships with respect to estimated events. The full results of the Kruskal-Wallis comparison are depicted in Figure 7 and Figure 8 below.

There is no obvious relationship among the airframes using the mishaps per departure/hour. On the other hand, the C-5, C-17, and KC-135 all show strong relationships to each other, when using mishaps per estimated event/hour. This is possibly due to their large fleet sizes and high flying volumes. In general, however, the KC-10 and C-130 show a low propensity to relate to other airframes with respect to estimated events using this test. Table 5 below shows the means for the airframes by mishap per event/hour. As depicted in Figure 8, the C-5, C-17, and KC-135 all have very similar means with their standard deviations resulting in very similar 95% confidence intervals.

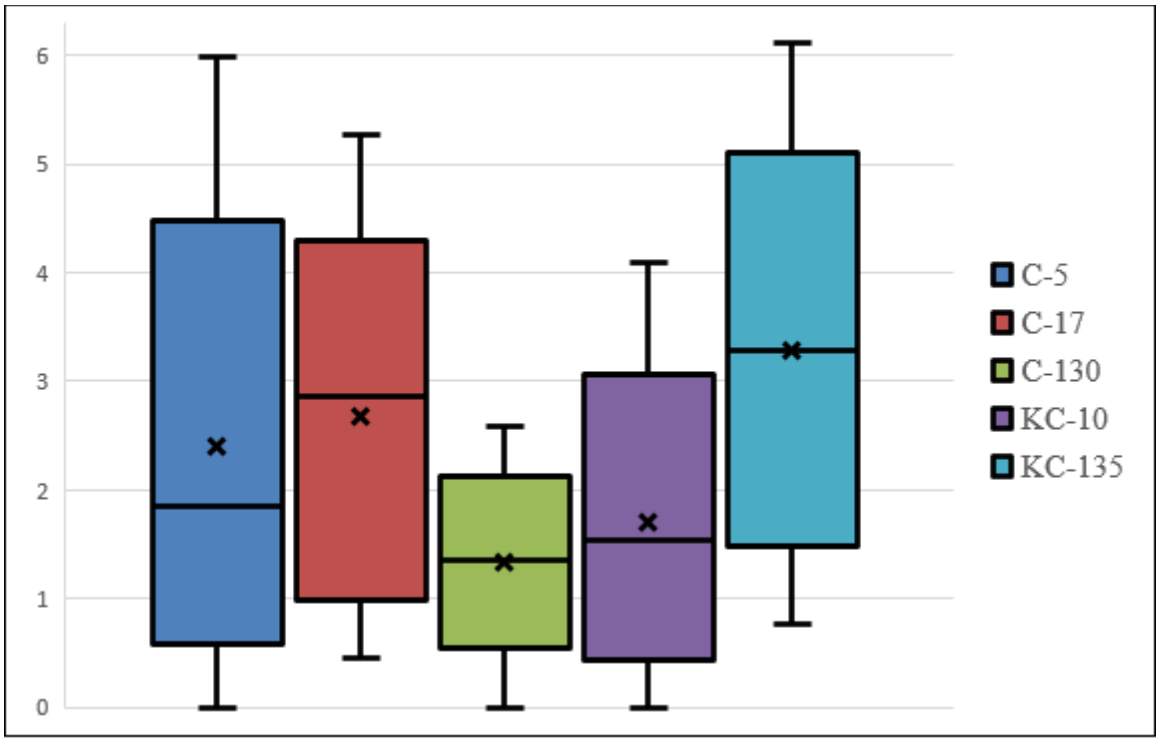

Figure 7: Mishap per Departure/Hour Comparison

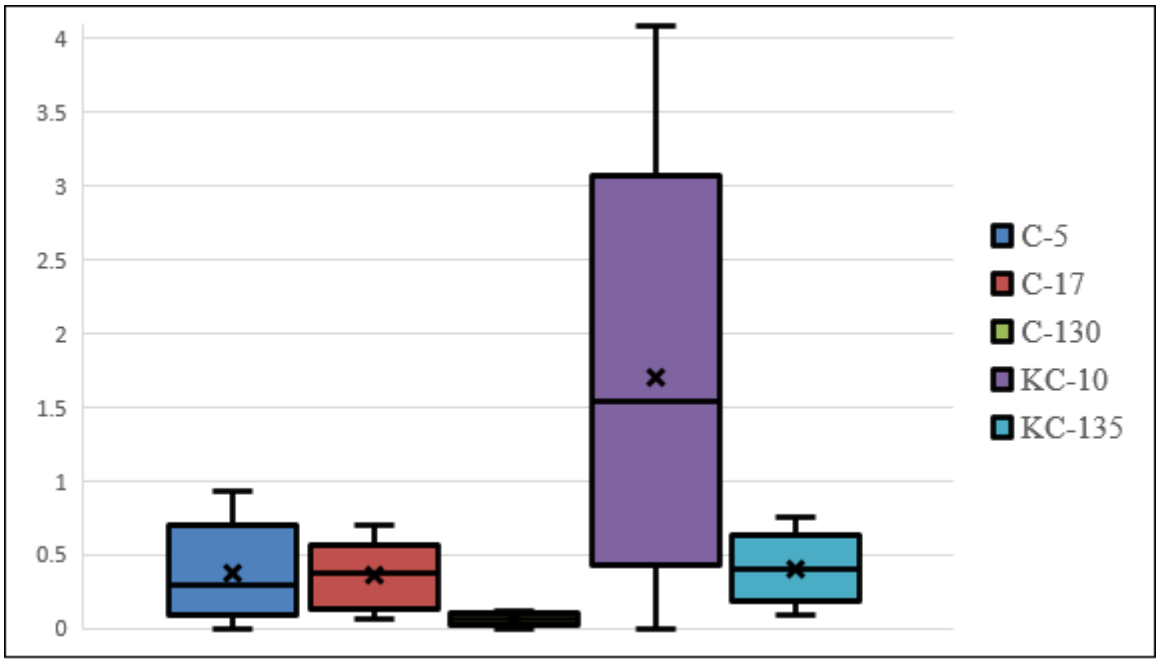

Figure 8: Mishap per Event/Hour Comparison

Table 5: Mishap per Event/Hour Numerical Comparison

Airframe	Mean	Standard Deviation	95% Confidence Interval
C-5	0.328	0.191	0.294 – 0.362
C-17	0.344	0.138	0.319 – 0.369
C-130	0.063	0.020	0.059 – 0.067
KC-10	1.516	1.000	1.337 – 1.694
KC-135	0.392	0.149	0.365 – 0.419

Investigative Questions Answered

This research has shown that there is a significant difference in determining the likelihood of aircraft mishap occurrence between flight hours and departures. The results are inconclusive with respect to flight events, as more fidelity is required in that aspect of the data in order to get an accurate representation of events. The results do lead to analyzing more than just flight hours, as there is a low percentage of the mishap correlation due to flight hours alone.

Summary

Overall, the data showed that it was not related with respect to departures per hour by airframe, but conclusions can be drawn by comparing airframes by events per hour. Further study is required, as the events in this data were estimated from actual departures, so obtaining actual event data will enhance the effort to determine whether events are a relevant indicator of mishap performance, and if so, which specific events or types of events are significant.

V. Conclusions and Recommendations

Chapter Overview

This chapter will discuss the conclusions the results lead to, as well as establish areas for further research. In general, the research requires higher fidelity events data to show better correlations between mishaps, hours, departures, and events. The major outcomes are also outlined in this chapter.

Conclusions of Research

The current USAF method of utilizing flight hours to determine safety program effectiveness does not tell the whole story. Flight hours only explain a small percentage of aircraft mishaps, but other flight events such as departures can help fill in some of those gaps. The USAF uses an ORM program to try to mitigate risk and minimize the possibility of aircraft mishaps. This ORM program recognizes that certain flight events are more dangerous than others, but there is no data to determine just how much more dangerous an assault landing is compared to a normal landing, or if an airdrop is more dangerous than and instrument approach. Utilizing specific flight events may improve the safety community's ability to explain aircraft mishaps. This data suggests that the Air Force should use more metrics than just flight hours to track the possibility for aircraft mishaps. The FAA uses both flight hours and departures, which show very similar trends in the Part 121 Commercial aviation world. The USAF could gain from using some combination of flight hours and flight events or departures to explain and predict aviation accidents.

Significance of Research

The research has shown that the USAF mishap reporting system of mishaps per 100,000 flight hours does not account for a significant amount of the indications for aircraft mishaps. Other factors such as departures help explain why aircraft mishaps occur. This is true of all the airframes analyzed. Combining multiple contributing factors into the explanation of aviation mishaps shows a significant improvement in the linear regression fit in all airframes with the exception of the C-130. This indicates using a single factor like flight hours is not the best approach to measuring mishap data, as more of the dependent variable can be better explained by including other variables.

In some cases, the departure data explains the mishap rate more accurately than the hourly data alone. Both the C-5 and KC-135 showed this propensity, with the departure data almost three times more explanatory than flight hours for the C-5. For the KC-135, departure data is 110 times more descriptive of the mishap data than flight hours. This would indicate that the KC-135 is more sensitive to critical phases of flight (e.g. takeoff or landing) than to the overall flight time. Notably, the C-17 and C-130 did not share similar trends in the data, even though they share similar mission sets and fleet sizes. The C-17 was much more sensitive to hours than departures, while the C-130 was equally sensitive to each. Along those same lines, the KC-135 and KC-10 did not display similar reactions to hours and departures, even though both are tanker aircraft. As previously stated, that could be due to the relative fleet sizes.

The data for flight events was not available, and other individual flight events may shed more light on why aircraft mishaps occur. There may also be specific flight events such as assault landings or airdrops to include on the ORM form to mitigate risk in

mission planning and just before execution. Even the use of one known flight event (departures) gave more insight into AMC mishaps than flight hours alone. This means investigating other flight events may be even more useful. In any case, using some combination of flight hours and departures is a better indicator of mishap occurrence than any individual indicator alone.

When comparing all the airframes based on departure data, there was no significant differentiation amongst them. This is possible because a departure is essentially equally risky for all airframes and therefore does not act as a significant discriminator. When compared using estimated flight events, however, three distinct groups formed: The KC-10 alone, the C-5, C-17, and KC-135 together, and the C-130 alone. This breakout could be due to the similarity in the fleet sizes and events these airframes have. The C-130 has a large fleet and the largest event-to-departure ratio of any airframe with 21.5. The C-5, C-17, and KC-135 all have relatively similar event-to-departure ratios with 6.4, 7.55, and 8.15 respectively. The KC-10 has a similar ratio to the other three airframes in the group with 8.95, but it has less than half the fleet size. Further investigation is required to determine these specific differences.

The major outcome of this research is that there is more to consider than just mishaps per 100,000 flight hours. By comparing mishap data to departures as well as flight hours, the USAF can immediately improve mishap prediction. Additionally, while departures matter in explaining mishap data, evidence suggests that events may also describe what is happening throughout the mishap data. This area is an excellent place to begin further research.

Recommendations for Future Research

Accurate events data and the ability to differentiate between particular events and departures (assault landings, airdrop, air refueling, etc.), will enable future researchers to determine their effect on aircraft mishap rate. The data presented above is accurate for departures, as the estimated events were derived from actual departure data as a percentage of required events. If actual event data can be obtained, specific events can be correlated to mishap likelihood. Additionally, the accurate events data may also be tied to fatigue data in order to determine what effect the pilots' levels of fatigue had on the mishap data.

Other avenues for research also include determining the number of hours the airframe had flown prior to a mishap. If there were additional stressors on the airframe, that might account for the mishap data. The crew compliment is also an important factor to consider. Additional relevant information not presented in this data was who was onboard the aircraft. If there were an aircraft commander on board, perhaps they caused or encountered a mishap that an instructor or evaluator pilot may have avoided. If the Squadron, Group, or Wing Commander is onboard the aircraft, the crew may be more vigilant for mistakes or distracted by the additional scrutiny of having a commander on the aircraft. All these factors could affect the data but are unknown in the data.

One final area for further research is the differences between individual airframes. Determining why the airframes react so differently to flight hours, flight events, or departures could inform what causes mishaps in each airframe or group of airframes.

Summary

Aviation mishaps are complex events that require multiple sources to explain and predict accurately. There is evidence to suggest that flight hours are not the only (or even the best) measure of aircraft mishaps. Departures often show a higher degree of explanation for mishap data, and the FAA currently tracks this metric in addition to flight hours to represent Part 121 commercial carrier mishaps. Accurate events data for each airframe could also yield further explanations for mishap data.

Appendix A: AMC ORM Worksheet

MAF MISSION AVIATION ORM WORKSHEET *(Complete Once for each Crew Duty Day)*

AvORM Web Application 3.0.5: https://avorm.maf.ustranscom.mil/default.aspx

Mission Number			ITINERARY						
	Risk Factors	Risk Factor Point Scale				Risk Factor Evaluation Level & Score			
		0 (LOW) Green	1 (MODERATE) Yellow	2 (HIGH) Orange	3 (SEVERE) Red	Initial Planner	Curr. Ops	SQ	Aircrew
	USER/CUSTOMER								
1	CJCS Priority	1B1 and Lower	1A1-1A4						
2	Participating Forces	US Military	Any Foreign						
3	AE/Passengers	Routine	Difficult	Challenging	Severe				
	TYPE								
4	Airland	Routine	Difficult	Challenging	Severe				
5	Aerial Refueling - Tanker	Routine	Difficult	Challenging	Severe				
6	Aerial Refueling - Receiver	Routine	Difficult	Challenging	Severe				
7	Airdrop	Routine	Difficult	Challenging	Severe				
8	Required Tactical Events (Not Training)	2 or less (OSAVIP=0)	3 to 8 (OSAVIP=1-2)	Greater than 8 (OSAVIP=3+)					
	TIMELINE								
9	Home Station Show Time	0631-1400L	1401-2000L/0531-0630L	2001-0530L					
10	Consecutive Days w/in 2 hrs of Max FDP	2 or less	3	Greater than 3					
11	Scheduled Work Hours vs Max FDP	<75%	75-95%	>95%					
12	Number of Legs in FDP	2 or less	3-4	5+ (or waiver reqd)					
13	Mission Planning	Standard	Nonstandard						
	ENVIRONMENT								
14	Perceived Threat	Low	Medium	High	Extreme				
15	Enroute Location(s) Mission Support	Meets requirements	Below requirements		None				
16	Operating Environment Language Difficulties	None	Minor	Major					
17	Airfield Complexity (runways, taxiways, hazards, etc)	Routine	Difficult	Challenging	Hazardous				
18	Departure, Enroute & Arrival WX (worst case)	AFI compliant	Multiple hazards (low vis, x-wind, rain, ice, etc.)		Waiver required				
19	Night Departures/Arrivals	2 or less	3 to 6	Greater than 6					
20	Bird/Wildlife Hazard	Low	Moderate		Severe				
21	Arrival/Approach/Departure Procedures/Terrain	No hazards	Minor hazard	Major hazard	Multiple major hazards				
22	Enroute complexity (ATC, rules, routing, C2, AE rqmnts etc.)	Routine	Difficult	Challenging					
23	Enroute Terrain/Geography	No hazards	Minor hazard	Major hazard	Multiple major hazards				
24	Additional Operational Risk Factors	None	Minor	Major	Hazardous				
25	Mission Impacting Waivers (Personnel, Equipment and Operations)	0	1-2	3-4	More than 4				
	CREW/AIRCRAFT								
26	Hrs spent Legal For Alert (N/A "Charlie")	0-6 & 24-30hrs	6-12 & 30-36 hrs	12-24 & 36-48 hrs					
27	Alert Resets (Since last flight)	0	1-2	3 or more					
28	Mission Changes Requiring Crew Action	None	Minor	Major					
29	Crew/Mission Match	Ideal	Suitable	Minimally acceptable					
30	Crew Qualification	Fully qualified	Upgrade training, In-unit requal, non current crewmember						
31	Acft Cmdr PIC Time in Type	500+ hrs (OSAVIP >= 100hrs) or IP on board	Less than 500 hrs (OSAVIP < 100 hrs)						
32	Critical Crewmember (Non-Pilot) Time in Type	500+ hrs	Less than 500 hrs						
33	Acft Cmdr Last 30 Day Time	20+ hrs (OSAVIP >= 10hrs) Flown in Type	Less than 20 hrs (OSAVIP < 10hrs) No Time in Type						
34	Critical Crewmember (non-pilot) Last 30 Day Time	20+ hrs	Less than 20 hrs						
35	Acft Cmdr Last Accomplish Highest Risk Event	Less than 90 days	More than 90 days						
36	Critical Crewmember (non-pilot) Last Accomplish Highest Risk Event	Less than 90 days	More than 90 days						
37	Combined Pilot Experience (time) in Type	1000+ hrs (OSAVIP >= 500 hrs) or IP on board	Less than 1000 hrs (OSAVIP < 500 hrs)						
38	Acft Cmdr PIC/Total Time-Hrs (All AC)	500/1000 + (OSAVIP 50/100+)	Less than 500/1000 (OSAVIP < 50/100)						
39	Aircraft MX Status	Mission capable	Negative mission impact	One-time flight (waiver required)					
	HUMAN FACTORS (ENTER THE HIGHEST RISK FACTOR CREWMEMBER SCORE USING THE PERSONAL CHECKLIST INSERT)								
40	Health and Stress Score	Minor	Elevated	Serious					
41	Fatigue Score	Low	Moderate	High	Severe				
					TOTALS (The Tier 4 column total is the worksheet total) --				

APPROVAL AUTHORITY -	RISK LEVEL *(Total Worksheet Score)*	NAME/INITIALS, RANK, OFFICE SYMBOL & DATE
Aircraft Commander	LOW (0-10 Moderate Points)	
SQ/DO or Designated Rep or TACC Branch Chief/DO	MODERATE (11-25 Moderate Points)	
SQ/CC or Designated Rep or TACC Division Chief/DDO	HIGH (≥ 1 High Event(s), or 26-50 Points)	
Operations Group Commander or TACC Senior Director	SEVERE (≥ 1 Severe Event(s), or ≥ 51 Points)	

RISK FACTOR EVALUATION LEVELS			
Initial Planner	Current Ops	SQ	Aircrew

RISK FACTOR EVALUATION LEVELS			
Initial Planner	**Current Ops**	**SQ**	**Aircrew**
Completed by any individual, group of individuals, or organization that plans a flight. Examples would include TACC planners, Wing planners, Theater Air Operations Center, and crew planned sorties.	Completed by Current Operations personnel or as designated by the Chief of Current Operations. Examples would include home station and deployed Current Operations supervisors.	Completed by Squadron level, or equivalent, leadership. Examples would include home station and deployed Squadron Commanders/Deputies, Squadron Operations Officers/Deputies, en route stage location leadership or those designated by the Squadron Commander.	Completed by the crew and verified (signed) by the Aircraft Commander. When feasible/available, TACC Flight Managers will assist in scoring Tier 4 items and begin appropriate mitigation actions in coordination with the aircrew.

HEALTH, STRESS, AND FATIGUE SCORECARD

3.2.1.5. Prior to the start of each flight duty period, every aircrew member will make every effort to use the Health, Stress, and Fatigue scorecard on the back of the AMC AvORM worksheet to self-evaluate his/her current health/stress and fatigue risk level. The AC will query the results, take the highest health/stress and fatigue score and copy it into the health/stress and fatigue worksheet section of the web application. These assessments will automatically populate to the health/stress and fatigue risk factors allowing the AC to select the applicable flight duty period in which they apply. If the aircrew is using the manual worksheet, the AC will enter the health/stress and fatigue results in the Aircrew column of the worksheet.

HEALTH & STRESS RISK FACTORS	LOW GREEN *0 Points*	MODERATE YELLOW *1 Point Ea*	HIGH ORANGE *2 Points Ea*
Personal Health Factors (hydration, nutrition, illness/injury, etc)	Minor	Elevated	Serious
Personal/Family Stress (health, finance, relationship, etc.)	Minor	Elevated	Serious
Work/Career Stress	Minor	Elevated	Serious
Perceived Mission Pressure (external & internal)	Minor	Elevated	Serious

HEALTH & STRESS SCORE: → Input to Item 40

Minor: Having little significance, influence or effect
Elevated: Greater than is normal or reasonable
Serious: Needing or deserving complete attention

Health and Stress Scoring:
- Any factor **HIGH**: overall score HIGH
- Total of all four factors **3** or more: overall score HIGH
- Total of all four factors **1-2**: overall score MODERATE
- Total of all four factors **0**: overall score LOW

FATIGUE RISK FACTORS	LOW GREEN *0 Points*	MODERATE YELLOW *1 Point Ea*	HIGH ORANGE *2 Points Ea*
16+ hr Work/Duty Days (past 7 days)	2	3	4
Combined Prior Sleep (past 3 days)	21 hours or more	18-21 hours	Less than 18 hours
Combined Sleep Quality (past 3 days)	Excellent	Fair	Poor
Prior Sleep (past day)	7 hours or more	6-7 hours	Less than 6 hours
Sleep Quality (past day)	Excellent	Fair	Poor
Net Time Zone Crossings Last Duty Day (jet lag)	5 or less	6 or more	

FATIGUE SCORE: → Input to Item 41

Excellent: Extremely good
Fair: Of a moderate quality, quantity or standard
Poor: Not good, being of a very LOW quality, quantity or standard

Fatigue Scoring:
- Total of all factors **7** or more: overall score SEVERE
- Any factor **HIGH**: overall score HIGH
- Total of all factors **4-6**: overall score HIGH
- Total of all factors **1-3**: overall score MODERATE
- Total of all factors **0**: overall score LOW

AMCI 90-903

Table 1. Approval/Signatures Required for Assessed Risk Levels.

RISK Approval Authority	Wing-Owned Missions	618 AOC (TACC)-Owned Missions
LOW	No Sign off Required	No Sign off Required
MODERATE	Operations Officer or Designated Representative (One sign-off per mission)	618 AOC (TACC) Duty Officer, if not already approved by TACC Branch Chief (one sign-off per mission)
HIGH	Squadron Commander or Designated Representative	618 AOC (TACC) DDO/Division Chief
SEVERE	Operations Group Commander or Designated Representative	618 AOC (TACC) Senior Director or General Officer

NOTE 1: In the event the AMC AvORM mission risk level has increased above the previously approved level and the AC while exhausting all communications options is unable to contact 618 AOC (TACC) or the home unit, he or she will carefully consider and evaluate the risk before continuing or aborting the mission.

NOTE 2: For 618 AOC (TACC)-tasked missions, or wing current operations planned missions, the planner is the only approval necessary to operate an entire mission in the LOW risk category. A one-time signature on the crew orders by the flight order authenticating official or 618 AOC (TACC) Branch Chief is the only approval necessary to operate an entire mission in the MODERATE risk category. If at any time during a mission an individual risk factor or total score as directed on the worksheet, reaches the HIGH or SEVERE category, additional approval will comply with Table 1.

The Effect of Aircrew Flight Events on AMC Aircraft Safety Incidents

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Advanced Studies of Air Mobility (ENS)
Air Force Institute of Technology

Introduction

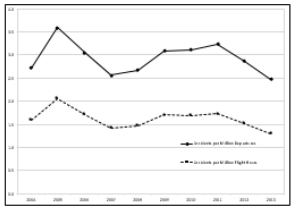
In aviation, mishaps are significant events that can cause massive amounts of damage and result in catastrophic losses to both lives and property. Determining the cause of mishap occurrence is the first step in preventing them. Understanding when a mishap is likely to occur will allow decision makers to enact preventative measures to stave off an aircraft mishap. By analyzing past mishap data, this research hopes to determine the most likely indicator of an aircraft mishap among three factors: flight hours, departures, and flight events

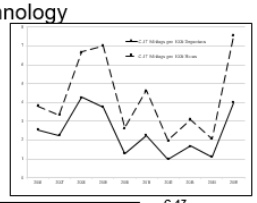
The USAF aviation safety program's primary metric is determining the number of mishaps based on flight hours. This metric does not account for the varying degrees of risk posed by different flight events performed while flying. Departure, is considered a flight event, and Air Force pilots perform many different flight events due to the diversity of its mission requirements. Thus, it is logical to analyze all flight events to determine their correlation to aircraft mishaps. The FAA tracks aircraft mishaps by both flight hours and departures for commercial carriers, but this accounts for the majority of aircraft activity for civilian aircraft. Most civilian aircraft only takeoff, climb, cruise, descend, and land. Whereas USAF aircrews are required to perform a wider variety of events, such as assault landings, air-drop, low-level flying, and air-to-air refueling. Therefore, this research investigates if there is also a relationship between flight events and aircraft mishaps for Air Force aircraft.

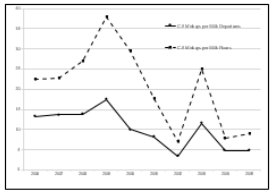
Research Questions

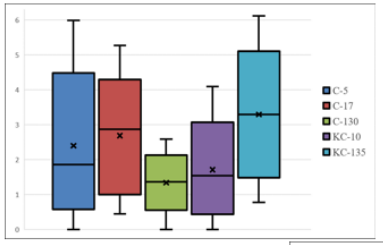
1. Is flight hours an accurate metric for measuring aviation mishaps?
2. Are flight events a more accurate metric than flight hours?

This research uses the FAA model of mishaps based on flight hours and departures (a specific flight event) to determine if flight events are a more accurate indicator of aviation mishaps.

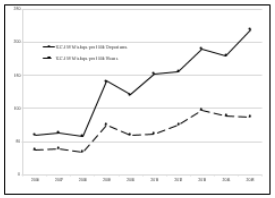

FAA

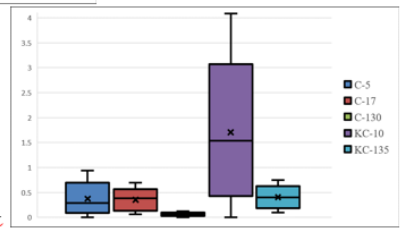

C-17


C-5



Mishap per Departure/Hr


KC-135



Mishap per Event/Hr

Methodology

This paper utilized several statistical analysis tools in order to determine the significance of various influences on aviation mishaps. The primary three sources investigated were flight hours, flight events, and departures. These sources were initially compared to the mishap rate for five MAF airframes (C-5, C-17, C-130, KC-10, and KC-135) via a linear regression analysis.

The airframes were also evaluated to determine if there were any significant relationships between the airframes. This was accomplished via a Kruskal-Wallis H-Test and subsequently via the Mann-Whitney U-Test.

Conclusions & Recommendations

The conclusion of this research is that flight hours is not the always the best indicator of aviation mishaps. For several airframes, departures was a more significant contributor to their propensity to have a mishap.

Additionally, the relationships that emerged between the airframes did not follow mission sets. The C-17 showed a higher influence due to flight hours, while the C-130 was almost equally sensitive to departures and flight hours. The KC-10 was also equally sensitive to flight hours and departures, but the KC-135 was more sensitive to departures. In all cases, the combination of flight hours and departures was more explanatory with respect to mishaps.

Implications

Based on this research, the USAF, and AMC specifically, should track individual flight events for a longer period than semi-annually. This will allow better analysis of aviation mishaps with respect to specific flight events and aid in ORM and risk mitigation.

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14. ABSTRACT

Aviation mishaps are costly events, both in price complicated events that involve a variety of contributing factors. The Federal Aviation Administration (FAA) and United States Air Force (USAF) determine the propensity for aviation mishaps by comparing total flight hour to mishaps. The USAF uses a mishap per 100,000 flight hour ratio, while the FAA uses a mishap per million flight hours as well as mishaps per million departures. This research aims to determine not only if departures are a better metric for determining possible aviation mishaps, but also other flight events, such as air refueling or assault landings. A variety of statistical tests will be performed to compare mobility aircraft safety data to determine if flight events or departures are more explanatory with respect to mishaps than flight hours. The airframes will also be compared against each other in order to determine any patterns among mobility aircraft mishaps.

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