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**ANALYSIS OF THE CAUSES OF INFLIGHT
REFUELING MISHAPS WITH THE KC-135**

THESIS

**Marvin L. Thomas
Captain, USAF**

AFIT/GSM/LSM/89S-41

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**ANALYSIS OF THE CAUSES OF INFLIGHT REFUELING
MISHAPS WITH THE KC-135**

THESIS

**Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology**

Air University

**In Partial Fulfillment of the
Requirement for the Degree of
Master of Science in Systems Management**

Marvin L. Thomas, B.S.

Captain, USAF

September 1989

Approved for public release; distribution unlimited

Preface

The purpose of this study was to determine the causes of inflight refueling mishaps with the KC-135. The information is structured to provide detailed information as to the causes of aerial refueling mishaps to pilots, maintenance, safety, and design personnel. If the causes of mishaps are known, more emphasis can be placed on controlling the causes.

In accomplishing this report, I had a great deal of help from others. I would like to thank my advisor, Professor Albert Rogers, for his patience and guidance. I would also like to thank Lt Donald McNeely, USN. His Naval experience and direction were invaluable assets in the completing of this report. Finally, I'd like to thank my wife, Capt Victoria Vitucci. Without her involvement I would have not obtained the data which became the genesis of this thesis.

Marvin L. Thomas

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Abstract

The purpose of this study was to determine the causes of inflight refueling mishaps with the KC-135. The study had three main objectives: (1) To categorize the causes of KC-135 inflight refueling mishaps. (2) To compare mishaps when refueling from the boom/drogue adapter (BDA) to mishaps when refueling from the boom. (3) To compare KC-135 mishaps with fighter/attack aircraft to KC-135 mishaps with heavy aircraft.

The study was accomplished by first determining the causes of inflight refueling mishap incidents. The data was then categorized, and finally analyzed.

The study found seven basic causes of inflight refueling mishaps with the KC-135. The predominate cause of inflight refueling mishaps is the receiver pilot. When comparing boom/drogue adapter inflight refueling mishaps to boom mishaps, the second leading cause of mishaps differs. In BDA inflight refueling mishap incidents, the second leading cause is BDA failure. In boom inflight refueling mishaps, the second leading cause is the boom operator. In comparing fighter/attack aircraft inflight refueling mishaps to heavy aircraft inflight refueling mishaps, the ranking of causes is the same. The leading cause was, again, receiver pilot error and the second leading cause was boom operator error.

Although useful, the format of the Air Force Inspection and Safety Center summary reports impede data analysis. The researcher recommends a study into the organizing of the information contained in the summary reports in a form more suitable for data collection and analysis.

ANALYSIS OF THE CAUSES OF INFLIGHT
REFUELING MISHAPS WITH THE KC-135

I. Introduction

Overview

The success of the United States aviation forces is directly related to the ability to manage aviation resources effectively and efficiently, sustaining the fewest number of personnel and/or machine failure, and the least possible accidental losses. The whole basis of the various services accident investigating and reporting system is to analyze accidents and mishaps and research ways to prevent recurrence. Many costly lessons have been learned from aviation accidents and those lessons learned have been applied to correct system inadequacies. This process of collecting information about the past and analyzing it with the intent to affect the future is the basis of mishap prevention.

The purpose of this report is to assist in the understanding and determination of aerial refueling mishaps with the KC-135 through the study of historical data. Nearly every mishap contains evidence which when analyzed will allow the cause to be determined so that action can be taken to minimize or eliminate recurrence. Thus, the objective of this report is to gather data and observe what cause factors

tend to recur across a variety of aircraft and within one aircraft type.

Statement of the Problem

Air Force Regulations require the investigation and reporting of all U.S. Air Force mishaps. AFR 127-4 explains how to do the various reports and the responsibilities required in investigating and reporting. The regulation stipulates that the Air Force Mishap Investigation and Reporting Program is to be managed by the Air Force Inspection and Safety Center (AFISC). Part of AFISC responsibilities as detailed in AFR 127-4, is to decide on the final mishap classification and the cause factors and to maintain a database of all mishap causing over \$10,000 worth of damage. The cause factors used by AFISC are operations related causes (personnel) and logistics related causes (maintenance or equipment). The determination of more specific causes is only done by reading the final summary reports maintained by AFISC.

Although this information is kept by AFISC, it is not in a format that is easy to use. The intent of this report is to format the operations and logistics related causes into more specific causes for one dimension of aircraft accidents, that being inflight refueling accidents with the KC-135. Therefore, the problem statement is: What are the causes of inflight refueling mishap incidents with the KC-135?

Research Objective and Hypotheses

The objective of the research was to detail the causes of inflight refueling mishaps with the KC-135. This research was intended to be used as a first step to doing a trend analysis of the causes of inflight refueling mishaps and to determine the relationship between various cause factors. Also, portions of this thesis were designed to allow statistical comparisons between boom/drogue adapter (BDA) refuelings and boom refuelings and between fighter/attack aircraft refuelings and heavy (bombers, tankers, and transport) aircraft refuelings. This report will also be used to substantiate or disprove the following hypotheses:

1. Aircraft using the boom method of refueling will have a substantially higher percentage of mishaps caused by aircrew when compared to aircraft using the BDA method of refueling.
2. Aircraft using the BDA method of refueling will have a substantially higher percentage of boom and receptacle failure mishaps when compared to aircraft using the boom method of refueling.
3. Fighter/attack aircraft will have a substantially higher percentage of mishaps caused by aircrews when compared to heavy aircraft (tankers, bombers, and transport).
4. Fighter/attack aircraft will have a substantially higher percentage of mishaps caused by boom and

receptacle failure when compared to heavy aircraft.

5. A small percentage of aircraft types will be involved in at least half of the mishap incidents.

Scope

1. The AFISC database that this study was derived from included 279 aerial refueling incidents with the KC-135 occurring in a period from 1978 to 1988. The requirements for an incident to be recorded as a mishap is that \$10,000 of damage or greater must have occurred to the tanker or receiver aircraft (2:6-7). The limitation of this type of information is that many potentially hazardous but relatively inexpensive mishaps do occur, but no reports of these incidents are maintained by a centralized database.

2. The analysis of inflight refueling mishaps with the KC-135 was only done on U.S. military aircraft. The KC-135 is capable of refueling NATO military aircraft, but no database is currently maintained.

3. Many of the mishaps have multiple causes. For the sake of simplification, the predominate cause was recorded as the cause of the mishap.

4. The comparison between heavy aircraft and fighter/attack aircraft is limited to U.S. Air Force aircraft.

5. For analysis purposes, the F-111 was considered to be a fighter aircraft.

6. The majority of the determination of the causes was done by AFISC. Twenty seven of the cases required the researcher to make a determination of the cause of the mishap.

7. A difference of 5% in the comparison for hypotheses one thru four is considered to be significant.

8. In the analysis of hypothesis five, the aircraft will be separated into BDA refueling mishaps and boom refueling mishaps.

9. Due to Air Force regulations, the actual reports from which the data was derived will not be included in this report. This limits the reader in attempting to validate the results of the researcher.

Definitions

1. Boom. The telescoping tube that fits under the aft fuselage of the KC-135. High pressure fuel is pumped thru the boom and into the receiver aircraft.

2. Boom operator. The person who controls the flyable boom.

3. Boom/drogue adapter (BDA). A device designed for the KC-135 that allows it to refuel probe equipped aircraft. The BDA consists of a nine foot hose with a drogue or metal conical basket attached to the end. It is manually attached to the boom of the KC-135.

4. Drogue. The metal conical basket which the probe of a receiver aircraft flies into.

5. Probe. A cylindrical shaped device approximately two feet in length and approximately five inches in diameter. The refueling end has a ball and cock type device that interlocks with the drogue. Fuel is passed from the tanker to the receiver aircraft once the connection is made.

6. Receptacle. A specially designed opening in the top of the fuselage of receiver aircraft. To refuel the aircraft, the boom is flown into the receptacle.

7. Envelope. The region that is determined to be safe for aerial refueling operations. If the receiver pilot leaves the envelope while refueling, aerial refueling becomes impossible.

Background

The first known attempt to transfer fuel from one aircraft to another during flight was accomplished on 12 November 1921 by Wesley May. More of a barnstormer's stunt than a serious attempt at inflight refueling, May climbed out on the wing of a Lincoln Standard biplane with a five gallon can of gasoline strapped to his back. He then walked to the end of the wing and grabbed hold of the overlapping wing of another Lincoln Standard biplane. He then made his way to the engine and poured the gasoline into the biplane tank (18:176-178).

The first serious attempts at inflight refueling were made by the Army Air Service. During the spring of 1923 in San Diego, California, a De Havilland DH-4 biplane was modified

with a 50 foot hose. This 'tanker' aircraft would trail the hose over the side while a crew member of the receiver aircraft would grab the hose and stick it into the tank (10:1-2).

Because of inflight refueling, record after record in distance and endurance flying were established. The most significant of these occurred in January of 1929. Major Carl Spaatz, Captain Ira Eaker, and crew broke all existing endurance records by remaining airborne for over a 150 hours. This feat lasted for seven days, consumed over eighty thousand pounds of fuel, and covered a distance equal to nearly halfway around the world (12:3-23). Although significant, this record only lasted for two years. In 1931, Al and Fred Key broke the record by staying airborne, with the aid of aerial refueling, for 653 hours. The American feats accomplished with the aid of aerial refueling quickly gained the attention of the British. While American interest started to wane, the British further developed the American invention of aerial refueling.

The British refined the process of aerial refueling and established companies to explore its use for both military and commercial purposes. One of those companies formed just prior to World War II was Flight Refueling Limited (FRL). In cooperation with the British Air Ministry, the Royal Air Force, and early airline companies, FRL perfected several methods of inflight refueling. In fact, during World War II, because of the United States' lack of capability in

aerial refueling technology, FRL was contracted to modified U.S. B-24's to be used as tankers. The B-24's were to refuel B-17's which would then bomb Tokyo. The plan never came to pass because of the development of the longer range B-29 which took the place of the B-17. World War II did establish the strategic importance of aerial refueling. Without aerial refueling, the U.S. did not truly possess an international strike capability. Therefore, the U.S. again became involved in the development of aerial refueling systems.

Prior to the end of World War II, aerial refueling technology had centered around the gravity hose system first developed in 1923. The drawback to the British developed gravity hose systems was that the system was not effective at speeds exceeding 190 miles per hour, the minimum speed for fully loaded B-29's and B-50's. The system was also not able to off load fuel quickly, which was a requirement of the bombers. These deficiencies in the gravity hose system prompted the development of the 'flying boom'.

In April, 1949, Boeing Aircraft Company introduced this revolutionary new system to the Air Force. The system basically consists of a rigid telescoping tube fitted under the aft fuselage of the tanker. It can be moved in all three dimensions by a combination of hydraulic and aerodynamic pressures and is controlled by a boom operator crewmember--who 'flies' it into a receptacle on the receiver aircraft. The two main advantages of this system is the much faster rate of fuel transfer and the much higher speeds which can be used for refueling(3:50-51).

The flying boom was initially used on non jet tankers. The performance disparity between SAC's new jet bombers (B-47's and B-52's) fleet and its nonjet tankers caused operational problems. In order to refuel, the bombers had to slow down and descend to lower altitudes. This made refueling more difficult because of turbulence and increased the vulnerability of the aircraft to enemy detection. In the early 1950's, Boeing Aircraft Company was contracted to develop a jet tanker. The final product was designated the KC-135. Of the 735 aircraft built, over 600 remain in service (1).

Although this chapter has dealt primarily with the history of aerial refueling as it pertains to the Air Force, the Navy and Marines faced the same problems of extending range and operational flexibility. The system of choice for the Navy and Marines was the FRL developed probe and drogue system. This gravity hose system is currently used by the Navy, Marines and the United States NATO allies. In this system the tanker trails a retractable hose with a conical shaped 'basket' or drogue on the end. The receiver aircraft is equipped with a nozzle or probe that is attached to the nose of the aircraft or from the leading edge of the wing. The receiver aircraft refuels from the tanker by flying the nozzle or 'probe' into the basket attached to the tanker boom (4:25-27).

The Navy currently has carrier based tankers that provide limited off load capability. With the advent of larger

offload requirements, the carrier based tankers are even less capable of meeting the Navy's needs. A device called the boom/drogue adapter (BDA) was designed to allow the KC-135 to refuel probe equipped aircraft. For extended and special missions the KC-135 supplements the Navy and Marine's tanker force (4:32).

Our current tanker force of KC-135's has been active since 1956. The basic method of aerial refueling has remained unchanged. Over the last 33 years of operations, a tremendous amount of knowledge about aerial refueling has been accumulated. The overall objective of this report is to analyze the information detailing aerial refueling mishaps with the KC-135. The specific goal is to determine the predominate causes of aerial refueling mishaps with the KC-135. With this information, pilots, boom operators, safety officers, maintenance personnel, researchers, and designers will have a better insight into the causes of aerial refueling and where emphasis should be placed to make aerial refueling more safe.

Literature Review

No study has been done specifically on the causes of aerial refueling mishaps, but a multitude has been done on aircraft mishaps. By synthesizing portions of the varying authors methods of investigation, analysis, and reporting, an adequate and efficient method of determining the causes of inflight refueling mishaps was developed. This literature

review shall briefly describe some of the methods used in aircraft mishap investigating and reporting.

The International Civil Aviation Organization (ICAO) collects reports of civilian aircraft accidents investigations and inquires and annually publishes an aircraft accident digest. The digest attempts to classify the accidents based upon accident cause and phase of operation. The ICAO Manual of Aircraft Accident Investigation allows the following causes of accidents:

1. Material failure
2. Pilot error
3. Weather
4. Errors of other personnel
5. Undetermined

The ICAO reports go to considerable measures in developing the tables to ensure that the information contained in the tables does not alter the initial findings. The brevity of the table may sometimes give the wrong impression. To counter this occurrence, the ICAO reports contains a summary of each accident investigation report (9:15,20).

Annually, the Air Force safety magazine, Flying Safety, prints the 'Mishap Review and Forecast' for each aircraft in the Air Force inventory. The report tabulates the classes of mishaps which occurred during the previous year. Air Force Regulation (AFR) 127-4 stipulates the classification

scheme that Flying Safety must use . The mishap classifications specified in AFR 127-4 are as follows:

1. Class A Mishap. A mishap resulting in:
 - a. Total cost of \$500,000 or more for injury, occupational illness, and property damage or
 - b. A fatality, or permanent total disability or
 - c. Destruction of , or damage beyond economical repair to an Air Force aircraft.
2. Class B Mishap. A mishap resulting in:
 - a. Total cost of \$100,000 or more, but less than \$500,000 for injury, occupational illness, and property damage or
 - b. A permanent partial disability, or
 - c. Hospitalization of five or more personnel.
3. Class C Mishap. A mishap resulting in:
 - a. Total damage which costs \$10,000 or more, but less than \$100,000 or
 - b. An injury or occupational illness which results in a lost workday case involving days away from work .(6:6-7)

The 'Mishap Review and Forecast' further stipulates what the most common mishaps are and what improvements are planned for the system to correct deficiencies (19:13-14).

The U.S. Army annually publishes the 'Lessons Learned from Aviation Mishaps'. The objective of the report is to identify, evaluate, and suggest corrections for inadequacies in the Army aviation system. The Army's method of evaluation uses a database with information meeting the same requirements of the mishap classes specified in AFR 127-4. The approach to mishap analysis used by the Army identifies what happened (human error or material failure), what caused it to happen (system inadequacies), and what to do about it (remedial measure). The final report is a system by system

listing of inadequacies and suggested corrective measures (11:4,25).

Lt Col Suh Ho Sun of the Republic of Korea Air Force (ROKAF) conducted a study to determine if there were relationships among variables which could help illuminate ROKAF accident rates. The report used contingency analysis to determine the dependency between variables. The variables selected were aircraft type, pilot rank, mission type, phase of operations, and flying time. The results of the study were that two thirds of the accidents were due to pilot error, and the pilot error accident rates decreased as the cumulative flying time increased (17:16,45).

Annually APPROACH, the Navy safety magazine, highlights the problems of Navy aircraft inflight refueling from Air Force tankers. As mentioned in the background, the KC-135 must be equipped with the boom-drogue adapter (BDA) to refuel Navy and Marine aircraft. The Naval aviators major complaint is the length of the hose that the drogue is attached to. The hose is nine feet long with no automatic take up capability. This short piece of hose limits the aerial refueling envelope. The Naval pilots state that this allows very little room for error. The pilots also state that the BDA sometimes oscillates. This makes it difficult to fly into the basket with out hitting the sides or without having the basket hit the receiver aircraft. Several incidents occurred where the receiver aircraft was plugged into the tanker and the hose whipped and snapped

the probe. In short, Navy pilots feel the current BDA is inefficient and needs to be redesigned (16:7-9,15:2-6).

In a 1986 Air Command and Staff College report, Major Patrick F. Dunn analyzed the mishap data of Air National Guard flight incidents. The study determined mishaps to be caused by either logistics or operations factors. In the attempt to determine trends, the data was divided into two time frames. One time frame was from 1965 to 1974 and the other time frame was from 1975 to 1984. The final result showed a decrease in mishaps across Class A,B, and C mishap categories (7:18,25).

Summary

The objective of this report is to determine categories of causes of inflight refueling mishaps with the KC-135. Since the KC-135's introduction into the U.S. Air Force aircraft inventory in 1956, numerous mishaps have occurred. This information is maintained by the Air Force Inspection and Safety Center. The database maintained by the Air Force Inspection and Safety Center is not specific enough in its determination of causes to allow trend analysis or comparisons across aircraft types. By reviewing literature, a method of determining specific causes was developed. Once categorized by causes, analysis were accomplished in response to the stated hypotheses.

II. Methodology

This chapter explains how causes were determined and how the data was acquired, organized and analyzed. With analysis being the end result, the logical flow of getting results was broken into three basic tasks. The tasks are as follows:

1. Isolation of Causes
2. Categorization of Data
3. Analysis of Data

Isolation of Causes

Isolation of the causes of aerial refueling mishaps with the KC-135 was done by accomplishing the following task:

1. Literature Review
2. Data Review

Literature Review. A review of the literature was conducted to determine how others determined the causes of aircraft accidents. Reports covering both military and civilian aircraft accidents, investigation, and reporting were reviewed. Also, Air Force regulations pertaining to mishap investigations provided the guidelines as to how mishaps were classified. From the literature review, the determination was made that all aerial refueling mishaps could be attributed to operations related causes (those mishaps caused by aircrew), logistics related causes (those

mishaps caused by material failure), weather related causes, or undetermined causes.

Data Review. As stated in Chapter I, AFISC is required to maintain a database of all aircraft mishaps causing \$10,000 damage or more. Therefore, a report summarizing inflight refueling incidents with the KC-135 from 1978 to 1988 was requested from the Air Force Inspection and Safety Center (AFISC). Upon review of the summary reports, it was determined that aerial refueling is seldom attempted in bad weather. Therefore, this category of cause was removed. Also based upon the data review, the generalized causes determined after the literature review, were subtiered into more specific causes. This subtiering of the generalized causes was accomplished by reading the summary reports and recording the various causes of each of the 279 mishap incidents. The researchers emphasis was on the human element of aerial refueling and on the refueling receptacle and receiving devices. Therefore, the category of causes covering these areas were included. All other causes were determined to be other maintenance failure or undetermined cause of mishap. The basic causes that were chosen as subsets of logistics or operations were as follows:

1. Receiver pilot error
2. Tanker pilot error
3. Boom operator error
4. Boom failure

5. Receptacle failure
6. Other maintenance failure
7. Undetermined cause

Categorization of Data

Once all possible causes of incidents were determined, each incident was tabulated as being caused by one of the seven cause factors. For analysis purposes, the causes were grouped by aircraft type.

Analysis of Data

The analysis of data was accomplished by completing the following tasks:

1. Collective analysis of causes.
2. Analysis of boom refueling versus BDA refueling mishaps.
3. Analysis of Air Force fighter/attack aircraft versus heavy aircraft mishaps.
4. Detailed analysis of the aircraft types involved in over fifty percent of the mishaps.

Collective Analysis of Causes. The total of each category of the causes was tabulated and the percentage of the total causes was computed for each cause category. This information was used to provide insight into whether the leading cause of aerial refueling mishaps was aircrew or material.

Analysis of Boom Refueling versus BDA Refueling Incidents. Observer's Directory of Military Aircraft was used to determine if the aircraft involved in the mishap was probe equipped or receptacle equipped. Based upon this information, the aircraft were separated into boom refueled aircraft and BDA refueled aircraft. The categories of causes were tabulated separately for the two groups and the percentage of the total causes of each cause for the two groups was computed. A comparison was done to determine if the ranking of causes were the same no matter which method of refueling was used.

Analysis of Air Force Fighter/Attack Aircraft versus Air Force Heavy Aircraft. As stated in Chapter I, analysis of fighter/attack aircraft versus heavy aircraft was limited to U.S. Air Force inventory aircraft. Again, Observer's Directory of Military Aircraft was used to determine which aircraft were fighter/attack aircraft and which aircraft were heavy aircraft (tankers, bombers, and transport aircraft). Based upon this information, the aircraft were separated into categories of fighter/attack aircraft and heavy aircraft. For the separate groups, the categories of causes and total causes were tabulated and the percentage of total causes of each category cause was computed. A comparison of percent causes of the two groups was then done.

Detailed Analysis of the Aircraft Involved in Over Fifty Percent of the Mishaps. Because a limited

number of aircraft types were responsible for over half the mishaps, more specific information about the causes was desired. The groups of BDA refueled and boom refueled aircraft were maintained. All aircraft types above the fifty percent cutoff were included for further analysis. The further analysis consisted of again reviewing the summary reports acquired from AFISC. The specific cause of a mishap was recorded for each report. Upon review of the summary reports, the specific causes were subtiered off of the seven basic causes as follows:

1. Receiver pilot error
 - 1.1 Pilot induced oscillation
 - 1.2 Leaving aerial refueling envelope
 - 1.3 Excessive closure rate
 - 1.4 Misjudgment of boom location
2. Tanker pilot error
3. Boom operator error
 - 3.1 Failure to move boom
 - 3.2 Improper commands to receiver pilot
 - 3.3 Misjudgment of receiver location
4. Boom/BDA failure
5. Receptacle failure
6. Other maintenance failure
7. Undetermined

Summary

The method described above was used to categorize the causes of inflight refueling mishaps. The objective of this methodology was to format the data in an usable form for purposes of analysis. The various analysis consisted of the determination of percent causes for all aircraft involved in mishaps with the KC-135, a comparision between boom refueled aircraft mishaps and BDA refueled aircraft mishaps, a comparision between fighter/attack aircraft mishaps and heavy aircraft mishaps, and a detailed analysis of aircraft types causing over fifty percent of the mishaps.

III. Results and Analysis

The analysis done in this chapter is in response to the hypotheses and objectives posed in Chapter I. The results of the analysis are as follows in the remainder of this chapter.

Overview

Twenty six different aircraft type were involved in 279 mishap incidents with the KC-135 in a time period from 1978 to 1988 . Seventeen of the aircraft were part of the U.S. Air Force aircraft inventory and the remaining nine were part of the U.S. Navy aircraft inventory. Of the seventeen U.S. Air Force aircraft, two were probe equipped, the F-105 and the A-7. All nine of the U.S. Navy aircraft were probe equipped. Eleven of the aircraft were considered to be heavies (transport, tankers, and bombers). The remaining 15 were considered to be fighter/attack aircraft. Overall, the F-4, B-52, C-141, and F-106 were involved in over fifty percent of the mishap incidents in the ten year period. When seperated into categories of boom refueled aircraft and BDA refueled aircraft, for boom refueled the F-4, B-52, and C-141 were involved in 53.5% of the mishaps and for BDA refueled the F-4(Navy), F-14, F-105, and OA-37B were involved in 59.2% (29 out of 49) of the mishaps.

Response to the Problem Statement

The objective of this chapter was twofold: (1) To format the various mishaps in a form suitable for analysis and (2) To analyze the data. The first objective is in response to the problem statement of what are the causes of inflight refueling mishaps with the KC-135. The methodology described in Chapter II derived the seven basic cause factors. The seven cause factors are restated as:

1. Receiver pilot error
2. Tanker pilot error
3. Boom operator error
4. Boom failure
5. Receptacle failure
6. Other maintenance failure
7. Undetermined cause

Table 1 breaks the 279 mishaps down as follows: 152 mishap incidents were attributed to receiver pilot error, one mishap incident was attributed to tanker pilot error, thirty eight mishap incidents were caused by boom operator error, thirty four mishap incidents were attributed to boom failure, fourteen mishap incidents were determined to be caused by receptacle failure, twenty nine mishaps were attributed to other maintenance failure, and eleven of the mishap incidents had no determined cause. Alternate ways to view this information is by percentages of causes and operations and logistics related causes. Cause categories one, two, and three are operations relate causes (caused by

personnel) and cause categories four, five, and six are operations related causes (caused by maintenance or material failure). Overall 68.4% of the 279 mishap incidents were caused by aircrew. The majority of them (54%) being caused by the receiver pilot. Twenty seven percent of the mishap incidents were caused by maintenance or material failure. Approximately 4% of the mishaps had undetermined causes.

Table 1. KC-135 Aerial Refueling Mishap Incidents from 1978 to 1988.

AIRCRAFT	CAUSES							TOTAL AIRCRAFT TYPE	PERCENT AIRCRAFT
	1	2	3	4	5	6	7		
F-4	34	0	8	6	0	8	3	59	21.15
B-52	18	0	10	4	1	6	0	39	13.98
C-141	14	0	1	1	3	4	2	25	8.96
F-106	13	0	2	0	0	1	2	18	6.45
A-10	4	0	2	2	4	1	0	13	4.66
A-7	8	0	1	0	1	1	1	12	4.30
F-111	5	0	5	0	1	1	0	12	4.30
F-15	7	0	0	2	1	2	1	13	4.66
F-4(N)	4	0	0	4	0	1	0	9	3.23
F-16	2	0	2	0	0	0	1	5	1.79
F-14	3	0	1	3	0	0	0	7	2.51
E-3	5	1	3	0	0	0	0	9	3.23
RC-135	8	0	1	0	0	2	0	11	3.94
KC-10	5	0	0	0	0	0	0	5	1.79
F-105	6	0	0	1	0	0	0	7	2.51
OA-37B	1	0	0	5	0	0	0	6	2.15
A-6(N)	2	0	0	0	2	1	0	5	1.79
F-100	2	0	0	2	1	0	0	5	1.79
AC-130	2	0	0	1	0	1	0	4	1.43
C-5	3	0	1	0	0	0	0	4	1.43
F-18	2	0	0	0	0	0	0	2	.72
A-4	0	0	0	2	0	0	1	3	1.08
S-3	1	0	0	0	0	0	0	1	.36
A-7(N)	3	0	0	0	0	0	0	3	1.08
B-1B	0	0	0	1	0	0	0	1	.36
ERA-3D	0	0	0	1	0	0	0	1	.36
TOTAL CAUSES	152	1	38	34	14	29	11	279	
PERCENT CAUSES	54	.4	14	12	5	10	4		100

Hypothesis One

Hypothesis one states that aircraft using the boom method of refueling will have a substantially higher percentage of mishaps caused by aircrew when compared to aircraft refueled using the BDA method. This hypothesis is posed because the boom method of refueling requires continuing interaction between the receiver pilot and boom operator. The boom operator must give the receiver pilot instructions to position him/her in the aerial refueling envelope. Once the receiver pilot positions the aircraft in the envelope, the boom operator must attempt to 'fly' the boom into the receptacle. The boom operator must continue to give instruction to the receiver pilot to keep him in the envelope. With BDA refueling, the boom operator positions the BDA in the aerial refueling envelope. The receiver pilot is responsible for flying the probe into the BDA without the aid of the boom operators instructions. The underling belief of the hypothesis is that less interaction of the aircrew will lead to fewer mishaps being caused by aircrews.

Table 2 provides the information for boom refueled aircraft. Of the 26 aircraft types involved in the study, fifteen are boom refueled. Overall, 166 out of 230 mishap incidents with the KC-135 when boom refueling, were attributed to aircrew. This accounted for 73.4% of the KC-135 boom refueling mishaps. One hundred twenty eight of the mishap incidents were attributed to the receiver pilot

and thirty seven of the mishap incidents were attributed to boom operator error. In only one case was the tanker pilot determined to be the cause of a mishap incident. In that single case, the tanker pilot banked too rapidly while refueling an E-3.

Table 2. KC-135 Aerial Refueling Mishap Incidents with Boom Refueled Aircraft from 1978 to 1988.

AIRCRAFT	CAUSES							TOTAL AIRCRAFT TYPE	PERCENT AIRCRAFT
	1	2	3	4	5	6	7		
F-4	34	0	8	6	0	8	3	59	25.65
B-52	18	0	10	4	1	6	0	39	17.00
C-141	14	0	1	1	3	4	2	25	10.90
F-106	13	0	2	0	0	1	2	18	7.80
A-10	4	0	2	2	4	1	0	13	4.65
A-7	8	0	1	0	1	1	1	12	5.22
F-111	5	0	5	0	1	1	0	12	5.22
F-15	7	0	0	2	1	2	1	13	4.65
F-16	2	0	2	0	0	0	1	5	2.17
E-3	5	1	3	0	0	0	0	9	4.00
RC-135	8	0	1	0	0	2	0	11	4.78
KC-10	5	0	0	0	0	0	0	5	2.17
AC-130	2	0	0	1	0	1	0	4	1.74
C-5	3	0	1	0	0	0	0	4	1.74
B-1B	0	0	0	1	0	0	0	1	.43
TOTAL CAUSES	128	1	37	16	11	27	10	230	
PERCENT CAUSES	56	.4	17	7	4.8	12	4		100

Table 3 details the information acquired on BDA refueled aircraft. The dataset consists of eleven different aircraft types, involved in forty nine mishap incidents. Twenty five of the 49 mishap incidents are attributed to receiver pilot or boom operator error. This accounts for 51% of the BDA mishap incidents. Twenty four of the

incidents were attributed to the receiver pilot and only one was attributed to the boom operator. No incidents were recorded where the tanker pilot was involved in a mishap.

Table 3. KC-135 Aerial Refueling Mishap Incidents with Boom/Drogue Adapter Refueled Aircraft from 1978 to 1988.

AIRCRAFT	CAUSES							TOTAL AIRCRAFT TYPE	PERCENT AIRCRAFT
	1	2	3	4	5	6	7		
F-4(N)	4	0	0	4	0	1	0	9	18.40
F-14	3	0	1	3	0	0	0	7	14.30
F-105	6	0	0	1	0	0	0	7	14.30
OA-37B	1	0	0	5	0	0	0	6	12.24
A-6(N)	2	0	0	0	2	1	0	5	10.20
F-100	2	0	0	2	1	0	0	5	10.20
F-18	2	0	0	0	0	0	0	2	4.10
A-4	0	0	0	2	0	0	1	3	6.12
S-3	1	0	0	0	0	0	0	1	2.00
A-7(N)	3	0	0	0	0	0	0	3	6.12
ERA-3D	0	0	0	1	0	0	0	1	2.00
TOTAL CAUSES	24	0	1	18	3	2	1	49	
PERCENT CAUSES	49	0	2	37	6	4	2		100

A significant difference exist between several causes categories when comparing KC-135 boom refueling to BDA refueling. Fifty six percent of the causes are attributed to the receiver pilot in boom refueling, where only 49% are attributed to the receiver pilot in BDA refueling. Although the difference is significant, it is not as substantial as the difference in mishap caused by boom operator when comparing boom refuelings to BDA refuelings. In boom refueling, the boom operator was the cause of

17% of the mishaps, where in BDA refuelings, the boom operator was responsible for only 2% of the mishaps. This result supports the hypothesis and the underlying belief that the interaction of aircrew in boom refuelings causes more mishaps to occur.

Hypothesis Two

Hypothesis two states that aircraft using the BDA method of refueling will have a substantially higher percentage of boom and receptacle failure mishaps when compared to aircraft using the boom method of refueling. This hypothesis is posed because the components required for a BDA refueling (probe and BDA) are more delicate than the components required for boom refueling. Also no design improvements have been done on the BDA since its inception in 1961. The original complaint of those refueling from the BDA was that the short length of hose allowed little room for maneuverability. Movement by the receiver pilot to the outer edges of the refueling envelope while refueling, strains the BDA hose. This eventually leads to the hose breaking. The drogue portion of the BDA also has a tendency to oscillate. When pilots attempt to 'mate' with the BDA, off centered contacts are made, which damage the probes. In boom refueling equipment, the receptacle is considered to be very durable. The current receptacle called the UARRSI (Universal Aerial Refueling Slipway Installation) is the evolution of thirty years of

receptacle improvements. Likewise, the boom has undergone many improvements to make it reliable and durable.

Table 2 shows that of the 230 boom refueling mishaps, 27 were attributed to boom failure and receptacle failure. In the 49 BDA refueling mishaps, 21 were caused by boom or receptacle failure (Table 3). In comparing the percentages of causes, no significant difference exist between probe failures causing the mishap and receptacle failure causing the mishap. Probe failure accounted for 6.1% of the BDA refueling mishaps (Table 3) and the receptacle accounted for 4.8% of the boom refueling mishaps (Table 2). A significant difference does exist between the percentages of mishap caused by boom failure compared to mishaps caused by BDA failure. The BDA was attributed with 37% of the BDA refuelings mishaps (Table 3), where as, the boom was attributed with only 7% of the mishaps (Table 4). These results support the hypothesis and the researchers underlying belief that BDA refuelings are more difficult than boom refuelings and therefore more susceptible to mishaps.

Hypothesis Three

Hypothesis three stated that fighter/attack aircraft will have a substantially higher percentage of mishaps caused by aircrew versus heavy aircraft. This hypothesis was posed because many incidents were cited in the AFISC summary reports of fighter/attack aircraft having a difficult time staying in the aerial refueling envelope. One possible

cause of this is attributed to the destabilizing effect of the wake turbulence created by the KC-135. Fifteen aircraft types were analyzed. Seven of the aircraft types were considered to be fighter/attack and the remaining eight aircraft were determine to be heavies.

Of the 230 mishaps attributed to fighter/attack and heavy aircraft, 132 were caused by fighter/attack aircraft (Table 4). Of that 132, 93 were caused by aircrew. The remaining 98 incidents were caused by heavy aircraft (Table 5). Of that 98, 73 mishaps were attributed to aircrew. When comparing percentages, 70% of the fighter/attack mishaps were caused by aircrews and 74% of the heavy mishaps were caused by aircrew. A comparision between the categories of receiver pilot percentages and boom operator percentages for heavy and fig' er/attack aircraft mishaps show no significant difference. The fighter/attack receiver pilots were attributed with causing 55% of the mishaps and the heavy receiver pilots were attributed with 56% of the mishaps. The boom operator was the cause of 15% of the fighter/attack mishaps and for 17% of the heavy mishaps.

Although there was no significant difference in the mishaps caused by aircrew when comparing fighter/attack aircraft to heavy aircraft, several important facts were obtained from the summary AFISC reports. Because of the size of heavy aircraft, the boom operators sometimes have a problem with depth perception. This affects the ability to

judge true distance. Several mishaps with the B-52 occurred because of this problem.

Table 4. KC-135 Aerial Refueling Mishap Incidents with Figher/Attack Aircraft from 1978 to 1988.

AIRCRAFT	CAUSES							TOTAL AIRCRAFT TYPE	PERCENT AIRCRAFT
	1	2	3	4	5	6	7		
F-4	34	0	8	6	0	8	3	59	44.70
F-106	13	0	2	0	0	1	2	18	13.60
A-10	4	0	2	2	4	1	0	13	9.90
A-7	8	0	1	0	1	1	1	12	9.10
F-111	5	0	5	0	1	1	0	12	9.10
F-15	7	0	0	2	1	2	1	13	9.90
F-16	2	0	2	0	0	0	1	5	3.80
TOTAL CAUSES	73	0	20	10	7	14	8	132	
PERCENT CAUSES	55	0	15	10	6.6	11	6		100

Table 5. KC-135 Aerial Refueling Mishap Incidents with Heavy Aircraft from 1978 to 1988.

AIRCRAFT	CAUSES							TOTAL AIRCRAFT TYPE	PERCENT AIRCRAFT
	1	2	3	4	5	6	7		
B-52	18	0	10	4	1	6	0	39	39.80
C-141	14	0	1	1	3	4	2	25	25.50
E-3	5	1	3	0	0	0	0	9	9.20
RC-135	8	0	1	0	0	2	0	11	11.20
KC-10	5	0	0	0	0	0	0	5	5.10
AC-130	2	0	0	1	0	1	0	4	4.10
C-5	3	0	1	0	0	0	0	4	4.10
B-1B	0	0	0	1	0	0	0	1	1.00
TOTAL CAUSES	55	1	17	6	4	13	2	98	
PERCENT CAUSES	56	1	17	6	4	13	2		100

Hypothesis Four

Hypothesis four states that fighter/attack aircraft will have a substantially higher percentage of mishaps caused by boom or receptacle failure versus the heavies. Hypothesis four was posed because of the belief that the turbulence created by the KC-135 not only affected the fighter/attack pilots ability to refuel but also stresses the equipment more so than heavy refuelings. The seven fighter/attack aircraft were involved in 17 mishaps caused by the failure of the boom or the receptacle (Table 4). The eight heavy aircraft had 10 mishaps caused by the failure of the receptacle or boom (Table 5). When boom and receptacle mishaps are considered together the difference is 6.6% (16.6% mishap incidents caused by boom or receptacle failure for the fighter/attack and 10% mishaps caused by the boom or receptacle failure for the heavies). These results support the hypothesis.

Hypothesis Five

Hypothesis five states that a relatively few aircraft types will be involved in at least fifty percent of the mishaps. This hypothesis was posed for two reasons: (1) Some aircraft types make up a larger percentage of the U.S. Air Force aircraft inventory. If that aircraft type makes up a larger percentage of the U.S. Air Force inventory, it will have more of the aerial refueling and therefore more chances for mishaps. (2) Certain aircraft type designs

make them more susceptible to mishaps. Aircraft design factors such as location of receptacle, location of engines, length of wings, speed, and flight characteristics, can contribute to mishaps.

Of the 230 boom refueling mishaps recorded in Table 2, three out of the 15 aircraft types were responsible for over half of the mishaps. The F-4 accounted for 59, the B-52 accounted for 39, and the C-141 was involved in 25 of the mishap incidents. Overall, these three aircraft type accounted for 53.5% of the mishaps. Chapter II developed not only the basic causes of aerial refueling mishaps, but also the specific causes and these causes are restated as follows:

1. Receiver pilot error
 - 1.1 Pilot induced oscillation
 - 1.2 Leaving aerial refueling envelope
 - 1.3 Excessive closure rate
 - 1.4 Misjudgment of boom location
2. Tanker pilot error
3. Boom operator error
 - 3.1 Failure to move boom
 - 3.2 Improper commands to receiver pilot
 - 3.3 Misjudgment of receiver location
4. Boom/BDA failure
5. Receptacle failure
6. Other maintenance failure
7. Undetermined

Table 6 and 7 isolates the more specific causes for boom refueling mishaps (Table 6) and BDA refueling mishaps (Table 7). Note Tables 6 and 7 do not contain cause category 2 because there were no tanker pilot errors in the candidate aircraft. Also cause categories 6 and 7 are omitted. The emphasis is on the human aspect of aerial refueling and the aerial refueling equipment specifically.

Table 6. Aircraft Types Causing Over Fifty Percent of the KC-135 Boom Aerial Refueling Mishap Incidents from 1978 to 1988.

CAUSES									
AIRCRAFT	1.1	1.2	1.3	1.4	3.1	3.2	3.3	4	5
F-4	6	16	8	4	5	1	2	6	0
PERCENT	10	27	13.6	7	8.5	1.7	3.4	10	0
B-52	0	7	5	6	7	0	3	4	1
PERCENT	0	18	13	15	18	0	7.7	10.3	3
C-141	0	4	8	2	1	0	0	1	.3
PERCENT	0	16	32	8	4	0	0	4	12

In the case of the F-4, 27% of the mishaps were caused by the receiver pilot leaving the refueling envelope (Table 6). The high percentage of mishaps caused by receiver pilots leaving the refueling envelope existed in all aircraft types. The F-4 is the only aircraft type analyzed that experienced mishaps caused by pilot induced oscillation. The summary reports do not state if the pilot induced oscillation is caused by the wake turbulence of the KC-135, the receiver pilot or the flight characteristics of the F-4. The receptacle on the F-4 was never the cause of a mishap

incidents. This supports the belief that the UARRSI is reliable and durable.

As stated in the case of the F-4, the pattern of mishaps caused by the pilot leaving the aerial refueling envelope while refueling is again the highest percentage of the causes when analyzing the B-52 (Table 6). In the analysis and results of hypothesis 3, it was noted that the boom operator, sometimes have a problem with depth perception when refueling large aircraft. This makes it difficult to judge the location of the receiver aircraft. As indicated in Table 6, 18% of the B-52 mishaps were attributed to the boom operator failing to move the boom. One of the problems of the AFISC summary reports is that those involved in the mishap incident are responsible for submitting reports. Therefore, there may be two perspectives as to what happen. Ultimately, the decision is made by AFISC. The point being that the receiver pilot may state that the boom operator misjudged the location of the receiver aircraft and the boom operator may state that the receiver pilot misjudged the boom location upon closure. In the cases of the B-52, relatively high percentages were attributed to both misjudgement of boom location and misjudgement of receiver location.

For the C-141, 32% of the mishaps were caused by excessive closure rate of the receiver aircraft (Table 6). This jams the boom into the aircraft. In many cases, the boom did not even hit the receptacle. Reason for excessive

closure rate, could be lack of training and experience, response rate of the receiver pilot, or faulty instructions given by the boom operator. More study needs to be done in this area. The excessive closure rate percentage and the leaving the aerial refueling envelope percentage suggest that the C-141 may not be as responsive or the receiver pilot as well trained.

Of the 49 BDA refueling mishaps (Table 3), the F-4(Navy) accounted for nine, the F-14 and F-105 accounted for seven each, and the OA-37B accounted for six. These 4 aircraft types accounted for 59.2% of the BDA refueling mishap incidents.

Table 7. Aircraft Types Causing Over Fifty Percent of the KC-135 Boom/Drogue Adapter Aerial Refueling Mishap Incidents from 1978 to 1988.

AIRCRAFT	CAUSES								
	1.1	1.2	1.3	1.4	3.1	3.2	3.3	4	5
F-4(N)	0	3	0	1	0	0	0	4	0
PERCENT	0	33	0	11	0	0	0	44	0
F-14	0	3	0	0	1	0	0	3	0
PERCENT	0	43	0	0	14	0	0	43	0
F-105	0	4	0	2	0	0	0	1	0
PERCENT	0	57	0	29	0	0	0	14	0
OA-37B	0	1	0	0	0	0	0	5	0
PERCENT	0	17	0	0	0	0	0	83	0

Overall, the percentage of aircraft leaving the refueling envelope is greater for BDA refuelings than with boom refuelings. This is attributed to the envelope being much smaller, the difficulty of refueling from the BDA, and the

lack of experience at refueling from the KC-135 for Navy pilots (15:2-3). Also, the cases of BDA failure from all four aircraft types is high. The BDA method of refueling has a history of BDA oscillation, hose whipping, and off center connects and disconnects. These factors damage the BDA. The combined effect is failure of the system. Although the percentages are high, the actual number of cases is low. This allows a distortion of the data.

The OA-37B has a higher percentage of mishaps caused by BDA failure. In all five cases of BDA failure with the OA-37B, the OA-37B injected fuel into the engines causing a flameout. In each case the engines were restarted, but extensive maintenance and repair were required.

Summary

In response to the problem statement, seven basic causes of aerial refueling mishaps with the KC-135 were determined. The primary cause of aerial refueling mishaps with the KC-135 was receiver pilot error. When KC-135 aerial refueling mishaps are divided into categories of BDA refuelings versus boom refueling mishaps, the second leading cause of mishaps differs. The second leading cause of mishaps for boom refuelings is boom operator error. The second leading cause for BDA refuelings is BDA failure. When the KC-135 aerial refueling mishaps are divided into categories of heavy aircraft versus fighter/attack aircraft, the ranking of causes based upon percentage of the total

causes are the same across the categories. These results were in response to hypothesis one thru four.

Hypothesis five addressed the desire to obtain more specific information on aircraft types causing over half of the mishaps. Again, aircraft were separated into categories of KC-135 aerial refueling mishaps with boom refuelings and KC-135 aerial refuelings mishaps with BDA refuelings. For the boom refuelings, the F-4, B-52, and C-141 were involved in 53.5% of all mishaps. For the BDA refuelings, the F-4(Navy), F-14, F-105, and OA37-B accounted for 59.2% of the BDA aerial refueling mishaps. Overshooting the aerial refueling envelope and excessive closure rate were the primary cause of mishaps in the seven aircraft types selected for further analysis, with the exception of the OA-37B. In the case of the OA-37B, the predominate cause of mishaps was the failure of the BDA.

IV. Conclusions and Recommendations

The objective of the United States and NATO defense forces is to protect western interest wherever they may be. This protection requires a myriad of defensive and offensive systems working together to achieve that objective. One support component of the system is the U.S. tanker force. Of the 988 tankers in the U.S. and NATO inventory, approximately 600 of the tankers are KC-135's (1). The uses of the KC-135 for defensive and offensive purposes varies. The U.S. Air Force uses the KC-135 primarily to support the strategic bomber force. It serves other missions in the Air Force, such as, ferrying aircraft across the ocean, serving as an airborne refueling source in battle field scenarios, and is used in the deployment of aircraft to other countries. The Navy requires the support of land based tankers for the employment and deployment of fighter aircraft to carriers. With only 68 tankers and 4637 air refuelable aircraft, NATO contingency plans depend heavily on KC-135 support (1).

With many of the U.S. and NATO systems depending this much on tanker support, the consequences of failure are great. Cases have occurred of aircraft being lost at sea because of aborted aerial refueling attempts. Other cases have been recorded of canopies being cracked by BDA's that have disconnected. There are other cases that show of

receiver aircraft having to land with a portion of the boom still in the receptacle. All of these cases impact the mission and therefore inhibit the U.S. and NATO allies ability to protect western interest. To minimize the loss or damage to aircraft and to support the objective of protection of western interest it is imperative that all systems work reliably, including aerial refueling. The intent of this effort was to note the causes of aerial refueling mishaps. Noting the causes is one of the steps to achieving the ultimate goal of resolving the system inadequacies. Once the causes are known, emphasis can be centered on ridding the system of the inefficiency and thus improving reliability.

Conclusion One

The U.S. Air Force has devised a very efficient method of collecting information on all aircraft mishaps including aerial refueling. The information maintained by the Air Force Inspection and Safety Center (AFISC) Reporting Program is essential a database giving the when, what, where, and why of aircraft accidents. Although effective, the information maintained by AFISC is in the form of reports. More needs to be done in the area of data collection, segregation, and analysis. Currently, AFISC is only required to collect information on incidents causing over \$10,000 of damage. Many incidents occur that cause less damage than \$10,000 but are extremely hazardous. A

centralized database needs to be maintained by the command operating the KC-135 (Strategic Air Command) that details all mishap incidents. This information should include receiver pilots age and experience, boom operators age and experience, time of day, number of sorties refuelled, and type of aircraft refuelled. With this type of information a contingency analysis can be done to determine the dependency between the independent variable of mishaps and various dependent variables, such as the ones mentioned above. Data analysis is limited in that the required information is imbedded in the summary reports. Analysis can not be done without manually segregating the results of the summary reports. The researcher recommends further study into ways to segregate the results obtained from the summary reports, for the purpose of easy data analysis.

Conclusion Two

Hypothesis one suggested that aircraft using the boom method of refueling experience a higher percentage of mishaps caused by aircrew than aircraft refuelled using the BDA method. This points to the fact that there may be advantages to BDA refueling. The researcher recommends trade off analysis detailing cost/benefits to maintaining a mix of aerial refueling capability as opposed to maintaining one method of aerial refueling. This trade off analysis should include items such as the cost/benefit of using the

BDA versus the boom for fighter/attack and heavy aircraft aerial refueling.

Conclusion Three

Percentage wise, the boom has less equipment failures but more aircrew mishaps when compared to BDA refuelings. Hypothesis one suggested that the interaction of aircrew (the boom operator and receiver pilot) lead to more mishaps. Although the interaction lends itself to more mishaps, there is no reason that mishaps cannot be minimized by training and educating the pilots and boom operators about the peculiarities of refueling each aircraft type. By the same token, BDA equipment failures can be attributed to the impact of many improper refuelings. The predominate use of the BDA is for refueling Navy aircraft. The KC-135 is an Air Force asset and therefore special arrangements must be made between the two services to allow Naval aircrews to receive aerial refueling training from Air Force tankers. The training that the Navy receives is minimal. Although this currently is the case, as mentioned in the Approach article written by LCDR Slowik, there is no reason that BDA mishaps can not be decreased by proper training, education, and most importantly experience at refueling from the KC-135 BDA (16:9).

Conclusion Four

Hypothesis three suggested that fighter/attack aircraft would have a higher percentage of mishaps caused by aircrews and hypothesis four suggested that fighter/attack would have a higher percentage of mishaps caused by boom and receptacle failure when comparing them to heavy aircraft. Hypothesis three was unsubstantiated by the data and hypothesis four was supported by the results. Therefore based upon the researchers criteria for substantial differences listed in the scope in Chapter I, fighter/attack aircraft do experience a higher percentage of boom and receptacle failure when compared to heavy aircraft. This generates the question of why do heavy aircraft experience less boom and receptacle failure. The summary reports gave an indication that fighter/attack aircraft are effected by the wake turbulence of the KC-135 more so than are heavy aircraft. The effect of the turbulence is an increase of stresses on the aerial refueling boom and receptacle. The results of hypothesis fours also bring up the question, are there positions on the KC-135 airframe that could be modified to accommodate aerial refueling and minimize the wake turbulence experienced by the aircraft in the aerial refueling envelope.

The researcher suggests a simple and inexpensive experiment of flying various aircraft in position of likely points on the KC-135 where aerial refueling does and

possible could take place. The observed effects would be a starting point in substantiating or disproving the belief upon which hypothesis four is based and in determining if there are more suitable points on the KC-135 other than the aft fuselage from which to aerial refuel.

Conclusion Five

The aircraft responsible for the majority of the mishap incidents is the F-4. This decreases the significance of some portions of this report because of the fact that the USAF is phasing out the F-4.

Conclusion Six

A relatively few aircraft types are responsible for the majority of aerial refueling mishaps. In the case of the boom refuelings this can be hypothesized to be caused by two main reasons, the large number of the aircraft type in the Air Force inventory and the lack of aerial refueling experience by the receiver pilot. The F-4 and B-52 make up a large part of the U.S. Air Force aircraft inventory. The responsibility of the KC-135 is to first and foremost support the U.S. bomber force. As stated in the background section of Chapter I, the KC-135 was developed to support the bomber forces. Without the KC-135, the B-52's international strike capability becomes very limited. Therefore, the ability of B-52's to aerial refuel is imperative and for that reason aerial refueling is practiced

very often. The F-4, prior to the development of the F-15 and F-16, was the mainstay of the U.S. Tactical Air Forces. For this reason, large numbers of the F-4 were maintained by the Air Force. A case of lack of experience can be attributed to the C-141 having a high percentage of the mishaps. The first C-141 capable of aerial refueling was delivered in 1979. The last C-141 modified was delivered in 1982. In a flying activity that is inherently hazardous, such as aerial refueling, it takes time for lessons to be learned and procedures modified to make the activity more safe. The report covers a period of 1978 to 1988, just when the modified C-141 was coming on line and beginning to gather experience at aerial refueling. Therefore, the researcher hypothesizes that the high mishap rate is attributed to the learning curve effect.

In the case of BDA refuelings, the relatively few aircraft types causing a large percentage of the mishaps is attributed to the number of that aircraft type requiring aerial refueling from the KC-135. As stated previously, the Navy uses the KC-135 primarily to ferry fighter aircraft to carriers at sea. In the time span that this report covered, the primary Navy fighter aircraft were the F-4 and F-14.

Conclusion Seven

The researcher has isolated the causes of aerial refueling mishaps. The next logical step would be to associate the

effects with each cause. The benefit of this type of information is that it would allow the association of cost with each effect. This type of information would also allow the pinpointing of the severity of each incident. An example of this would be the case of the OA37-B. As shown by Table 1, the OA37-B experienced six mishaps with the KC-135, one by the receiver pilot and five by BDA failure. The effect of each of the BDA failures was fuel leakage from the BDA and probe connection. The leaked fuel was injected into the engines of the OA37-B and caused them to flameout. By having this information cataloged in an easily used form, those responsible for minimizing mishaps can put emphasis on the causes that occur most frequently or on the causes that have the severest effects, such as loss of lives and aircraft.

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The purpose of this study was to determine the causes of inflight refueling mishaps with the KC-135. The study had three main objectives:

- (1) To categorize the causes of KC-135 inflight refueling mishaps.
- (2) To compare mishaps when refueling from the boom/drogue adapter (BDA) to mishaps when refueling from the boom.
- (3) To compare KC-135 mishaps with fighter/attack aircraft to KC-135 mishaps with heavy aircraft.

The study was accomplished by first determining the causes of inflight refueling mishaps. The data was then categorized and analyzed.

The study found seven basic causes of inflight refueling mishaps with the KC-135. The predominate cause of inflight refueling mishaps is the receiver aircraft pilot. When comparing boom/drogue adapter inflight refueling mishaps to boom mishaps, the second leading cause of mishaps differs. In BDA inflight refueling mishaps, the second leading cause is BDA failure. In boom inflight refueling mishaps, the second leading cause is the boom operator. In comparing fighter/attack aircraft inflight refueling mishaps to heavy aircraft inflight refueling mishaps, the ranking of causes is the same. The leading cause was, again, receiver pilot error and the second leading cause was boom operator error.

Although extremely useful, the format of the Air Force Inspection and Safety Center summary reports impede data analysis. The researcher recommends a study into the organizing of the information contained in the summary reports in a form more suitable for data collection and analysis.

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