THE EFFECT OF CORROSION ON ARMY AND DEPARTMENT OF THE NAVY AVIATION MISHAPS

NUMBER OF MISHAPS, COST, AND INJURIES

REPORT AKN31T4

Trevor K. Chan

MAY 2015

LMI

The Effect of Corrosion on Army and Department of the Navy Aviation Mishaps: Number of Mishaps, Cost, and Injuries

AKN31T4/MAY 2015

Executive Summary

LMI was tasked by the Corrosion Policy and Oversight (CPO) Office to measure the effect of corrosion on Army and Department of the Navy (DON) aviation mishaps. Using data from FY1983 through FY2013, we estimated corrosion contributed to 87 of 4,664, or 1.9 percent, Army aviation mishaps, and 179 of 8,445, or 2.1 percent, DON aviation mishaps. Table ES–1 summarizes these findings.

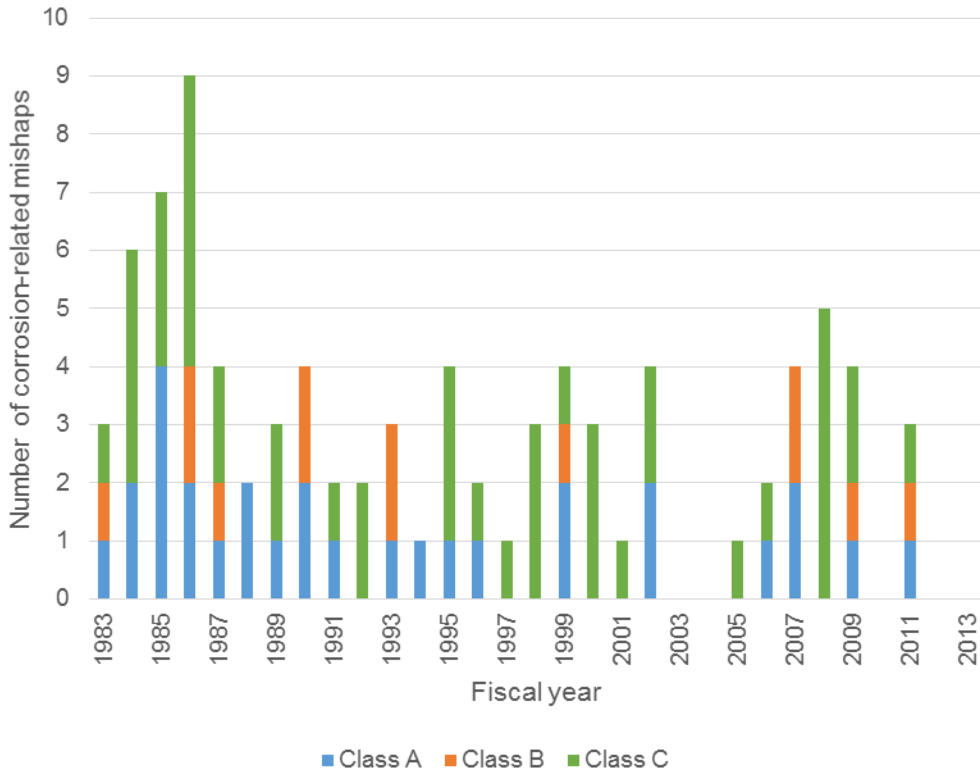
Table ES–1. Army and DON Aviation Corrosion-Related Mishaps, FY1983–FY2013

Service	Total mishaps	Total corrosion-related mishaps	Corrosion-related mishaps as a percentage of total
Army	4,664	87	1.9%
DON	8,445	179	2.1%

To assess corrosion's effect on aviation safety, we first identified whether corrosion was the root cause or a factor in any mishaps. We then analyzed corrosion's effect on the number of mishaps, property damage cost, aircraft total losses, and fatal injuries. We show these measures by severity class, end item type, end item type model, aircraft system, and failed object for both the Army and DON. The percent of Class A and B corrosion-related mishaps for the Air Force, as identified by the Air Force Corrosion Prevention and Control Office (AFCPCO), are consistent with the Army and DON percentages in this report.

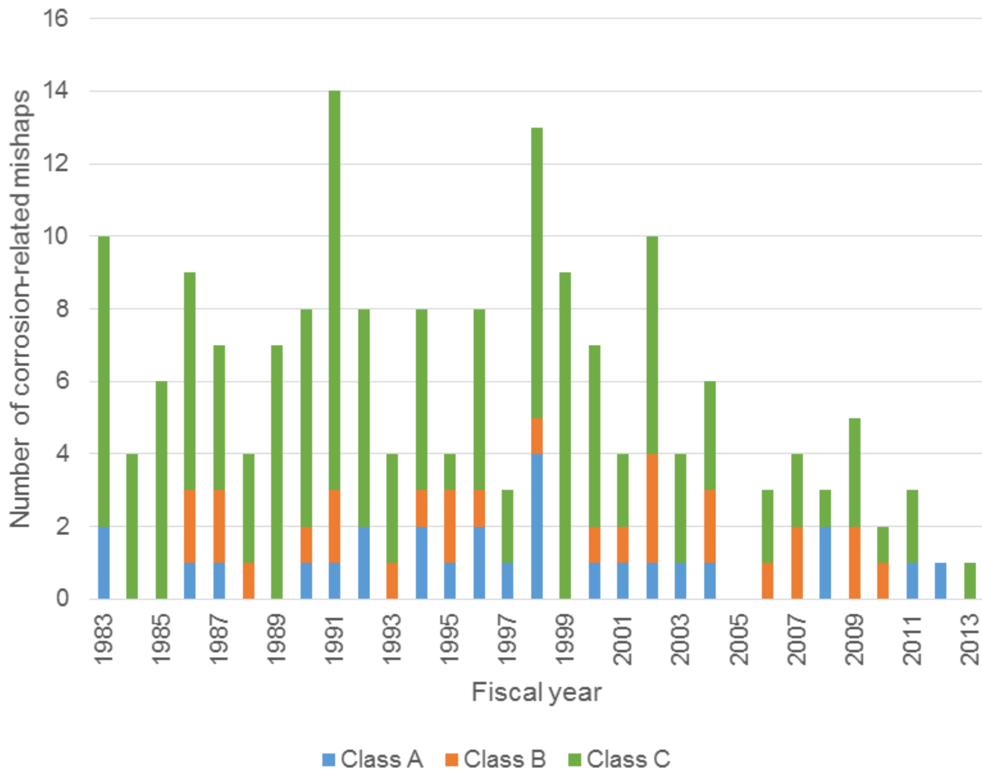
For the Army, there were 5 fiscal years (FY2003, FY2004, FY2010, FY2012, and FY2013) without a corrosion-related aviation mishap; however, we noted a high number corrosion-related mishaps between FY1984 and FY1986 (six in FY1984, seven in FY1985, and nine in FY1986). The number of corrosion-related mishaps for the remaining fiscal years appears to be cyclic, as we show in **Error! Reference source not found.**.

Figure ES–1. Army Aviation Corrosion-Related Mishaps, FY1983–FY2013



The DON experienced at least one corrosion-related aviation mishap each year between FY1983 and FY2013, with the exception of FY2005, when there were none. FY1991 and FY1998 were the 2 years the DON had the highest number of corrosion-related aviation mishaps, 14 and 13, respectively. There has been a noticeable decrease in the number of corrosion-related mishaps for the DON in the past 10 fiscal years, as we show in Figure ES–2.

Figure ES–2. DON Aviation Corrosion-Related Mishaps, FY1983–FY2013



The scope of our study included all Army and DON severity Class A, B, and C on-duty aviation mishaps from FY1983 through FY2013. The current definition of the severity classes are defined below:

- *Class A*: $2 million or more in damage, aircraft destroyed, or fatality or permanent total disability. (Note: A destroyed or missing unmanned aerial vehicle [UAV] is not a class A unless the cost of damage is $2 million or more.)
- *Class B*: $500,000 or more in damage (less than $2 million), permanent partial disability, or three or more people hospitalized as inpatients
- *Class C*: $50,000 or more in damage (less than $500,000), nonfatal injury, or occupational illness that cause loss of 1 or more days from work.

Severity classification level C events were the most numerous for corrosion-related mishaps for both the Army (45, or 52 percent) and the DON (125, or 70 percent), as shown in Table ES–2.

Table ES–2. Corrosion-Related Aviation Mishaps by Severity Class and Service, FY1983–FY2013

Class	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total
	the cause	a factor		
Army				
A	17	12	29	33%
B	7	6	13	15%
C	27	18	45	52%
Army total	51	36	87	100%
DON				
A	14	13	27	15%
B	19	8	27	15%
C	76	49	125	70%
DON total	109	70	179	100%

Even though there are more Class C corrosion-related mishaps, the Army and DON may be better served by focusing resources on mishaps that result in fatal injuries or permanent or partial disability and high-cost property damage (see Table ES–3). For the Army, 9 corrosion-related aviation mishaps resulted in 23 fatal injuries and a total loss of 9 aircraft. For the DON, 4 corrosion-related aviation mishaps resulted in 11 fatal injuries and the total loss of 4 aircraft.

Table ES–3. Corrosion-Related Mishaps with Fatal Injuries by Service, FY1983–FY2013

Service	Corrosion-related mishaps	Aircraft total losses	Fatal injuries
Army	9	9	23
DON	4	4	11

We also investigated corrosion-related mishaps by equipment type. For Army aviation, rotary aircraft accounted for 90 percent corrosion-related mishaps, $110 million[1] (97 percent) in mishap costs, and all 23 fatalities. The average inventory ratio of rotary to fixed wing aircraft in the Army is 9:1. Therefore, focusing resources for corrosion-related maintenance on rotary aircraft will have the greatest effect on improving aviation safety. Table ES–4 shows the top five Army corrosion-related aviation mishaps by end item type model. The OH-58 model aircraft experienced the highest number of corrosion-related mishaps at 16, or 18 percent of all Army aviation corrosion-related mishaps.

[1] Costs in this report are normalized to an FY1983 baseline using the Bureau of Labor Statistics Consumer Price Index, unless otherwise noted.

Table ES–4. Top Five Army Aviation Corrosion-Related Mishaps by End Item, FY1983–FY2013

Model	Type	Mishaps in which corrosion was… the cause	Mishaps in which corrosion was… a factor	Corrosion-related mishaps	Percentage of total
OH-58	Rotary	11	5	16	18%
AH-64	Rotary	7	8	15	17%
UH-1	Rotary	7	5	12	14%
CH-47	Rotary	7	4	11	13%
UH-60	Rotary	6	1	7	8%
Total for all end items		51	36	87	100%

For the DON aviation, fixed-wing aircraft accounted for 79 percent of corrosion-related mishaps, $236 million (89 percent) in mishap costs, and 10 of the 11 corrosion-related fatalities. The average inventory of the DON aircraft is approximately 69 percent fixed-wing aircraft and 31 percent rotary aircraft. Focusing resources for corrosion-related maintenance on fixed-wing aircraft will have the greatest effect on improving DON aviation safety. Table ES–5 shows the top five DON corrosion-related aviation mishaps by end item type mode. The F-18 experienced the highest number of corrosion-related mishaps (31, or 17 percent).

Table ES–5. Top Five DON Aviation Corrosion-Related Mishaps by End Item, FY1983–FY2013

Model	Type	Mishaps in which corrosion was… the cause	Mishaps in which corrosion was… a factor	Corrosion-related mishaps	Percentage of total
F-18	Fixed wing	13	18	31	17%
F-14	Fixed wing	3	10	13	7%
S-3	Fixed wing	8	4	12	7%
SH-60	Rotary	8	3	11	6%
P-3	Fixed wing	7	1	8	4%
Total for all end items		109	70	179	100%

Contents

Chapter 1 Background and Analysis Method 1-1
Study Objectives 1-1
Analysis Method and Scope 1-1
Data Shortfalls 1-4
Event Severity Classification 1-5
Report Organization 1-6
Chapter 2 Effect of Corrosion on Army Aviation Mishaps 2-1
Study Steps 2-1
Requesting Data 2-1
Import Data 2-2
Identify Investigative Terms 2-2
Perform Investigative Term Search 2-2
Review Identified Potential Corrosion-Related Mishaps 2-3
Identify Failed Object 2-4
Alternative Aviation Work Breakdown Structure 2-4
Army Aviation Summary and Analysis 2-6
Corrosion-Related Mishaps by Fiscal Year 2-6
Corrosion-Related Mishaps by AWBS 2-8
Corrosion-Related Mishaps by Failed Object 2-13
Corrosion-Related Mishaps by End Item Type Model 2-16
Comparison to AFCPCO Air Force Study 2-18
Chapter 3 Effects of Corrosion on DON Aviation Mishaps 3-1
Study Steps 3-1
Requesting Data 3-1
Import Data 3-2
Identify Investigative Terms 3-2
Perform Investigative Term Search 3-2
Review Identified Potential Corrosion-Related Mishaps 3-2
Identify Failed Object 3-4
Alternative Aviation Work Breakdown Structure 3-4

DON Aviation Summary and Analysis 3-5
Mishaps by Fiscal Year 3-6
Corrosion-Related Mishaps by AWBS 3-11
Corrosion-Related Mishaps by Failed Object 3-15
Corrosion-Related Mishaps by End Item Type Model 3-17
Comparison to AFCPCO Air Force Study 3-19
Naval Air Systems Command Comment 3-20
Chapter 4 Conclusions and Recommendations 4-1
Class A Mishaps 4-1
Rotary versus Fixed-Wing Aircraft 4-2
Final Recommendations 4-3
Appendix A Normalized FY1983 Cost and Actual Reported Cost
Appendix B Event Severity Classification
Appendix C Army Aviation Mishap Cause or Type of Failure
Appendix D Investigative Terms
Appendix E Abbreviations

Figures

Figure 2-1. Number of Army Aviation Corrosion-Related Mishaps, FY1983–FY2013 2-6
Figure 2-2. Army Aviation Total Cost of Corrosion-Related Mishaps, FY1983–FY2013 2-7
Figure 2-3. Army Aviation Corrosion-Related Cost per Mishap, FY1983–FY2013 2-8
Figure 3-1. Number of DON Aviation and Corrosion-Related Aviation Mishaps, FY1983–FY2013 3-6
Figure 3-2. The Percentage of Corrosion-Related DON Aviation Mishaps, FY1983–FY2013 3-7
Figure 3-3. Number of DON Aviation Corrosion-Related Mishaps, FY1983–FY2013 3-8
Figure 3-4. DON Aviation Total Cost of Corrosion-Related Mishaps, FY1983–FY2013 3-9
Figure 3-5. Aviation Corrosion-Related Cost per Mishap, FY1983–FY2013 3-10

Tables

Table 1-1. Fiscal Year Average CPI and Percent Change from the FY1983 Baseline ... 1-3

Table 1-2. Mishap Records with Missing Detailed Text Descriptions by Fiscal Year, FY1983–FY2013 ... 1-4

Table 1-3. Event Severity Classification ... 1-6

Table 2-1. Summary of Army Aviation Corrosion-Related Mishaps, FY1983–FY2013 ... 2-1

Table 2-2. Army Aviation Mishap Corrosion-Related Cause/Type of Failure ... 2-2

Table 2-3. Army Aviation Mishap Descriptive Text Fields ... 2-3

Table 2-4. Army Aviation Mishap Classification Sample—Corrosion-Related ... 2-3

Table 2-5. Army Aviation Mishap Classification Sample—Not Corrosion-Related ... 2-4

Table 2-6. AWBS End Item Types ... 2-4

Table 2-7. AWBS System Codes ... 2-5

Table 2-8. Army Corrosion-Related Mishaps by Class, FY1983–FY2013 ... 2-6

Table 2-9. Army Aviation Corrosion-Related Mishaps by End Item Type Model, FY1999 ... 2-7

Table 2-10. Army Aviation Corrosion-related Mishaps by End Item Type, FY1983–FY2013 ... 2-9

Table 2-11. Army Aviation Average Equipment List Inventory, FY2004–FY2014 ... 2-9

Table 2-12. Army Corrosion-Related Aviation Mishaps and Costs, FY1983–FY2013 ... 2-10

Table 2-13. Army Corrosion-Related Aviation Mishaps, Total Loss of Aircraft, and Fatal Injuries, FY1983–FY2013 ... 2-10

Table 2-14. Systems with the Highest Number of Corrosion-Related Mishaps, FY1983–FY2013 ... 2-10

Table 2-15. Top 5 Army Corrosion-Related Aviation Mishaps Costs by AWBS Major System Character, FY1983–FY2013 ... 2-11

Table 2-16. Top 5 Army Corrosion-Related Aircraft Total Losses by AWBS Major System Character, FY1983–FY2013 ... 2-12

Table 2-17. Corrosion-Related Aviation Mishaps with Fatal Injuries by AWBS Major System Character, FY1983–FY2013 ... 2-12

Table 2-18. Failed Objects Associated with Corrosion-Related Aviation Mishaps, FY1983–FY2013 ... 2-13

Table 2-19. Failed Objects Associated with Corrosion-Related Aviation Mishaps by Cost, FY1983–FY2013 2-14

Table 2-20. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Total Loss of Aircraft, FY1983–FY2013.................. 2-14

Table 2-21. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Fatal Injuries, FY1983–FY2013.............................. 2-15

Table 2-22. Top 10 Army Aviation EITMs with Corrosion-Related Mishaps, FY1983–FY2013 2-16

Table 2-23. Top 5 Army Aviation EITMs with Corrosion-Related Fatal Injuries, FY1983–FY2013 2-17

Table 2-24. Top 5 Army Aviation EITMs with Corrosion-Related Aircraft Total Losses, FY1983–FY2013 2-17

Table 2-25. Air Force and Army Mishaps, FY1983–FY2013............................... 2-18

Table 2-26. Air Force and Army Corrosion-Related Mishaps, FY1983–FY2013... 2-18

Table 3-1. Summary of DON Aviation Corrosion-Related Mishaps, FY1983–FY2013 3-1

Table 3-2. DON Aviation Mishap Descriptive Text Fields 3-2

Table 3-3. DON Aviation Mishap Classification Sample—Corrosion-Related......... 3-3

Table 3-4. DON Aviation Mishap Classification Sample—Not Corrosion-Related.. 3-3

Table 3-5. AWBS End Item Types 3-4

Table 3-6. AWBS System Codes... 3-5

Table 3-7. DON Corrosion-Related Mishaps by Class, FY1983–FY2013............... 3-5

Table 3-8. DON Aviation Corrosion-Related Mishaps, Aircraft Total Losses, and Costs by TMS for FY1998 3-9

Table 3-9. DON Aviation Corrosion-Related Mishaps by End Item Type, FY1983–FY2013 3-11

Table 3-10. DON Aviation Average Equipment List Inventory, FY1983–FY2013 3-12

Table 3-11. DON Corrosion-Related Aviation Mishaps and Costs, FY1983–FY2013 3-12

Table 3-12. DON Corrosion-Related Aviation Mishaps, Aircraft Total Losses, and Fatal Injuries, FY1983–FY2013 3-12

Table 3-13. Top 10 DON Corrosion-Related Aviation Mishaps by AWBS Major System Character, FY1983–FY2013.................................... 3-13

Table 3-14. Top 5 DON Corrosion-Related Aviation Mishap Costs by AWBS Major System Character, FY1983–FY2013.................................... 3-13

Table 3-15. Top 5 DON Corrosion-Related Aircraft Total Losses by AWBS Major System Character, FY1983–FY2013 3-14

Table 3-16. Top 5 DON Corrosion-Related Aviation Mishaps with Fatal Injuries by AWBS Major System Character, FY1983–FY2013 3-14

Table 3-17. Top 5 DON Aviation Mishaps Failed Objects Associated with Corrosion-Related Mishaps, FY1983–FY2013 3-15

Table 3-18. Top 5 DON Aviation Mishaps Failed Objects Associated with Corrosion-Related Mishaps by Cost, FY1983–FY2013 3-15

Table 3-19. Corrosion-Related Failed Objects Associated with DON Aviation Mishaps that Resulted in the Total Loss of an Aircraft, FY1983–FY2013 3-16

Table 3-20. Corrosion-Related Failed Objects Associated with DON Aviation Mishaps that Resulted in Fatal Injuries, FY1983–FY2013 3-17

Table 3-21. Top 10 DON Aviation EITMs with Corrosion-Related Mishaps, FY1983–FY2013 3-17

Table 3-22. Top 4 DON Aviation EITMs with Corrosion-Related Fatal Injuries, FY1983–FY2013 3-18

Table 3-23. Top 5 DON Aviation EITMs with Corrosion-Related Total Aircraft Losses, FY1983–FY2013 3-18

Table 3-24. Air Force and DON Mishaps, FY1983–FY2013 3-19

Table 3-25. Air Force and DON Corrosion-Related Mishaps, FY1983–FY2013 3-19

Table 4-1. Army and DON Aviation Corrosion-Related Mishaps 4-1

Table 4-2. Army and DON Aviation Corrosion-Related Class A Mishaps 4-1

Table 4-3. Summary of Army and DON Aviation Corrosion-Related Mishaps by End Item Type 4-2

Chapter 1
Background and Analysis Method

Recent GAO audits of the DoD Corrosion Policy and Oversight (CPO) Office noted that, although progress has been made in measuring the cost of corrosion, the effects of corrosion on readiness and safety have not been adequately addressed.

LMI recently developed a way to measure the effect of corrosion on readiness (or materiel availability), and, in the past year, LMI completed three studies that address this area. The time is right to expand this corrosion-related assessment to the relationship between corrosion and the incidence of safety-related events.

The Air Force Corrosion Prevention and Control Office (AFCPCO) recently studied the role of corrosion in safety mishaps for Air Force aviation assets. The CPO Office tasked LMI to analyze the effect of corrosion on the Army and Department of the Navy (DON) aviation, following a method similar to what was used by the AFCPCO. The scope of the study performed by the AFCPCO included both aviation and non-aviation and on- and off-duty mishaps. The Army and DON mishaps in this report include aviation and on-duty only mishaps.

Study Objectives

We had two specific objectives for this study:

- Estimate the effect corrosion has on Army and DON aviation mishaps.
- Analyze trends and draw conclusions on the safety-related effect of corrosion on Army and DON aviation systems.

Analysis Method and Scope

To identify corrosion-related mishaps in Army and DON aviation programs, we applied an analysis method that was similar to what the AFCPCO applied to the Air Force data in their report, "The Role of Corrosion in Safety Mishaps."[1]

[1] Carl Perazzola, *The Role of Corrosion in Safety Mishaps* [PowerPoint slides], Corrosion Prevention & Control Integrated Product Team Forum, McLean, Virginia, 03 December 2013.

For the Army and DON, we performed the following steps:

- Request aviation mishap data with the following criteria:
  - FY1983–FY2013
  - Severity classes A, B, and C
  - On-duty activities.
- Import data into a standard data structure.
- Identify investigative terms to identify potential corrosion-related mishaps.
- Perform investigative term search to identify potential corrosion-related mishaps.
- Review identified potential corrosion-related mishaps and place into one of the following bins:
  - Cause—corrosion was likely the root cause of the mishap.
  - Factor—corrosion influenced the mishap, but was not the root cause.
  - Not related to corrosion—corrosion was not a contributing factor.
- Identify failed object.
- Identify failed system.
- Normalize cost to FY1983 baseline using average fiscal year Consumer Price Index (CPI).

The actual reported cost is normalized to FY1983 cost baseline so that trends over the 30 year time period can be compared without inflation. To calculate the FY1983 baseline normalized cost, the seasonally adjusted CPI for all urban consumers from the Bureau of Labor Statistics was used. Since the CPI's are provided in months, the fiscal year CPI was first calculated, followed by the percent change in average fiscal year CPI from FY1983. The normalized cost equals the actual reported cost multiplied by the sum of one plus the percent change in average CPI from FY1983:

$Normalized\ cost = Actual\ reported\ cost$ × (1 + [% change in average CPI from FY1983]).

Costs displayed in this report are normalized to the FY1983 cost baseline unless otherwise noted. Appendix A shows the costs normalized to the FY1983 cost baseline and actual reported cost for the Army and DON, FY1983–FY2013. Table 1-1 shows the fiscal years with their respective average CPI's and percent change from the FY1983 baseline.

Table 1-1. Fiscal Year Average CPI and Percent Change from the FY1983 Baseline

Fiscal year	Average CPI	% Change, base FY1983
1983	98.79	0.0%
1984	102.88	4.1%
1985	106.68	8.0%
1986	109.33	10.7%
1987	112.40	13.8%
1988	117.03	18.5%
1989	122.55	24.0%
1990	128.68	30.3%
1991	135.18	36.8%
1992	139.23	40.9%
1993	143.49	45.2%
1994	147.28	49.1%
1995	151.40	53.3%
1996	155.62	57.5%
1997	159.78	61.7%
1998	162.39	64.4%
1999	165.51	67.5%
2000	170.74	72.8%
2001	176.23	78.4%
2002	178.87	81.1%
2003	183.09	85.3%
2004	187.34	89.6%
2005	193.51	95.9%
2006	200.58	103.0%
2007	205.31	107.8%
2008	214.41	117.0%
2009	213.77	116.4%
2010	217.41	120.1%
2011	223.10	125.8%
2012	228.52	131.3%
2013	232.25	135.1%

To ensure consistency throughout the report, we used the definition of corrosion that was developed by Congress: "The deterioration of a material or its properties due to a reaction of that material with its chemical environment."[2]

[2] *The Bob Stump National Defense Authorization Act for Fiscal Year 2003,* Public Law 107-314, 2 December 2002, p.202; Public Law 107-314 was enhanced by Public Law 110-181, *The National Defense Authorization Act for Fiscal Year 2008,* Section 371, 28 January 2008.

DATA SHORTFALLS

In our analysis, we determined if corrosion was involved in the mishap using the following information in the order listed:

Army:

1) Detailed text description search for corrosion key word
2) CauseFailure field
3) Individually reviewed mishap data where corrosion was identified

DON:

1) Detailed text description search for corrosion keywords
2) Individually reviewed mishap data where corrosion was identified

The Naval Safety Center moved to a new reporting system in 2010. This new reporting system, WHAMRS, was more robust in causal factor tracking but resulted in 41 records not having a detailed text description. The corrosion analysis could not be performed for these 41. This was a minor issue however, as these 41 records were only 0.5 percent of the total of 8,445 DON mishap records.

Even though the Army had a significantly higher number of mishap records without a detailed text description, this did not create the same issue as the DON records because we relied on the CauseFailure field to assess corrosion for Army records.

The number of mishaps without narrative descriptions by fiscal year and service are shown in Table 1-2.

Table 1-2. Mishap Records with Missing Detailed Text Descriptions by Fiscal Year, FY1983–FY2013

Army				DON			
Fiscal year	Mishaps without detailed description	Total mishaps	Percentage without detailed description	Fiscal year	Mishaps without detailed text description	Total mishaps	Percentage without detailed description
1983	142	330	43.0%	1983	0	821	0.0%
1984	8	138	5.8%	1984	0	738	0.0%
1985	8	142	6.3%	1985	0	632	0.0%
1986	20	143	14.0%	1986	0	652	0.0%
1987	8	129	6.2%	1987	0	483	0.0%
1988	7	91	7.7%	1988	0	335	0.0%
1989	2	126	1.6%	1989	0	254	0.0%
1990	2	126	1.6%	1990	0	254	0.0%
1991	19	172	11.0%	1991	0	291	0.0%
1992	0	118	0.0%	1992	0	221	0.0%
1993	0	134	0.7%	1993	0	235	0.0%

Table 1-2. Mishap Records with Missing Detailed Text Descriptions by Fiscal Year, FY1983–FY2013

Army				DON			
Fiscal year	Mishaps without detailed description	Total mishaps	Percentage without detailed description	Fiscal year	Mishaps without detailed text description	Total mishaps	Percentage without detailed description
1994	5	125	4.0%	1994	0	175	0.0%
1995	9	115	7.8%	1995	0	163	0.0%
1996	9	117	7.7%	1996	0	171	0.0%
1997	5	103	4.9%	1997	0	153	0.0%
1998	14	113	12.4%	1998	0	172	0.0%
1999	8	123	6.5%	1999	0	157	0.0%
2000	13	101	12.9%	2000	2	168	1.2%
2001	19	115	16.5%	2001	0	151	0.0%
2002	33	131	25.2%	2002	0	179	0.0%
2003	22	130	16.9%	2003	0	218	0.0%
2004	44	162	27.2%	2004	0	205	0.0%
2005	48	216	22.2%	2005	0	190	0.0%
2006	34	236	14.8%	2006	0	184	0.0%
2007	17	203	8.9%	2007	0	176	0.0%
2008	20	212	9.9%	2008	0	165	0.0%
2009	36	194	18.6%	2009	0	199	0.0%
2010	23	142	16.2%	2010	4	164	2.4%
2011	42	192	22.9%	2011	15	184	8.2%
2012	73	178	41.0%	2012	10	174	5.7%
2013	74	107	69.2%	2013	10	181	5.4%
Army total	764	4,664	16.4%	DON total	41	8,445	0.5%

EVENT SEVERITY CLASSIFICATION

The Army and DON both classify a mishap depending on the total property damage cost,[3] whether a fatality occurred, and the type of injury (Army uses A, B, C, D, E, and F;[4] the DON uses A, B, C, and D[5]). We analyzed data for classes A, B, and C only.

Table 1-3 shows the event severity classification for FY1983 and what is currently used by both the USACR/SC and the Naval Safety Center.

---

[3] Throughout this report, the term "cost" refers to property damage cost.

[4] Army Regulation 385-10, *The Army Safety Program*, 27 November 2013, p. 25, http://www.apd.army.mil/pdffiles/r385_10.pdf.

[5] OPNAVINST 3750.6S, *Naval Aviation Safety Management System*, 13 May 2014, para. 313, pp. 3-14–3-15, http://Navyi.daps.dla.mil/Directives/03000 Naval Operations and Readiness/03-700 Flight and Air Space Support Services/3750.6S.pdf.

Table 1-3. Event Severity Classification

Mishap class	Total property damage		Fatality or injury
	FY1983	FY2013	
A	$500,000 or more	$2 million or more or aircraft destroyed (excluding unmanned aircraft systems groups 1, 2, or 3)	Fatality or permanent total disability
B	$100,000 or more, but less than $499,999	$500,000 or more, but less than $2 million	Permanent partial disability or three or more people hospitalized as inpatients
C	$10,000 or more, but less than $99,999	$50,000 or more, but less than $500,000	Nonfatal injury resulting in loss of time from work beyond the day or shift when the injury occurred

Sources: DoD Instruction 6055.07, *Mishap Notification, Investigation, Reporting, and Record Keeping*, 6 June 2011, p. 36, http://www.dtic.mil/whs/directives/corres/pdf/605507p.pdf., OPNAV 3750.6, M, N, Q, R, and S, May 13, 2014, Army Regulation 385-10.

Over time, mishap classifications have evolved. Appendix B lists this evolution for the Army and DON.

Report Organization

In this chapter, we explained our analysis approach, the scope of the study, and its shortfalls. In Chapters 2 and 3, we turn our attention to the effects of corrosion on Army and DON aviation safety. In Chapter 4, we provide overall conclusions about the trends and patterns we identified in the data for corrosion-related mishaps. The appendixes provide supporting data and analysis.

Chapter 2
Effect of Corrosion on Army Aviation Mishaps

Between FY1983 and FY2013, corrosion was a either the cause or a factor in 87 Army aviation mishaps. The total number of Army aviation mishaps during this period was 4,664, so corrosion-related mishaps accounted for 1.9 percent of all Army aviation mishaps. In this chapter, we explain how we arrived at this estimate and draw conclusions about the trends and patterns in the data for corrosion-related mishaps.

A summary of Army corrosion-related aviation mishaps is provided in Table 2-1.

Table 2-1. Summary of Army Aviation Corrosion-Related Mishaps, FY1983–FY2013

Class	Mishaps in which corrosion was…		Corrosion-related mishaps	Total mishaps
	the cause	a factor		
A	17	12	29	811
B	7	6	13	620
C	27	18	45	3,233
Total	51	36	87	4,664

Study Steps

Requesting Data

We requested from the USACR/SC Army aviation mishap data that satisfied the following criteria:[1]

1. FY1983–FY2013
2. Class A, B, and C event severities
3. On-duty activities.

[1] The USACR/SC data contains privileged safety information. A memorandum of agreement (MOA) between the CPO and the USACR/SC was required before we could acquire the needed data. In addition, LMI employees who require access to the data completed a nondisclosure agreement (NDA).

Import Data

Data tables from the USACR/SC were imported into a Microsoft SQL Server database, and combined into a structured table for analysis.

Identify Investigative Terms

We identified investigative terms in two steps.

- *Step 1.* The data from USACR/SC identified the cause and type of failure associated with each mishap. We noted the causes and types of failure that were corrosion-related. A full listing of these terms can be found in Appendix C.
- *Step 2.* The AFCPCO identified 75 investigating terms used to search the narratives and primary finding fields to identify potentially corrosion-related mishaps. In addition to these 75 terms, we identified terms in all descriptive text fields that may indicate a mishap is corrosion-related. Included in these additional words are common misspellings of words, such as "corrosiion" and "corrodded." A full list of these terms is provided in Appendix D.

Perform Investigative Term Search

We performed the investigative term search in two steps, as well.

- *Step 1.* We identified the mishaps with corrosion-related investigative terms from the cause and type of failure data element and excluded these mishaps from the second step. Table 2-2 shows these corrosion-related investigative terms.

Table 2-2. Army Aviation Mishap Corrosion-Related Cause/Type of Failure

Corrosion-related cause or type of failure	
◆ Corroded	◆ Paint peeling off
◆ Fretting corrosion	◆ Peeled
◆ Galvanic corrosion	◆ Peeling
◆ Hot corrosion (sulfidation)	◆ Pitted
◆ Hydrogen embrittlement	◆ Pitting corrosion
◆ Insufficient protection from moisture	◆ Rusty
◆ Intergranular corrosion	◆ Salt water damage
◆ Moisture saturation	◆ Stress corrosion

- *Step 2*. We searched all descriptive text fields in the Army mishap data for matching investigative terms. The Army descriptive text fields are found in Table 2-3.

Table 2-3. Army Aviation Mishap Descriptive Text Fields

Army aircraft mishap descriptive text fields	
ACCIDENT_DESCRIPTION	SANITIZED_SUMMARY
ANALYSIS	SUMMARY
FINDINGS	SYNOPSIS
RECOMMENDATIONS	

Phrases, such as "caustic embrittlement" and certain corrosion words, such as "corrosion" and "corrosive" were searched first, followed by the length of the investigative term. Up to three unique investigative terms were associated with each mishap to help identify whether the mishap was related to corrosion.

Review Identified Potential Corrosion-Related Mishaps

We reviewed each mishap that contained an investigative term to determine if corrosion was the cause, a factor, or not-related to the mishap, as defined in Table 1-2. Table 2-4 provides a sample of the descriptive text, investigative terms, and assigned classification for an Army aviation mishap.

Table 2-4. Army Aviation Mishap Classification Sample—Corrosion-Related

Classification	Investigative terms			Text description
	1st	2nd	3rd	
Cause	Corrosion	Fracture	Bearing	…this fracture allowed the spherical bearing to be pulled from the bearing bore and resulted in the incomplete extension of the nose wheel landing gear….Conclusions: 1. the nose landing gear piston housing failed due to fatigue. The origin of the fatigue was found to be a corrosion pit located along the outer edge of the spherical bearing bore….
Factor	Corrosion	Stress		…B. the corrosion and stress corrosion in the bore were contributing factors to the failure. Conclusions: 1. the torque arm failed through overstress mechanisms. 2. the corrosion in the bore was a contributing factor to the failure…

The presence of an investigative term, such as "corrosion," does not indicate the mishap is corrosion-related. Table 2-5 contains examples of Army aviation mishap descriptive text in which an investigative term was found, but the mishap was not corrosion-related.

Table 2-5. Army Aviation Mishap Classification Sample—Not Corrosion-Related

Classification	Investigative terms			Text description
	1st	2nd	3rd	
Not corrosion-related	Corrosion	Pitting	Bearing	…The bearing races appeared to be in good serviceable condition. No corrosion pitting & progressive type failures were noted…
Not corrosion-related	Corrosion	Decaying		…Final CCAD report, USASC 83-057, UH-1H 69-15339 1. Conclusions. A. The submitted parts show no evidence of corrosion or fatigue that might have initiated the failure… The A/C became airborne again; however, due to decaying rotor RPM, it was uncontrollable…

Identify Failed Object

Every aviation mishap record was inspected to identify the corrosion-related object that failed. This was done manually, which helped us to categorize the system that failed in the alternative aviation work breakdown structure (AWBS).

Alternative Aviation Work Breakdown Structure

We developed the aviation work breakdown structure to definitively and efficiently identify the types of maintenance and the system, subsystem, or item on which the maintenance was performed. We initially created the AWBS in conjunction with a cost-of-corrosion study for Army aviation equipment.[2] We applied a paired down version of the AWBS to the Army corrosion-related aviation mishaps.

The AWBS is a five-character alphanumeric code. The first, third, and fourth characters of the AWBS apply to this study. The codes we used describe the end item type and the primary system that failed.

The first character in the AWBS denotes the end item type (see Table 2-6).

Table 2-6. AWBS End Item Types

End item type	Description
F	Fixed-wing aircraft
R	Rotary aircraft
M	Missiles
E	Engines
X	Common use across aircraft types

[2] LMI, *The Annual Cost of Corrosion for Army Aviation and Missile Equipment 2007–2008 Update*, Report DL907T4, David A. Forman et al., September 2010.

We omitted from this study the second character, which denotes the maintenance action. The third and fourth characters identify the system that failed. Table 2-7 shows these codes.

Table 2-7. AWBS System Codes

Code	Failed system
01	Engines
02	Airframe
03	Landing gear
04	Power distribution and electrical
05	Rotor and propeller system
06	Drive system
07	Hydraulics/pneudraulics
09	Miscellaneous aircraft
10	Fuel system
11	Flight control
12	Measuring and testing instruments
13	Environmental control
14	Ground support equipment
19	Avionics
20	Consumables and toolbox hardware
21	Bearings
22	Valves and pumps
31	Fire control system and target acquisition
34	Night vision assembly
35	Armament

We also omitted the last character, which denotes the sub-system that failed. Instead, we analyzed the mishap data from a failed object perspective, which provided greater detail in the safety report.

ARMY AVIATION SUMMARY AND ANALYSIS

For the 4,664 Army aviation mishaps within the scope of this study, 87 (or 1.9 percent) were related to corrosion. Of these 87 corrosion-related mishaps, Class C severities made up the largest proportion, as seen in Table 2-8.

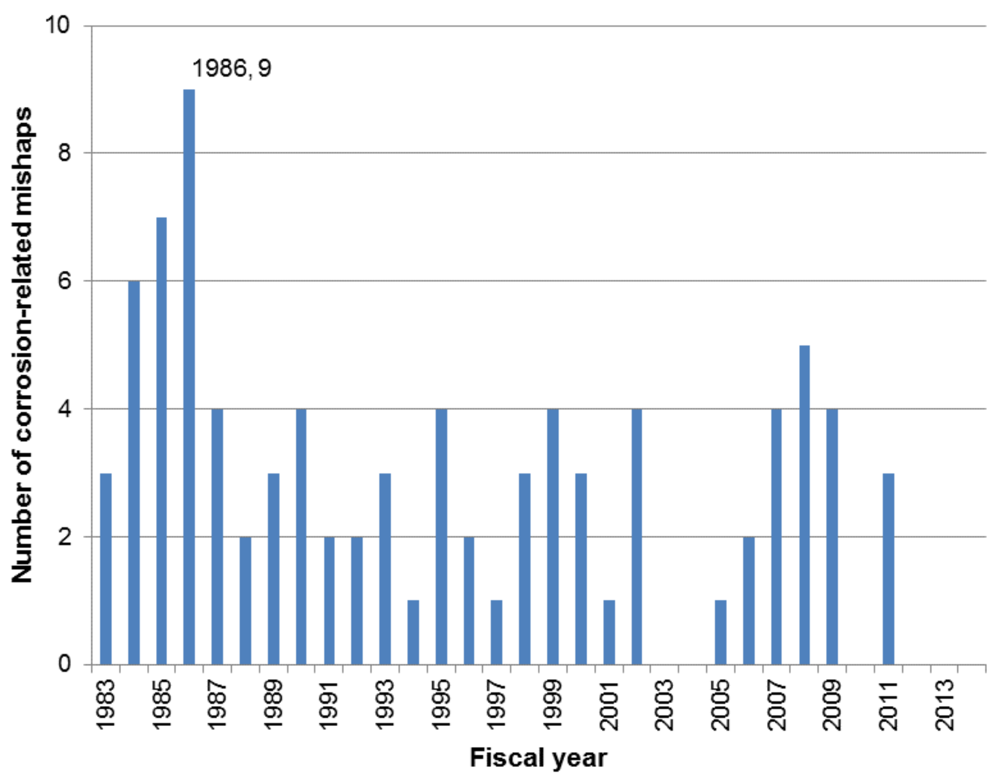
Table 2-8. Army Corrosion-Related Mishaps by Class, FY1983–FY2013

Class	Mishaps in which corrosion was the cause or a factor	Percentage of total corrosion-related mishaps
A	29	33%
B	13	15%
C	45	52%
Total	87	100%

Corrosion-Related Mishaps by Fiscal Year

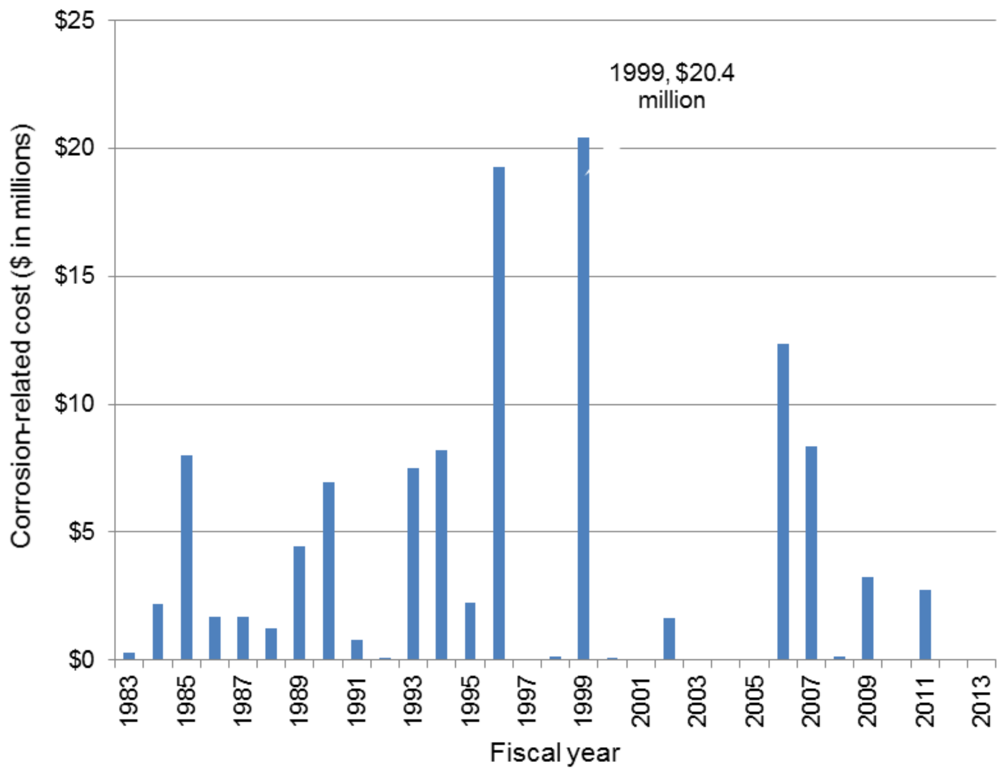
The last corrosion-related mishap occurred in FY2011. Figure 2-1 shows a cyclic trend in the number of corrosion-related mishaps, with higher number of corrosion-related mishaps in FY1984–FY1986, and no corrosion-related mishaps in FY2003, FY2004, FY2010, and FY2012–FY2013.

Figure 2-1. Number of Army Aviation Corrosion-Related Mishaps, FY1983–FY2013



In FY1999, the Army incurred the highest total event cost ($20.4 million) for corrosion-related aviation mishaps, as shown in Figure 2-2. There were four corrosion-related mishaps that year; corrosion was determined to be the cause of three.

Figure 2-2. Army Aviation Total Cost of Corrosion-Related Mishaps, FY1983–FY2013



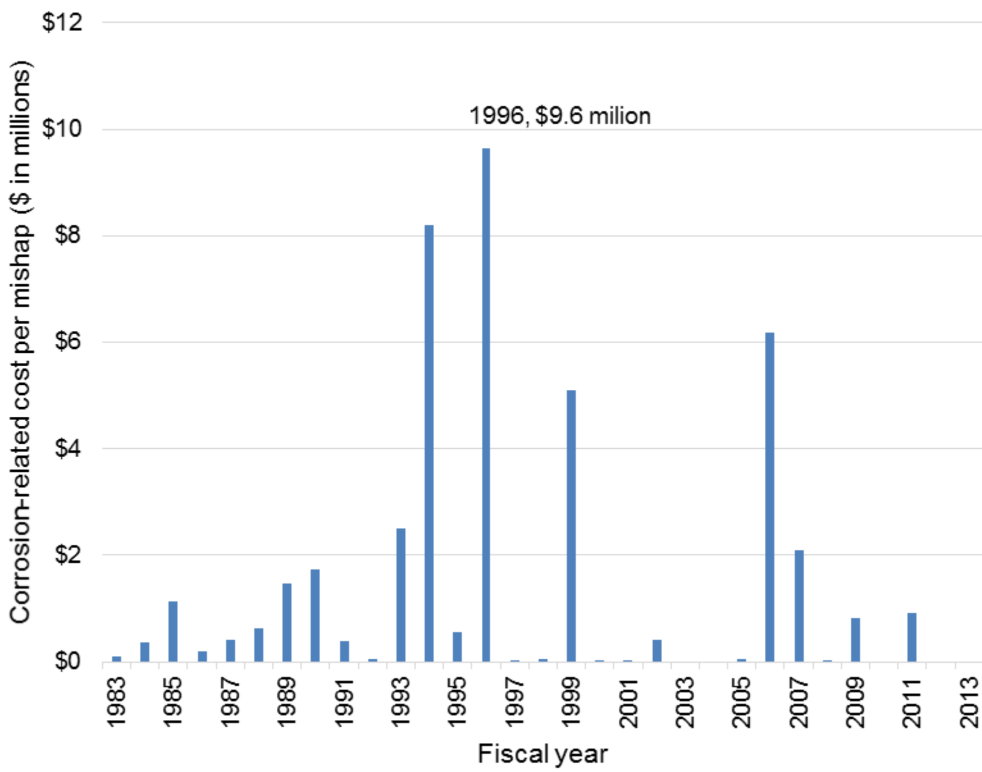
The AH-64 accounted for three of the four corrosion-related mishaps in FY1999, two aircraft total losses, and a significant portion of the cost. Table 2-9 shows the Army aviation corrosion-related mishaps for FY1999 by end item type model (EITM) with their associated aircraft losses and costs, ordered by highest cost.

Table 2-9. Army Aviation Corrosion-Related Mishaps by End Item Type Model, FY1999

End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Aircraft total losses	Corrosion-related cost (in millions)	Percentage of cost
	the cause	a factor				
AH-64	2	1	3	2	$20.394	100%
UH-60	1	0	1	0	$0.011	0%
Total	3	1	4	2	$20.405	100%

We also looked at the corrosion-related cost per mishap. With two mishaps, FY1996 stood out as the year with the highest per-mishap cost ($9.6 million per mishap) as shown in Figure 2-3.

Figure 2-3. Army Aviation Corrosion-Related Cost per Mishap, FY1983–FY2013



In FY1996, the Army experienced one Class A and one Class C corrosion-related mishap. Corrosion was a factor in the Class A mishap: the total loss of an MH-47E after a circuit breaker failed because of water intrusion. The total cost for this mishap was $16.8 million. A conductive path of salt corrosion as well as a deficiency in the circuit breaker design were contributing factors to the aircraft loss.

Corrosion-Related Mishaps by AWBS

Another way to view corrosion-related mishaps is by AWBS. As we discussed earlier in this chapter, the AWBS is a five-character alphanumeric code, of which we used the first, third, and fourth characters. The AWBS describes the end item type and the primary system that failed in this study.

AWBS End Item Type

First we identified the end item type (the first character of the AWBS) and the number of corrosion-related mishaps associated with that end item. Table 2-10 shows that 90 percent of Army corrosion-related aviation mishaps occurred on rotary aircraft; the remaining 10 percent were associated with fixed-wing aircraft.

Table 2-10. Army Aviation Corrosion-related Mishaps by End Item Type, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
		the cause	a factor		
R	Rotary aircraft	45	33	78	90%
F	Fixed-wing aircraft	6	3	9	10%
Total		51	36	87	100%

To understand the high percentage of rotary aircraft mishaps that are corrosion-related, we used the equipment list inventory gathered from other corrosion reports and averaged the inventory by end item type from the most recent 10 fiscal years on file. We then compared the inventory ratio between rotary and fixed-wing aircraft.

We found roughly the same proportions for average aviation inventory as for corrosion-related mishaps by end item type. Table 2-11 shows the average equipment list inventory by end item type between FY2004 and FY2014 and their percentage of total average annual inventory. There is a roughly 9:1 ratio between rotary and fixed-wing aircraft inventories. We, therefore, concluded that the reason rotary aircraft account for 90 percent of Army corrosion-related aviation mishaps may be because rotary aircraft make up 90 percent of the Army's aircraft inventory.

Table 2-11. Army Aviation Average Equipment List Inventory, FY2004–FY2014

AWBS, 1st character	Description	Total average annual inventory	Percentage of total average annual inventory
M	Missiles	10,509	51%
R	Rotary aircraft	6,684	32%
X	Common equipment	954	5%
F	Fixed-wing aircraft	772	4%
G	Ground vehicle	25	0%
Total average annual inventory		20,663	100%

Corrosion-related rotary aircraft mishaps accounted for an estimated $110 million of the estimated $114 million (or 97 percent) of corrosion-related total mishap cost, as shown in Table 2-12.

Table 2-12. Army Corrosion-Related Aviation Mishaps and Costs, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost (in millions)	Percentage of total corrosion-related cost
		the cause	a factor			
R	Rotary aircraft	45	33	78	$10	97%
F	Fixed-wing	6	3	9	$4	3%
Total		51	36	87	$114	100%

Not surprisingly, rotary aircraft also accounted for the majority of the Army's corrosion-related aircraft total losses and fatal injuries to military and civilian personnel. As Table 2-13 shows, corrosion-related rotary aircraft mishaps accounted for 24 of the 25 aircraft total losses and all 23 fatal injuries.

Table 2-13. Army Corrosion-Related Aviation Mishaps, Total Loss of Aircraft, and Fatal Injuries, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses	Corrosion-related fatal injuries
		the cause	a factor			
R	Rotary aircraft	45	33	78	24	23
F	Fixed-wing	6	3	9	1	0
Total		51	36	87	25	23

AWBS System

We examined four corrosion-related measures related to the third and fourth character of the AWBS: number of mishaps, cost, aircraft total losses, and fatal injuries. Table 2-14 lists the third and fourth character of the AWBS for the 10 systems with the highest number of corrosion-related mishaps.

Table 2-14. Systems with the Highest Number of Corrosion-Related Mishaps, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of corrosion-related mishaps
		the cause	a factor		
01	Engines	14	10	24	28%
03	Landing gear	9	3	12	14%
05	Rotor and propeller system	5	7	12	14%
02	Airframe	7	3	10	11%
20	Consumables and toolbox hardware	4	2	6	7%

Table 2-14. Systems with the Highest Number of Corrosion-Related Mishaps, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of corrosion-related mishaps
		the cause	a factor		
04	Power distribution and electrical	3	2	5	6%
07	Hydraulics/pneudraulics	2	2	4	5%
35	Armament	1	3	4	5%
10	Fuel System	1	3	4	5%
06	Drive System	1	1	2	2%
All other systems		4	0	4	5%
Total for all systems		51	36	87	100%

At 28 percent of the total, engines represented the highest number of corrosion-related mishaps by AWBS system, followed by the rotor and propeller and landing gear systems (both at 14 percent) and airframes (at 11 percent). These four systems present significant opportunities. The Army may bring about the greatest improvement in aviation safety by focusing resources for corrosion-related maintenance on these systems.

Corrosion-related mishaps resulting from the failure of the rotor and propeller system are the costliest, representing 32 percent of all corrosion-related mishap costs. The top five systems (shown in Table 2-15) by cost accounted for 92 percent of all Army corrosion-related aviation mishap costs.

Table 2-15. Top 5 Army Corrosion-Related Aviation Mishaps Costs by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost (in millions)	Percentage of total corrosion-related cost
		the cause	a factor			
05	Rotor and propeller system	5	7	12	$36	32%
04	Power distribution and electrical	3	2	5	$22	19%
01	Engines	14	10	24	$20	18%
20	Consumables and toolbox hardware	4	2	6	$15	13%
07	Hydraulics/ pneudraulics	2	2	4	$11	10%
All other systems		23	13	36	$9	8%
Total for all systems		51	36	87	$113	100%

Corrosion-related failures of the aircraft engine resulted in the highest number of aircraft total losses, followed by the rotor and propeller system. Together, they account for 15 of the 25 Army corrosion-related aircraft total losses, as shown in Table 2-16.

Table 2-16. Top 5 Army Corrosion-Related Aircraft Total Losses by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
		the cause	a factor		
01	Engines	14	10	24	10
05	Rotor and propeller system	5	7	12	5
20	Consumables and toolbox hardware	4	2	6	3
02	Airframe	7	3	10	2
07	Hydraulics/pneudraulics	2	2	4	2
All other systems		19	12	31	3
Total for all systems		51	36	87	25

Army aviation corrosion-related mishaps resulting from consumables and toolbox hardware failures account for 8 of the 23 military and civilian fatal injuries, as shown in Table 2-17.

Table 2-17. Corrosion-Related Aviation Mishaps with Fatal Injuries by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
		the cause	a factor		
20	Consumables and toolbox hardware	4	2	6	8
04	Power distribution and electrical	3	2	5	5
02	Airframe	7	3	10	3
01	Engines	14	10	24	2
05	Rotor and propeller system	5	7	12	2
All other systems		18	12	30	3
Total for all systems		51	36	87	23

Consumables and toolbox hardware failures include the failure of such items as nuts and bolts, seals, washers, studs, and clevises that lead to the failure of a larger system.

Corrosion-Related Mishaps by Failed Object

The USACR/SC data contained detailed information regarding the parts that failed in aviation mishaps. We used this data to further analyze corrosion-related mishaps, mishap costs, aircraft total losses, and fatal injuries. As Table 2-14 showed, the three systems that contributed to the most corrosion-related mishaps were the engine, rotor and propeller system, and landing gear system. We further examined the data associated with failures to identify the specific objects that failed.

The top five failed objects that contributed to the most corrosion-related mishaps were from engines, rotor and propeller systems, and the landing gear system. As shown in Table 2-18, landing gear contributed to most Army corrosion-related aviation mishaps, followed by engine bearings. These two objects accounted for 17 of the 87 corrosion-related mishaps.

Table 2-18. Failed Objects Associated with Corrosion-Related Aviation Mishaps, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
	the cause	a factor		
Landing gear	8	1	9	10%
Engine bearing	4	4	8	9%
Gas turbine engine	2	3	5	6%
Rotor blade	2	2	4	5%
Turboshaft engine	3	1	4	5%
All other objects	32	25	57	66%
Total for all objects	51	36	87	100%

Although the objects in Table 2-18 accounted for the most corrosion-related mishaps, they were not necessarily the costliest or deadliest mishaps.

As shown in Table 2-19 (as well as Table 2-20 and Table 2-25), corrosion was a factor in an Army aviation mishap (the result of a circuit breaker failure) that resulted in the total loss of the aircraft (an MH-47E), $19 million in cost, and five fatal injuries.

Table 2-19. Failed Objects Associated with Corrosion-Related Aviation Mishaps by Cost, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost (in millions)
	the cause	a factor		
Circuit breaker	0	1	1	$19
Rotor blade	2	2	4	$13
Engine bearing	4	4	8	$12
Servocylinder	1	1	2	$11
Hanger bearing	1	0	1	$9
All other objects	43	28	71	$49
Total for all objects	51	36	87	$114

Corrosion also contributed to the failure of bearings, which accounted for the highest number of aircraft total losses. The corrosion-related failed objects that resulted in the total loss of an aircraft are shown in Table 2-20.

Table 2-20. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Total Loss of Aircraft, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
	the cause	a factor		
Engine bearing	4	4	8	4
Gas turbine engine	2	3	5	2
Rotary compressor	2	1	3	2
Rotor blade	2	2	4	1
Nuts and bolts	1	1	2	1
Pneumatic components	1	0	1	1
Gearshaft	1	0	1	1
Hanger bearing	1	0	1	1
Hinge	1	0	1	1
Driveshaft	1	0	1	1
Engine compressor	1	0	1	1
Clevis	1	0	1	1
Compressor	1	0	1	1
Servocylinder	1	1	2	1

Table 2-20. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Total Loss of Aircraft, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
	the cause	a factor		
Structural support	1	0	1	1
Washer	1	0	1	1
Circuit breaker	0	1	1	1
Blade	0	1	1	1
Engine fuel system	0	1	1	1
Main rotor	0	1	1	1
All other objects	29	20	49	0
Total for all objects	51	36	87	25

Together, the failure of a washer and the failure of a circuit breaker contributed to the total loss of 2 aircraft (Table 2-20) and 10 fatal injuries (Table 2-21); however, there does not appear to be a trend for the corrosion-related failure of an object resulting in fatal injuries.

Table 2-21. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Fatal Injuries, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
	the cause	a factor		
Washer	1	0	1	5
Circuit breaker	0	1	1	5
Clevis	1	0	1	3
Engine bearing	4	4	8	2
Servocylinder	1	1	2	2
Hinge	1	0	1	2
Blade	0	1	1	2
Gearshaft	1	0	1	1
Structural support	1	0	1	1
All other objects	41	29	70	0
Total for all objects	51	36	87	23

Corrosion-Related Mishaps by End Item Type Model

We also explored the corrosion-related mishaps by EITM with respect to the number of mishaps, fatal injuries, and aircraft total losses.

CORROSION-RELATED MISHAPS

The EITM with the highest number of corrosion-related mishaps was the OH-58 and AH-64, which accounted for 18 percent and 17 percent, respectively, of all Army aviation corrosion-related mishaps. Nine of the 10 EITMs with the highest number of corrosion-related mishaps are rotary aircraft (see Table 2-22).

Table 2-22. Top 10 Army Aviation EITMs with Corrosion-Related Mishaps, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
		the cause	a factor		
OH-58	R	11	5	16	18%
AH-64	R	7	8	15	17%
UH-1	R	7	5	12	14%
CH-47	R	7	4	11	13%
UH-60	R	6	1	7	8%
AH-1	R	1	3	4	5%
MH-6	R	2	1	3	3%
MH-47	R	0	2	2	2%
Q-7	F	0	2	2	2%
OH-6	R	0	2	2	2%
All others		10	3	13	15%
Total		51	36	87	100%

CORROSION-RELATED FATAL INJURIES

Next we examined the number of fatal injuries that resulted from corrosion-related Army aviation mishaps. We estimate there were 23 corrosion-related military and civilian fatal injuries between FY1983 and FY2013. Rotary aircraft accounted for the five EITMs with the highest number of fatal injuries, as shown in Table 2-23.

Table 2-23. Top 5 Army Aviation EITMs with Corrosion-Related Fatal Injuries, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
		the cause	a factor		
UH-60	R	6	1	7	6
MH-47	R	0	2	2	5
OH-58	R	11	5	16	3
UH-1	R	7	5	12	3
AH-64	R	7	8	15	2
All others		20	15	35	4
Total of all EITMs		51	36	87	23

Corrosion-Related Aircraft Total Loss

We estimated the Army lost a total of 25 aircraft to corrosion-related mishaps between FY1983 and FY2013. Again, the top five EITMs for aircraft total losses were rotary aircraft. The OH-58 experienced the most corrosion-related mishaps as well as the most total losses, as shown in Table 2-24.

Table 2-24. Top 5 Army Aviation EITMs with Corrosion-Related Aircraft Total Losses, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
		the cause	a factor		
OH-58	R	11	5	16	7
AH-64	R	7	8	15	5
UH-1	R	7	5	12	5
UH-60	R	6	1	7	2
CH-47	R	7	4	11	1
All others		13	13	26	5
Total for all EITMs		51	36	87	25

COMPARISON TO AFCPCO AIR FORCE STUDY

We analyzed only Army aviation mishaps that occurred on duty. The AFCPCO's Air Force study included both aviation and non-aviation mishaps as well as mishaps that occurred either on- or off-duty.

For the AFCPCO's study, Class C mishaps accounted for 124,319 of the 130,068 (96 percent) total Air Force mishaps. We found Class C mishaps accounted for 3,233 of 4,664 (69 percent), of the mishap Army aviation total (see Table 2-25).

Table 2-25. Air Force and Army Mishaps, FY1983–FY2013

Class	AFCPCO Air Force study		Army aviation	
	Mishaps	Percentage of total mishaps	Mishaps	Percentage of total mishaps
A + B	5,749	4%	1,431	31%
C	124,319	96%	3,233	69%
Total	130,068	100%	4,664	100%

The large proportion of Air Force Class C mishaps (compared to Army aviation mishaps) led us to assume[3] the majority of the Air Force's off-duty and non-aviation mishaps were categorized as Class C mishaps. Under this assumption, we would expect the Air Force's Class A and Class B mishaps contain mostly on-duty and aviation-specific mishaps, which better align with the scope of this report.

Corrosion was either a factor or a cause in only 1.6 percent of Air Force Class A and Class B mishap; whereas corrosion-related Class A and B mishaps accounted for 2.9 percent of all Army aviation mishaps. This relationship between the Air Force and Army mishaps are shown in Table 2-26.

Table 2-26. Air Force and Army Corrosion-Related Mishaps, FY1983–FY2013

Class	AFCPCO Air Force study			Army aviation		
	Corrosion-related mishaps	Total mishaps	Corrosion percentage	Corrosion-related mishaps	Total mishaps	Corrosion percentage
A + B	90	5,749	1.6%	42	1,431	2.9%
C	233	124,319	0.2%	45[a]	3,233	1.4%
Total	323	130,068	0.2%	87	4,664	1.9%

[a] When comparing Class C mishaps, the Army's corrosion-related mishaps are under-represented because of the inclusion of the Air Force off-duty and non-aviation mishaps.

[3] The detailed data from the Air Force study is not available.

Chapter 3
Effects of Corrosion on DON Aviation Mishaps

Between FY1983 and FY2013, corrosion was either the cause or a factor in 179 DON aviation mishaps. The total number of DON aviation mishaps during this period was 8,445, so corrosion-related mishaps accounted for 2.1 percent of all DON aviation mishaps. In this chapter, we explain how we arrived at this estimate and draw conclusions about the trends and patterns in the data for corrosion-related mishaps.

A summary of DON aviation corrosion-related mishaps is shown in Table 3-1.

Table 3-1. Summary of DON Aviation Corrosion-Related Mishaps, FY1983–FY2013

Class	Mishaps in which corrosion was…		Corrosion-related mishaps	Total mishaps
	the cause	a factor		
A	14	13	27	1,329
B	19	8	27	979
C	76	49	125	6,137
Total	109	70	179	8,445

STUDY STEPS

Requesting Data

We requested from the Naval Safety Center[1] aviation mishap data that satisfied the following criteria:

1. FY1983–FY2013
2. Class A, B, and C event severities
3. On-duty activities.

[1] The Naval Safety Center data contains privileged safety information. LMI employees who require access to the data were required to complete an NDA.

Import Data

Data tables from the Naval Safety Center were imported into a Microsoft SQL Server database, and combined into a standard-structured table for analysis.

Identify Investigative Terms

The AFCPCO identified 75 terms that we used to search the narratives and primary finding fields to identify potentially corrosion-related mishaps.

In addition to these 75 terms, we identified terms in all descriptive text fields that may indicate the mishap is corrosion-related. Included in these additional words are common misspellings of words, such as “Corrosiion” and “Corrodded.” A full list of these terms can be found in Appendix D.

Perform Investigative Term Search

Using the list of 75 investigative terms and additional words and misspelling, we searched all descriptive text fields in the Naval Safety Center mishap data. We found matching terms in the descriptive text fields listed in Table 3-2.

Table 3-2. DON Aviation Mishap Descriptive Text Fields

DON aviation mishap descriptive text fields
EVENT_SHORT_NARRATIVE
EVENT_NARR
DMG_CMTS
HFACS_EVENT_CMTS
INVLVD_FAC_NARR
PRIV-MISHAP_ANALYSIS_NARR

Phrases, such as “caustic embrittlement” and certain corrosion words, such as “corrosion” and “corrosive” were searched first, followed by the length of the investigative term. Up to three unique investigative terms were associated with each mishap to help identify whether the mishap was related to corrosion.

Review Identified Potential Corrosion-Related Mishaps

Each mishap that contained an investigative term was reviewed to determine if corrosion was the cause, a factor, or not related to the mishap, as defined in Table 1-2. Table 3-3 provides a sample of DON aviation mishap’s descriptive text, investigative terms, and the classification we assigned.

Table 3-3. DON Aviation Mishap Classification Sample—Corrosion-Related

Classification	Investigative term			Phrase
	1st	2nd	3rd	
Cause	Corrosion	Intergranular	Cracking	…Cause factor: Material failure - engine first stage turbine airseal/second stage vane positioning lugs failed due to stress corrosion and intergranular cracking…
Factor	Corrosion	Deterioration	Intergranular	…The failure was a result of an overload condition caused by a decreased load bearing capacity of the FWD lug of the lower aft female vert stab attach fitting due to intergranular corrosion…This corrosion was allowed to advance to this state of deterioration through failure to properly inspect a known high risk area…

The presence of an investigative term, such as "corrosion" does not indicate the mishap is corrosion-related. Table 3-4 contains examples of descriptive text in which an investigative term was found, but the mishap was not corrosion-related.

Table 3-4. DON Aviation Mishap Classification Sample—Not Corrosion-Related

Classification	1st investigative term	2nd investigative term	3rd investigative term	Phrase
Not corrosion-related	Corrosion	Fracture	Stress	…The fracture was characteristic of a single overstress with no signs of fatigue or stress corrosion at the initiation pt…EI revealed the fitting failed from an overstress condition resulting from a single overload. Although past failures of this fitting have been related to corrosion or fatigue, it is believed an uncoupling of the pylon due to misrigging or pylon failure caused this fitting failure….
Not corrosion-related	Corrosion	Fracture	Cracking	…Interim EI of piece of cpy beam actuator attach fitting indicated failure due to overload. No evidence of prior fracture/progressive failure such as fatigue or stress corrosion cracking…

Identify Failed Object

We inspected every aviation mishap record to identify the corrosion-related object that failed. This was performed manually, which helped us to categorize the system that failed in the alternative AWBS.

Alternative Aviation Work Breakdown Structure

We developed the AWBS to definitively and efficiently identify the types of maintenance and the system, subsystem, or item on which the activity was performed for our impact of corrosion reports. We initially created the AWBS in conjunction with a cost-of-corrosion study for Army aviation equipment.[2] We applied a paired down version of the AWBS to the DON aviation corrosion-related mishaps.

The AWBS is a five-character alphanumeric. We use the first and the second and third characters of the AWBS to apply to this study from a failed object perspective. The codes we use describe the end item type and the primary system that failed.

The first character in the AWBS denotes the end item type (see Table 3-5).

Table 3-5. AWBS End Item Types

End item type	Description
F	Fixed wing aircraft
R	Rotary aircraft
M	Missiles
E	Engines
X	Common use across aircraft types

We omitted from this study the second character, which denotes the maintenance action. The third and fourth characters identify the system that failed. Table 3-6 shows these codes.

[2] LMI, *The Annual Cost of Corrosion for Army Aviation and Missile Equipment 2007–2008 Update*, Report DL907T4, David A. Forman et al., September 2010.

Table 3-6. AWBS System Codes

Code	Failed system
01	Engines
02	Airframe
03	Landing gear
04	Power distribution and electrical
05	Rotor and propeller system
06	Drive system
07	Hydraulics/pneudraulics
09	Miscellaneous aircraft
10	Fuel system
11	Flight control
12	Measuring and testing instruments
13	Environmental control
14	Ground support equipment
19	Avionics
20	Consumables and toolbox hardware
21	Bearings
22	Valves and pumps
31	Fire control system and target acquisition
34	Night vision assembly
35	Armament

We also omitted the last character, which denotes the sub-system that failed. Instead, we analyzed the mishap data from a failed object perspective, which provided greater detail in this safety report.

DON Aviation Summary and Analysis

For the 8,445 DON aviation mishaps within the scope of this study, 179 (or 2.1 percent) were corrosion-related. Class C mishaps made up the largest proportion of these 179 corrosion-related mishaps, as seen in Table 3-7.

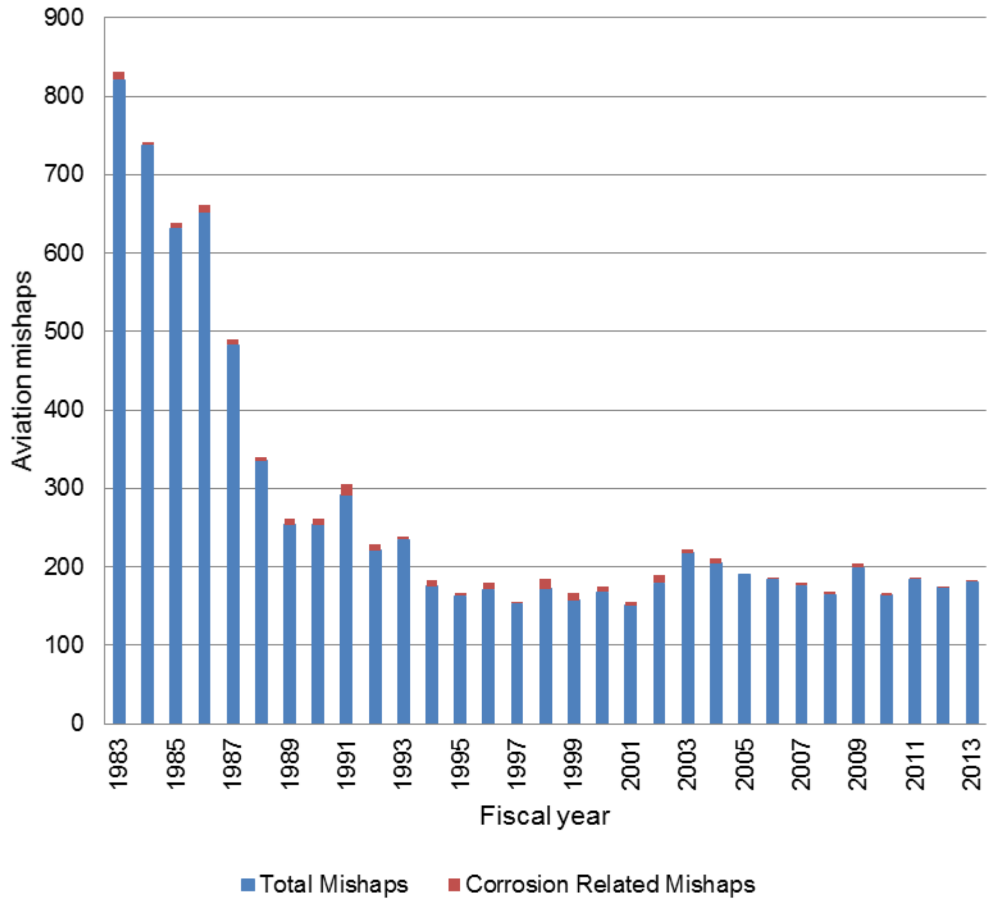
Table 3-7. DON Corrosion-Related Mishaps by Class, FY1983–FY2013

Class	Mishaps in which corrosion was the cause or a factor	Percentage of total corrosion-related mishaps
A	27	15%
B	27	15%
C	125	70%
Total	179	100%

Mishaps by Fiscal Year

The DON saw a large decrease in the number of aviation mishaps since FY1983, where there were 821, as shown in Figure 3-1.

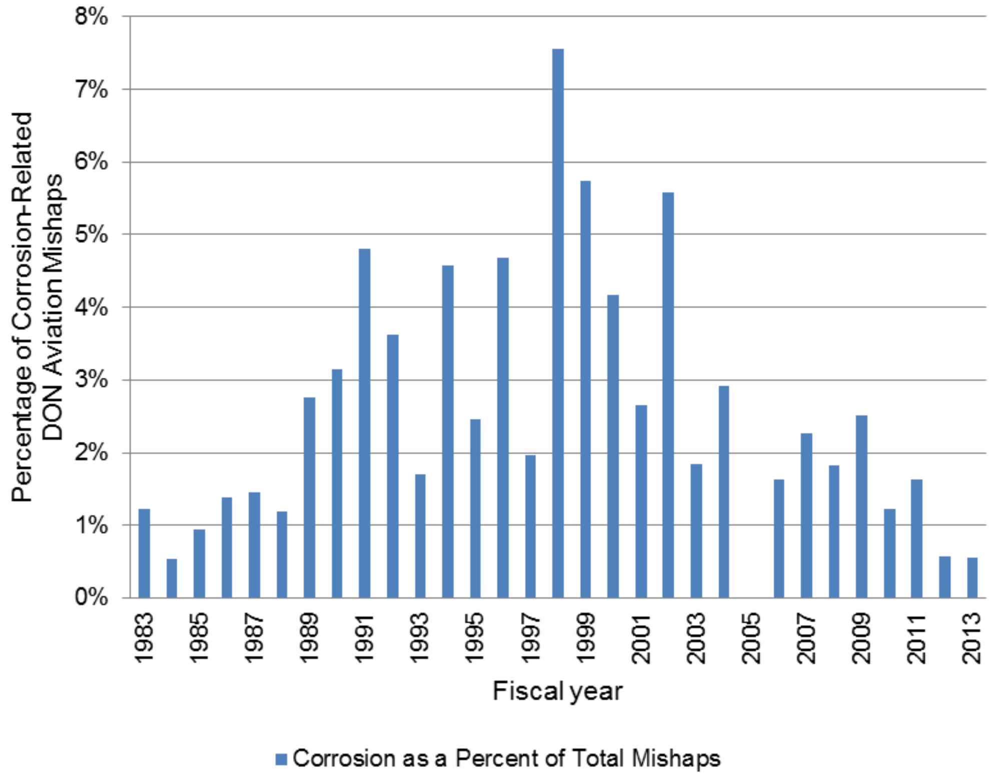
Figure 3-1. Number of DON Aviation and Corrosion-Related Aviation Mishaps, FY1983–FY2013



The large decrease in overall mishaps and their severity was a result of many improvements made to aircraft design as well as pilot and crew seats and restraints. Examples include damage tolerant dynamic components like composite rotor blades, improved bearings, drive systems, and rotor heads; tougher steel alloys; more stress corrosion cracking resistance aluminum alloys; cold worked holes in aluminum structure; and higher fidelity life tracking models. In addition, nondestructive inspection techniques improved, allowing higher quality data and a reduction of the number and severity of detected cracks.

The number of aviation mishaps has hovered at or below 200 since FY1994, while the percent of corrosion-related aviation mishaps sees a decrease trend from 7.5 percent in FY1998 to 0.6 percent in FY2013, as shown in Figure 3-2.

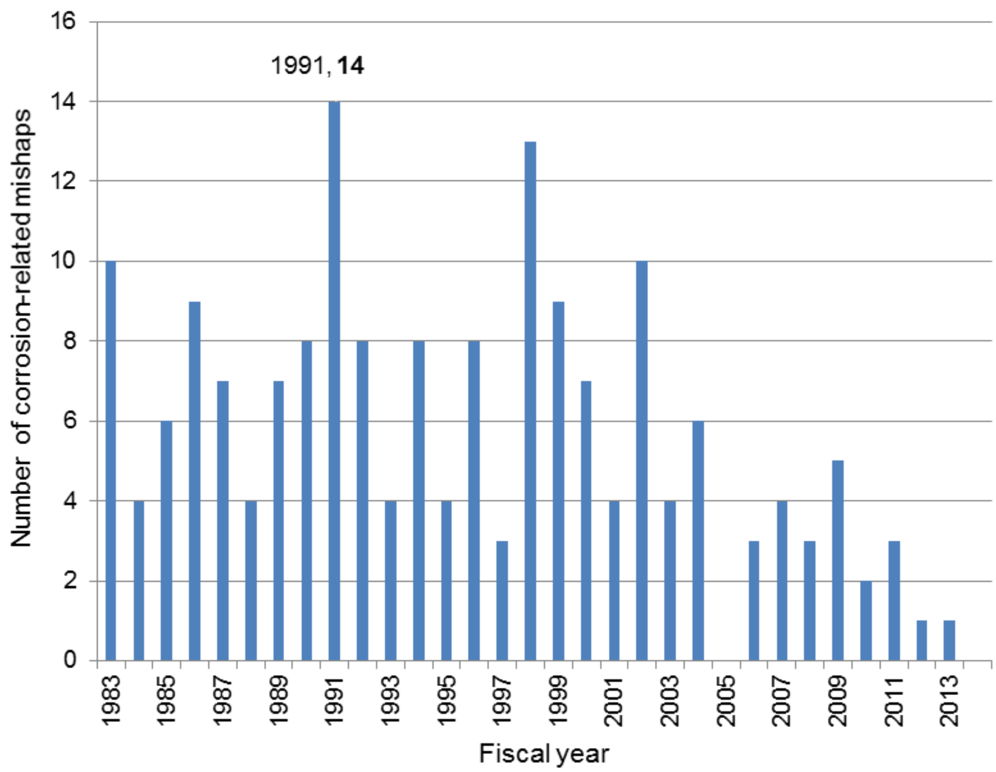
Figure 3-2. The Percentage of Corrosion-Related DON Aviation Mishaps, FY1983–FY2013



U.S. Navy Air Systems Command (NAVAIR) corrosion activities began to be formalized with a broad assessment of corrosion-related needs in the late 1990's which led to the recommendation to form an "Aircraft Corrosion Control and Prevention Program" to systematically address corrosion across the aircraft life cycle and integrate uncoordinated efforts across NAVAIR. The report supported the initiation of the Corrosion Fleet Focus Team (CFFT) in late 2001. The CFFT focuses on connecting engineering to the fleet to more rapidly implement new technologies, train maintainers on current and new technologies and identify problems in the fleet. In FY2005, OSD Corrosion Integrated Product Team (IPT) funding began in support of new technology maturation and implementation efforts. An example of the first year funding was the tri-service implementation of conductive (AvDEC) gaskets and floorboard tapes. This has been a strong success for H-60, F/A-18 and other platforms. In FY2007, the Naval Aviation Enterprise (NAE) Corrosion Prevention Team was established. This brought together engineering, logistics and other parts of NAVAIR into a cohesive team to address corrosion across the life cycle. Efforts were further strengthened with the establishment of the Navy Corrosion Executive in FY2008 and Navy Corrosion Working Group charter in FY2011. This brought Navy-level organization to complement what was already underway at OSD and NAVAIR.

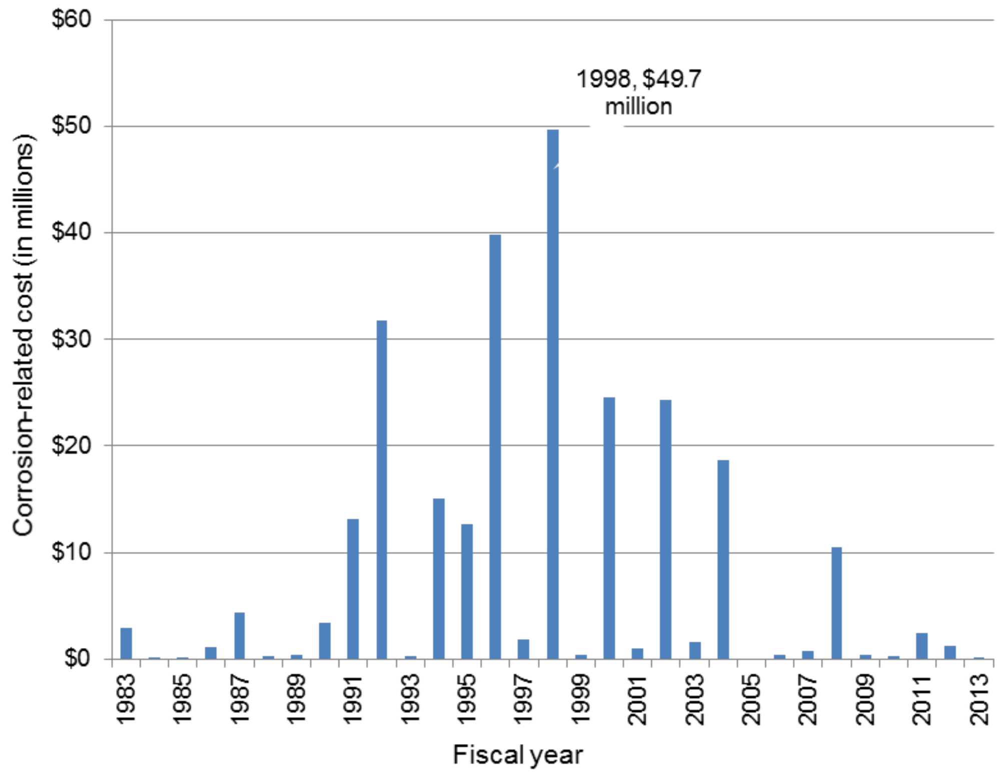
All of these efforts, while not able to be proven as the cause of decreases in corrosion mishaps, align with the clear decrease in them over the past 15 years. From FY1983 to about FY2002, the number of corrosion-related mishaps is relatively consistent, averaging 7.4 a year, as shown in Figure 3-3. In the same time period total mishaps decrease 78 percent and have stayed relatively constant through FY2013, at an average of 185 per year. Starting in FY2004, corrosion-related mishaps have decreased, with only 1 each in FY2012 and FY2013.

Figure 3-3. Number of DON Aviation Corrosion-Related Mishaps, FY1983–FY2013



In FY1998, the DON incurred the highest total event cost ($49.7million) for DON corrosion-related aviation mishaps, as shown in Figure 3-4. In that year, there were 13 corrosion-related mishaps, with corrosion being the cause of 8 of the 13. Fortunately, none resulted in a fatal injury.

Figure 3-4. DON Aviation Total Cost of Corrosion-Related Mishaps, FY1983–FY2013



The F-18 accounted for four of the corrosion-caused mishaps and 42 percent of the mishap costs in FY1998. Table 3-8 shows the DON aviation corrosion-related mishaps for FY1998 by EITM with their associated aircraft total losses and costs, ordered by highest cost.

Table 3-8. DON Aviation Corrosion-Related Mishaps, Aircraft Total Losses, and Costs by TMS for FY1998

End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Aircraft total losses	Corrosion-related cost (in millions)	Percentage of cost
	the cause	a factor				
F-18	2	2	4	1	$20.961	42%
P-3	0	1	1	1	$13.929	28%
T-45	1	0	1	1	$11.558	23%
KC-130	1	0	1	0	$3.042	6%
CH-53	1	0	1	0	$.049	0%
T-34	1	1	2	0	$.045	0%
S-3	1	0	1	0	$.043	0%
SH-60	0	1	1	0	$.027	0%
E-2	1	0	1	0	$.008	0%

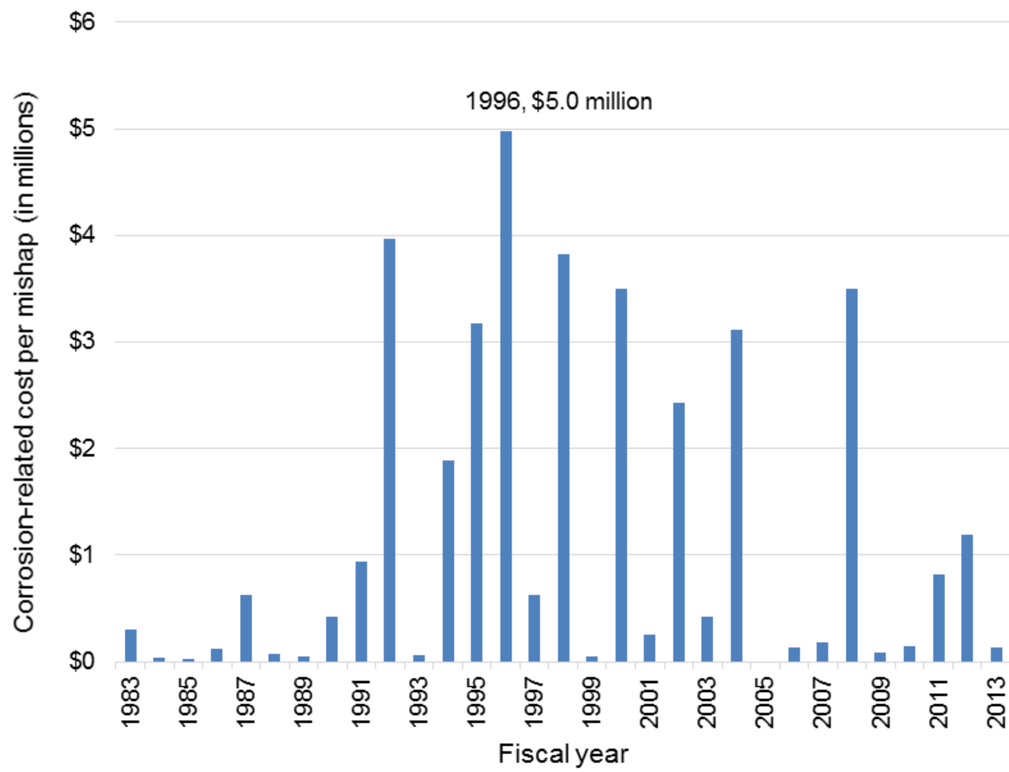
Table 3-8. DON Aviation Corrosion-Related Mishaps, Aircraft Total Losses, and Costs by TMS for FY1998

End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Aircraft total losses	Corrosion-related cost (in millions)	Percentage of cost
	the cause	a factor				
Total	8	5	13	3	$49.663	100%

Four different EITMs and seven total mishaps contributed to nearly all of the FY1998 mishap costs: F-18, P-3, T-45, and KC-130.

Next we looked at the corrosion-related cost per mishap. With eight mishaps, FY1996 stood out as the year with the highest per-mishap cost—$5.0 million, as shown in Figure 3-5.

Figure 3-5. Aviation Corrosion-Related Cost per Mishap, FY1983–FY2013



In FY1996, the DON experienced two Class A, one Class B, and five Class C corrosion-related mishaps. In the two Class A mishaps, corrosion was a factor in the total-loss of an F-14B and an F-18A aircraft. There were no fatal injuries in these two mishaps. The cost of the F-14B and F-18A mishaps were $23.8 million and $15.3 million, respectively; however, however, because corrosion was only a contributing factor, we did not consider the entire cost to be corrosion-related. For the F-14B mishap, corrosion in the electro-hydraulic servo armature caused an uncommanded actuation/deflection, resulting in an uncommanded roll. The F-18A left main landing gear collapsed because of corrosion in the cross bolt lug area.

Corrosion-Related Mishaps by AWBS

Another way to view corrosion-related mishaps is by AWBS. As we discussed earlier, the AWBS is a five-character alphanumeric code. We used the first, third, and fourth characters in this study. The AWBS describes the end item type and the primary system that failed in this study.

AWBS End Item Type

First we identified the end item type (the first character of the AWBS) and the number of corrosion-related mishaps. Table 3-9 shows that 79 percent of DON corrosion-related aircraft mishaps occurred on fixed-wing aircraft; the remaining 21 percent were associated with rotary aircraft.

Table 3-9. DON Aviation Corrosion-Related Mishaps by End Item Type, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
		the cause	a factor		
F	Fixed-wing aircraft	77	55	132	79%
R	Rotary aircraft	32	15	47	21%
Total		109	70	179	100%

To understand the high percentage of corrosion-related fixed-wing mishaps, we used the equipment list inventory gathered from other corrosion reports[3], and averaged the inventory by end item type from the most recent 10 fiscal years on file. We then compared the inventory ratio between fixed-wing and rotary aircraft.

We found roughly the same proportion for average aviation inventory as for corrosion-related mishaps by end item type. Table 3-10 shows the average equipment list inventory by end item type between FY1983 and FY2013 and their percentage of total average annual inventory. The ratios between fixed-wing and rotary aircrafts for corrosion-related mishaps and average inventory are similar. We therefore concluded the reason fixed-wing aircraft account for more corrosion-related mishaps than rotary aircraft may be because the DON has more fixed-wing aircraft in inventory.

[3] Source: Deckplate, Aircraft Inventory Readiness and Reporting System (AIRRS) module.

Table 3-10. DON Aviation Average Equipment List Inventory, FY1983–FY2013

End item type	Description	Average annual inventory	Percentage of total average annual inventory
F	Fixed-wing aircraft	3,202	69%
R	Rotary aircraft	1,425	31%
Total		3,627	100%

Corrosion-related fixed-wing aircraft mishaps accounted for an estimated $236 million of the estimated $264 million (or 89 percent) of corrosion-related total mishap cost, as shown in Table 3-11.

Table 3-11. DON Corrosion-Related Aviation Mishaps and Costs, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost (in millions)	Percentage of total corrosion-related cost
		the cause	a factor			
F	Fixed-wing	77	55	132	$236	89%
R	Rotary aircraft	32	15	47	$28	11%
Total		109	70	179	$264	100%

Although fixed-wing aircraft accounted for 79 percent of all DON corrosion-related aviation mishaps and 89 percent of corrosion-related costs, rotary aircraft accounted for 10 of the 11 fatal injuries, as shown in Table 3-12.

Table 3-12. DON Corrosion-Related Aviation Mishaps, Aircraft Total Losses, and Fatal Injuries, FY1983–FY2013

End item type	Description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses	Corrosion-related fatal injuries
		the cause	a factor			
F	Fixed-wing	77	55	132	15	1
R	Rotary aircraft	32	15	47	4	10
Total		109	70	179	19	11

AWBS System

We examined four corrosion-related measures related to the third and fourth character of the AWBS: number of mishaps, cost, aircraft total losses, and fatal injuries. Table 3-13 lists the third and fourth character of the AWBS for the 10 systems with the highest number corrosion-related mishaps.

Table 3-13. Top 10 DON Corrosion-Related Aviation Mishaps by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
		the cause	a factor		
03	Landing gear	39	18	57	32%
02	Airframe	21	13	34	19%
09	Miscellaneous aircraft	7	6	13	7%
01	Engines	7	2	9	5%
20	Consumables and toolbox hardware	4	4	8	4%
05	Rotor and propeller system	5	2	7	4%
11	Flight control	5	2	7	4%
19	Avionics	4	3	7	4%
21	Bearings	4	3	7	4%
07	Hydraulics/pneudraulics	3	4	7	4%
All other systems		10	13	23	13%
Total		109	70	179	100%

At 57, landing gear systems accounted for the most corrosion-related mishaps by AWBS (32 percent of total), followed by the airframe at 34 (19 percent of total). The DON may bring about the greatest improvement in aviation safety by focusing corrosion-related maintenance resources on these two systems.

Corrosion-related mishaps resulting from the failure of the landing gear were the costliest, representing 35 percent of all corrosion-related mishap costs. Five systems (shown in Table 3-14) accounted for 88 percent of all DON corrosion-related aviation mishap costs.

Table 3-14. Top 5 DON Corrosion-Related Aviation Mishap Costs by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost ($ in millions)	Percentage of total corrosion-related cost
		the cause	a factor			
03	Landing gear	39	18	57	$91	35%
02	Airframe	21	13	34	$50	19%
09	Miscellaneous aircraft	7	6	13	$38	14%
20	Consumables and toolbox hardware	4	4	8	$31	12%
07	Hydraulics/pneudraulics	3	4	7	$21	8%
All other systems		35	25	60	$33	12%
Total		109	70	179	$264	100%

The corrosion-related failure of the aircraft landing gear resulted in the highest number of aircraft total losses, followed by the airframe. The top five corrosion-related aircraft system failures that resulted in the total loss of an aircraft are shown in Table 3-15.

Table 3-15. Top 5 DON Corrosion-Related Aircraft Total Losses by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
		the cause	a factor		
03	Landing gear	39	18	57	6
02	Airframe	21	13	34	3
09	Miscellaneous aircraft	7	6	13	2
20	Consumables and toolbox hardware	4	4	8	2
01	Engines	7	2	9	1
All other systems		31	27	58	5
Total		109	70	179	19

DON aviation corrosion-related mishaps resulting from the failure of the airframe and flight control systems account for an estimated 8 of the total 11 military and civilian fatal injuries, as shown in Table 3-16. Examples of the airframe system failures include doors failing due to stress corrosion, sealant that allows water intrusion, and the failure of seam welds, wing fold hinges, and wing slats from corrosion.

Table 3-16. Top 5 DON Corrosion-Related Aviation Mishaps with Fatal Injuries by AWBS Major System Character, FY1983–FY2013

AWBS 3rd/4th character	System description	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
		the cause	a factor		
02	Airframe	21	13	34	4
11	Flight control	5	2	7	4
10	Fuel system	3	2	5	2
03	Landing gear	39	18	57	1
09	Miscellaneous aircraft	7	6	13	0
All other systems		34	29	63	0
Total		109	70	179	11

Corrosion-Related Mishaps by Failed Object

As Table 3-13 showed, landing gear contributed to the most corrosion-related naval aviation mishaps. We investigated deeper to identify the failed object associated with most failures. Three of the top five objects with corrosion-related failures are from an aircraft landing gear system, as shown in Table 3-17 and Table 3-18.

Table 3-17. Top 5 DON Aviation Mishaps Failed Objects Associated with Corrosion-Related Mishaps, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
	the cause	a factor		
Landing gear	11	10	21	12%
Nose landing gear	13	5	18	10%
Bearing	3	3	6	3%
Body, frame, or hull	2	3	5	3%
Landing gear strut	4	1	5	3%
All other objects	76	48	124	69%
Total	109	70	179	100%

Although a landing gear object, which consists of the left and right main landing gears, had the highest number of corrosion-related failures, the failure of the nose landing gear resulted in much higher total corrosion-related mishap cost ($70 million versus $18 million for the main gear), as Table 3-18 shows.

Table 3-18. Top 5 DON Aviation Mishaps Failed Objects Associated with Corrosion-Related Mishaps by Cost, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related mishap cost ($ in millions)
	the cause	a factor		
Nose landing gear	13	5	18	$70
Actuator	1	2	3	$24
Reservoir	0	1	1	$20
Landing gear	11	10	21	$18
Conduit	0	1	1	$18
All other objects	84	51	135	$113
Total	109	70	179	$264

The failure of the nose landing gear also contributed to the most corrosion-related aircraft total losses, as shown in Table 3-19.

Table 3-19. Corrosion-Related Failed Objects Associated with DON Aviation Mishaps that Resulted in the Total Loss of an Aircraft, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft loss
	the cause	a factor		
Nose landing gear	13	5	18	4
Landing gear	11	10	21	1
Shroud	4	0	4	1
Bearing	3	3	6	1
Fuel nozzle	2	0	2	1
Actuator	1	2	3	1
Liner	1	0	1	1
Lug nuts	1	0	1	1
Propeller	1	1	2	1
Spacer	1	0	1	1
Truss	1	0	1	1
Conduit	0	1	1	1
Oxygen tank	0	1	1	1
Pitch assembly	0	1	1	1
Reservoir	0	1	1	1
Stabilizer	0	1	1	1
All other objects	70	44	114	0
Total	109	70	179	19

Although the corrosion-related failures of the landing gear and nose landing gear contributed to the most mishaps, aircraft total losses, and costs, together their failure resulted in only one fatal military or civilian injury. The corrosion-related failure of a liner (airframe system) and a pitch assembly (flight control system) resulted in four fatal injuries. The corrosion-related failed objects and their relationship to fatal injuries are shown in Table 3-20.

Table 3-20. Corrosion-Related Failed Objects Associated with DON Aviation Mishaps that Resulted in Fatal Injuries, FY1983–FY2013

Failed object	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
	the cause	a factor		
Liner	1	0	1	4
Pitch assembly	0	1	1	4
Fuel nozzle	2	0	2	2
Nose landing gear	13	5	18	1
Landing gear	11	10	21	0
All other objects	82	54	136	0
Total	109	70	179	11

Corrosion-Related Mishaps by End Item Type Model

We also explored the corrosion-related mishaps by EITM with respect to the number of mishaps, fatal injuries, and aircraft total losses.

CORROSION-RELATED MISHAPS

The EITM with the highest number of corrosion-related mishaps was the F-18, which experienced 17 percent of all DON corrosion-related aviation mishaps. The 10 EITMs with the highest number of corrosion-related mishaps are listed in Table 3-21. These 10 EITMS are a mixture of rotary and fixed-wing aircraft.

Table 3-21. Top 10 DON Aviation EITMs with Corrosion-Related Mishaps, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Percentage of total corrosion-related mishaps
		the cause	a factor		
F-18	F	13	18	31	17%
F-14	F	3	10	13	7%
S-3	F	8	4	12	7%
SH-60	R	8	3	11	6%
P-3	F	7	1	8	4%
AV-8	F	5	3	8	4%
E-2	F	5	2	7	4%
CH-53	R	5	2	7	4%
SH-3	R	5	2	7	4%
KC-130	F	5	1	6	3%
All others		45	24	69	39%
Total		109	70	179	100%

It is important to note that as of FY13 the F-14 and SH-3 are no longer in service, the S-3 has five in inventory, and the SH-60 is being phased out with 25 in inventory.

Corrosion-Related Fatal Injuries

Next we examined the number of fatal injuries that resulted from corrosion-related mishaps. We estimated there were 11 corrosion-related fatal injuries (military or civilian) between FY1983 and FY2013. Rotary aircraft experienced fewer corrosion-related mishaps than fixed wing aircraft, yet account for 10 of the 11 corrosion-related fatal injuries. Table 3-22 shows the EITMs with corrosion-related fatal injuries.

Table 3-22. Top 4 DON Aviation EITMs with Corrosion-Related Fatal Injuries, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Fatal injuries
		the cause	a factor		
CH-53	R	5	2	7	4
UH-46	R	0	2	2	4
AH-1	R	1	0	1	2
F-14	F	3	10	13	1
All others		100	56	156	0
Total		109	70	179	11

Corrosion-Related Aircraft Total Loss

The DON lost a total of 21 aircraft to corrosion-related mishaps between FY1983 and FY2013. The F-18 and F-14 contributed to 24 percent of all corrosion-related mishaps. They also contributed to 7 of the 21 aircraft total losses from corrosion-related mishaps. Table 3-23 shows the top five DON aviation EITMs for corrosion-related total losses.

Table 3-23. Top 5 DON Aviation EITMs with Corrosion-Related Total Aircraft Losses, FY1983–FY2013

EITM	End item type	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related aircraft total losses
		the cause	a factor		
F-18	F	13	18	31	4
F-14	F	3	10	13	3
P-3	F	7	1	8	2
T-45	F	3	1	4	2
AV-8	F	5	3	8	1
All others		78	37	115	7
Total		109	70	179	19

COMPARISON TO AFCPCO AIR FORCE STUDY

We analyzed only DON aviation mishaps that occurred on duty. The AFCPCO's Air Force study included both aviation and non-aviation and mishaps that occurred either on- or off-duty. Non-aviation and off-duty mishaps include mishaps in private motor vehicles.

For the AFCPCO's study, Class C mishaps accounted for 124,319 of 130,068, or 96 percent, total mishaps compared to the DON's 6,137 of 8,445, or 73 percent, total mishaps as show in Table 3-24.

Table 3-24. Air Force and DON Mishaps, FY1983–FY2013

Class	AFCPCO Air Force study		DON aviation	
	Mishaps	Percentage of total	Mishaps	Percentage of total
A + B	5,749	4%	2,308	27%
C	124,319	96%	6,137	73%
Total	130,068	100%	8,445	100%

The large proportion of Air Force Class C mishaps (compared to DON aviation mishaps) led us to assume[4] the majority of the Air Force's off-duty and non-aviation mishaps were categorized as Class C mishaps. Under this assumption, we would expect the Air Force's Class A and Class B mishaps contain mostly on-duty and aviation-specific mishaps, which better align with the scope of this report.

Corrosion was either a factor or a cause in only 1.6 percent of Air Force Class A and Class B mishap; whereas corrosion-related Class A and B mishaps accounted for 2.3 percent of all naval aviation mishaps. This relationship between the Air Force and DON mishaps are shown in Table 3-25.

Table 3-25. Air Force and DON Corrosion-Related Mishaps, FY1983–FY2013

Class	AFCPCO Air Force study			DON aviation		
	Corrosion-related mishaps	Total mishaps	Corrosion percentage	Corrosion-related mishaps	Total mishaps	Corrosion percentage
A + B	90	5,749	1.6%	54	2,308	2.3%
C	233	124,319	0.2%	125[a]	6,137	2.0%
Total	323	130,068	0.2%	179	8,445	2.1%

[a] When comparing Class C mishaps, the DON's corrosion-related mishaps are under-represented because of the inclusion of the Air Force off-duty and non-aviation mishaps.

[4] The detailed data from the Air Force study is not available.

NAVAL AIR SYSTEMS COMMAND COMMENT

Over a decade ago, The Naval Air Systems Command (NAVAIR) engaged with the Naval Safety Center to evaluate the impact of corrosion on Class A, B and C aviation mishaps. The results from that study showed that corrosion was either a primary or secondary causal factor in a regular number of mishaps over the ten year target period for the study (1994–2003). Unfortunately, a formal report was never published documenting the NAVAIR/Naval Safety Center study. While the data from this investigation was slightly higher in magnitude than this report, the results were in general alignment with those developed in this report. Additionally, the NAVAIR study identified similar downward trends in the number of corrosion related mishaps in recent years, which is in line with the trends identified in this report.

Chapter 4
Conclusions and Recommendations

Within the scope of our study, corrosion was the cause or a factor in 1.9 percent and 2.1 percent of Army and DON aviation mishaps, respectively, as summarized in Table 4-1.

Table 4-1. Army and DON Aviation Corrosion-Related Mishaps

Service	Aviation mishaps	Corrosion-related aviation mishaps	Corrosion-related mishaps as a percentage of total
Army	4,664	87	1.9%
DON	8,445	179	2.1%

Class A Mishaps

Corrosion is a very small contributor to aviation mishaps; however, each current Class A mishap results in at least $2 million in total property damage or a fatality or permanent total disability.

Between FY1983 and FY2013, the Army experienced 29 Class A corrosion-related mishaps, with corrosion being the cause of 17 of the 29 mishaps. During that same period, the DON experienced 27 Class A corrosion-related mishaps, 14 of which were the caused by corrosion. More importantly, the corrosion was either the cause or factor in 23 fatal injuries for the Army and 11 fatal injuries for the DON.

A summary of Class A corrosion-related mishaps is shown in Table 4-2. The prevention of Class A corrosion-related mishaps has the potential to save lives as well as millions of dollars.

Table 4-2. Army and DON Aviation Corrosion-Related Class A Mishaps

Service	Mishaps in which corrosion was…		Corrosion-related mishaps	Corrosion-related fatal injuries
	the cause	a factor		
Army	17	12	29	17
DON	14	13	27	11

ROTARY VERSUS FIXED-WING AIRCRAFT

For the Army, 90 percent of corrosion-related mishaps occurred on rotary aircraft, and rotary aircraft accounted for 98 percent of the total cost for corrosion-related mishaps, 24 of 25 corrosion-related aircraft total losses, and all 23 corrosion-related fatal injuries.

For the DON, 74 percent of corrosion-related mishaps occurred on fixed-wing aircraft, and fixed-wing aircraft accounted for 91 percent of the total cost for corrosion-related mishaps, 15 of 19 corrosion-related aircraft total losses, and one of the 11 corrosion-related fatal injuries. Table 4-3 presents a summary of corrosion-related mishaps, mishap costs, aircraft total losses, and fatal injuries by end item type. For both the Army and DON, the percentage of corrosion-related mishaps by end item type (rotary versus fixed-wing aircraft) closely mirrors the percentage of aircraft inventory percentages.

Table 4-3. Summary of Army and DON Aviation Corrosion-Related Mishaps by End Item Type

End item type	Description	Corrosion-related mishaps	Corrosion-related cost (in millions)	Corrosion-related aircraft total losses	Corrosion-related fatal injuries
Army					
R	Rotary aircraft	78	$110	24	23
F	Fixed-wing aircraft	9	$4	1	0
Total		87	$114	25	23
DON					
F	Fixed-wing aircraft	132	$236	15	1
R	Rotary aircraft	47	$28	4	10
Total		179	$264	19	11

From a fatal injury perspective, corrosion-related mishaps by rotary aircraft lead to the highest number of lives lost, independent of the service's inventory or the number of corrosion-related mishaps. This statistic can be attributed to the fact that the pilot and passengers in rotary aircraft cannot safely eject.

From a total cost and loss of aircraft perspective, rotary aircraft are the costliest for the Army, but fixed-wing aircraft are the costliest for the DON. Again, the proportion of corrosion-related mishaps for either service by end item type is proportional to their respective inventory.

FINAL RECOMMENDATIONS

Detailed documentation of safety investigations is critical for determining whether a mishap was related to corrosion and presenting recommendations to improve safety fleet wide.

For the data supplied by the Army Safety Center, 764 of 4,664, or 16.4 percent of the mishaps were missing detailed mishap descriptions, such as event narratives, involved factors, findings, and recommendations. Only 41 of 8,445, or 0.5 percent of the data supplied by the Naval Safety Center were missing detailed mishap descriptions. Therefore, we recommend detailed descriptions of every mishap be captured properly in updated data fields.

The data supplied by the Army Safety Center contained data fields that identify the cause and type of failure for each mishap. This was helpful when identifying corrosion-related mishaps. The data supplied by the Naval Safety Center did not contain such data fields; we relied entirely on the detailed text descriptions. We therefore recommend cause-of-failure and type-of-failure fields be added to the Naval Safety Center database to better identify mishaps.

Safety investigators may not all be familiar with the congressional definition of corrosion. Congress defines corrosion as “The deterioration of a material or its properties due to a reaction of that material with its chemical environment.”[1] Understanding this definition will help investigators identify mishaps related to corrosion.

[1] *The Bob Stump National Defense Authorization Act for Fiscal Year 2003,* Public Law 107-314, 2 December 2002, p.202; Public Law 107-314 was enhanced by Public Law 110-181, *The National Defense Authorization Act for Fiscal Year 2008,* Section 371, 28 January 2008.

Appendix A
Normalized FY1983 Cost and Actual Reported Cost

Table A-1and Table A-2 present the total corrosion mishaps costs normalized to FY1983 baseline and total corrosion mishap cost as reported for the Army and DON, FY1983–FY2013.

Table A-1. Army Costs

Fiscal year	Total corrosion mishap cost, normalized to FY1983	Total corrosion mishap cost, actual reported
1983	$310,427	$310,427
1984	$2,177,861	$2,268,062
1985	$7,990,951	$8,628,609
1986	$1,679,969	$1,859,090
1987	$1,674,873	$1,905,583
1988	$1,268,941	$1,503,248
1989	$4,435,102	$5,501,696
1990	$6,966,852	$9,074,832
1991	$773,320	$1,058,121
1992	$105,444	$148,609
1993	$7,509,728	$10,907,634
1994	$8,198,378	$12,221,842
1995	$2,234,803	$3,424,876
1996	$19,258,482	$30,335,968
1997	$22,893	$37,024
1998	$144,938	$238,246
1999	$20,404,742	$34,184,613
2000	$95,769	$165,518
2001	$18,226	$32,511
2002	$1,653,506	$2,993,746
2003	$0	$0
2004	$0	$0
2005	$45,455	$89,035
2006	$12,345,826	$25,066,556
2007	$8,376,539	$17,407,805
2008	$143,527	$311,506
2009	$3,240,431	$7,011,774
2010	$0	$0
2011	$2,730,112	$6,165,239
2012	$0	$0
2013	$0	$0

Table A-2. DON Costs

Fiscal year	Total corrosion mishap cost, normalized to FY1983	Total corrosion mishap cost, actual reported
1983	$2,985,889	$2,985,889
1984	$136,262	$141,906
1985	$167,737	$181,122
1986	$1,087,874	$1,203,865
1987	$4,402,543	$5,008,984
1988	$283,468	$335,810
1989	$354,667	$439,961
1990	$3,387,128	$4,411,981
1991	$13,091,741	$17,913,212
1992	$31,777,186	$44,785,594
1993	$241,736	$351,113
1994	$15,109,430	$22,524,585
1995	$12,718,444	$19,491,243
1996	$39,828,348	$62,737,627
1997	$1,883,604	$3,046,338
1998	$49,663,335	$81,635,547
1999	$436,735	$731,674
2000	$24,524,089	$42,384,990
2001	$999,076	$1,782,156
2002	$24,334,338	$44,058,392
2003	$1,663,304	$3,082,619
2004	$18,677,274	$35,418,288
2005	$0	$0
2006	$390,668	$793,199
2007	$706,839	$1,468,926
2008	$10,492,795	$22,773,251
2009	$452,998	$980,216
2010	$280,255	$616,752
2011	$2,457,728	$5,550,132
2012	$1,193,913	$2,761,666
2013	$129,177	$303,684

Appendix B
Event Severity Classification

The severity of aircraft mishaps depends on the cost of the mishap and injuries involved. Through the years, the event severity classification based on cost changed, but the injury severity remained constant. Table B-1 through Table B-4 capture these changes.

ARMY CLASSIFICATIONS

Table B-1. Army Aviation Total Property Damage Cost for Mishap Event Severity Classification

Start Date	Class A	Class B	Class C
1 August 1982	≥ $200,000	$50,000–$199,999	$700–$49,999
1 October 1983	≥ $500,000	$100,000–$499,999	$10,000–$99,999
1 October 1988	≥ $1,000,000	$200,000–$999,999	$10,000–$99,999
1 October 2001	≥ $1,000,000	$200,000–$999,999	$20,000–$199,999
1 October 2009	≥ $2,000,000	$500,000–$1,999,999	$50,000–$499,999

Source: Army Regulation 385–10.

Note: Unmanned aircraft system (UAS) accidents are classified based on the cost to repair or replace the UAS. A destroyed, missing, or abandoned UAS will not constitute a Class A accident unless replacement or repair cost is $2 million or more.

Table B-2. Army aviation Injury Severity for Mishap Classification

Date	Class A	Class B	Class C
FY1983–FY2013	Fatal, permanent total disability, missing and presumed dead	Permanent partial disability[a]	Lost workday case–days away from work

[a] Before October 1, 1983, Class B had no injury severity requirement.

DON CLASSIFICATIONS

Table B-3. DON Aviation Total Property Damage Cost for Mishap Classification

Start Date	Class A	Class B	Class C
27 October 1982	≥ $200,000	$50,000–$199,999	$300–$49,999
30 November 1982	≥ $500,000	$100,000–$499,999	$10,000–$99,999
27 February 1986	≥ $1,000,000	$200,000–$999,999	$10,000–$199,999
1 March 2001	≥ $1,000,000	$200,000–$999,999	$20,000–$199,999
1 October 2009	≥ $2,000,000	$500,000–$1,999,999	$50,000–$499,999

Source: OPNAV 3750.6, M, N, P, Q, R, and S, May 13, 2014.

Note: A destroyed or missing UAV is not a Class A unless the cost of damage is $2 million or more.

Table B-4. DON Aviation Injury Severity for Mishap Classification

Date	Class A	Class B	Class C
FY1983–FY2013	Fatal, permanent total disability, missing and presumed dead	Permanent partial disability	Lost workday case—days away from work

Appendix C

Army Aviation Mishap Cause or Type of Failure

The unique cause and type of failure from the Army aviation mishap data are listed in **Error! Reference source not found.**

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Corroded	Yes
Fretting corrosion	Yes
Galvanic corrosion	Yes
Hot corrosion (sulfidation)	Yes
Hydrogen embrittlement	Yes
Insufficient protection from moisture	Yes
Intergranular corrosion	Yes
Moisture saturation	Yes
Paint peeling off	Yes
Peeled	Yes
Peeling	Yes
Pitted	Yes
Pitting corrosion	Yes
Rusty	Yes
Salt water damage	Yes
Stress corrosion	Yes
Sunlight damage	Yes
Weather damage	Maybe
A/C elec. power loss	No
A/C elec. system faulty	No
A/C fire warning light	No
A/C fuel system faulty	No
A/C oil system faulty	No
A/C temp. indication error	No
Abraded	No
Accepted as is	No
Activates incorrectly	No
Adjusted	No
Adjustment improper	No
Admits dust	No
Air leak	No
Air leak A/C system	No
Air leak closed bleed	No
Air leak open bleeds	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Air leak, faulty gasket	No
Air start failure	No
Alignment improper	No
Ammeter pegged	No
Arcing, arced	No
Arithmetic error	No
Armature dirty	No
Attack display malfunction	No
Audio and video faulty	No
Audio faulty	No
Backed off (or out)	No
Backfiring	No
Base-to-collector, short	No
Base-to-emitter, open	No
Battered	No
Bearing failure	No
Bent	No
Beyond specified tolerance	No
Binding	No
Blistered	No
Blown	No
Bolts-nuts-screws loose	No
Bosses not cast in proper location	No
Bound together	No
B-plus incorrect	No
Brake fail	No
Brittle	No
Broken	No
Broken envelope	No
Broken glass	No
Broken linkage	No
Broken or missing safety wire or key	No
Brush failure/worn excessively	No
Brushes, improper tension	No
Buckled	No
Burned	No
Burned out	No
Burred	No
Burst	No
Bushing failure	No
Calibration, incorrect	No
Carboned	No
Chafed	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Chalking	No
Chipped	No
Circuit, open	No
Circuit, shorted	No
Circuits raised or broken	No
Clearance under minimum	No
Clogged	No
Cloudy	No
Cocked	No
Cold solder joint	No
Collapsed	No
Collision	No
Compressed	No
Condensation	No
Contact/connection defective	No
Contacts do not open/close properly	No
Contaminated with metal	No
Contamination	No
Controls, inoperative	No
Corona effect	No
Cracked	No
Creep from overstress	No
Creep from overtemperature	No
Creeping	No
Crimped	No
Cross threaded	No
Crossed	No
Crushed	No
Crystallized	No
Current, incorrect	No
Cut	No
Damaged	No
Defective	No
Defective material	No
Defective solder joint	No
Defective wire wrapped connection	No
Deformed	No
Delaminated	No
Delustered	No
Dented	No
Deposits	No
Design deficiency	No
Detent action poor	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Deteriorated	No
Detonation	No
Differential zero	No
Dimension over maximum	No
Dimension under minimum	No
Dirty	No
Dirty, foreign matter	No
Discolored	No
Disconnected	No
Disengaged	No
Disintegrated	No
Dissimilar metal corrosion	No
Distorted-twisted	No
Distortion	No
Drifts	No
Droop	No
Drop-out time out of limit	No
Drops out	No
Dry	No
Dust damage	No
Eccentric	No
Elec caging defective	No
Electrical trouble	No
Elongated	No
Enabling transient, high	No
Engine failed to start	No
Engine mounts vibration	No
Engine removed, engine mod.	No
Engine removed, overhaul scheduled	No
Engine removed-a/c mod.	No
Engine vibration	No
Erection torque, high	No
Eroded	No
Erratic	No
Erratic torque indication	No
Erratic, engine power	No
Evaluation	No
Excessive "g" forces	No
Excessive current	No
Excessive hum	No
Excessive jitter	No
Excessive load	No
Excessive lubrication	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Excessive play	No
Exploded	No
Explosion-engine	No
Explosion-other	No
External power source	No
Failed to fire	No
Failed to operate	No
Fails diagnostic	No
Fails to open	No
Fails to position	No
Fails to recycle	No
Fails to regulate	No
Fails to stop	No
Fails to switch	No
Fails to tune or drifts	No
Fails to zero	No
Failure caused by other component failure	No
Fatigue cracks	No
Fatigue-mechanical	No
Fatigue-thermal	No
Faulty part, material	No
Feathered	No
Feedback incorrect	No
Fell out	No
Fil voltage, high	No
Fin, deflection, none	No
Fire damage	No
Fired irregularly	No
Firing signal malfunction	No
Fitting leak	No
Flame-out	No
Flash over	No
Flat	No
Flatten out	No
Fluctuates, unstable	No
Fluorescent indication	No
Folded	No
Foreign object damage	No
Foreign object damage, origin engine	No
Foreign object damage, origin exterior	No
Foreign object damage, origin unknown	No
Forward resistance high	No
Frayed	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Frequency erratic or incorrect	No
Friction excessive	No
Frozen	No
Fuel contamination-chemical compounds	No
Fuel contamination-fibrous material	No
Fuel contamination-organic matter (micro organism)	No
Fuel contamination-sand, grit or dirt	No
Fuel contamination-water	No
Fuel flow incorrect	No
Fuel flow low	No
Fuel nozzle coking	No
Fuel pressure erratic	No
Fuel saturated	No
Fuse blown	No
Galled	No
Gassey	No
Gouged	No
Grabbing	No
Grease leakage	No
Grooved	No
Grounded	No
Handling improper	No
Hard shifting	No
Heat damage	No
Heated	No
High current	No
High engine power	No
High freq. vibration	No
High idle	No
High null	No
High reading	No
High torque indication	No
High voltage breakdown	No
Hole in part	No
Hole, elongated/double punched	No
Hot firing damage	No
Hot start	No
Human error	No
Hung	No
Hydraulic contamination-metal	No
Hydraulic contamination-water	No
Hydro lock	No
Hysteresis	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Icing	No
ICO high	No
Identification illegible/poor, or rubs off	No
Impending or incipient failure indicated by spectro oil anal	No
Impending or incipient failure indicated by spectro oil anal	No
Improper amplitude	No
Improper assy. mfg.	No
Improper assy. User	No
Improper cycling	No
Improper datum	No
Improper directivity	No
Improper fit	No
Improper force	No
Improper frequency response	No
Improper handling	No
Improper identification	No
Improper lubrication	No
Improper maintenance	No
Improper motion	No
Improper operation	No
Improper pre-load on bearings	No
Improper pre-load on gears	No
Improper seated, poppet in valve	No
Improper source output	No
Improper time	No
Improper tracking	No
Improper trigger level	No
Improper viscosity	No
Improper weight	No
Improperly installed	No
Improperly machined	No
Improperly serviced	No
Inaccessible	No
Inclusions	No
Incomplete	No
Incorrect gain	No
Incorrect reading	No
Incorrect voltage	No
Indexed incorrectly	No
Inductance incorrect	No
Inoperative	No
Insect damage	No
Insufficient heat dissipation	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Insufficient insulation	No
Insufficient noise level	No
Insufficient protection from contamination	No
Insufficient protection from light	No
Insufficient protection from radiation	No
Insufficient specific gravity	No
Insulation breakdown	No
Insulation damage, mech.	No
Insulator flashover	No
Interference	No
Intermittent	No
Intermittent operation	No
Intermittent short	No
Internal failure	No
Jammed	No
Lack of lubrication	No
Lack of pressure, oxidizer tank	No
Lacks engr. and dwg. revisions	No
Leads, short (length)	No
Leakage, air pressure regulator	No
Leakage, propulsion air tank	No
Leakage, solenoid valve	No
Leaked (not electrical)	No
Leaking	No
Leaks fuel	No
Leaks oil	No
Link jam	No
Liquid lock	No
Lock on malfunction	No
Loose	No
Loose base	No
Loose elements	No
Loose or missing rivets	No
Lost in flight	No
Low 50/50 flows	No
Low engine power	No
Low flows	No
Low frequency vibration	No
Low gm or emission	No
Low idle	No
Low lub pressure	No
Low performance	No
Low power (electronic)	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Low power or thrust	No
Low reading	No
Low sensitivity	No
Low torque indication	No
Lubrication failure	No
Lubrication omitted	No
Magnetic indication	No
Maintenance error	No
Malfunctioning	No
Manufacturer defect	No
Marginal parts replaced	No
Mated power sec. Removed unnecessarily	No
Mechanical binding	No
Melted	No
Metal embedded	No
Metal fatigue	No
Metal on magnetic plug	No
Microphonic	No
Misaligned	No
Misdisposition	No
Misfires	No
Mishandled	No
Mismatched	No
Missing	No
Missing bolts, nuts, screws	No
Missing part	No
Miswired	No
Moisture saturation	No
Mud, accumulation	No
Mutilated	No
Nicked	No
No defect	No
No defect, component removed and/or reinstalled	No
No defective part, removed in trouble shooting	No
No defect-MWO compliance	No
No defect-MWO not applicable	No
No defect-MWO previously complied with	No
No defect-program requirements	No
No fuel cut off	No
No indicating lights	No
No oscillation	No
No output	No
No response	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
No start	No
No torqued indication	No
No vision	No
Noisy	No
Not damaged	No
Not determined-expl. Symptoms	No
Not evaluated	No
Not modified	No
Not reported	No
Obstructed	No
Oil breathing excessive	No
Oil consumption excessive	No
Oil consumption, high	No
Oil consumption, low	No
Oil contamination	No
Oil contamination-metal	No
Oil contamination-rust or corrosion products	No
Oil contamination-sand, grit, or dirt	No
Oil contamination-water	No
Oil leak	No
Oil pressure, erratic	No
Oil pressure, high	No
Oil pressure, indicator out	No
Oil pressure, low	No
Oil saturation	No
Oil temperature erratic	No
Oil temperature, high	No
Oil temperature, low	No
Oily	No
Old age	No
Open	No
Open filament or tube circuit	No
Open secondary	No
Open winding	No
Open wiring	No
Operating error	No
Operating rate too slow	No
Operations incomplete	No
Orifice, plugged	No
Oscillating	No
Out of adjustment	No
Out of balance	No
Out of parallel	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Out of phase	No
Out of position	No
Out of round	No
Out of specification (explain)	No
Out of square	No
Out of time	No
Out of tolerance minus	No
Out of tolerance plus	No
Output, incorrect	No
Output, none	No
Output, too high	No
Output, too low	No
Over lubricated	No
Overheated	No
Overheats	No
Overloaded	No
Overspeed	No
Overstressed	No
Oxidized	No
Packaging defective	No
Part not received for analysis	No
Parts loose	No
Parts omitted	No
Parts, improper	No
Parts, incompatibility	No
Peened	No
Performance unusual	No
Picked up	No
Pin sheared or missing	No
Pinched	No
Pitted	No
Poor bonding	No
Poor focus	No
Poor welding	No
Poor workmanship	No
Popped	No
Porous	No
Precessibility, high	No
Precessibility, low	No
Pressure too high	No
Pressure too low	No
Pressure, none	No
Pressures erratic	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Primer-none/wrong	No
Processing improper	No
Prop governing faulty electron	No
Prop governing faulty hydraulic	No
Publication error	No
Pulled loose	No
Pulled out	No
Punctured	No
Random error	No
Relay contact failure	No
Removed unnecessarily	No
Replacement, 100%	No
Resistance high	No
Resistance, incorrect	No
Resistance, low	No
Result of other component failure	No
Retraction failure	No
Rings out of level	No
Rolled over	No
Rough	No
Rpm beta governing faulty	No
Rpm bias, due to elec control	No
Rpm bogs down	No
Rpm droop round	No
Rpm fluctuation	No
Rpm hunting	No
Rpm none	No
Rpm too high	No
Rpm too low	No
Rubbing	No
Run out excessive	No
Runaway	No
Running leakage	No
Ruptured	No
Safety wire, omitted	No
Safety-wire, incorrect	No
Sand damage	No
Saturation resistance high	No
Scarred	No
Scheduled maintenance	No
Scored	No
Scraped	No
Scrapped or salvaged	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Scratched	No
Screen gird voltage low	No
Seal blown	No
Seal broken	No
Seal leaking	No
Seated, improperly	No
Seized	No
Sharp	No
Shattered	No
Sheared	No
Shifted	No
Shock load or sudden stop	No
Shorted	No
Shorted permanent	No
Shorted to case	No
Shorted to frame	No
Shorted to ground	No
Shorted to primary	No
Shorted wiring	No
Shorts, external	No
Shorts, internal	No
Slip ring or commutator failure	No
Slippage	No
Slippage or communication failure	No
Slow acceleration	No
Sluggish	No
Smoking	No
Solder deteriorated	No
Spalled	No
Speed incorrect	No
Split	No
Spread	No
Stained	No
Stalls-compressor	No
Starting stall	No
Static leakage	No
Steering incorrect	No
Stepped	No
Sticking	No
Sticks	No
Sticky	No
Stiffness	No
Stretched	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Stripped	No
Stripped threads	No
Structural failure	No
Stuck	No
Stuck indicator needle missile gauge	No
Sudden stop	No
Surface rough	No
Surged	No
Sweep malfunction	No
Swollen	No
Sync absent or incorrect	No
Tachometer out	No
Temperature incorrect	No
Temperature indication faulty	No
Temperature none	No
Temperature too high	No
Temperature too low	No
Tension incorrect	No
Tension under minimum (sprgs. and rings)	No
Tight	No
Timing, incorrect	No
Timing, off	No
Timing, too fast	No
Tire failure	No
Tooth broken on gear	No
Torching	No
Torn	No
Torque calibration a not obtained	No
Torque incorrect	No
Torque oil pressure, erratic	No
Torque unbalance, incorrect	No
Torque, low	No
Transportation damage	No
Twisted	No
Unable to adjust to limits	No
Unbalanced	No
Undersize	No
Undetermined	No
Unfeather slow	No
Unknown	No
Unstable	No
Unstable flight characteristics	No
Values, improper	No

Table C-1. Army Aviation Mishap Cause or Type of Failure

Cause/type of failure	Corrosion-related?
Vapor, lock	No
Vibration excessive	No
Video faulty	No
Voltage, erratic	No
Voltage, high	No
Voltage, low	No
Voltage, none	No
Warped	No
Warranty expired	No
Washed	No
Weak	No
Weak electrically	No
Weld cracked or broken	No
Wet	No
Wind damage	No
Winding shorted, term #	No
Wire pulled loose	No
Wire-broken	No
Within specified tolerance	No
Worn (less than 2,500 hrs.)	No
Worn excessively	No
Wrong part	No
Wrong part-position	No
Wrong part-size	No
Wrong size	No
Yaws	No

Appendix D
Investigative Terms

Table D-1 and Table D-2 contain the investigative terms we used to search the descriptive text fields. Table D-1 lists the investigative terms used in the AFCPCO study, and Table D-2 lists additional investigative terms. Mishaps that contain these investigative terms were further reviewed to identify their relationship to corrosion.

Table D-1. Investigative Search Terms

Investigative term from AFCPCO study
Bearing Failure
Binding
Blistered
Blush
Cass
Caustic Cracking
Caustic Embrittlement
Corrosion
Crack
Crateri
Crevice
Cure
Decay
Decomposition
Degeneration
Delamination
Deposition
Deterio
Deterioration
Disbond
Disintegration
Embrittlement
Environmental Crack
Environmental Stress Fracture
Environmentally Assisted Cracking
Exfoliate
Exfoliation

Investigative term from AFCPCO study
Flake
Fogged Metal
Fouling
Fracture
Fretting
Galling
Galvanic (Couple)
Grain Drop
Hot Crack
Hydration
Hydroly
Induced Cracking
Interdentric
Intergranular
Lapping
Matte
Mechanical Binding
Mechanical Bond
Moisture
Mottle
Oxidat
Oxidation
Oxide
Oxygen Attack
Ozone
Passivation
Passivity

Table D-1. Investigative Search Terms

Investigative term from AFCPCO study
Peening
Pitted
Pitting
Poor Bonding
Potentio
Rot
Rust
Scale
Selective Leaching
Silking

Investigative term from AFCPCO study
Skinning
Spalling
Splat
Stress
Stress Cracking
Terne
Warped
Wet
Wrinkling

Table D-2. Additional Investigative Search Terms

Investigative term, additional
Afoul
Bearing
Brittle
Brittleness
Corrodded
Corroded
Corroding
Corrosiion
Corrosions
Corrosive
Cracked
Cracking
Crackle
Crackling
Cracks
Cured
Decayed
Decaying
Delam
Delaminated
Delaminating
Delaminted
Deposit
Fouled
Fractured
Fractures
Fracturing
Intrusion
Microcracks
Moist
Oxidization
Peen
Peened
Pitt
Refractured

Investigative term, additional
Deposited
Depositing
Deposits
Deteriorate
Deteriorated
Deteriorating
Disbonded
Disbonding
Disintegrate
Disintegrated
Disintegrating
Disintergrated
Disintergration
Disintigrated
Embrittled
Environmental Degradation
Fatigue Cracking
Fatigue Fracturing
Flak
Flakes
Flaky
Foul
Foulded
Rusted
Rusty
Stress Fracture
Vibrapeened
Warp
Warpage
Warping
Warps
Wetness
Wrinkle
Wrinkles

Appendix E
Abbreviations

AFCPCO	Air Force Corrosion Prevention and Control Office
AIRRS	Aircraft Inventory Readiness and Reporting System
AvDEC	tri-service implementation of conductive gasket and floor-board types
AWBS	aviation work breakdown structure
CFFT	Corrosion Fleet Focus Team
CPI	Consumer Price Index
CPO	Corrosion Policy and Oversight office
DON	Department of the Navy
EITM	end item type model
GAO	Government Accountability Office
IPT	Integrated Product Team
MOA	memorandum of agreement
NAE	Naval Aviation Enterprise
NAVAIR	U.S. Navy Air Systems Command
NDA	nondisclosure agreement
OPNAVINST	Office of the Chief of Naval Operations Instruction
UAV	unmanned aerial vehicle
USACR/SC	U.S. Army Combat Readiness/Safety Center