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The role of weather in Class A Naval aviation mishaps FY 90-98

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THESIS

THE ROLE OF WEATHER IN CLASS A NAVAL AVIATION MISHAPS FY 90-98

by

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March 2001

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THE ROLE OF WEATHER IN CLASS A NAVAL AVIATION MISHAPS FY 90-98

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LIST OF ACRONYMS

AGL	Above Ground Level
AMB	Aircraft Mishap Board
ASO	Aviation Safety Officer
ASOS	Automated Surface Observing System
CFIT	Controlled Flight into Terrain
DOD	Department of Defense
FM	Flight Mishap
FY	Fiscal Year
HF	Human Factors
HFACS	Human Factor Analysis and Classification System
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
JAG	Judge Advocate General
METOC	Meteorology and Oceanography
NCDC	National Climatic Data Center
NSC	Naval Safety Center
NTSB	National Transport Safety Board
ORM	Operational Risk Management
TACAIR	Tactical Aircraft
VFR	Visual Flight Rules

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I. INTRODUCTION

It is widely known that the weather has contributed towards many United States Navy and Marine (Naval) aviation mishaps. The benefits of knowing more about weather contributions to Naval Aviation mishaps are far reaching. These include identifying: 1) What weather elements should get the most attention for improving aviation weather forecasts; 2) What improvements can be made to help pilots make better decisions and minimize mistakes; and 3) What weather elements are most beneficial for including in flight simulators. The last two benefits are important in the analysis of human factors in aviation safety.

Reducing the number of Naval aviation accidents will not only reduce the number of casualties due to mishaps, but also greatly reduce the financial loss. The combined costs of all United States Navy (USN) and United States Marine Corps (USMC) aviation mishaps for Fiscal Year (FY) 2000 was 716 million dollars. For comparison, all Naval mishaps (aviation, afloat, shore/ground, private motor vehicle, and recreation) accounted for $878 million dollars in FY 2000. In other words, Naval aviation mishaps accounted for over 82 percent of all Naval mishap costs in FY 2000 (Pruhs, 2001). A Class A mishap is a Naval aviation mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater, or a naval aircraft is destroyed or missing, or any fatality or permanent total disability occurs with direct involvement of Naval aircraft. More definitions related to Naval aviation accident investigations and reports are provided in chapter 2. A list of acronyms is available on page xiii.

A goal of the NSC, located in Norfolk, VA, is to reduce the Naval and Marine Corps Aviation Mishap annual rate. A Naval aircraft mishap is a signal of failure of the Naval Aviation Safety Program (OPNAV 3750.6Q, 1989). By identifying the causal factors of a mishap, it is possible to prevent recurrence of future mishaps due to the same causes. The NSC maintains an aviation mishap database that has successfully led to reducing the annual Naval aviation mishap rate. This database includes narrative and statistical summaries of major Naval Aviation mishaps. The cause of Naval aviation mishaps is well documented in mishap investigation reports. Causal factors include material failure, maintenance error, aircrew error, and supervisory error. Most mishaps that involve weather list human error as the causal factor. The Navy instruction governing accident investigations (OPNAV 3750.6Q, 1989) states,

> "Environmental conditions are not casual factors. Environmental conditions are those conditions over which there is no human control; such as weather, sea state, etc... For example, a causal factor of a mishap might be an inadequate weather forecast or improper weather avoidance procedures, but not the environmental conditions of thunderstorm turbulence or lightning. Since environmental conditions are not causal factors, all causal factors are under human control, and may therefore be eliminated. Thus all mishaps are preventable."

Even though weather is not a causal factor, it can still be regarded as a contributing factor. However, contributing factors (such as weather) are not included in Naval aviation mishap investigations. Therefore, there is no easily discernable information on weather related mishaps in the NSC database. The weather data in most cases is never studied to determine how it might have contributed to a mishap. As a result, the extent of the weather's role in contributing to Naval aviation mishaps is not fully documented.

A detailed reference search has shown that there has been only one statistical study of the weather impact on Naval Aviation safety. Without this information it is difficult to determine objectively what meteorological areas should get the most attention from meteorology community (for research, weather observations, weather forecasting) and from the aviation community (pilot training, NSC, simulators, cockpit design).

A. GOALS AND OBJECTIVES

This thesis will study all Class "A" Naval aviation mishaps involving aircrew error for FY 1990-98. The primary goal is to use this information to better understand weather related mishaps. From this data this thesis will:

1) determine the role weather played as a contributing mishap factor,

2) determine which weather elements and weather groups contributed the most,

3) determine the number of preventable mishaps for aircrew if they received an accurate forecast, and

4) for the weather mishaps, this thesis will describe the types of aircraft, types of mishaps, basic human error types, phase of flight, and other aspects of the mishap.

This thesis research will:

1) provide areas for improving the DD-175 dash 1 used in military aviation weather briefs,

2) improve communications between weather and aviation communities in general and specifically between the forecaster and pilot,

3) help aircrews make better decisions regarding the weather on the ground, which will also help aircrews reduce weather related human factors mishaps,

4) show the benefit and need to better document and track the weather's contribution in future Naval aviation mishaps,

5) produce more effective mishap reports, and

6) help aircrews make better decisions regarding the weather.

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II. BACKGROUND AND METHODOLOGY

In this chapter, definitions used in Naval aviation investigations, past research, and the data and methodology of this study are described.

The definitions used in aircraft accident investigations are provided in Table 1. Human factors related definitions are contained in Appendix A.

Table 1. Naval Aviation Mishap Definitions (From OPNAVINST 3750.6Q, 1991)

Naval Aircraft. Refers to U.S. Navy, U.S. Naval Reserve, U.S. Marine Corps, and U.S. Marine Corps Reserve aircraft.
Mishap. A Naval mishap is an unplanned event or series of events directly involving naval aircraft, that results in $10,000 or greater of cumulative damage to naval aircraft or personal injury.
Mishap Class. Mishap severity elements are based on personnel injury and property damage. a. Class A Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability occurs with direct involvement of naval aircraft. b. Class B Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $200,000 or more, but less than $1,000,0000 and/or a permanent partial disability, and/or the hospitalization of five or more personnel. c. Class C Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $10,000 or more but less than $200,000 and/or injury results in one or more lost workdays.
Mishap Categories (Types). Naval aircraft mishap categories are defined below: a. Flight Mishap (FM). Those mishaps in which there was $10,000 or greater DOD aircraft damage or loss of a DOD aircraft, and intent for flight for DOD aircraft existed at the time of the mishap. Other property damage, injury, or death may or may not have occurred. b. Flight Related Mishap (FRM). Those mishaps in which there was less than $10,000 DOD aircraft damage, and intent for flight (for DOD aircraft) existed at the time of the mishap, and $10,000 or more total damage or a defined injury or death occurred. c. Aircraft Ground Mishap (AGM). Those mishaps in which no intent for flight existed at the time of the mishap and DOD aircraft loss, or $10,000 or more aircraft damage, and /or property damage, or a defined injury occurred.

A. LITERATURE REVIEW

Calvert (1996) showed the importance of including environmental elements in flight simulation software. In his study, the environment is defined as both man-made (signals and lights, wires, smoke) and natural (day/night, weather). Class A mishaps from 01 January 1985 to 31 May 1995 were reviewed (625 total). Out of the 625 events, 92 events (15%) identified environmental factors that contributed to the mishap. A naval aviator helped Calvert, who is an engineer, in this analysis.

This was the first known research investigating weather events with naval mishaps. Frequency of weather phenomenon for the environmental influenced mishaps were 59% for visibility, 42% for haze, 28% for clouds, 20% for ceiling, 14% for fog, 13% for rain, 7% for wind gusts, 4% for wind, 4% for turbulence, 3% for thunderstorms, and 2% for lightning. Unfortunately, no quantitative definitions were provided in the paper. It was also found that 79% of all environmentally related mishaps would likely have not occurred if the environment were benign (clear, level terrain, zero object, VFR scenario).

Instruction OPNAV 3750.6Q (1989) states that the purpose of the Naval aviation safety program is to preserve human and material resources. This instruction provides procedures for mishap investigations and submission of reports. Most mishaps result from at least two mishap causal factors. Causal factors are events, with removal of, would prevent a mishap. The instruction states "There is, therefore, no logic in attempts to rank causal factors as 'direct,' 'primary,' 'contributing,' etc." By not including environmental conditions as causal factors, all causal factors are under human control. Therefore, causal factors can be eliminated which means that all mishaps are preventable.

B. NAVAL MISHAP INVESTIGATIONS & REPORTING

When a class A Naval aviation mishap occurs, two different investigation boards are convened, each with a distinct and separate mission. The board that immediately investigates the mishap is the Aviation Mishap Board (AMB). The AMB at a minimum is made up of personnel from the Operations, Maintenance, and Safety departments of the squadron involved as well as a flight surgeon. The mission of the board is to determine the causal factors of the mishap in an attempt to prevent a future re-occurrence of an accident under similar causal factors (Stevens, 1988).

The second type of board that investigates a mishap is a formal Judge Advocate General (JAG) board. It acts under the Judge Advocate General jurisdiction and is part of the military legal branch. The purpose of this board is to investigate administrative and legal considerations concerning the conduct and possible culpability of those persons involved with the mishap (Stevens, 1988).

The AMB receives their guidance and direction from OPNAVINST 3750.6P (Stevens, 1988). The goal of the AMB is to determine the cause of the aviation mishap. The cause or cause factors are generally classified as being either human or material. Human cause factors require identification of the elements who, what, and why to fully describe the occurrence. The "who" can be aircrew (personnel in the aircraft or formation), supervisory (personnel engaged in command and operations related support), facilities (support personnel involved in traffic control, ground handling, crash and rescue, and weather briefing), and maintenance (personnel involved in production, servicing, and repair). Material cause factors frequently identify the weak link in the chain, which can lead to remedial actions, such as improved design of a part that failed, thus preventing a future similarly related mishap (OPNAV 3750.6Q, 1989).

C. CONCEPT OF PRIVILEGE

The AMB investigations are different from those of the JAG in that the AMB applies the concept of privileged information. In order for the Naval Aviation Safety Program to be successful, privileged information provided by those involved in a mishap must be protected. It is important that those involved with a mishap investigation be protected from any kind of negative consequences for their full cooperation. The concept of privilege is that information designated as privileged cannot be used as evidence for disciplinary action, and those participating are assured confidentiality. The purpose of designating information as privileged is to encourage individuals to provide complete and candid information pertaining to the circumstances surrounding a mishap and to encourage investigators and endorsers to provide complete, open and forthright information, opinions, and recommendations regarding a mishap (OPNAV 3750.6Q, 1989).

If privileged information were allowed to be used for purposes other than safety, vital safety information might be withheld by individuals because they believed certain uses of the information could be embarrassing or detrimental to themselves, their fellow service members, their command, their employer, or others. In addition, individuals might withhold information based on their constitutional right to avoid self-incrimination. Similarly, if investigators and endorsers believe that their deliberations, opinions, and recommendations could be used for other than safety purposes, they might be reluctant to develop, or include in their reports and endorsements, information which would be vital for safety (OPNAV 3750.6Q, 1989).

Because of this, failure to properly handle or safeguard privileged information can result in disciplinary action. This report is based on data that falls under the concept of privilege. However, this thesis has been written in such a way that the report itself contains no privileged information.

Most documents are destroyed after an investigation is complete. All OPNAV 3750.6Q required documentation must be destroyed two years after the mishap date. Only the NSC is exempt from this requirement. Documents such as statements, diagrams, photographs, and notes acquired or created by the investigators are destroyed once the mishap investigation is complete unless higher authorities order that it be retained (OPNAV 3750.6Q, 1989). Therefore, most mishap data is not available for post-investigation research. However, the NSC does keep a detailed database that summarizes most of the information contained in the Mishap Investigation Reports submitted by the investigating command.

D. HUMAN FACTORS THEORY

It has been shown (Pruhs 2001) that the majority of Naval Aviation mishaps are due to human error. These errors are a function of Human Factors (HF); the study of how people interact with their environment. In the case of aviation, these studies involve such issues as how pilot or aircrew performance is affected by the design of cockpits, human physiological and psychological variations, and the environment (School of Aviation Safety, 2000). Human factors analysis has an operational benefit of helping the aviation community reduce mishaps. This analysis can also help the meteorology community understand more about how and why the weather contributes towards human error leading to weather related mishaps. A detailed discussion of Human Factors theory is provided in Appendix A.

The NSC has classified all aircrew human factors Class A mishaps according to the NSC HFACS taxonomy (Figure 1). The system first classifies FMs as (A) Unsafe Acts, (B) Preconditions for Unsafe Acts, (C) Unsafe Supervision, (D) Organizational Influences. More specific descriptions follow under these categories. Details about the NSC HFACS taxonomy are provided in Appendix B.

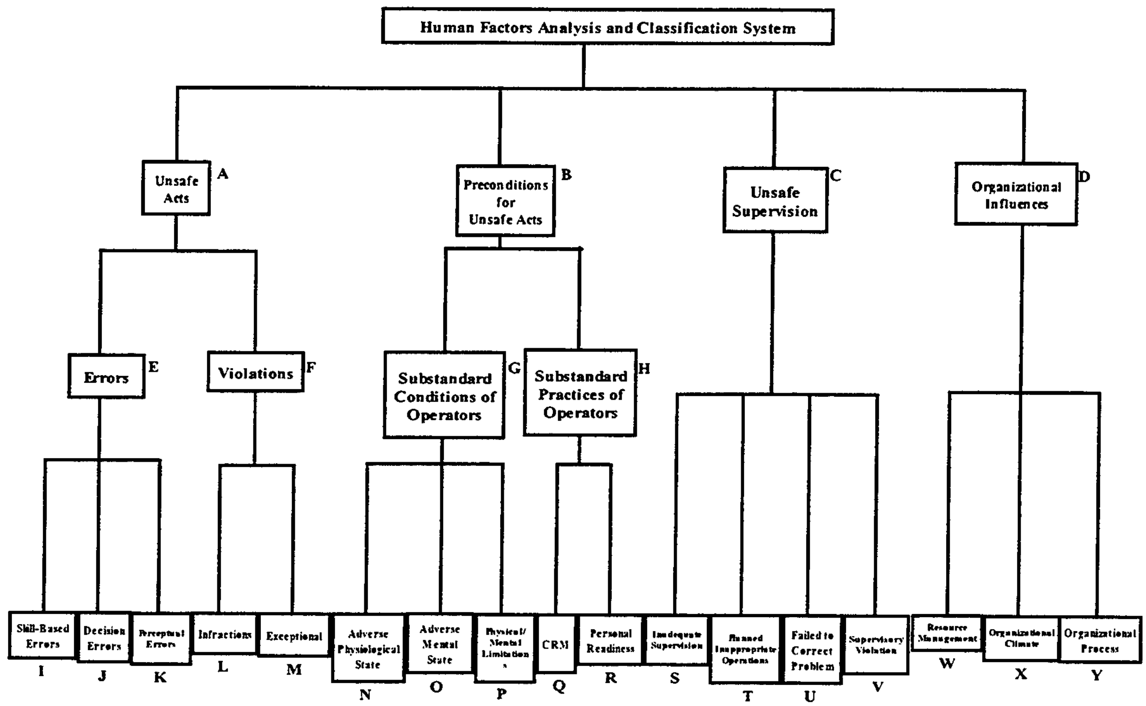

Figure 1. Hierarchical Representation of the HFACS Taxonomy (from Denham, 2000). Each weather related mishap has been categorized into one or more of these basic human error types.

E. DEVELOPMENT OF THESIS MISHAP DATABASE

All 236 Class A Navy and Marine (Naval) aviation mishaps involving aircrew error between FY 90 and FY 98 were analyzed for the possibility of being weather related. Aviation mishaps included both fixed wing and rotary wing aircraft. Mishap and meteorological data from the NSC, School of Aviation Safety, Naval Postgraduate School, and National Climate Data Center were studied. One of the 236 mishaps contained restricted data that prevented a narration of what took place. As a result, this mishap was not included in the study and the database was reduced to 235 mishaps.

Each mishap was classified according to the likelihood that it was weather related. A weather related mishap was defined as a mishap in which, if the weather had been benign, the mishap would not have happened. A benign environment is defined to be one of unlimited visibility, no ceiling, no wind, no turbulence, no precipitation, and standard atmospheric temperature and pressure. A benign environment is defined as being unaffected by the amount of sunlight or moonlight. So a benign environment can exist under all types of illumination provided by the sun or moon. This is different from the benign environment definition used by Calvert (1996), who defined a benign environment as occurring only under conditions of daylight.

A confidence factor was assigned to each mishap based on the likelihood that a benign environment would have resulted in the mishap not occurring. Confidence values (dY, pY, M, pN, and dN) were assigned. The confidence value criteria are shown in Table 2.

Table 2. Weather Related Mishap Confidence Categories

	Confidence That Mishap Would Not Have Occurred In A Benign Environment
Definitely Yes (dY)	≥ 90%
Probably Yes (pY)	51% to 89%
Maybe (M)	50%
Probably No (pN)	11% to 49%
Definitely No (dN)	≤ 10%

Details on the categorization process are given in the Methodology section, below.

Each mishap that had at least a 50% probability of being weather related was classified according to the likelihood that, if aircrew had received a perfect weather forecast and believed it with 100% confidence, the mishap would not have happened. The same confidence values (dY, pY, M, pN, and dN) were assigned.

Each mishap that had at least a 50% probability of being weather related was classified according to how the weather contributed to the mishap. In most cases, the weather contributed directly to the mishap. On example of a mishap involving a direct (D) contribution is a pilot on a low-level bombing run who flies into a cloud and then flies into a mountain that had been hidden by the cloud. In some cases, the weather indirectly contributed to the mishap. This indirect contribution could either occur on the ground or after the aircraft becomes airborne. An example of an indirect ground (IG) mishap is a mishap due to an aircrew rushing a brief, rushing a preflight, or being apprehensive due to an approaching weather feature. An example of an indirect flight (IF) mishap is one in which weather conditions limit cause the exercise to be altered on such short notice that the crews do not take the time to safely re-plan the exercise, and their failure to re-plan leads to a mishap.

Each mishap that had at least a 50% probability of being weather related was classified according to all the contributing weather elements. A mishap can have more than one weather element as a contributor. The weather elements used in this study are:

1. icing
2. turbulence
3. visibility/ceiling (low ceiling, fog, horizon difficult to discern, clouds, obscuration, inadvertent instrument meteorological conditions (IMC), below published approach minimums, sand/dust storm, sun related, or other visibility/ceiling)
4. winds (crosswind, gusts, tailwind, unfavorable wind, high wind, sudden wind shift, variable wind, dust devil/whirlwind, or other winds)
5. wind shear
6. density altitude
7. precipitation
8. thunderstorm
9. perceived pressure from deteriorating weather
10. combined sea state (pitching deck)
11. other elements
12. unable to determine which additional weather elements are applicable.

The definitions of these weather elements are provided in the Methodology section that follows.

The weather elements chosen are similar to those used by the National Transport Safety Board (NTSB). Definitions for weather elements are provided in the

Methodology section below. No formal definitions could be located for the weather elements used by the NTSB (Crispin, 2000). In most cases, weather element definitions are intuitive. Definitions were based partly on the standardized weather definitions found in the Federal Meteorological Handbook (FMH-1) (Office Of The Federal Coordinator For Meteorological Services And Supporting Research, 1995).

F. METHODOLOGY

The following is the step-by-step process used to determine if and how a mishap was weather related. For steps providing predetermined choices, the coding used in the database and found in the results section are provided to the right of the choices.

STEP 1: REVIEW Mishap Summary Narrative, Causal Factors, Naval Safety Center (NSC) weather information, Mishap Investigation Report (MIR), National Climatic Data Center, and Naval Postgraduate School archived weather observations and answer the questions below.

STEP 2: IS ADDITIONAL RESEARCH NEEDED? IF YES, What information is needed?

STEP 3: IS A SECOND OPINION DESIRED? IF YES, from whom should the opinion come? What information is desired from this person?

STEP 4: IS MISHAP WEATHER RELATED? (In other words, would the mishap have been prevented had the environment been benign?)

Definitely No ($\leq$10%)	dN
Probably No (11-49%)	pN
Maybe (50%)	M
Probably Yes (51-89%)	pY
Definitely Yes ($\geq$90%)	dY
Not enough information	ni

STEP 5: IF PILOT HAD RECEIVED A PERFECT WEATHER FORECAST AND BELIEVED IT WITH 100% CONFIDENCE AT BRIEF TIME WOULD MISHAP STILL HAPPENED?

Definitely No (≤10%)	dN
Probably No (11-49%)	pN
Maybe (50%)	M
Probably Yes (51-89%)	pY
Definitely Yes (≥90%)	dY
Not enough information	ni

STEP 6: WAS WEATHER IMPACT DIRECT OR INDIRECT? (Note: If both direct and indirect, select direct.)

Direct	D
Indirect	
Indirect-In Flight	IF
Indirect-On Ground (Rushed Brief or Preflight)	IG

STEP 7: WHICH WEATHER ELEMENTS APPLY? (Select each element that applies to mishap and rank in order with the first choice being the most significant.)

☐ Icing

☐ Turbulence

☐ Visibility/Ceiling

☐ Low Ceiling (Ceiling below 1000ft AGL).

☐ Fog (Visibility is reduced to less than 5/8 statute mile during the take-off or landing phase of flight due to a visible aggregate of minute water particles (droplets) which are based at the Earth's surface and reduces horizontal visibility and, unlike drizzle, does not fall to the ground).

☐ Horizon Difficult to Discern (Visibility reduced enough that horizon is no longer visible).

☐ Clouds (Provide a ceiling and are not classified as fog or obscuration. Generally clouds are located above 200 ft AGL).

☐ Obscuration (Visibility less than 7 nautical miles during flight [other than take-off or landing] due to Fog, Mist, or Haze). Obscuration is a factor when visibility results in a collision with surface features including mountains, towers, and the ocean surface).

☐ Inadvertent IMC (Mishaps where aircrew were not prepared for or not expecting IMC conditions. Inadvertent IMC also includes mishaps resulting from trying to avoid clouds to stay VFR.

☐ Below Published Approach Minimums (NTSB category).

☐ Sand/Dust Storm (Sand/dust raised by the wind to a height sufficient to reduce horizontal visibility to the point that it contributed to the mishap).

☐ Other Visibility/Ceiling. A visibility/ceiling related mishap that does not fall into any of the visibility/ceiling elements above or for which not enough information is available to determine exactly which visibility/ceiling category the mishap applies to.

☐ Winds

☐ Crosswind (Wind direction 45 to 135 degrees off from favorable).

☐ Tailwind (Wind direction 136 to 180 degrees off from favorable).

☐ Unfavorable Wind (NTSB category).

☐ High Wind (Wind speed over 25 knots).

☐ Gusts (Rapid fluctuations in wind speed with a variation of 10 knots or more between peaks and lulls over a 10-minute period. The speed of a gust is the maximum instantaneous wind speed).

☐ Sudden Wind Shift (At least a 45 degree shift in last 1 minute).

☐ Variable Wind (Wind direction varies by at least 60 degrees within a 2-minute period).

☐ Dust Devil/Whirlwind

☐ Other Winds. A wind related mishap that does not fall into any of the wind elements above or that not enough information is available to determine exactly which wind category the mishap applies to.

☐ Windshear (Local variation of wind speed or direction in a horizontal or vertical reference plane of sufficient magnitude to contribute to a mishap. An example of a windshear is a significant microburst).

☐ Density Altitude (Applies to mishaps where density altitude was higher than expected resulting in less lift than expected).

☐ Precipitation (Frozen or liquid form which contributes by either reducing visibility and/or reducing friction while on the ground).

☐ Thunderstorm

☐ Perceived Pressure From Deteriorating Weather

☐ Combined Sea State (pitching deck)

☐ Other Elements

☐ Unable To Determine (Unable to determine if weather related due to insufficient data. Also applies to mishaps where it was difficult to determine which, or if, additional weather elements applied to a weather related mishap).

STEP 8: PROVIDE ANY ADDITIONAL COMMENTS.

Categorizing a mishap according to the likelihood that it was weather related is a complex and somewhat subjective process. The methodology used in this study is designed to minimize that subjectivity. Some of the features of the methodology that are intended to reduce subjectivity are: (1) establishing a carefully documenting set of steps; (2) expecting that people using the methodology have a high level of understanding of aviation and meteorology; and (3) including reviews of the more complex analyses by independent experts in aviation and meteorology. It is possible that different people with similar credentials and resources who use this methodology would come up with different results. However, it is probable that the major differences would be due mainly to differences in the availability of detailed information about the FMs being analyzed. To be used successfully, and to give repeatable results, people using this system need to have access to a number of critical pieces of information about the mishaps and related weather conditions.

G. SCOPE AND LIMITATIONS

The intent of this study is to gain a better understanding of the weather's impact on Naval aviation safety from a meteorological perspective. This study did not review

Army, Air Force, or non-DoD mishaps because data for those mishaps was not readily available.

This thesis does not contain any *detailed* studies of meteorological conditions related to any specific mishaps. Basic observational weather information is included.

This thesis only studied the most damaging Naval aviation mishaps, Class A Flight Mishaps, between FY 1990 and FY 1998, that involve aircrew human error. It was assumed that the majority of Naval aviation weather related mishaps involve aircrew human error. The aircrew consists of the pilot and any other people onboard the aircraft involved with the performance of the aircraft's mission and flight safety.

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III. RESULTS

A. OVERVIEW

This thesis determines the role of weather in Naval (Navy and Marine Corps) Class A aviation flight mishaps (FMs). In addition, relationships are developed between weather related mishaps and the 17 basic human error types found in the Human Factors Analysis and Classification System (HFACS) taxonomy (Figure 1) for tactical aircraft (TACAIR), rotary wing (helicopter), training, and other Flight Mishaps (FMs). 395 Class A FMs occurred in the period FY90-98. 160 of these mishaps were due to non-aircrew errors (mechanical, maintenance, facilities, etc.) that most likely were not weather related. For reasons stated earlier, only the 235 (59%) Class A FMs FY 90-98 involving aircrew errors are examined. Of the 235 Class A FMs, 139 were TACAIR, 57 were helicopter, 32 were training, and 7 involved other types of aircraft. Also, 159 FMs were Navy, while 76 were Marine Corps (Marine).

The Naval Safety Center (NSC) mishap summary, NSC Squadron & Type Command HFACS Analysis Aeromedical Resource Material Mishap Characteristics narratives, and weather observation data base for each mishap was initially examined to determine the likelihood of a FM being weather related. Despite the narrative information and weather data from the NSC, 92 of the 235 did not have enough weather information to make a weather related determination. Also, 47 of the mishaps required a second opinion because the narrative description was too vague. The NSC database and narratives were not originally written to support this type of study, so it is understandable that not all information would be immediately available.

To reduce the uncertainties, additional weather observations were obtained from the National Climatic Data Center (NCDC), Department of Meteorology of the Naval Postgraduate School, and Mishap Investigation Reports (MIRs). In addition, second opinions were obtained from experts with an aviation and/or meteorological background. A list of those solicited for second opinions is presented in Appendix C. With the above help, a classification was made for 235 FMs.

B. OVERALL WEATHER INFLUENCED PERCENTAGE OF FLIGHT MISHAPS

Out of the 235 Human Factors (HF) FMs examined, 45 (19%) are classified as weather related. Weather related includes both pY and dY categories. None of the FM's were classified as maybe (M). The 45 weather related FMs accounted for 12% of all 395 Class A FM's. Based on data provided by the NSC, the 45 weather related FMs were estimated to account for $620 million damage and 95 deaths. Annually, weather related FMs produced $68.9 million damage and led to 11 deaths. Table 3 shows that weather related FMs are more likely to produce a fatality, and also have a higher number of fatalities per mishap, than HF mishaps overall.

Table 3. Summary Of Mishap Fatalities

	Weather Related Mishaps	All 235 HF Mishaps
Number of Fatalities	95	254
Number FM with at least 1 fatality	29	133
Fatalities per year	11	26
Fatalities per FM	2.1	1.1
Percent of FMs with fatality	64%	57%

Naval aviation HF Class A FY 90-98 FMs have been divided into four aircraft type groupings. These groupings are tactical aircraft (TACAIR), rotary wing (helicopter), training, and other. Tactical aircraft (TACAIR) include fixed wing ship based and adversary training aircraft (A-4F, A-6E, A-7E, AV-8B, E-2C, EA-6B, F-4S, F-5E, F-14A, F-14B, F-14D, F-16N, F/A-18A, F/A-18C, F/A-18D, QF-86F, RF-4B, S-3A, and S-3B). Rotary wing aircraft are all Naval helicopters (AH-1, CH-46, CH-53, HH-1N, HH-46, HH-60H, MH-53E, RH53D, SH-2F, SH-60B, SH60F, VH-40D, UH-1, UH-1N, UH-46D, VH-3, and VH-60). Training aircraft include T-2C, T-34C, T-44A, T-45A, TA-4F, and TA-4J. Types of aircraft in the Other category are C-2A, CT-39G, MU-2, OV-10D, and P-3C.

Direct weather related FMs for the four types of aircraft are shown in Figure 2 as the percent of all Class A mishaps. Table D1 (Appendix D) shows the actual count, while Table D2 shows the percent breakdown. Results show 12% of all Naval aviation Class A FMs FY 90-98 were weather related. Percentage values may differ between figures and tables due to round off. The grouping with the largest percentage (18%) of weather related FMs is the Helicopter Class.

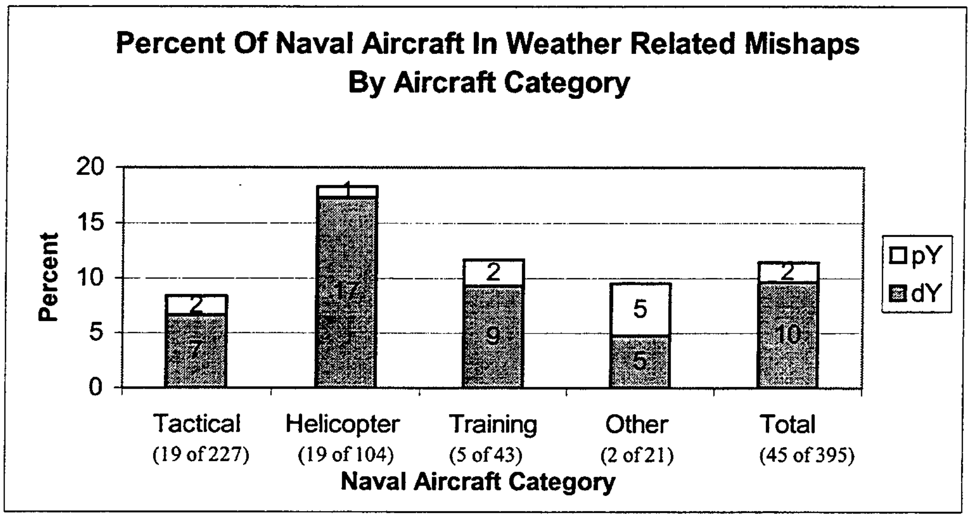

Figure 2. Percent of All Class A Naval aviation mishaps that are definitely (dY) and probably (pY) weather related.

The query above was for weather that directly contributed to a FM. However, weather indirectly contributed (indirect weather) to three additional FMs. Again, indirect weather mishaps are broken into indirect ground (IG) or indirect flight (IF) categories. Two of these FMs resulted from changes made once airborne due to weather, while the other was due to shortcuts made on the ground due to approaching severe weather. Unless stated otherwise, all tables and figures in this thesis do not include the three indirect mishaps. A summary of the three indirect mishaps is shown in Table 4.

Table 4. Summary Of Indirect Weather Related Mishaps

Type Impact	Service	Date	Category	Weather Group	Weather Element
IF	Navy	29-Jun-91	TACAIR	Vis	OVC
IG	Navy	23-Jul-94	Training	Trw	Trw
IF	Navy	5-Dec-94	TACAIR	Vis	OVC

Weather related aircrew error (HFACS) FMs were compared. Figure 3 shows the percent of HF Class A mishaps which are weather related for the four types of aircraft. Table D3 shows the count, while Table D4 shows the percent breakdown for this query. Results show 19% of all Naval aviation HF Class A FMs FY 90-98 were weather related. The largest categories are 34% (19 out of 57) for Naval Helicopter HF FMs and 28% (2 out of 7) of Other HF FMs.

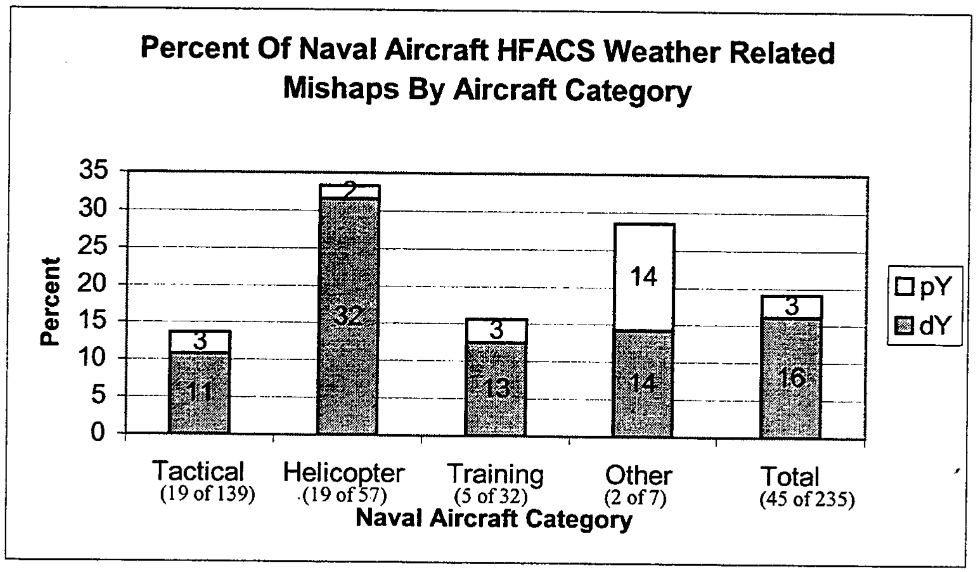

Figure 3. Percent of HF Naval aviation mishaps that are definitely (dY) and probably (pY) weather related.

Figure 4 and 5 break into Navy and Marine the weather impact on the four types of aircraft platforms. Details are contained in Tables D3 and D4. Overall the Navy had 20% of weather related FM's compared to 17% for the Marines. Also, the Navy (16%) had nearly twice as many tactical weather related FM's compared to the Marines (9%). The helicopter category again dominates, with 37% of all Navy helicopter and 30% of all Marine helicopter HF FMs being weather related.

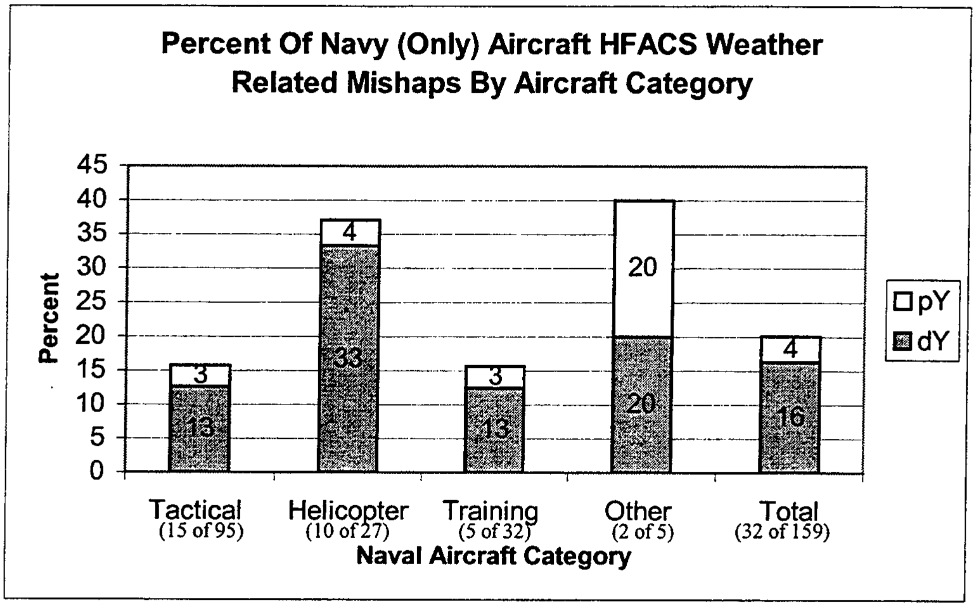

Figure 4. **Percent of HF USN aviation mishaps that are definitely (dY) and probably (pY) weather related.**

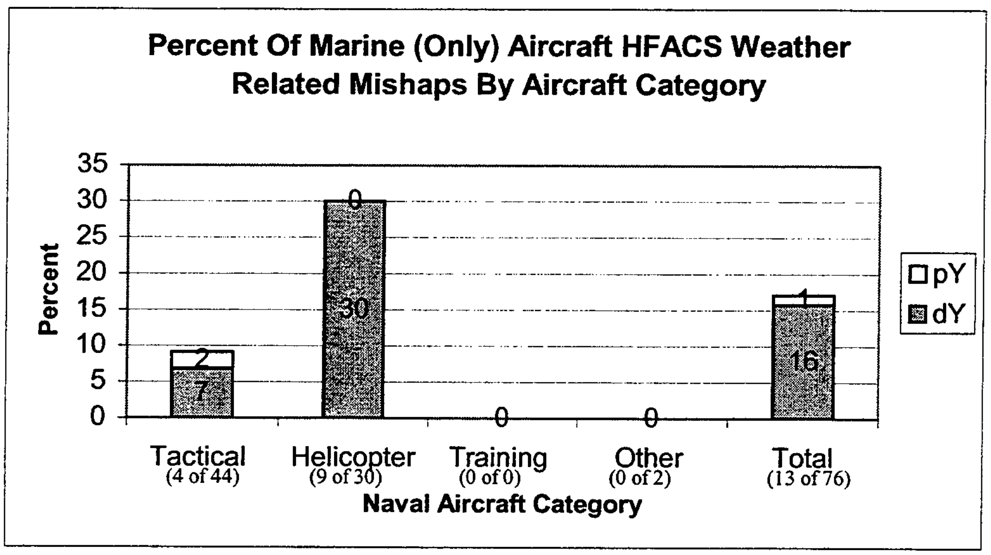

Figure 5. **Percent of HF USMC aviation mishaps that are definitely (dY) and probably (pY) weather related.**

C. WEATHER CONTRIBUTION TO FLIGHT MISHAPS COMPARED TO MISHAP CHARACTERISTICS

The Naval Safety Center has grouped all human factors flight mishaps into eight distinct groupings called Mishap Characteristics. These are Catastrophic Failure (Cat Fail), Controlled Flight Into Terrain (CFIT), MidAir, Out-Of-Control Flight (OOCF), Physiological Episode (PhysEp), Bird/Animal Aircraft Strike Hazard (BASH), Other, and Undefined. Examples have been provided by the author to help clarify the definitions.

Bird/Animal Aircraft Strike Hazard (BASH): aircraft strikes an animal or bird that damages the aircraft or places the aircraft and aircrew at risk.

Catastrophic Failure (CAT. FAIL): material or software failure, malfunction or unexpected operation, with no aircrew involvement, renders the aircraft no longer flyable, causes severe damage, forces an emergency landing attempt or places the aircrew and aircraft at risk. This characteristic occurs when aircrew incorrectly responds to a mechanical failure.

Controlled Flight Into Terrain (CFIT): a perfectly sound aircraft is flown into terrain (ground or water), without the aircrew being aware ahead of time of the hazard, or being aware too late to prevent the event (excludes physiological episodes (Gravity Loss Of Consciousness, Hypoxia, etc.)). Examples of CFIT include a helicopter flying into the water or a tactical aircraft striking a gondola cable.

MIDAIR Collision (MIDAIR): aircraft sustains in-flight damage or is lost due to an in-flight collision with another manned or unmanned aircraft.

Other (OTH): all mishaps not otherwise described. These are generally mishaps that occur while taking off (prior to becoming airborne) or after touchdown while landing. An example would be an aircraft departing the runway on the take-off roll or an aircraft striking the ramp (back) of an aircraft carrier while landing.

Out-of-Control Flight (OOCF): aircraft aerodynamically departs, either from a recoverable and manageable material failure/malfunction, or the aircrew departs the aircraft and fails to recover (excludes exceptional violations, physiological episodes, and catastrophic failures). Examples of OOCF include: a TACAIR loosing an engine just after the catapult shot, followed by plane stall; a helicopter which experienced a lack of lift (i.e., the rotor blades stalled) and landed hard on a mountain slope while trying to clear a hill.

Physiological Episode (PHYS. EP.): aircrew suffers incapacitation from uncontrollable spatial disorientation, loss of consciousness, illness, and traumatic injury or health effects. Examples of PHYS. EP include a mishap from gravity-induced loss of consciousness and a mishap where fatigue hindered the pilot's decision making ability.

Undetermined (UND): The mishap investigation is closed out as undetermined. Generally, these are mishaps that can be defined as more than one of the above mishap categories.

Weather related aircrew error (HFACS) FM percentages within the eight Mishap Characteristic groupings are shown in Figure 6. Details of this query can be found in Table D5 and Table D6. The largest percentage for weather related mishap characteristics was Controlled Flight Into Terrain (CFIT) with 41%. In addition, 27% of Undefined, and 19% of Other HF FMs were weather related. The Other mishap characteristic weather related FMs generally consisted of mishaps that occurred before the aircraft became airborne while taking off or occurred as or after the aircraft was touching down upon landing either ashore o,r at sea (e.g. take-off/landing on a wet runway, or ramp strike on the back of an aircraft carrier in a heavy sea state).

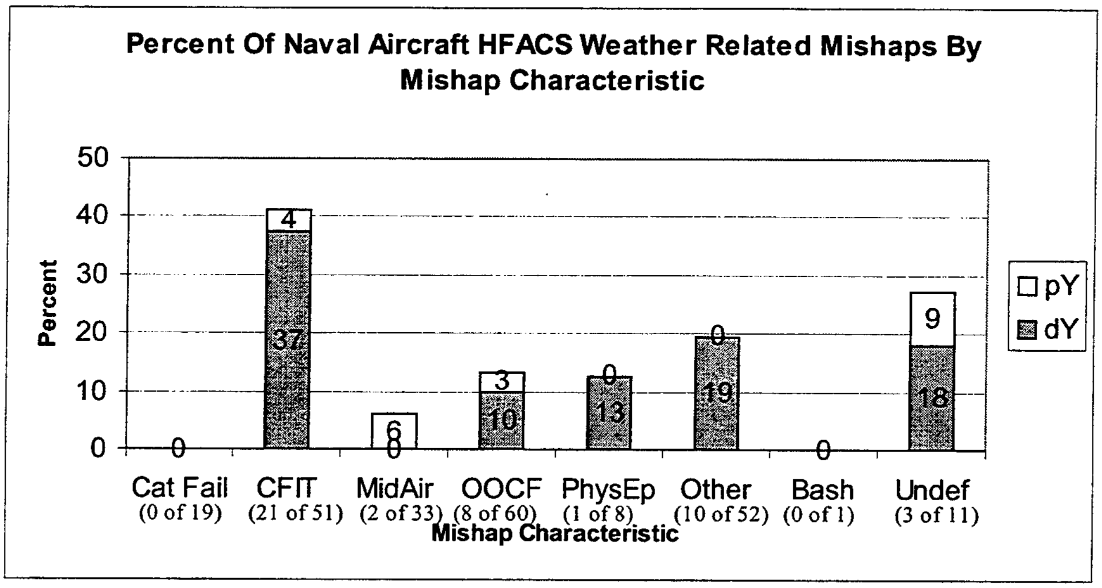

Figure 6. Percent of HF Naval aviation mishaps compared to mishap characteristic's that are definitely (dY) and probably (pY) weather related.

Because of the high percentage of weather related helicopter HF FMs, weather related aircrew error (HFACS) FMs for helicopters are compared to the eight Mishap Characteristic groupings for helicopters. Results are shown in Figure 7. Details can be found in Table D7 and Table D8. Results show 100% of Physiological Episode (PhysEp)

HF FMs, 50% Controlled Flight Into Terrain (CFIT) HF FMs, and 45% of Out-of-Control Flight (OOCF) are weather related.

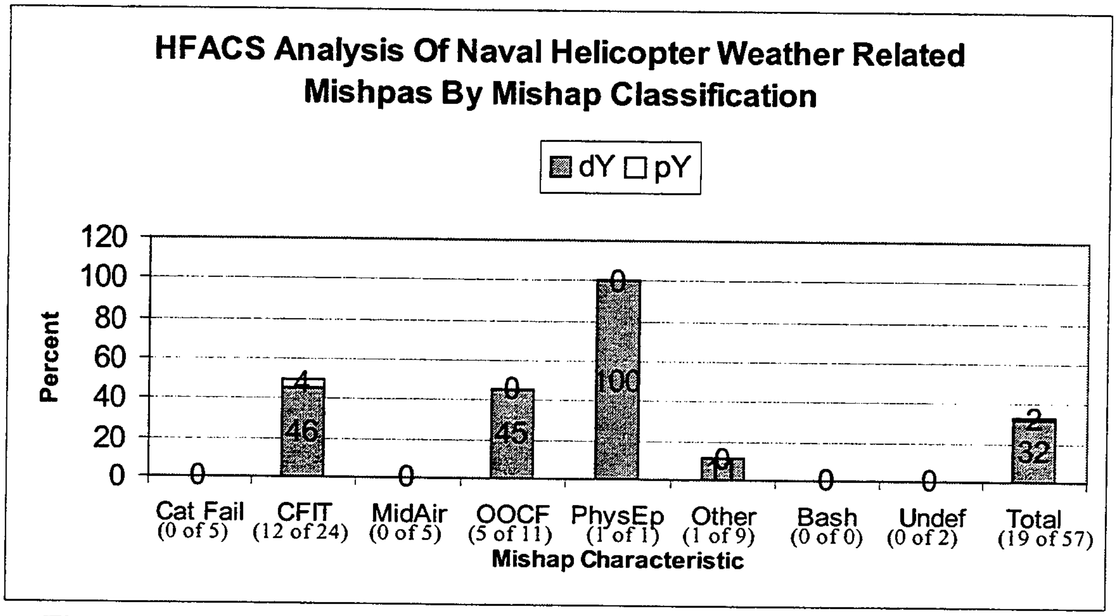

Figure 7. Percent of HF Naval helicopter mishaps compared to mishap characteristics that are definitely (dY) and probably (pY) weather related.

D. DISTRIBUTION OF WEATHER ELEMENTS AMONG WEATHER RELATED FLIGHT MISHAPS

Weather elements present during the weather related FMs are now discussed. There are 27 possible weather elements. An individual weather related FM can have more than one weather element assigned to it. Results of the query are shown in Figure 8 with details shown in Table D9. Only weather elements that contributed to at least one FM are shown in the figure and listed in the table. Table D9 shows that Horizon Difficult to Discern contributed to 16 FMs, Obscuration contributed to 14 FMs, and Inadvertent IMC contributed to 13 FMs. Table D9 also shows that 87 weather element occurrences were determined for the 45 weather related FMs, almost 2 per FM. Horizon Difficult to Discern accounted for 19% of all weather elements and occurred in 36% of all weather related FMs, Obscuration accounted for 16% of all weather elements and occurred in 29% of all weather related FMs, and Inadvertent IMC accounted for 15% of all weather elements and occurred in 29% of all weather related FMs.

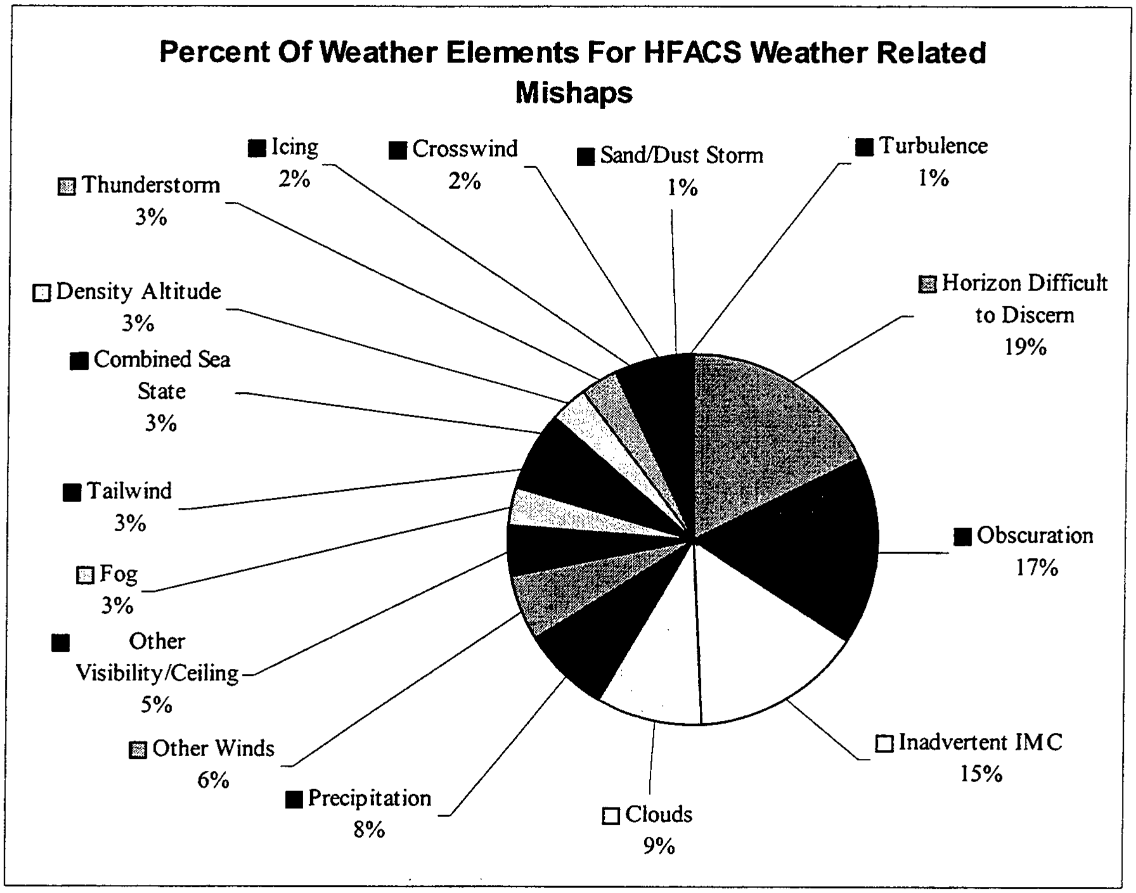

Figure 8. Weather element type as a percentage of all combined weather elements.

E. DISTRIBUTION OF WEATHER ELEMENT GROUPS AMONG WEATHER RELATED FLIGHT MISHAPS

The 27 weather elements have been consolidated into 13 weather groupings. Actual distribution of these groupings is shown in Figure 9 with details shown in Table D10. Only eight weather element groups contained at least one FM. Table D10 shows that Visibility Related contributed to 32 FMs, Wind Related contributed to 10 FMs, and Precipitation contributed to 7 FMs. Table D10 also shows that 61 weather group occurrences were made for the 45 weather related FMs, a little over 1.5 per FM. Visibility Related accounted for 53% of all weather element groups and occurred in 71% of all weather related FMs, Wind Related accounted for 17% of all weather element groups and occurred in 22% of all weather related FMs, and Precipitation accounted for 12% of all weather element groups and occurred in 16% of all weather related FMs. Visibility related elements account for a large percentage of major Naval FMs. Results from Calvert (1996) similarly show that visibility related elements account for the majority of major Naval FMs. This indicates that cloud and visibility parameters of a weather brief and forecast are very important.

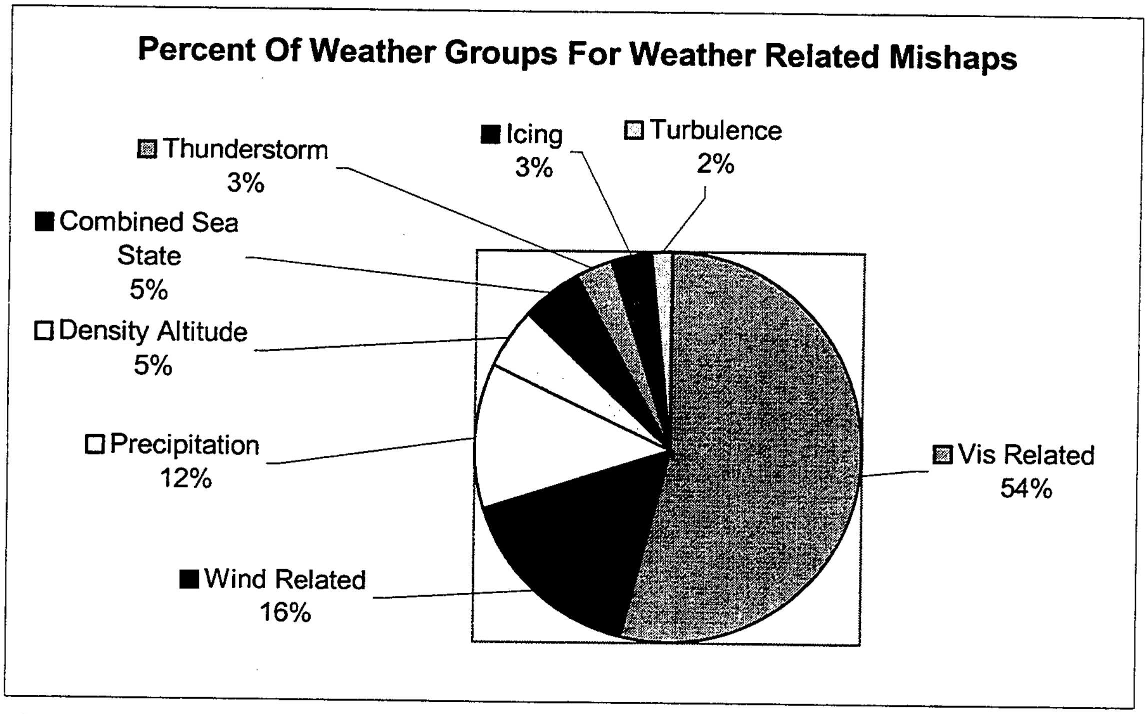

Figure 9. Individual weather group as a percentage of all combined weather groups.

F. WEATHER CONTRIBUTION TO FLIGHT MISHAPS COMPARED TO HFACS TAXONOMY

The NSC has developed a HFACS taxonomy that identifies 17 basic human error types that may contribute to each mishap. An individual mishap can have more than one of the 17 basic human error types assigned to it. The number and percentage of weather related FMs for each human error type along with the causal factors of maintenance error, material failure, and facility error are presented in Figure 10 and Tables D11 and D12.

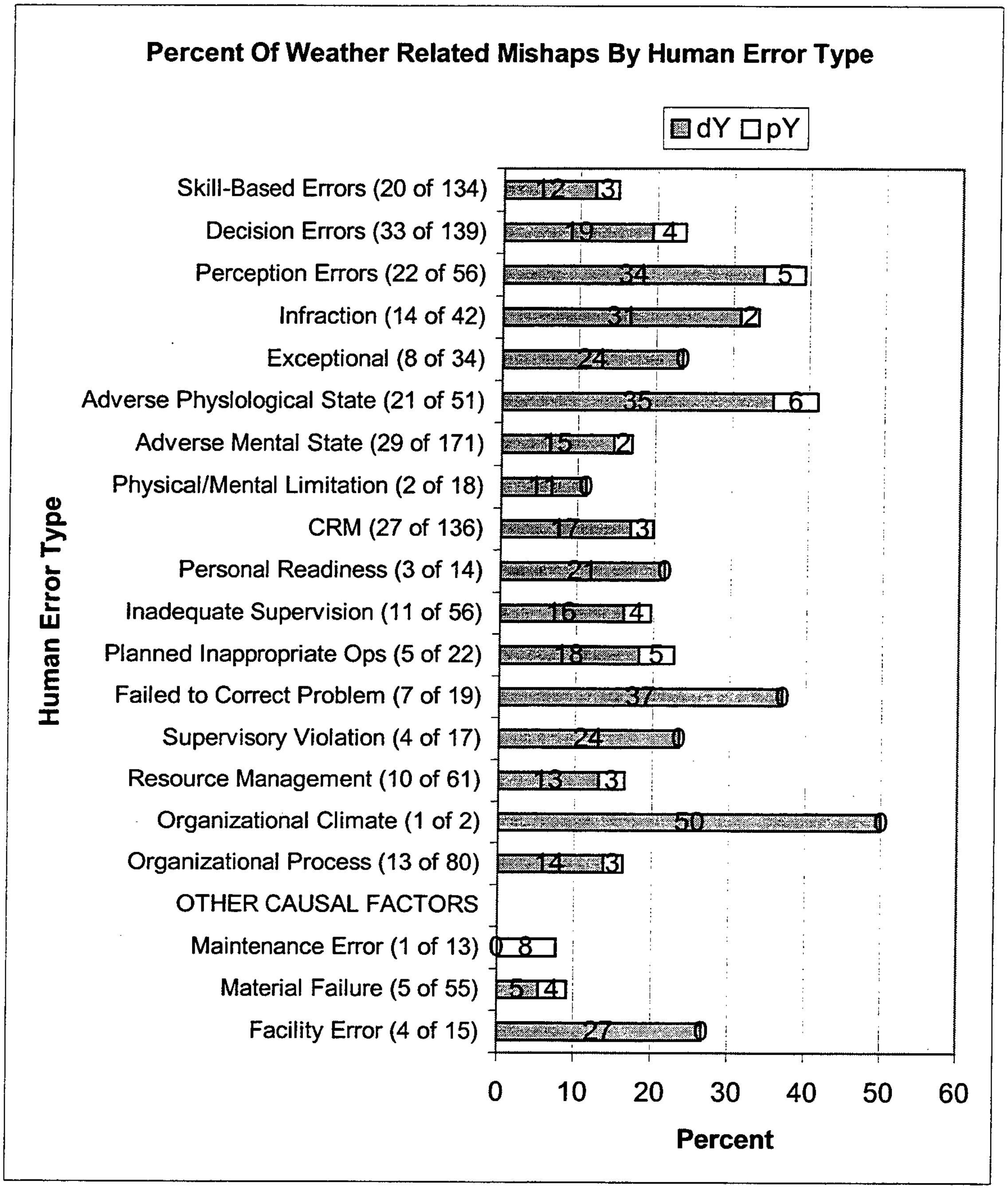

Figure 10. Percent of being definitely (dY) and probably (pY) weather related for each human error type.

Results show that weather contributed to 23% of Decision Error FMs, 39% of Perceptual Error FMs, 33% of Infraction FMs, 41% of Adverse Physiological State FMs, 37% of Failed To Correct Problem FMs, and 27% (4 of 15) of Facility Error FMs. Of note, one of 15 facility error FMs was due to the ship's meteorologist failing to accurately forecast fog. The remaining three weather related Facility Error FMs were due to air traffic control errors. 50% of Organizational Climate HF FMs were weather related; however, there were only two FMs in this category. It is important to note that the HF causal categories assigned to each weather related mishap may not necessarily have been weather related. Weather element and group distribution for perception error, adverse physiological state, failed to correct problem, and infractions are shown in tables D13 to D18. Horizon Difficult to Discern (Hor) is the most dominant in all cases.

The role of weather in perception error, adverse physiological state, failed to correct problem, and infraction FMs are presented. All perceptual error FMs are directly tied to the weather, with the majority due to spatial disorientation from being in horizon difficult to discern (Hor) or obscuration (Obs) weather elements. Over two-thirds of infraction error FMs are directly tied to the weather and include failing to obtain a weather brief and failing to avoid instrument meteorological conditions (inadvertent IMC) while flying under visual flight rules. 80% of Adverse Physiological State FMs are linked to the weather, with the majority due to spatial disorientation from being in horizon difficult to discern (Hor) or obscuration (Obs) weather elements. Finally, nearly all of Failed To Correct Problem FMs are weather related, with two-thirds due to leadership failing to correct aviators with a history of violating the rules, and one-third due to leadership failing to ensure aviators had the required skill level for the flight.

G. WEATHER CONTRIBUTION TO FLIGHT MISHAPS COMPARED TO LIGHTING CONDITIONS AND CONTROL LOCATION

The Naval Safety Center classified mishaps as occurring during the day or night (lighting conditions). Day is defined as occurring from the instant the sun rises to the instant the sun sets (Hyson, 2001). The distribution of FMs between day and night was determined and are shown in Figure 11 with details located in Table D19. Results show that weather related FMs occur twice as often at night vs. day.

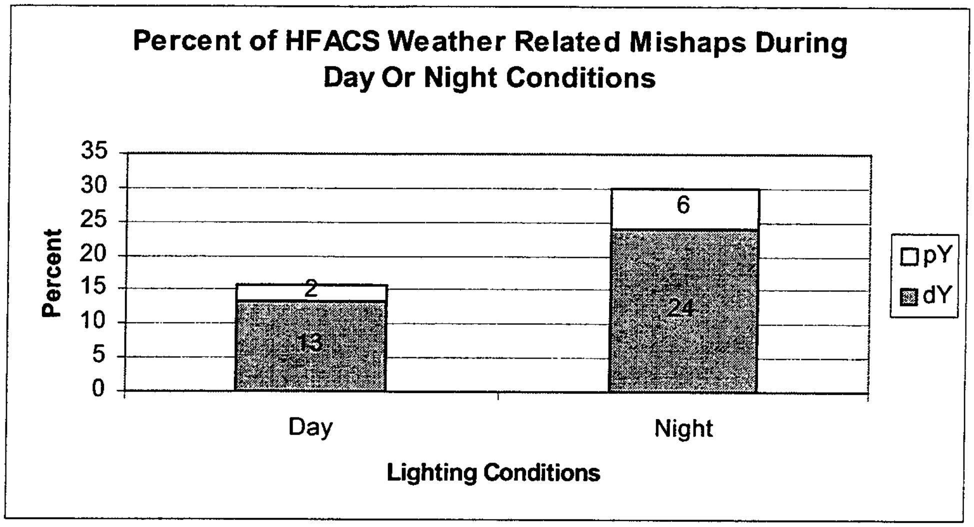

Figure 11. Percent of HF Naval aviation mishaps which occurred in day or night conditions for being definitely (dY) and probably (pY) weather related.

The Naval Safety Center classified mishaps as being ashore or embarked. Embarked refers to mishaps under the control of a ship, which can occur over water or land. Ashore refers to mishaps not under the control of a ship, which can occur over land or water (Kinzey, 2001). Most Embarked mishaps happen over water. The distribution of FMs between ashore and embarked is shown in Figure 12 with details located in Table D20. Results indicate that the weather related mishap percentage is slightly higher for embarked than ashore FMs.

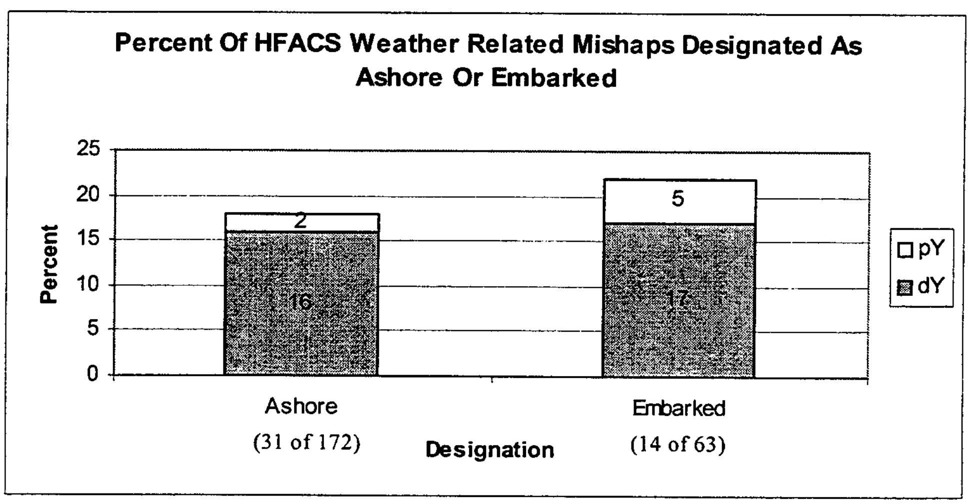

Figure 12. Percent of HF Naval aviation mishaps designated by NSC as being ship (embarked) or shore (ashore) for being definitely (dY) and probably (pY) weather related.

The distributions of weather related FMs between day and night, and ashore and embarked was also determined and are shown in Figure 13 and Table D21. While the percentages of weather related FMs ashore are similar for day and night, the percentages for embarked night are significantly greater. Over one-third of all FMs embarked at night are weather related. The weather groups found in the 12 embarked-night mishaps were examined, and it was revealed that 63% were visibility related, 19% were combined sea-state, 12% were precipitation, and 6% were wind related. The weather groups found in the two embarked-day mishaps were examined, and it was revealed that 100% were visibility related.

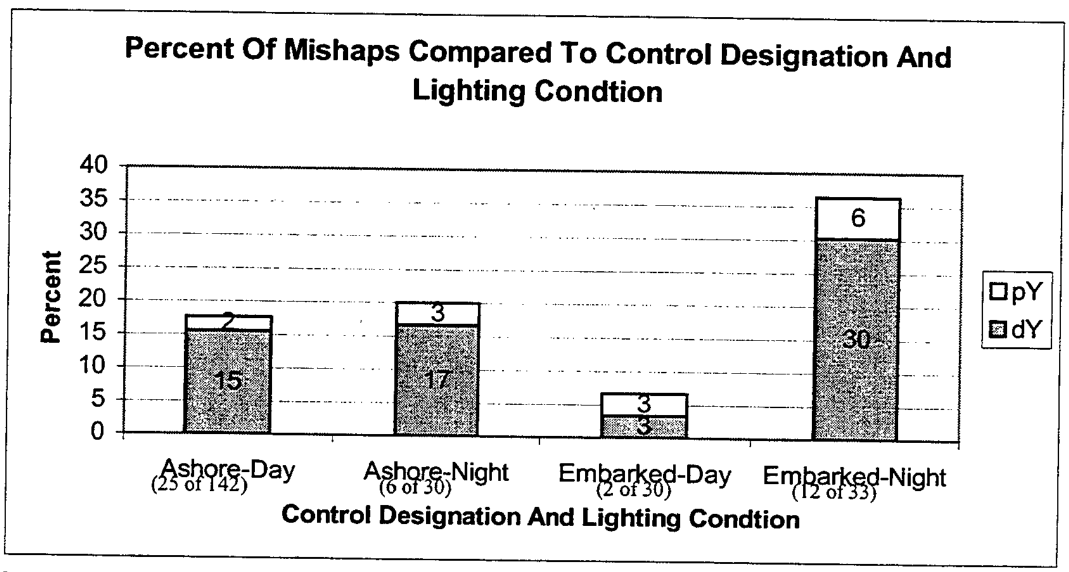

Figure 13. Percent of HF Naval aviation mishaps designated by NSC as being day/night and ship/shore for being definitely (dY) and probably (pY) weather related.

H. MISHAP RATE COMPUTATIONS AND TRENDS

One tool used to track the number of Naval aviation mishaps is the mishap rate. The mishap rate is determined by multiplying the number of mishaps by 100,000 flight hours and then dividing by the total number of hours actually flown.

In the 1950's, the mishap rate for Naval aviation Class A mishaps averaged over 50. Over the succeeding years, advances such as adding angled aircraft carrier decks, developing the Naval Aviation Safety Center, and initiating NATOPS has significantly reduced the mishap rate, so that in the 1990's the mishap rate dropped below 5.

The number of weather, HFACS, and total mishaps per fiscal year are shown in Table D22 for Naval, Navy, and Marines. The number of flight hours flown per fiscal year are shown in Table D23 for Naval, Navy, and Marines.

The mishap rate for all Naval aircraft Class A, HF Class A, and weather related Class A FM's FY90-98 is presented in Figure 14 and Table D24. Figures 15 and 16 show mishap rates for Navy and Marine aircraft. Although a general decreasing trend is observed for all types of mishap rates during this period, the mishap rate varies considerably from year to year.

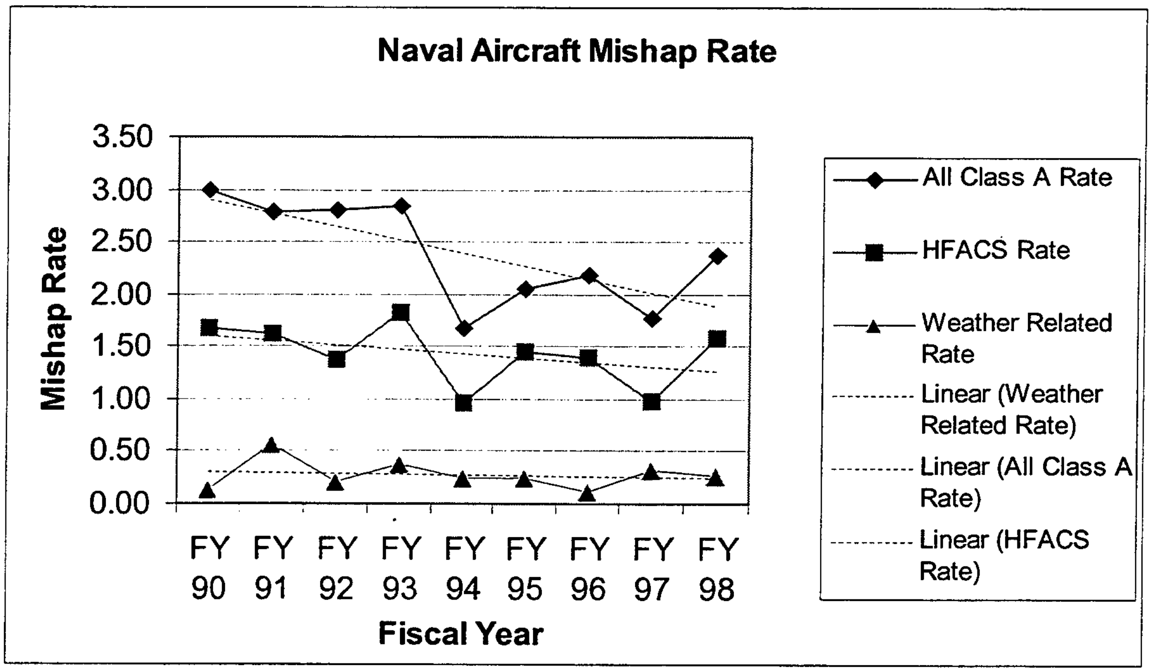

Figure 14. Naval aircraft mishap rate and trend FY90-98 for all Class A, HFACS, and weather related mishaps.

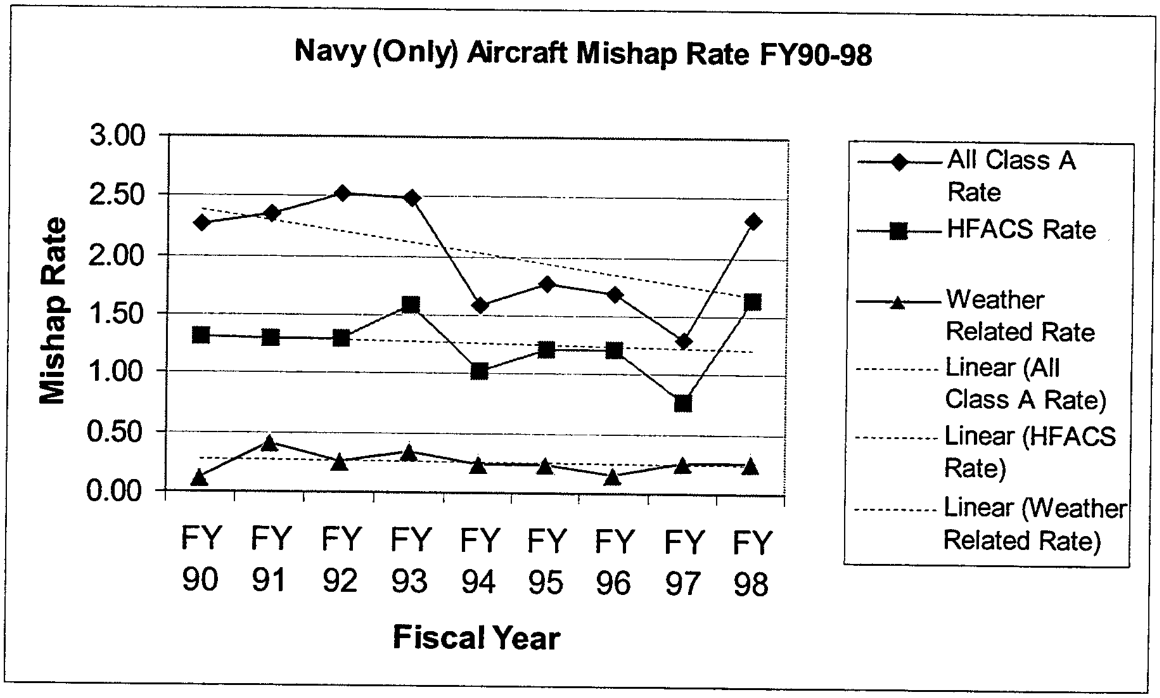

Figure 15. **Navy aircraft mishap rate and trend FY90-98 for all Class A, HFACS, and weather related mishaps.**

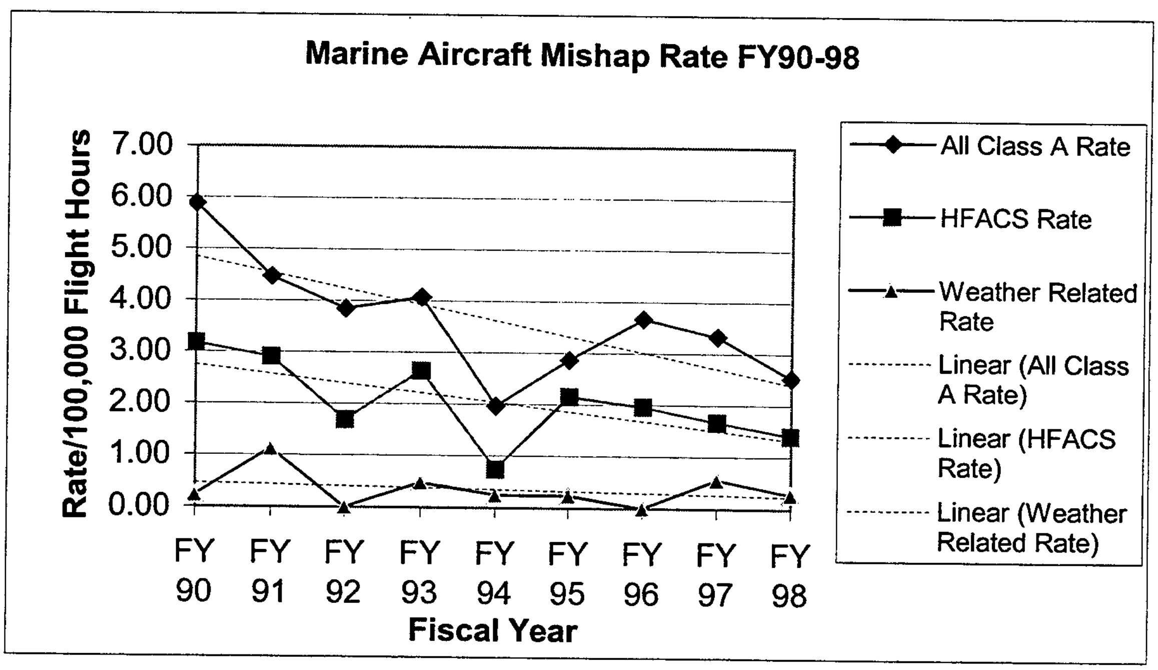

Figure 16. **Marine aircraft mishap rate and trend FY90-98 for all Class A, HFACS, and weather related mishaps.**

To study the magnitude of change in the different types of FMs, mishap rates from FY90-93 are compared to FY95-98 in Table 5. This table shows that from FY90 to FY98, the overall mishap rate dropped from a four year average of 2.86 to 2.10 (27% decline), the HF mishap rate dropped from 1.63 to 1.35 (17% decline), while the weather related mishap rate dropped from 0.32 to 0.24 (27% decline). This table shows that the weather related (WX) mishap rate decreased approximately 9% more than the HF mishap rate from the FY90-93 period to the FY95-98 period.

A hypothesis test was performed which compared the population mean of the FY90-93 to the population mean of FY95-98 for each mishap rate series. An assumption was made that the two population standard deviations are equal for each case. The results of this hypothesis testing indicate that for Class A mishap rates, shown in Table 5, the FY90-93 average rate is greater than the FY95-98 average rate with 90% confidence. However, the same hypothesis test for the other mishap rate comparisons did not show the same results. Therefore a declining mishap rate trend for the other mishap rate comparisons cannot be statistically confirmed at 90% confidence.

Statistically a trend cannot be confirmed for all mishap rates, except for All Class A mishap rates, as shown in Table 5. However, if a declining mishap rate trend is accepted, this decrease in the weather related mishap rate might be due to improvements in meteorological observing (Doppler Radar, improved satellite imagery, additional ASOS sites, etc.), meteorological modeling, and better data assimilation.

Table 5. Mishap Rate Trend And Standard Deviation

	Class A Rate	Class A StdDev	HF Rate	HFACS StdDev	WX Rate	WX StdDev
First 4 year Average	2.86	*0.57*	1.63	*0.37*	0.32	*0.16*
Last 4 year Average	2.10	*0.25*	1.35	*0.26*	0.24	*0.09*
Percent change	**-27**		**-17**		**-26**	

Another way to study the changes of weather related FMs is to compare the number of weather related FMs to all Class A FMs and HF FMs. The results are shown in Table 6.

Table 6. Weather Related Mishap Dominance Trend

	Class A	Class A StdDev	HFACS	HFACS StdDev
First 4 year WX% of total	11.11	*5.21*	19.55	*8.21*
Last 4 year WX% of total	11.28	*5.31*	17.44	*10.37*
%Chg of WX% of total	+2		-11	

Weather related mishaps as a percentage of all HF mishaps have decreased by 11% from the FY90-93 period to the FY95-98 period, while class A mishaps show little change. Again, statistically a trend cannot be confirmed using the hypothesis testing described earlier. However, if the trends are accepted, then results show that improvements made over the years have been paying off. Additional improvements in meteorological observations, modeling, and dissemination may further reduce weather related mishaps. Little has been changed over the last 10 years in the meteorological training and education aircrews receive. Student aviators and Naval Flight Officers still get a little over two weeks of meteorology training their first year of flying, followed by about half an hour of training each year during instrument refresher (Stull, 2001 and Woehler, 2001). Improvements in training and education would contribute to lowering the weather mishaps further compared to all HF mishaps.

I. OTHER FINDINGS

Flight Phase of all HF FMs were determined using the categories developed by Calvert (1996). These 11 Flight Phase categories are landing, hover, approach, wave-off/Go-around, descent, formation/rendezvous, low level/terrain following, ground attack, air-to-air, cruise/loiter, and takeoff. Definitions for these categories could not be obtained, so a best guess was used to separated FMs into each category.

Weather related aircrew error (HFACS) FM's were compared to the twelve categories of flight phase. The results are shown in Figure 17, with details provided in Tables D25 and D26. Figure 17 shows that the greatest percentage of weather related mishaps occur when aircraft are in the process of returning from a mission. For example, 38% of all wave-off/go-around FMs, 22% of all approach FMs, and 22% of landing FMs were weather related. Note also that 24% of all take-off FMs and 23% of all cruise/loiter FMs were weather related.

Weather related aircrew error (HFACS) TACAIR FM's were compared to the twelve categories of flight phase. The results are shown in Figure 18, with details provided in Tables D27 and D28. Figure 18 shows that 40% of all TACAIR wave-off/go-around flight phase FMs are weather related. 25% of all TACAIR low-level/terrain following flight phase FMs are weather related.

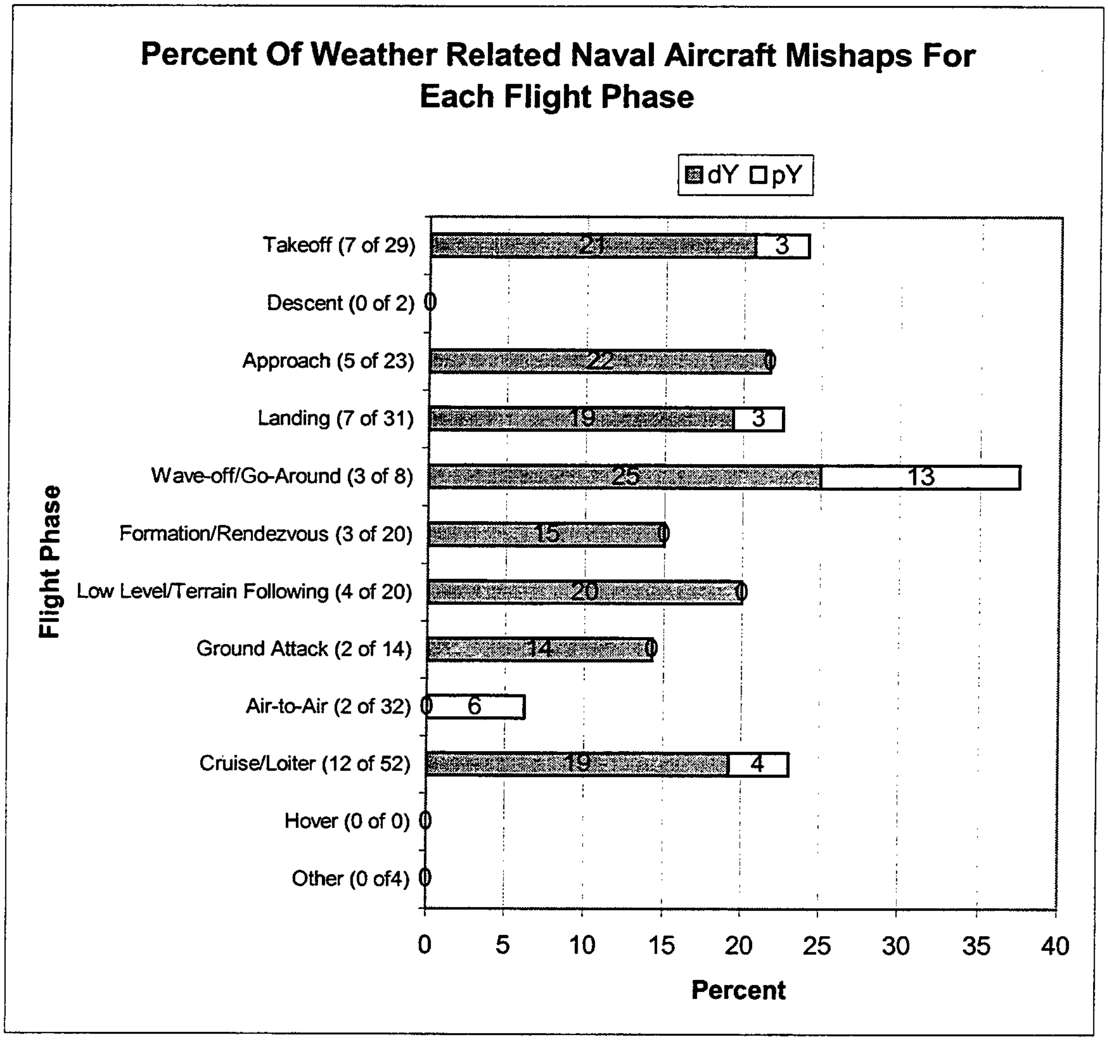

Figure 17. Percent of HF Naval aircraft mishaps compared to flight phase that are definitely (dY) and probably (pY) weather related.

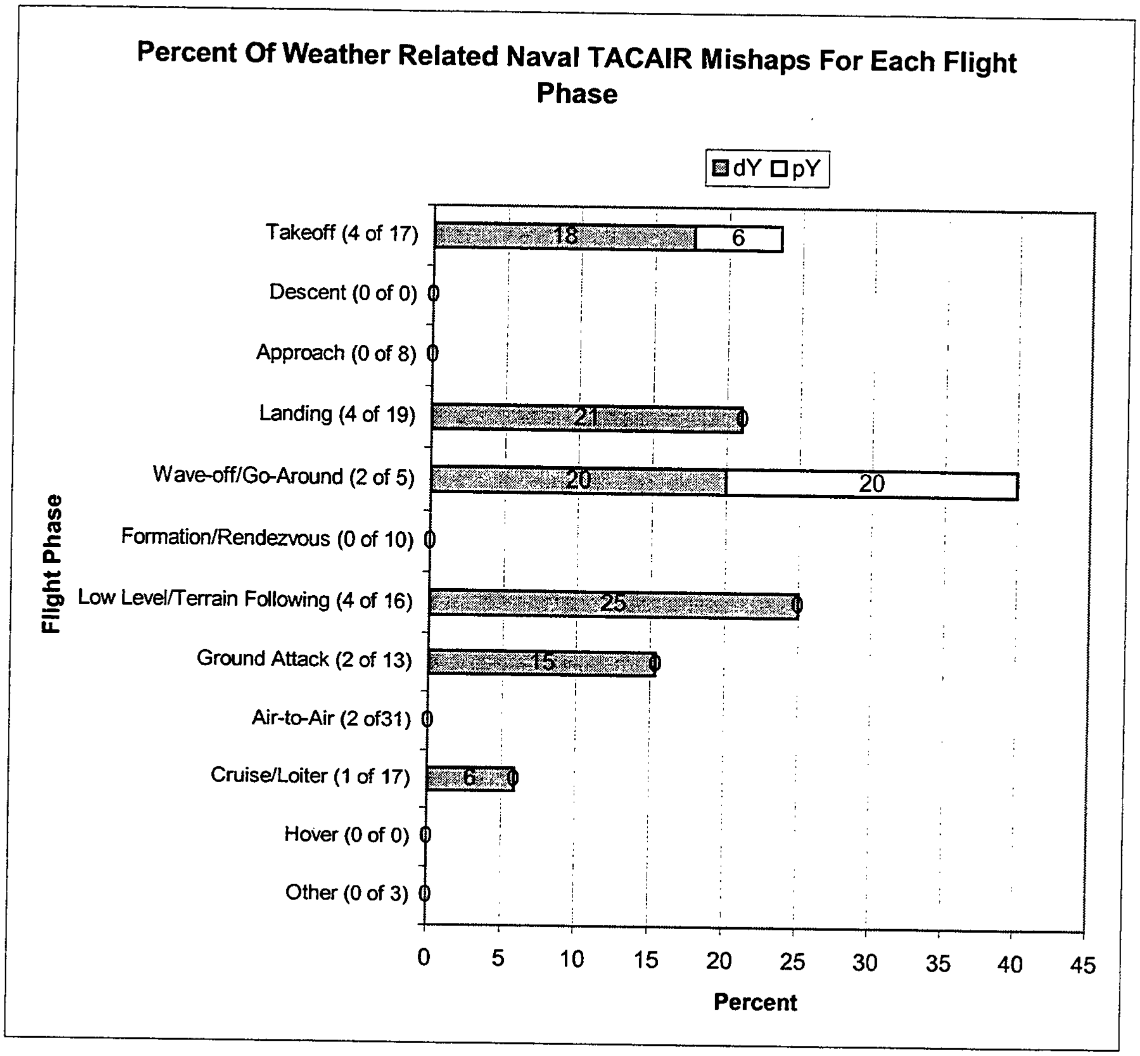

Figure 18. Percent of HF Naval TACAIR mishaps compared to flight phase that are definitely (dY) and probably (pY) weather related.

Weather related aircrew error (HFACS) helicopter FMs were compared to the twelve categories of flight phase. The results are shown in Figure 19, with details provided in Tables D29 and D30. Figure 19 shows that 66% of all landing flight phase helicopter FMs are weather related. Of note, 40% of all helicopter formation/rendezvous flight phase FMs are weather related.

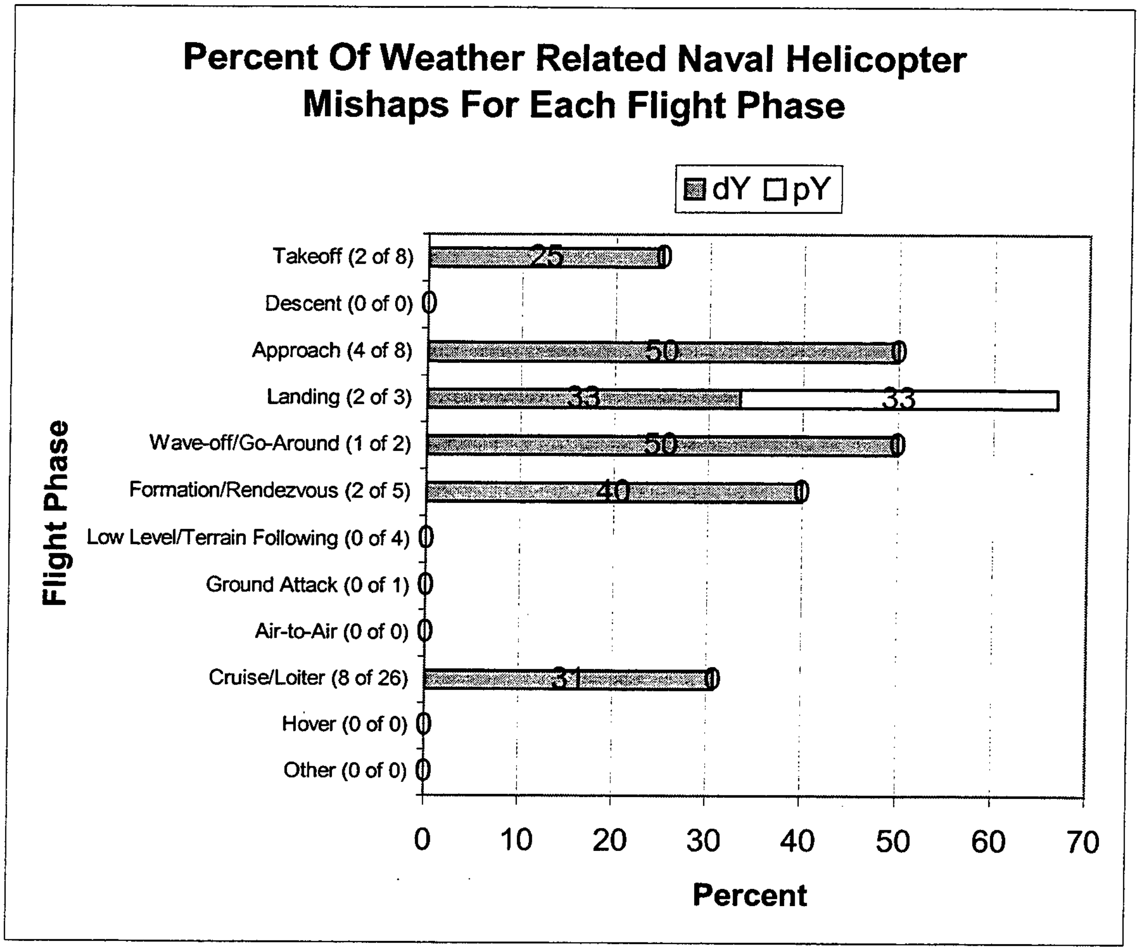

Figure 19. Percent of HF Naval helicopter mishaps compared to flight phase that are definitely (dY) and probably (pY) weather related.

Each weather related mishap was analyzed to answer the question: If the aircrew had received a perfect weather forecast and believed it with 100% confidence at brief time would the mishap still have happened? Results are shown in figure 20 and 21, with details available in Tables D31 and D32. A little over half of these preventable mishaps were due to inadvertent IMC. An example of this situation is one in which an aircrew would have developed a more careful mission plan based on a perfect and believed forecast of clouds (instrument conditions) and thereby have avoided getting into an inadvertent IMC condition. Another example of a preventable FM is a situation in which knowing the impeding weather (icing and low clouds) would most likely have led to a decision to not take off. This situation applied to three (12%) FMs. Knowing the rain intensity in advance would have prevented two FMs that occurred while landing. Figure

21 shows that 40 percent of all weather related FMs are not preventable from a perfect forecast. This does not mean that the FM was not preventable, only that a perfect forecast itself would not have prevented the FM. An example of a weather related mishap not preventable with a perfect forecast follows. Two experienced instrument rated helicopter pilots are given a forecast for a night flight with no discernable horizon due to 4 mile visibility in haze. These pilots are fully qualified to fly in these conditions. Two hours into their flight, they are distracted and don't realize that the helicopter is slowly descending. Moments later the aircraft hits the water.

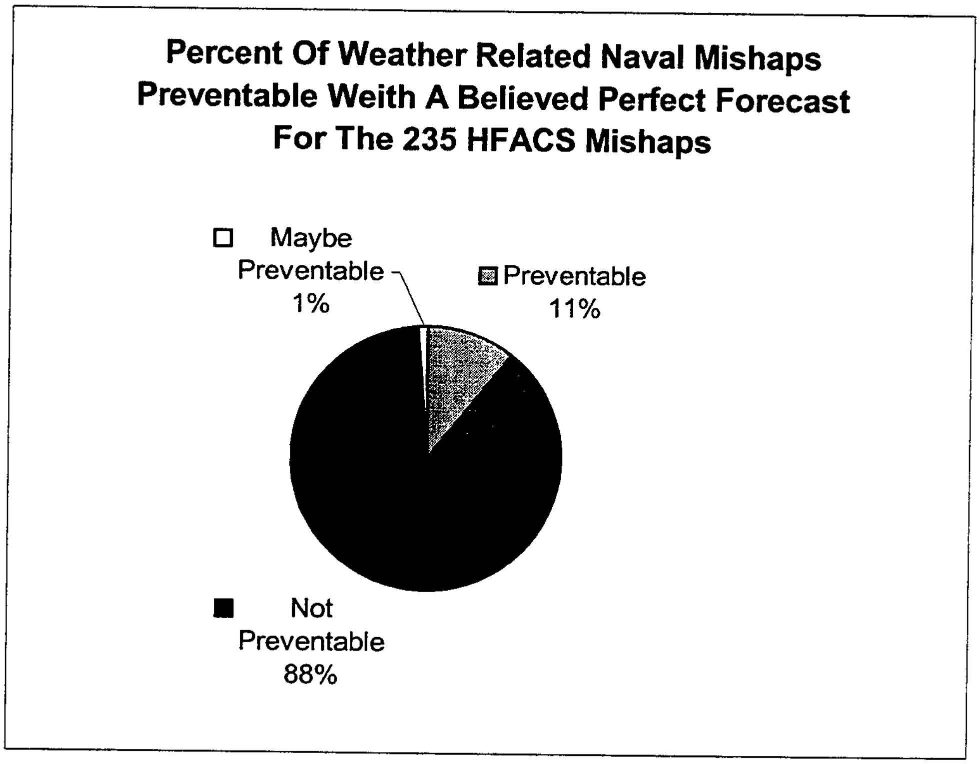

Figure 20. Percent of weather related Naval aircraft FM's which would have been prevented with a perfect forecast believed by aircrew .

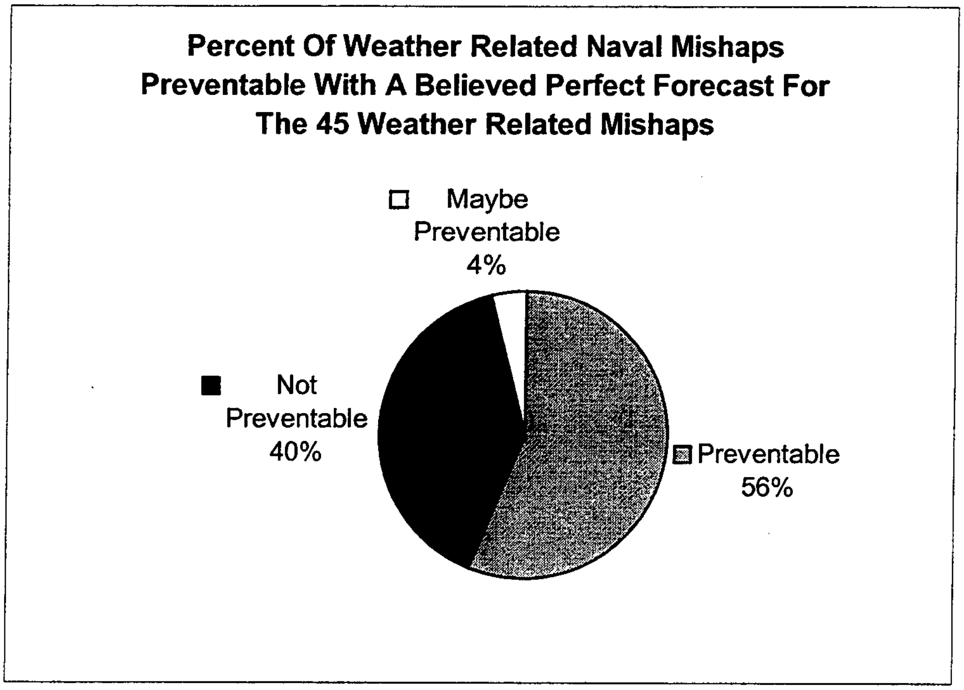

Figure 21. Percent of HF Naval aircraft FM's which would have been prevented with a perfect forecast believed by aircrew .

Initially, only the NSC data base and narratives were used to determine if a FM was weather related. Using only NSC data, there was insufficient data available to properly classify 92 (39%) of the 233 HF Class A FMs. Classification refers to determining if a FM was weather related and/or which weather elements contributed to a FM. Mishap Investigation Reports (MIRs) and historic weather observation data were used to supplement the NSC data, leading to the classification of 47 of the 92 originally unclassifiable FMs. In the end, 45 (19%) of the 235 HF Class A FMs were not classified due to insufficient data being available (Figure 22). The lack of data leads to uncertainty in the classification of the mishaps. With more and better data, there would be fewer pY and pN classifications. Additionally, there was some uncertainty in the determination of weather elements for some of the FMs.

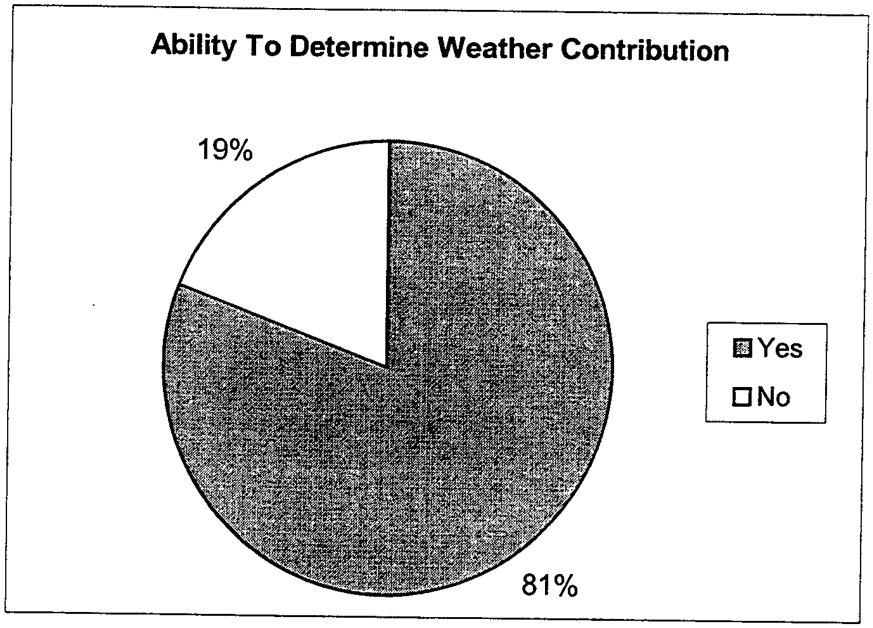

Figure 22. Ability to determine if a mishap was weather related and/or which weather elements contributed to a mishap.

This shows that the NSC data alone is not sufficient to properly assess whether a FM is or is not weather related. It is most likely that if a mishap was assessed as being weather related during or soon after the investigation, there would be sufficient data available to make an accurate analysis.

It would be helpful if the NSC data base recorded weather observations in the common meteorological format. Such a digital summary of all information contained in shore and ship hourly observations would provide much more information than is in the present data base. This is especially true for determining such things as multiple cloud covers and heights. Ideally, the NSC would incorporate a weather related classification similar to that used in this thesis that would become part of the NSC aviation mishap database. The benefit of doing this would be that many more resources would be available immediately following a mishap to help determine if the mishap was weather related.

A survey of the mishaps revealed that in at least 3 cases no weather brief had been obtained by the aircrew and in at least 1 case the aircrew elected to take-off with an expired weather brief.

IV. CONCLUSIONS

A. FINDINGS

This thesis found that 11% of all class A Flight Mishaps (FMs) FY90-98 and 19% of all Class A FM involving human factors (HFACS) are weather related. Weather related mishaps cause $69 million damage and produce 11 fatalities per year. Weather indirectly contributed to three additional mishaps. As a result, 12% of all Class A FMs and 20% of all Class A HF FMs are directly or indirectly weather related. Review of the 235 HF FMs revealed that, in at least three cases, the aircrew did not receive a weather brief, and in at least one case, the aircrew elected to take-off with an expired weather brief. Of the 45 weather related mishaps, one listed an inadequate weather forecast as a contributing factor.

Weather related FMs were classified by aircraft category. 34% of all helicopter HF FMs are weather related. This is understandable, since helicopters fly at low altitudes where weather is most likely to be significant to aviation. Preventing weather related helicopter mishaps could eliminate 2.4 mishaps each year.

Mishap characteristics of the weather related FMs were also studied. 41% of all CFIT FMs are weather related. This is not surprising, since low visibility greatly increases the likelihood of a controllable aircraft flying into the ground or ocean. Preventing CFIT mishaps could eliminate 2.6 mishaps each year.

The key weather element of a FM is Horizon Difficult To Discern (Hor). This element is present in 36% of all weather related mishaps. When the weather elements placed into several major groups, the visibility related (Vis) group accounted for 73% of weather related mishaps.

Basic human error types concerning weather related FMs were studied. 41% of all Adverse Physiological State FMs are weather related. Most of these resulted from spatial disorientation due to a lack of horizon. Preventing these mishaps could eliminate 2.6 mishaps each year.

Investigations of control source and lighting for weather related FMs show that 36% of all embarked-night FMs were weather related. At sea and at night there is no man-made lighting to help define a horizon. If there is also no moon light, then a small reduction of visibility or development of a ceiling can eliminate a horizon, which greatly increases the risk of a mishap. Preventing embarked-night mishaps could eliminate 1.5 mishaps each year. Although only 18% of all ashore-day mishaps were weather related, prevention of these mishaps could eliminate 3.1 mishaps each year.

Mishap rates for FY90-98 were determined for all Class A FMs, HF FMs, and weather related FMs. A downward trend was noted, but the mishap rate varied considerable from year to year. A downward trend could not be confirmed statistically. However, if the number of weather related mishaps were reduced each year, over time it would show up in the mishap rate trends. Therefore, it would be useful to continue tracking weather related mishaps to assess the success of the meteorology and aviation communities in reducing the number of weather related mishaps.

Flight phases were compared to weather related FMs. Weather related mishaps are most likely to occur during the beginning or end of a flight. 40% of all TACAIR wave-off/go-around mishaps were weather related, while 67% of all helicopter landing mishaps were weather related. Preventing take-off and landing weather related mishaps could eliminate 2.8 mishaps each year.

It was found that with a perfect forecast, 11% of all HF FMs could be eliminated. Considering only the 45 weather related mishaps, it was found that 56% of these mishaps were preventable with a perfect forecast. Providing a perfect forecast could eliminate 3.1 mishaps each year. It would be useful to continue tracking the number of mishaps preventable with a perfect forecast as a way of gauging how improvements in forecasting affect aviation safety.

This thesis has demonstrated that there are clear benefits to understanding how the weather contributes to major Naval aviation mishaps. This knowledge can directly lead to the reduction of future weather related mishaps. This research has shown which weather elements should get the most attention for improving aviation weather forecasts. Also, the aviation community can benefit form knowing what meteorological issues should be emphasized in aircrew education and training.

OPNAVINST 3500.39 (1997) describes Operational Risk Management (ORM). ORM is a tool used by the aviation community to manage the risks involved in flying under hazardous circumstances. The results of this thesis indicate that there is an opportunity for the aviation community to use ORM to reduce the number of weather related mishaps, with little reduction in the ability to meet mission requirements. The findings in this thesis can assist with the first two steps in ORM: identifying hazards and assessing hazards.

ORM could be used to reduce many types of weather related FMs. 33% of all infractions are weather related, with many resulting from aircrews continuing into IMC conditions when doing so was against the rules. Also, 37% of all Failed To Correct Problem FMs are weather related, with two-thirds of these due to violations. Leadership can use ORM to schedule aircrews so that risks are minimized when flying low-level flights where IMC conditions might be encountered. ORM might guide leadership to reinforce that aircrews should feel no pressure to complete a low-level flight if IMC is encountered. Perhaps ORM might guide aircrew to go through "what if inadvertent IMC is encountered" scenarios when briefing for low level flights. This would most likely reduce violations if an IMC situation is encountered.

B. RECOMMENDATIONS

Several recommendations have emerged from the results of this study of the role that weather in major Naval aviation mishaps. It is recommended that:

1) All future Class A Naval Aviation mishaps be examined to determine the impact of weather. It would be much easier to determine if and how a mishap was weather related at the time the mishap happened rather than waiting several years to make this determination. More meteorological information, as well as information from witnesses and investigators, would be available soon after the mishap that would be difficult to obtain several long afterwards. It is understood that there would have to be coordination between the meteorology and aviation communities to have this happen. There are many benefits of tracking the role of weather's, with the primary benefit being the reduction of major Naval aviation mishaps.

2) The role of weather on Class B and C Naval Aviation mishaps should be studied. These are mishaps with damage between $10,000 and $1 million. It is most likely that weather plays a different role in these types of mishaps than in Class A mishaps. Visibility related mishaps represented over half the weather related Class A mishaps, and in most of these mishaps, the aircraft was completely destroyed. This suggests that

weather elements other than visibility may be the dominant weather factors for Class B and C mishaps.

3) The role of weather on non-HF (Human Factors) mishaps should be studied. This would test the hypothesis that most weather related mishaps involve aircrew human error.

4) The METOC community should ensure that digital weather data related to Class A, Class B, and Class C mishaps are archived. Modern weather observation technology (e.g., Automated Surface Observing System (ASOS), digital radar, digital satellite data) can greatly assist in determining the weather's relation to FMs. Digital Doppler radar provides precipitation and wind velocity information throughout the United States. Many airports continuously monitor the weather via ASOS stations, and satellite imagery is available for the entire world. It is understood that coordination would have to be made between the aviation and METOC communities to ensure timely notification of FMs, so that data could be collected before it disappeared.

5) The Naval Safety Center should add data on the impacts of weather on FMs to the NSC data base, beginning with the data from this thesis. Updates could easily be made as major mishaps occurred.

6) Flight simulators (especially for helicopters) should be able to allow pilots to simulate flying in various visibility and ceiling conditions. Simulations should include inadvertent Instrument Meteorological Conditions, and low or no visible horizon training.

7) The results of this thesis should be shared with the Naval METOC community. By knowing how weather contributes to major Naval mishaps, research and training resources can be better tailored to help reduce future mishaps. Increased meteorological observations and nowcasting ability could be one way the METOC community could help reduce mishaps, since nearly two-thirds of all weather related Class A mishaps would have been prevented had the aircrews received a perfect weather brief, and, just as important, believed it. The more detail both the forecaster (weather briefer) and the aircrew have regarding weather along a planned route of flight, the easier it will be to make a decision regarding flight risk vs. operational needs.

8) The results of this thesis should be shared with the Naval aviation community. The more aviators are aware of how the weather contributes to major Naval mishaps, the less likely they are to experience one of these mishaps. Many pilots learn to respect the

weather through on the job training. Either the METOC community or the aviation community should provide annual meteorological training and education to aircrews. This training could include a review of the results of this and similar future studies, along with a review of mishap reports, to drive home the importance of paying attention to the weather. In some cases, this is being done in the aircrew's annual Instrument Ground School refresher training. However, even this training is not done as detailed as it could be.

9) The Naval Safety Center should add the weather data collected in this study to the NSC data base in order to correct and update the data base.

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APPENDIX A. HUMAN FACTORS THEORY

I The study of Human Factors can be divided into five topics. These are (1) Human Error, HF and Systems Theory; (2) Vision and Visual Illusions; (3) Vestibular System and Spatial Disorientation; (4) Attention and Situational Awareness; and (5) Experience and Judgment. A brief weather related example follows the discussion of each topic.

1. Human Error, HF and Systems Theory

Human error or aircrew error is when an action, if not corrected, could contribute to the occurrence of a mishap (School Of Aviation Safety, 2000). Some of the most common aircrew errors identified by the NSC are: inadequate aircrew coordination, NATOPS violation, physical or mental condition, judgment error, or poor flight preparation. Human Factors is used to answer the question of why these errors occurred. It has been realized recently that many "human error" accidents may have roots that are not necessarily in the aviator's hands. Instead, the roots go back to flawed strategy and poor managerial practices.

The Navy uses the Human Factors Accident Classification System (HFACS) to organize human causal factors (School of Aviation Safety, 2000). HF takes the view that aviator error is preceded by a chain of latent and active failures. HF uses the "Domino Theory" to help identify and mitigate active and latent failures. Another HF tool used is the "Swiss Cheese" model. This model helps investigators focus on latent failures as well the active failures leading up to a mishap.

There are four levels of failure described by HF that can lead to mishaps. These are unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences (School of Aviation Safety, 2000).

(1) Unsafe acts can be subdivided into errors and violations. Errors (decision errors, skill-based errors, and perceptual errors) are unintended mistakes. Violations (routine and exceptional) are the willful disregard for the rules and occur less often than errors.

(2) Preconditions for unsafe acts are the underlying conditions that lead to a mishap. These acts are separated into two categories. The first, substandard conditions of operators, include adverse mental states, adverse physiological states, and

physical/mental limitations. The second, substandard practices of operators include crew resource management and personal readiness.

(3) Unsafe supervision has often been found to be part of the mishap causal chain of events. Unsafe supervision can be subdivided into inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations.

(4) Organizational influences are those decisions made by upper-level management that affect supervisory practices as well as the conditions and actions of the aviators. Organizational influences can be divided into resource management, organizational climate, and organizational process.

Systems theory is the study of the interaction of people, equipment, materials, facilities, procedures, software, etc… and how they work to accomplish a common goal (School Of Aviation Safety, 2000). The "SHEL" model facilitates an understanding of how all elements of a system interact (Hawkins, 1987). SHEL stands for Software, Hardware, Environment, and Liveware. The SHEL model organization is shown next.

H
S L E
L

Figure A1. The "SHEL" model (From Hawkins, 1987)

The "L" in the center of the model is Liveware (man). Physical traits, fuel requirements, input characteristics, information processing, output characteristics, and environmental tolerances make all people different. The first relationship is the Liveware-Hardware interface. This describes the man-machine interaction. It includes items such as the comfort of a seat, the location of controls, and the design of instruments. The second relationship is the Liveware-Software interface. This covers the non-physical parts of the system including procedures, checklist layout, and computer programs. The third relationship is the Liveware-Environment interface. This includes G-suits, pressurization systems, and air conditioning. The fourth relationship is the Liveware-Liveware interface. This is the interaction between people and involves leadership, crew cooperation, teamwork, and personality interactions.

HF Weather Related Example. A T-34 Class C mishap due to hail damage occurred when the aircrew attempted to circumnavigate several thunderstorms (NSC, 1993). The causal factors included the CO's failure to provide adequate training. Leadership is part of the Liveware-Liveware relationship in the SHEL model.

2. Vision and Visual Illusions

Vision is the most important sense for flying. Vision is the result of light striking the retina located at the back of the eye (Sanderson, 1995). The retina is made of light sensitive cones and rods. The cones, which view bright light and color, are located directly behind the lens in a notched area called the fovea. Rods view dim light and are concentrated outside the fovea area. Rods see only in black and white and their location creates a blind spot in the center of the viewing area. Rods can take up to 30 minutes to fully adapt to the dark.

Visual Illusions result from the senses misinterpreting sensory data (School of Aviation Safety, 2000). Missing or ambiguous visual cues are usually unavoidable because they are a result of the way the eye and brain process information. The majority of illusions occur when visibility is restricted by either darkness or weather (Sanderson, 1995). Some of the common forms are Autokinesis, Ground Light Misinterpretation, Relative Motion, False Horizons, Waterfall Effect, Height Illusion, Flicker Vertigo, and Size-Distance Illusion (School of Aviation Safety, 2000).

Vision and Visual Illusions Weather Related Example. An AV-8B Class A mishap resulted from CFIT during a night Instrument Flight Rules (IFR) shipboard takeoff (NSC, 1995). There was no visible horizon at the time of takeoff. It is possible that the mishap pilot (wingman) fixated on the mishap lead or, finding the mishap lead, did not crosscheck his primary flight instruments and failed to notice his angle of bank or rate of descent. Poor visibility contributed to this mishap.

3. Vestibular System and Spatial Disorientation

Located in the inner ear, the vestibular system detects changes in motion through the semicircular canals (angular acceleration) and the otolith organ (linear acceleration). Angular acceleration detects pitch, roll, and yaw motion while linear acceleration detects forward/backward, left/right, up/down motion (School of Aviation Safety, 2000, and Sanderson, 1995). One big weakness of the otolith organ is its inability to tell the difference between gravity and centrifugal G-force. Types of vestibular illusions include coriolis, somatogyral, and somatogravic.

Spatial disorientation occur when the brain receives conflicting messages from the sensory inputs. The sensory inputs are vision, vestibular, and somatosensory (seat-of-pants). A pilot must rely on instrumentation when visibility is restricted because the vestibular and somatosensory sensors are not reliable enough. There are three types of spatial disorientation (School of Aviation Safety, 2000). Type I is called "unrecognized" and occurs when the aviator is spatially disoriented and is not aware of it. Type I results in many CFIT mishaps. Type II is called "recognized" and occurs when the spatially disoriented aviator is aware of disorientation. Type II is also known as vertigo and recovery is usually possible. Type III is called "incapacitating" and occurs when the aviator is seriously disoriented and so confused in perception that sensory/perceptual control is nearly impossible to regain.

Spatial Disorientation Weather Related Example. A T-34 Class A mishap occurred when the instructor was inadvertently forced to bail out during practice spins (NSC, 1995). The mishap board found that the instructor prematurely released from the parachute and fell to his death during the decent due to probable spatial disorientation caused by haze obscuring the horizon.

4. Attention and Situational Awareness

Attention is defined as "selective awareness" and can be limited in ability to process and respond to incoming sensory information. With experience and training the aviator can improve his attention. The three learning stages are cognitive, consolidation, and automatic. Problems occur when aviators are affected by attention failures which can affect both inexperienced and highly proficient pilots. Attention failures can be itemized as inattention, habituation, channelization, distraction, and task overload. Control action errors can occur while pilots are on automatic and include omission, substitution, adjustment, reversal, unintentional, and outside reach. These descriptions only explain what happened, but not why.

Situational Awareness is the accurate perception of factors and conditions that affect an aircraft and flight crew. Loss of situational awareness can occur when the pilot is not monitoring the situation, monitors the wrong information, or does not correctly interpret the situation. Research has shown there are ways to improve situational awareness. Further research continues today.

Attention and Situational Awareness Weather Related Example. A T-2 class A mishap occurred when a student pilot lost situational awareness and improperly raised flaps during simulated instrument takeoffs during an ICS failure (NSC, 1995). Deteriorating weather had already delayed the flight and created a narrow window between weather systems. The student false sense of urgency prior to arrival of severe weather caused considerable anxiety from the start of preflight. The brief was rushed because the instructor was in a hurry to get the "X" before the weather system moved in. As a result crucial emergency procedures concerning loss of ICS were not briefed.

5. Experience and Judgment

The majority of fatal aircraft mishaps result from a series of poor pilot decisions. Judgment is defined as the mental process by which an individual analyzes, evaluates, and estimates risk, using information regarding their own ability, aircraft, mission tasking, environment, and situational factors (School of Aviation Safety, 2000). Risk judgment can be intellectual (rational) or motivational (emotional). Poor judgment has been correlated to pilots with attitudes such as anti-authority, impulsivity, invulnerability, or macho. Social and self induced pressures can also be a cause of poor judgment. Usually judgment related mishaps occur when knowledge, skill, and ability to handle a particular high risk situation are exceeded. It has been shown that judgment can be taught. As a result judgment training now occurs in many flight programs.

Experience and Judgment Weather Related Example. A P-3 class C mishap occurred from golf ball size hail damage as the aircraft penetrated embedded thunderstorm (NSC, 1999). Causal factors included failure of the aircrew to update weather information enroute when their radar failed. An update would have alerted them a SIGMET and the embedded cell could have been avoided. The decision to fly into clouds without an operating weather radar and without updating current weather conditions showed poor judgment.

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APPENDIX B. EXCERPT FROM DRAFT OPNAV 3750.6R (APPENDIX O) HFACS TAXONOMY

Human Factors Analysis and Classification System (HFACS)

Drawing upon Reason's (1990) concept of latent and active failures, a framework was developed to identify the "holes" called the Human Factors Analysis and Classification System (HFACS). HFACS describes four levels of failure: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organizational Influences. A brief description of the major components and causal categories follows, beginning with the level most closely tied to the accident, unsafe acts.

1. Unsafe Acts

The unsafe acts committed by aircrew generally take on two forms, errors and violations. The first, errors, are not surprising given the fact that human beings by their very nature make errors. Consequently, aircrew errors are seen in most mishaps – often as that last fatal flaw before a mishap occurs. Violations, on the other hand, represent the willful disregard for the rules and typically occur less frequently. Still, not all errors are alike. Likewise, there are different types of violations. As such, the unsafe acts aircrew commit can be classified among three basic error types (skill-based, decision, and perceptual) and two forms of violations (infractions and exceptional). Each will be described in turn (Figure 2).

Using this simple classification scheme, the investigator must first decide if an unsafe act (active failure) was committed by the operator (aircrew, maintainer, etc.). If so, the investigator must then decide if an error occurred or a rule was willfully violated. Once this is done, the investigator can further define the causal factor as a specific type of error or violation as described below.

Error

Skill-based Errors. Skill-based behavior is best described as those "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. As a result, skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, and the misordering of steps in a procedure, among others (Table 1). Consider, for example, the pilot so intent on putting bombs on target that he disregards his low altitude warning only to collide with the ground. Closer to home, have you ever locked yourself out of your car or missed your exit because your were either distracted, in a hurry, or daydreaming? These are all examples of attention failures that occur during highly automatized behavior. While on the ground they may be frustrating, in the air they can become catastrophic.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, most of us have experienced going to the refrigerator only to forget what we came for. Likewise, it's not difficult to imagine that in emergency situations, when under stress, steps in boldface emergency procedures or radio calls can be missed. Even when not particularly stressed however, individuals have forgotten to set the flaps on approach or lower the landing gear.

Skill-based errors can happen even when no apparent attention of memory failure is present. The individual flying skill/techniques of Naval aviators differ from one pilot to next. We've all known individuals that fly smooth and effortless and those who make every mission an adventure. It is the skill-based errors of the latter that often leads to mishaps as well. The bottom line is that skill-based errors are unintended behaviors. That is, individuals typically do not choose to limit their scan patterns, forget a boldface procedure, or fly poorly – it just happens, unbeknownst to the individual.

Decision Errors. The second error form, decision errors, represent intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes", these unsafe acts represent the actions or inactions of individuals whose heart is in the right place, but they either did not have the appropriate knowledge available or just simply chose poorly. Regardless of the outcome, the individual made a conscious decision.

Decision errors come in many forms, and occur for a variety of reasons. However, they typically represent poor decisions, improper procedural execution, or the misinterpretation or misuse of relevant information (Table 1). The bottom line is that for good or bad the individual made a conscious choice and elected to do what was done in the cockpit – unfortunately, in the case of mishaps, it didn't work.

Table 1. Select examples of Unsafe Acts of Operators	
Unsafe Acts of Operators	
Errors	Violations
<u>Skill-based Errors</u> Breakdown in Visual Scan Delayed Response Omitted Step in Procedure <u>Decision Errors</u> Improper Approach/Landing Improper Procedure Misdiagnosed Emergency <u>Perceptual Errors</u> Misjudged Distance/Altitude/Airspeed Spatial Disorientation Visual Illusion	<u>Routine (Infractions)</u> Failed to Adhere to Brief Violation of NATOPS/Regulations/SOP <u>Exceptional</u> Not Current/Qualified for Mission Violation of NATOPS/Regulations/SOP

<u>Perceptual Errors</u>. Not surprisingly, when your perception of the world is different then reality, errors can, and often do, occur. Typically, perceptual errors occur when sensory input is degraded or 'unusual', as is the case when visual illusions or spatial disorientation occurs (Table 1). Visual illusions occur when the brain tries to 'fill in the gaps' with what it feels belongs in a visually impoverished environment, like that seen at night or in the weather. Likewise, spatial disorientation occurs when the vestibular system cannot resolve your orientation in space and therefore makes a "best guess" -- typically when visual (horizon) cues are absent at night or in weather. In either event, the individual is left to make a decision based on faulty information leading to and error, and often a mishap. Likewise, it is often quite difficult to judge precise distance and closure between aircraft and the ground when relative cues like clouds or terrain features are absent. Consequently, aircrews are left to make control inputs based upon misperceived or absent information. Tragically, these sorts of errors often lead to midair collisions or controlled flight into terrain.

Violations

Routine/Infractions. Violations in general are the willful departure from authority that simply cannot be tolerated. We have identified two distinct types of violations (Table 1). The first, infractions, tend to be routine/habitual by nature constituting a part of the individual's behavioral repertoire. For example, the individual that drives consistently 5-10 mph faster than allowed by law. While certainly against the law, many folks do it. Furthermore, if you go 64 in a 55 mph zone, you always drive 64 in a 55 mph zone. That is, you 'routinely' violate the law. Commonly referred to as "bending" the rules, these violations are often tolerated and, in effect, sanctioned by supervisory authority (that is, you're not likely to get a ticket going 64 in a 55). If however, the local authorities started handing out tickets for exceeding the speed limit on the highway by 9 mph (like is often done on military installations) then it is less likely that individuals would violate the rules. Therefore, by definition, if a routine violation/infraction is identified, one must look further up the supervisory chain to identify those that are condoning those violations.

Exceptional. Unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of an individual's typical behavior pattern nor condoned by management. For example, an isolated instance of driving 105 mph in a 55 mph zone, or in Naval Aviation, *flathatting*, is considered an exceptional violation. It is important to note that while most exceptional violations are heinous, they are not considered 'exceptional' because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority.

2. Preconditions for Unsafe Acts

Arguably the unsafe acts of operators can be directly linked to nearly 80 percent of all Naval aviation mishaps. However, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it. As such, investigators must dig deeper into why the unsafe acts took place. As a first step, we describe two major subdivisions of unsafe aircrew conditions, each with their specific causal categories. Specifically, they include the Substandard Conditions of operators (i.e., Adverse Mental States, Adverse Physiological States, and Physical/Mental Limitations) as well as those Substandard Practices they commit (Figure 3). Each are described briefly below.

Substandard Conditions of Operators

Adverse Mental States. Being prepared mentally is critical in nearly every endeavor, perhaps more so in aviation. As such, the category of adverse mental states, was created to account for those mental conditions that affect performance (Table 2). Principle among these is the loss of situational awareness, task fixation, distraction, and *mental* fatigue due to sleep loss or other stressors. Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation. For example, if an individual is mentally tired for whatever reason, the likelihood that an error would occur increases. Likewise, overconfidence, arrogance, and other pernicious attitudes will influence the likelihood that a violation is committed. While errors and violations are important causal factors, adverse mental states such as these are no less important, perhaps even more so, in the causal sequence.

Adverse Physiological States. The second category, adverse physiological states, refers to those medical or physiological conditions that preclude safe operations (Table 2). Particularly important to Naval aviation are conditions such as spatial disorientation, visual illusions, G-induced loss of consciousness (G-LOC), hypoxia, *physical* fatigue, and the myriad of pharmacological and medical abnormalities known to affect performance. If, for example, an individual were suffering from an inner ear infection, the likelihood of spatial disorientation occurring when entering IMC goes up markedly. Consequently, the medical condition must be addressed within the causal chain of events.

Physical/Mental Limitations. The third, and final, category of Aeromedical Conditions, Physical/Mental Limitations, refers to those instances when the mission requirements exceed the capabilities of the individual at the controls. Physical/Mental Limitations can take many forms (Table 2). For example, at night our visual systems are limited by the capability of the photosensors in our eyes and hence vision is severely degraded. Yet, like driving a car, we do not necessarily slow down or take additional precautions. In aviation, this often results in not seeing other aircraft, obstacles, or power lines due to the size or contrast of the object in the visual field. Similarly, there are occasions when the time required to complete a task or maneuver exceeds human capacity. It is well documented that if individuals are required to respond quickly (i.e., less time is available to consider all the possibilities or choices thoroughly), the probability of making an error goes up markedly.

There are two additional instances of physical/mental limitations that need to be addressed; albeit they are often overlooked in most mishap investigations. They involve individuals who simply are not compatible with aviation. For example, some individuals simply don't have the physical strength to operate in high-G environments or for anthropometric reasons simply have difficulty reaching the controls. In other words, cockpits have traditionally not been designed with all shapes, sizes, and physical abilities in mind. Likewise, not everyone has the mental ability or aptitude for flying Naval aircraft. Just as not all of us can be concert pianists or NFL linebackers, we can't all fly Naval aircraft. The hard part is identifying whether this might of played a role in the mishap causal sequence.

Table 2. Select examples of Unsafe Aircrew Conditions	
Preconditions for Unsafe Acts	
Aeromedical <u>Adverse Mental States</u> Channelized Attention Complacency Loss of Situational Awareness <u>Adverse Physiological States</u> G-Induced Loss of Consciousness Impaired Physiological State Physical Fatigue <u>Physical/Mental Limitation</u> Insufficient Reaction Time Visual Limitation Incompatible Intelligence/Aptitude	<u>Crew Resource Management</u> Failed to Back-up Failed to Communicate/Coordinate Failed to Conduct Adequate Brief <u>Personal Readiness</u> Excessive Physical Training Self-Medicating Violation of Crew Rest Requirement Violation of Bottle-to-Brief Requirement

Substandard Practices of Operators

Crew Resource Mismanagement. To account for occurrences of poor coordination among aircrew and other personnel associated with the safe conduct of the flight, the category of crew resource management was created (Table 2). This includes coordination both within and between aircraft, ATC, and maintenance control, as well as facility and other support personnel. Anywhere communication between individuals is required, the potential for miscommunication, or simply poor resource management, exists. However, aircrew coordination does not stop with the aircrew in flight. It also includes coordination before and after the flight with the brief and debrief of the aircrew. Literally volumes have been written on the topic, yet it still continues to permeate both fixed-wing and rotary-wing aviation, as well as multi-crew and single-seat aircraft. The conscientious investigator must always be aware of the potential for poor CRM practices.

Personal Readiness. In aviation, or for that matter in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels. For Naval aviation however, personal readiness failures occur when individuals fail to prepare physically or mentally for flight. For instance, violations of crew rest requirements, bottle-to-brief rules, and self-medicating all will affect performance in the aircraft. It's not hard to imagine that when you violate crew rest requirements, you run the risk of mental fatigue and other adverse mental states. (*Note that violations that effect personal readiness are not considered "unsafe act, violation" since they typically do not happen in the cockpit, nor are they active failures with direct and immediate consequences*)

Still, not all personal readiness failures occur as a result of violations of rules. For example, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional "candy bar and coke" lunch of the naval aviator may sound good but may not be sufficient to sustain performance in the rigorous environment of military aviation. Even cramming for exams may significantly impair your sleep and may in some cases influence your performance the next day in the cockpit. While, there may be no rules governing such behavior, aircrew must be their own best judge. Certainly, additional education and physical exercise is a good thing when taken in moderation, but aircrew must always assess their condition objectively before manning the aircraft.

3. Unsafe Supervision

It is the experience of the NSC that often the mishap causal chain of events can be traced back up the supervisory chain of command. As such, we have identified four categories of Unsafe Supervision: Inadequate Supervision, Planned Inappropriate Operations, Failed to Correct a Known Problem, and Supervisory Violations (Figure 4). Each are described briefly below.

Inadequate Supervision. The role of any supervisor is to provide the opportunity to succeed. To do this the supervisor, no matter what level he operates at, must provide guidance, training opportunities, leadership, motivation, and the proper role model. Unfortunately, this is not always the case. It's not difficult to conceive of a situation where adequate crew resource management training was either not provided, or the opportunity to attend was not afforded, to a particular aircrew member. Conceivably, his aircrew coordination skills would be compromised and if put into an adverse situation (an emergency for instance), he would be at risk for errors and potentially a mishap. Therefore, the category Inadequate Supervision was created to account for those times when supervision proves inappropriate, improper, or may not occur at all (Table 3).

Planned Inappropriate Operations. Occasionally, the operational tempo and/or schedule is planned such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such operations, though arguably unavoidable during emergency situations, are unacceptable during normal operations. Therefore, we have created a second category, Planned Inappropriate Operations, to account for these supervisory failures (Table 3). Included in this category are issues of crew pairing and improper manning. It's not surprising to anyone that when two individuals with marginal skills are paired together, problems can, and often do, arise. With down-sizing and the current level of operational commitments, it is difficult to manage crews. However, pairing two weak or inexperienced aircrew together on the most difficult mission may not be prudent.

Failure to Correct a Known Problem. The third category of known unsafe supervision, Failed to Correct a Problem, refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue uncorrected (Table 3). For example, the failure to consistently correct or discipline inappropriate behavior certainly fosters an unsafe atmosphere, but is not considered a violation if no specific rules or regulations were broken.

Supervisory Violations. Supervisory violations, on the other hand, are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors when managing assets (Table 3). For instance, permitting an individual to operate an aircraft without current qualifications or license is a flagrant violation that invariably sets the stage for the tragic sequence of events that predictably follow.

Table 3. Select examples of Unsafe Supervision	
Inadequate Supervision	Failed to Correct a Known Problem
Failed to Provide Guidance	Failed to Correct Document in Error
Failed to Provide Operational Doctrine	Failed to Identify an At-Risk Aviator
Failed to Provide Training	Failed to Initiate Corrective Action
Planned Inappropriate Operations	Supervisory Violations
Failed to Provide Adequate Brief Time	Failed to Enforce NATOPS/Regs/SOP
Improper Manning	Failed to Enforce T&R Manual
Mission Not IAW with NATOPS/Regs/SOP	Authorized Unqualified Crew for Flight

4. Organizational Influences

Fallible decisions of upper-level management directly effect supervisory practices, as well as the conditions and actions of operators. These latent failures generally revolve around issues related to resource management, organizational climate, and operational processes.

Resource Management. This category refers to the management, allocation, and maintenance of organizational resources, such as human, monetary, and equipment/facilities. The term 'human' refers to the management of operators, staff, and maintenance personnel. Issues that directly influence safety include selection (including background checks), training, and staffing/manning. Monetary issues refer to the management of nonhuman resources, primarily monetary resources. For example, excessive cost-cutting, a lack of funding for proper and safe equipment and resources both have adverse effects on operator performance and safety. Finally, Equipment/Facility refers to issues related to equipment design, including the purchasing of unsuitable equipment, inadequate design of work spaces, and failures to correct known design flaws. Management should ensure that human factors engineering principles are known and utilized and that specifications for equipment and work space design are identified and met.

Table 4. Select examples of Organizational Influences

Resource/Acquisition Management	Organizational Process
Human Resources	Operations
Staffing/Manning	Operational tempo
Training	Time pressure
Monetary/Budget Resources	Procedures
Excessive cost cutting	Standards
Lack of funding	Instructions
Equipment/Facility Resources	Oversight
Poor design	Risk Management
Unsuitable equipment	Safety Programs
Organizational Climate	
Structure	
Chain-of-command	
Communication	
Policies	
Hiring and firing	
Drugs and alcohol	
Culture	
Norms and rules	
Values and beliefs	

Organizational Climate. Organizational climate refers to a broad class of organizational variables that influence worker performance (Glick, 1985). It can be defined as the "situationally based consistencies in the organization's treatment of individuals." (Jones, 1988). In general, organizational climate is the prevailing atmosphere or environment within the organization. Within the present classification system, climate is broken down into three categories- structure, policies, and culture. The term 'structure' refers to the formal component of the organization (Mintzberg, 1993). The "form and shape" of an organization are reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Organizations with maladaptive structures (i.e., do not optimally match to their operational environment or are unwilling to change), will be more prone to accidents and "will ultimately cease to exists." (Muchinsky, 1997). Policies refer to a course or method of action that guides present and future decisions. Policies may refer to hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, use of safety equipment, etc. When these policies are ill-defined, adversarial, or conflicting, safety may be reduced. Finally, culture refers to unspoken or unofficial rules, values, attitudes, beliefs, and customs of an organization. "The way things really get done around here." Other issues related to culture included organizational justice, psychological contracts, organizational citizenship behavior, esprit de corps, and union/management relations. All these issues affect attitudes about safety and the value of a safe working environment.

Organizational Process. This category refers to the formal process by which things get done in the organization. It is subdivided into three broad categories - operations, procedures, and oversight. The term 'operations' refers to the characteristics or conditions of work that have been established by management. These characteristics included operational tempo, time pressures, production quotas, incentive systems, schedules, etc. When set up inappropriately, these working conditions can be detrimental to safety. Procedures are the official or formal procedures as to how the job is to be done. Examples include performance standards, objectives, documentation, instructions about procedures, etc. All of these, if inadequate, can negatively impact employee supervision, performance, and safety. Finally, oversight refers to management's monitoring and checking of resources, climate, and processes to ensure a safe and productive work environment. Issues here relate to organizational self-study, risk management, and the establishment and use of safety programs.

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APPENDIX C. LIST OF AVIATORS AND METEOROLOGIST PROVIDING SECOND OPINIONS

Daziens, LCDR John, USN, METOC Officer and SH-60B Pilot. 1200 hours in Naval aircraft, 1000 hours in SH-60B.

Keane, Maj Chris, USMC. CH-46 Pilot. 1500 hours in Naval aircraft, 1300 in CH-46.

Schmeiser, LCDR Greg S, USN. METOC Officer and P-3 Pilot. 2200 hours in Naval aircraft, 2000 hours (1500 as pilot) in P-3.

Wash, Dr. Chuck. Chairman, Department of Meteorology, Naval Postgraduate School, Monterey.

Wellons, Capt James, USMC. AV8-B pilot. 950 hours in Naval aircraft, 700 hours in AV-8B

Witzleb, LCDR Robert. METOC Officer, F-14 pilot. 700 hours in Naval aircraft, 400 hours in F-14D.

Woehler, CDR Markus, USN. H-60 pilot. 4,300 hours in Naval aircraft, 1,300 hours in H-60.

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APPENDIX D. TABLES OF RESULTS

Table D1. Count Of All Class A Naval Aircraft Weather Related Mishaps By Category And Branch Of Service

HF COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Navy & Marine										
Tactical	15	4	0	11	109	**227**		19	0	120
Helicopter	18	1	0	5	33	**104**		19	0	38
Training	4	1	0	3	24	**43**		5	0	27
Other	1	1	0	1	4	**21**		2	0	5
Total	**38**	**7**	**0**	**20**	**170**	**395**		**45**	**0**	**190**
Navy										
Tactical	12	3	0	7	73	**144**		15	0	80
Helicopter	9	1	0	3	14	**56**		10	0	17
Training	4	1	0	3	24	**41**		5	0	27
Other	1	1	0	0	3	**19**		2	0	3
Total	**26**	**6**	**0**	**13**	**114**	**260**		**32**	**0**	**127**
Marine										
Tactical	3	1	0	4	36	**83**		4	0	40
Helicopter	9	0	0	2	19	**48**		9	0	21
Training	0	0	0	0	0	**2**		0	0	0
Other	0	0	0	1	1	**2**		0	0	2
Total	**12**	**1**	**0**	**7**	**56**	**135**		**13**	**0**	**63**

Table D2. Percent Of All Class A Naval Aircraft Weather Related Mishaps By Category And Branch Of Service

HF PERCENT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Navy & Marine										
Tactical	7	2	0	5	48	100		8.4	0	53
Helicopter	17	1	0	5	32	100		18	0	37
Training	9	2	0	7	56	100		12	0	63
Other	5	5	0	5	19	100		9.5	0	24
Total	**10**	**2**	**0**	**5**	**43**	**100**		**11**	**0**	**48**
Navy										
Tactical	8	2	0	5	51	100		10	0	56
Helicopter	16	2	0	5	25	100		18	0	30
Training	10	2	0	7	59	100		12	0	66
Other	5	5	0	0	16	100		11	0	16
Total	**10**	**2**	**0**	**5**	**44**	**100**		**12**	**0**	**49**
Marine										
Tactical	4	1	0	5	43	100		5	0	48
Helicopter	19	0	0	4	40	100		19	0	44
Training	0	0	0	0	0	100		0	0	0
Other	0	0	0	50	50	100		0	0	100
Total	**9**	**1**	**0**	**5**	**41**	**100**		**10**	**0**	**47**

Table D3. Count Of HF Naval Aircraft Weather Related Mishaps By Category And Branch Of Service

HF COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Navy & Marine										
Tactical	15	4	0	11	109	139		19	0	120
Helicopter	18	1	0	5	33	57		19	0	38
Training	4	1	0	3	24	32		5	0	27
Other	1	1	0	1	4	7		2	0	5
Total	**38**	**7**	**0**	**20**	**170**	**235**		**45**	**0**	**190**
Navy										
Tactical	12	3	0	7	73	95		15	0	80
Helicopter	9	1	0	3	14	27		10	0	17
Training	4	1	0	3	24	32		5	0	27
Other	1	1	0	0	3	5		2	0	3
Total	**26**	**6**	**0**	**13**	**114**	**159**		**32**	**0**	**127**
Marine										
Tactical	3	1	0	4	36	44		4	0	40
Helicopter	9	0	0	2	19	30		9	0	21
Training	0	0	0	0	0	0		0	0	0
Other	0	0	0	1	1	2		0	0	2
Total	**12**	**1**	**0**	**7**	**56**	**76**		**13**	**0**	**63**

Table D4. Percent Of HF Naval Aircraft Weather Related Mishaps By Category And Branch Of Service

HF PERCENT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Navy & Marine										
Tactical	11	3	0	8	78	100		14	0	86
Helicopter	32	2	0	9	58	100		33	0	67
Training	13	3	0	9	75	100		16	0	84
Other	14	14	0	14	57	100		29	0	71
Total	**16**	**3**	**0**	**9**	**72**	**100**		**19**	**0**	**81**
Navy										
Tactical	13	3	0	7	77	100		16	0	84
Helicopter	33	4	0	11	52	100		37	0	63
Training	13	3	0	9	75	100		16	0	84
Other	20	20	0	0	60	100		40	0	60
Total	**16**	**4**	**0**	**8**	**72**	**100**		**20**	**0**	**80**
Marine										
Tactical	7	2	0	9	82	100		9.1	0	91
Helicopter	30	0	0	7	63	100		30	0	70
Training	0	0	0	0	0	0		0	0	0
Other	0	0	0	50	50	100		0	0	100
Total	**16**	**1**	**0**	**9**	**74**	**100**		**17**	**0**	**83**

Table D5. Count of HF Naval Aircraft Weather Related Mishaps By Mishap Characteristic.

CHARACTERISTIC COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Cat Fail	0	0	0	2	17	19		0	0	19
CFIT	19	2	0	9	21	51		21	0	30
MidAir	0	2	0	0	31	33		2	0	31
OOCF	6	2	0	5	47	60		8	0	52
PhysEp	1	0	0	1	6	8		1	0	7
Other	10	0	0	3	39	52		10	0	42
Bash	0	0	0	0	1	1		0	0	1
Undef	2	1	0	0	8	11		3	0	8
Total	**38**	**7**	**0**	**20**	**170**	**235**		**45**	**0**	**190**

Table D6. Percent of HF Naval Aircraft Weather Related Mishaps By Mishap Characteristic.

CHARACTERISTIC PERCENT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Cat Fail	0	0	0	11	89	100		0	0	100
CFIT	37	4	0	18	41	100		41	0	59
MidAir	0	6	0	0	94	100		6.1	0	94
OOCF	10	3	0	8	78	100		13	0	87
PhysEp	13	0	0	13	75	100		13	0	88
Other	19	0	0	6	75	100		19	0	81
Bash	0	0	0	0	100	100		0	0	100
Undef	18	9	0	0	73	100		27	0	73
Total	**16**	**3**	**0**	**9**	**72**	**100**		**19**	**0**	**81**

Table D7. Count of HF Naval Helicopter Weather Related Mishaps By Mishap Characteristic.

HELICOPTER CHARACTERISTIC COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Cat Fail	0	0	0	1	4	5		0	0	5
CFIT	11	1	0	4	8	24		12	0	12
MidAir	0	0	0	0	5	5		0	0	5
OOCF	5	0	0	0	6	11		5	0	6
PhysEp	1	0	0	0	0	1		1	0	0
Other	1	0	0	0	8	9		1	0	8
Bash	0	0	0	0	0	0		0	0	0
Undef	0	0	0	0	2	2		0	0	2
Total	**18**	**1**	**0**	**5**	**33**	**57**		**19**	**0**	**38**

Table D8. **Percent of HF Naval Helicopter Weather Related Mishaps By Mishap Characteristic.**

HELICOPTER CHARACTERISTIC PERCENT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Cat Fail	0	0	0	20	80	100		0	0	100
CFIT	46	4	0	17	33	100		50	0	50
MidAir	0	0	0	0	100	100		0	0	100
OOCF	45	0	0	0	55	100		45	0	55
PhysEp	100	0	0	0	0	100		100	0	0
Other	11	0	0	0	89	100		11	0	89
Bash	0	0	0	0	0	0		0	0	0
Undef	0	0	0	0	100	100		0	0	100
Total	**32**	**2**	**0**	**9**	**58**	**100**		**33**	**0**	**67**

Table D9. **HF Naval Aircraft Weather Element Count and Percent.**

WEATHER ELEMENT & NUMBER OF MISHAPS	Mishaps Count	Percent of 88 Elements	Percent of 45 WX mishaps
Horizon Difficult to Discern (Hor)	16	18	36
Obscuration (vis less than 7nm during flight) (Obs)	14	16	31
Inadvertent IMC (IMC)	13	15	29
Clouds (Ceiling above 1000ft AGL) (Cld)	8	9	18
Precipitation (Pcp)	7	8	16
Other Winds (Owd)	5	6	11
Other Visibility/Ceiling (OVC)	4	5	9
Fog (Fog)	3	3	7
Tailwind (wind direction 136 to 180 degrees off from favorable) (TWD)	3	3	7
Combined Sea State (pitching deck) (CSS)	3	3	7
Density Altitude (Dal)	3	3	7
Thunderstorm (Trw)	2	2	4
Icing (Ice)	2	2	4
Crosswind (Wind direction 45 to 135 degrees off from favorable) (Cwd)	2	2	4
Sand/Dust Storm (SDs)	1	1	2
Turbulence (Trb)	1	1	2
TOTAL Weather Element	**87**	**100**	**196**

Table D10. HF Naval Aircraft Weather Group Count and Percent.

WEATHER GROUP	Mishaps Count	Percent of 61 Groups	Percent of 45 WX mishaps.
Vis Related (Vis)	33	54	73
Wind Related (Wnd)	10	16	22
Precipitation (Pcp)	7	12	16
Density Altitude (Dal)	3	5	7
Combined Sea State (pitching deck) (CSS)	3	5	7
Thunderstorm (Trw)	2	3	4
Icing (Ice)	2	3	4
Turbulence (Trb)	1	2	2
TOTAL Weather Group	**61**	**100**	**136**

Table D11. Count Of HF Naval Aircraft Weather Related Mishaps By Human Error.

HUMAN ERROR COUNT	dY	pY	M	pN	dN	TOTAL	Yes	Maybe	No
******Unsafe Acts******	37	7	0	20	168	232	44	0	188
***Errors**	34	7	0	19	158	218	41	0	177
Skill-Based Errors	16	4	0	17	97	134	20	0	114
Decision Errors	27	6	0	9	97	139	33	0	106
Perception Errors	19	3	0	4	30	56	22	0	34
***Violations**	17	1	0	5	48	71	18	0	53
Infraction	13	1	0	3	25	42	14	0	28
Exceptional	8	0	0	1	25	34	8	0	26
******Unsafe Condition******	31	6	0	18	153	208	37	0	171
***Substandard Condition**	28	5	0	18	134	185	33	0	152
Adverse Physiological State	18	3	0	5	25	51	21	0	30
Adverse Mental State	25	4	0	16	126	171	29	0	142
Physical/Mental Limitation	2	0	0	1	15	18	2	0	16
***Substandard Practice**	24	4	0	11	102	141	28	0	113
CRM	23	4	0	11	98	136	27	0	109
Personal Readiness	3	0	0	2	9	14	3	0	11
******Unsafe Supervision*****	16	2	0	10	55	83	18	0	65
Inadequate Supervision	9	2	0	7	38	56	11	0	45
Planned Inappropriate Ops	4	1	0	1	16	22	5	0	17
Failed to Correct Problem	7	0	0	4	8	19	7	0	12
Supervisory Violation	4	0	0	2	11	17	4	0	13
******Organizational Influence*****	16	3	0	11	87	117	19	0	98
Resource Management	8	2	0	8	43	61	10	0	51
Organizational Climate	1	0	0	0	1	2	1	0	1
Organizational Process	11	2	0	8	59	80	13	0	67
NON-PILOT									
Maintenance Error	0	1	0	2	10	13	1	0	12
Material Failure	3	2	0	3	47	55	5	0	50
Facility Error	4	0	0	0	11	15	4	0	11

Table D12. Percent Of HF Naval Aircraft Weather Related Mishaps By Human Error.

HUMAN ERROR PERCENT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
****Unsafe Acts****	16	3	0	9	72	100		19	0	81
*Errors	16	3	0	9	72	100		19	0	81
Skill-Based Errors	12	3	0	13	72	100		15	0	85
Decision Errors	19	4	0	6	70	100		24	0	76
Perception Errors	34	5	0	7	54	100		39	0	61
*Violations	24	1	0	7	68	100		25	0	75
Infraction	31	2	0	7	60	100		33	0	67
Exceptional	24	0	0	3	74	100		24	0	76
****Unsafe Condition****	15	3	0	9	74	100		18	0	82
*Substandard Condition	15	3	0	10	72	100		18	0	82
Adverse Physiological State	35	6	0	10	49	100		41	0	59
Adverse Mental State	15	2	0	9	74	100		17	0	83
Physical/Mental Limitation	11	0	0	6	83	100		11	0	89
*Substandard Practice	17	3	0	8	72	100		20	0	80
CRM	17	3	0	8	72	100		20	0	80
Personal Readiness	21	0	0	14	64	100		21	0	79
****Unsafe Supervision***	19	2	0	12	66	100		22	0	78
Inadequate Supervision	16	4	0	13	68	100		20	0	80
Planned Inappropriate Ops	18	5	0	5	73	100		23	0	77
Failed to Correct Problem	37	0	0	21	42	100		37	0	63
Supervisory Violation	24	0	0	12	65	100		24	0	76
****Organizational Influence***	14	3	0	9	74	100		16	0	84
Resource Management	13	3	0	13	70	100		16	0	84
Organizational Climate	50	0	0	0	50	100		50	0	50
Organizational Process	14	3	0	10	74	100		16	0	84
NON-PILOT										
Maintenance Error	0	8	0	15	77	100		7.7	0	92
Material Failure	5.5	4	0	5	85	100		9.1	0	91
Facility Error	27	0	0	0	73	100		27	0	73

Table D13. HF Naval Aircraft Weather Element Count and Percent. For Perception Errors.

WEATHER ELEMENT & NUMBER OF MISHAPS (PERCEPTION ERRORS)	Count	Percent of 48	Percent of 56 Perception Errors
Horizon Difficult to Discern (Hor)	13	27	23
Obscuration (vis less than 7nm during flight) (Obs)	11	23	20
Inadvertent IMC (IMC)	7	15	13
Clouds (Ceiling above 1000ft AGL) (CDL)	4	8	7
Other Visibility/Ceiling (OVC)	3	6	5
Precipitation (Pcp)	2	4	4
Fog (Fog)	2	4	4
Tailwind (wind direction 136 to 180 degrees off from favorable) (TWD)	2	4	4
Density Altitude (Dal)	1	2	2
Other Winds (Owd)	1	2	2
Icing (Ice)	1	2	2
Sand/Dust Storm (SDs)	1	2	2
TOTAL Perception Errors WX Element	**48**	**100**	

Table D14. HF Naval Aircraft Weather Group Count and Percent. For Perception Errors.

WEATHER GROUP & NUMBER OF MISHAPS (PERCEPTION ERRORS)	Count	Percent of 28	Percent of 56 Perception Errors
Vis Related (Vis)	20	74	36
Wind Related (Wnd)	3	11	5
Precipitation (Pcp)	2	7	4
Density Altitude (Dal)	1	4	2
Icing (Ice)	1	4	2
TOTAL Weather Group	**27**	**100**	

Table D15. HF Naval Aircraft Weather Element Count and Percent. For Adverse Physiological State.

WEATHER ELEMENT & NUMBER OF MISHAPS (ADVERSE PHYSIOLOGICAL STATE)	Count	Percent of 45	Percent of 51 Adverse Physiological State Errors
Horizon Difficult to Discern (Hor)	13	29	25
Obscuration (vis less than 7nm during flight) (Obs)	10	22	20
Inadvertent IMC (IMC)	7	16	14
Clouds (Ceiling above 1000ft AGL) (CDL)	4	9	8
Other Visibility/Ceiling (OVC)	3	7	6
Precipitation (Pcp)	2	4	4
Fog (Fog)	2	4	4
Tailwind (wind direction 136 to 180 degrees off from favorable) (TWD)	1	2	2
Other Winds (Owd)	1	2	2
Icing (Ice)	1	2	2
Sand/Dust Storm (SDs)	1	2	2
TOTAL Adverse Physiological State Errors WX Element	**45**	**100**	

Table D16. HF Naval Aircraft Weather Group Count and Percent. For Adverse Physiological State.

WEATHER ELEMENT GROUP & NUMBER OF MISHAPS (ADVERSE PHYSIOLOGICAL STATE)	Count	Percent of 25	Percent of 51 Adverse Physiological State Errors
Vis Related (Vis)	20	80	39
Wind Related (Wnd)	2	8	4
Precipitation (Pcp)	2	8	4
Icing (Ice)	1	4	2
TOTAL Weather Group	**26**	**100**	

Table D17. HF Naval Aircraft Weather Element Count and Percent. For Failed To Correct Problem.

WEATHER ELEMENT & NUMBER OF MISHAPS (FAILED TO CORRECT PROBLEM)	Count	Percent of 12	Percent of 11 Failed To Correct Problem
Horizon Difficult to Discern (Hor)	4	33	36
Obscuration (vis less than 7nm during flight) (Obs)	2	17	18
Inadvertent IMC (IMC)	2	17	18
Clouds (Ceiling above 1000ft AGL) (CDL)	2	17	18
Other Winds (Owd)	1	8	9
Combined Sea State (pitching deck) (CSS)	1	8	9
TOTAL Adverse Physiological State Errors WX Element	**12**	**100**	

Table D18. HF Naval Aircraft Weather Group Count and Percent. For Failed To Correct Problem.

WEATHER ELEMENT GROUP & NUMBER OF MISHAPS (FAILED TO CORRECT PROBLEM)	Count	Percent of 8	Percent of 11 Failed To Correct Problem
Vis Related (Vis)	6	75	55
Wind Related (Wnd)	1	13	9
Combined Sea State (pitching deck) (CSS)	1	13	9
TOTAL Weather Group	**8**	**100**	

Table D19. Count and Percent of HF Weather Related Mishaps During Day Or Night Conditions.

DAY/NIGHT COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Day	23	4	0	10	135	172		27	0	145
Night	15	3	0	10	35	63		18	0	45
DAY/NIGHT PERCENT	**dY**	**pY**	**M**	**pN**	**dN**	**TOTAL**		**Yes**	**Maybe**	**No**
Day	13	2	0	6	78	100		16	0	84
Night	24	5	0	16	56	100		29	0	71

Table D20. Count and Percent of HF Weather Related Mishaps For Ashore Or Embarked.

EMBARKED/ASHORE COUNT	dY	pY	M	pN	dN	TOTAL		Yes	Maybe	No
Ashore	27	4	0	13	128	172		31	0	141
Embarked	11	3	0	7	42	63		14	0	49
EMBARKED/ASHORE PERCENT	**dY**	**pY**	**M**	**pN**	**dN**	**TOTAL**		**Yes**	**Maybe**	**No**
Ashore	16	2	0	8	74	100		18	0	82
Embarked	17	5	0	11	67	100		22	0	78

Table D21. Count and Percent of HF Weather Related Mishaps For Control And Lighting.

CONTROL & LIGHTING COUNT	dY	pY	M	pN	dN	TOTAL	Yes	Maybe	No
Ashore-Day	22	3	0	9	108	142	25	0	117
Ashore-Night	5	1	0	4	20	30	6	0	24
Embarked-Day	1	1	0	1	27	30	2	0	28
Embarked-Night	10	2	0	6	15	33	12	0	21
CONTROL & LIGHTING PERCENT	**dY**	**pY**	**M**	**pN**	**dN**	**TOTAL**	**Yes**	**Maybe**	**No**
Ashore-Day	15	2	0	6	76	100	18	0	82
Ashore-Night	17	3	0	13	67	100	20	0	80
Embarked-Day	3	3	0	3	90	100	7	0	93
Embarked-Night	30	6	0	18	45	100	36	0	64

Table D22. Mishaps Per Fiscal Year By Weather, HFACS, And Total For Naval, Navy, And Marine.

Number of Combined Mishaps	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	TOTAL
Weather	3	12	4	7	4	4	2	5	4	45
HFACS	37	35	27	34	16	24	23	15	24	235
Total	66	60	55	53	28	34	36	27	36	395

Number of Navy Mishaps	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	TOTAL
Weather	2	7	4	5	3	3	2	3	3	32
HFACS	23	22	20	23	13	15	15	9	19	159
Total	40	40	39	36	20	22	21	15	27	260

Number of Marine Mishaps	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	TOTAL
Weather	1	5	0	2	1	1	0	2	1	13
HFACS	14	13	7	11	3	9	8	6	5	76
Total	26	20	16	17	8	12	15	12	9	135

Table D23. Flight Hours Per Fiscal Year For Naval, Navy, And Marine.

Flight Hours	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	TOTAL
Total	2,201,634	2,154,079	1,962,943	1,865,703	1,675,241	1,656,449	1,650,026	1,523,506	1,518,109	16,207,691
Navy	1,759,401	1,706,212	1,546,997	1,448,061	1,266,856	1,237,106	1,240,688	1,162,920	1,161,305	12,529,546
Marine	442,233	447,867	415,946	417,642	408,385	419,343	409,338	360,586	356,804	3,678,145

Table D24. Mishap Rates Per Fiscal Year For Naval, Navy, And Marine.

COMBINED MISHAP	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	Overall
All Class A Rate	3.00	2.79	2.80	2.84	1.67	2.05	2.18	1.77	2.37	2.44
HF Rate	1.68	1.62	1.38	1.82	0.96	1.45	1.39	0.98	1.58	1.45
Weather Related Rate	0.14	0.56	0.20	0.38	0.24	0.24	0.12	0.33	0.26	0.28

NAVY MISHAP	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	Overall
All Class A Rate	2.27	2.34	2.52	2.49	1.58	1.78	1.69	1.29	2.32	2.08
HF Rate	1.31	1.29	1.29	1.59	1.03	1.21	1.21	0.77	1.64	1.27
Weather Related Rate	0.11	0.41	0.26	0.35	0.24	0.24	0.16	0.26	0.26	0.26

MARINE MISHAP	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	Overall
All Class A Rate	5.88	4.47	3.85	4.07	1.96	2.86	3.66	3.33	2.52	3.67
HF Rate	3.17	2.90	1.68	2.63	0.73	2.15	1.95	1.66	1.40	2.07
Weather Related Rate	0.23	1.12	0.00	0.48	0.24	0.24	0.00	0.55	0.28	0.35

Table D25. Count of HF Naval Aircraft Weather Related Mishaps By Flight Phase.

Flight Phase Count	dY	pY	M	pN	dN	Total		Yes	Maybe	No
Takeoff	6	1	0	4	18	29		7	0	22
Descent	0	0	0	0	2	2		0	0	2
Approach	5	0	0	2	16	23		5	0	18
Landing	6	1	0	3	21	31		7	0	24
Wave-off/Go-Around	2	1	0	1	4	8		3	0	5
Formation/Rendezvous	3	0	0	0	17	20		3	0	17
Low Level/Terrain Following	4	0	0	1	15	20		4	0	16
Ground Attack	2	0	0	2	10	14		2	0	12
Air-to-Air	0	2	0	2	28	32		2	0	30
Cruise/Loiter	10	2	0	5	35	52		12	0	40
Hover	0	0	0	0	0	0		0	0	0
Other	0	0	0	0	4	4		0	0	4

Table D26. Percent of HF Naval Aircraft Weather Related Mishaps By Flight Phase.

Flight Phase Percent	dY	pY	M	pN	dN	Total		Yes	Maybe	No
Takeoff	21	3	0	14	62	100		24	0	76
Descent	0	0	0	0	100	100		0	0	100
Approach	22	0	0	9	70	100		22	0	78
Landing	19	3	0	10	68	100		23	0	77
Wave-off/Go-Around	25	13	0	13	50	100		38	0	63
Formation/Rendezvous	15	0	0	0	85	100		15	0	85
Low Level/Terrain Following	20	0	0	5	75	100		20	0	80
Ground Attack	14	0	0	14	71	100		14	0	86
Air-to-Air	0	6	0	6	88	100		6	0	94
Cruise/Loiter	19	4	0	10	67	100		23	0	77
Hover	0	0	0	0	0	0		0	0	0
Other	0	0	0	0	100	100		0	0	100

Table D27. Count of HF Naval TACAIR Weather Related Mishaps By Flight Phase.

Flight Phase Count	dY	pY	M	pN	dN	Total	Yes	Maybe	No
Takeoff	3	1	0	4	9	17	4	0	13
Descent	0	0	0	0	0	0	0	0	0
Approach	0	0	0	1	7	8	0	0	8
Landing	4	0	0	2	13	19	4	0	15
Wave-off/Go-Around	1	1	0	0	3	5	2	0	3
Formation/Rendezvous	0	0	0	0	10	10	0	0	10
Low Level/Terrain Following	4	0	0	0	12	16	4	0	12
Ground Attack	2	0	0	2	9	13	2	0	11
Air-to-Air	0	2	0	2	27	31	2	0	29
Cruise/Loiter	1	0	0	0	16	17	1	0	16
Hover	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	3	3	0	0	3
Total	15	4	0	11	109	139	19	0	120

Table D28. Percent of HF Naval TACAIR Weather Related Mishaps By Flight Phase.

Flight Phase Percent	dY	pY	M	pN	dN	Total	Yes	Maybe	No
Takeoff	18	6	0	24	53	100	24	0	76
Descent	0	0	0	0	0	0	0	0	0
Approach	0	0	0	13	88	100	0	0	100
Landing	21	0	0	11	68	100	21	0	79
Wave-off/Go-Around	20	20	0	0	60	100	40	0	60
Formation/Rendezvous	0	0	0	0	100	100	0	0	100
Low Level/Terrain Following	25	0	0	0	75	100	25	0	75
Ground Attack	15	0	0	15	69	100	15	0	85
Air-to-Air	0	0	0	0	0	0	0	0	0
Cruise/Loiter	6	0	0	0	94	100	6	0	94
Hover	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0

Table D29. Count of HF Naval Helicopter Weather Related Mishaps By Flight Phase.

Flight Phase Count	dY	pY	M	pN	dN	Total		Yes	Maybe	No
Takeoff	2	0	0	0	6	8		2	0	6
Descent	0	0	0	0	0	0		0	0	0
Approach	4	0	0	1	3	8		4	0	4
Landing	1	1	0	0	1	3		2	0	1
Wave-off/Go-Around	1	0	0	1	0	2		1	0	1
Formation/Rendezvous	2	0	0	0	3	5		2	0	3
Low Level/Terrain Following	0	0	0	1	3	4		0	0	4
Ground Attack	0	0	0	0	1	1		0	0	1
Air-to-Air	0	0	0	0	0	0		0	0	0
Cruise/Loiter	8	0	0	2	16	26		8	0	18
Hover	0	0	0	0	0	0		0	0	0
Other	0	0	0	0	0	0		0	0	0
Total	18	1	0	5	33	57		19	0	38

Table D30. Percent of HF Naval Helicopter Weather Related Mishaps By Flight Phase.

Flight Phase Percent	dY	pY	M	pN	dN	Total		Yes	Maybe	No
Takeoff	25	0	0	0	75	100		25	0	75
Descent	0	0	0	0	0	0		0	0	0
Approach	50	0	0	13	38	100		50	0	50
Landing	33	33	0	0	33	100		67	0	33
Wave-off/Go-Around	50	0	0	50	0	100		50	0	50
Formation/Rendezvous	40	0	0	0	60	100		40	0	60
Low Level/Terrain Following	0	0	0	25	75	100		0	0	100
Ground Attack	0	0	0	0	100	100		0	0	100
Air-to-Air	0	0	0	0	0	0		0	0	0
Cruise/Loiter	31	0	0	8	62	100		31	0	69
Hover	0	0	0	0	0	0		0	0	0
Other	0	0	0	0	0	0		0	0	0

Table D31. Count For Mishap Prevention With A Believed Perfect Forecast Prevention.

FORECAST PREVENTION	dY	pY	M	pN	dN	TOTAL	Yes	Maybe	No
Number Naval Mishaps	17	8	2	9	9	45	25	2	18

Table D32. Percent For Mishap Prevention With A Believed Perfect Forecast Prevention.

FORECAST PREVENTION PERCENT	dY	pY	M	pN	dN	TOTAL%	Yes	Maybe	No
Naval Aircraft (51 WX Mishaps)	38	18	4	20	20	100	56	4	40
Naval Aircraft (All 235 Mishaps)	7	3	1	4	94	100	11	1	89

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