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

NUMBER OF MISHAPS, COST, AND INJURIES

REPORT AKN31T4

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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>
<thead>
<tr>
<th>Service</th>
<th>Total mishaps</th>
<th>Total corrosion-related mishaps</th>
<th>Corrosion-related mishaps as a percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Army</td>
<td>4,664</td>
<td>87</td>
<td>1.9%</td>
</tr>
<tr>
<td>DON</td>
<td>8,445</td>
<td>179</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

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..
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.
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>
<thead>
<tr>
<th>Class</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Army</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>17</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>C</td>
<td>27</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>Army total</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
<tr>
<td>DON</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>14</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>B</td>
<td>19</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>C</td>
<td>76</td>
<td>49</td>
<td>125</td>
</tr>
<tr>
<td>DON total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Service</th>
<th>Corrosion-related mishaps</th>
<th>Aircraft total losses</th>
<th>Fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Army</td>
<td>9</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>DON</td>
<td>4</td>
<td>4</td>
<td>11</td>
</tr>
</tbody>
</table>

We also investigated corrosion-related mishaps by equipment type. For Army aviation, rotary aircraft accounted for 90 percent corrosion-related mishaps, $110 million1 (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

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>OH-58</td>
<td>Rotary</td>
<td>11</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>AH-64</td>
<td>Rotary</td>
<td>7</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>UH-1</td>
<td>Rotary</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>CH-47</td>
<td>Rotary</td>
<td>7</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>UH-60</td>
<td>Rotary</td>
<td>6</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total for all end items</strong></td>
<td></td>
<td><strong>51</strong></td>
<td><strong>36</strong></td>
<td><strong>87</strong></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>F-18</td>
<td>Fixed wing</td>
<td>13</td>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>F-14</td>
<td>Fixed wing</td>
<td>3</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>S-3</td>
<td>Fixed wing</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>SH-60</td>
<td>Rotary</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>P-3</td>
<td>Fixed wing</td>
<td>7</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total for all end items</strong></td>
<td></td>
<td><strong>109</strong></td>
<td><strong>70</strong></td>
<td><strong>179</strong></td>
</tr>
</tbody>
</table>
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
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 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 3-25. 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.”

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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:

\[
\text{Normalized cost} = \text{Actual reported cost} \times (1 + \% \text{ change in average CPI from FY1983}).
\]

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

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

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.”

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


Table 1-3. Event Severity Classification

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


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 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

<table>
<thead>
<tr>
<th>Class</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Total mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>17</td>
<td>29</td>
<td>811</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>13</td>
<td>620</td>
</tr>
<tr>
<td>C</td>
<td>27</td>
<td>45</td>
<td>3,233</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>87</td>
<td>4,664</td>
</tr>
</tbody>
</table>

**STUDY STEPS**

**Requesting Data**

We requested from the USACR/SC Army 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 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 “corrosion” and “corroded.” 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>
<thead>
<tr>
<th>Corrosion-related cause or type of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corroded</td>
</tr>
<tr>
<td>Fretting corrosion</td>
</tr>
<tr>
<td>Galvanic corrosion</td>
</tr>
<tr>
<td>Hot corrosion (sulfidation)</td>
</tr>
<tr>
<td>Hydrogen embrittlement</td>
</tr>
<tr>
<td>Insufficient protection from moisture</td>
</tr>
<tr>
<td>Intergranular corrosion</td>
</tr>
<tr>
<td>Moisture saturation</td>
</tr>
<tr>
<td>Paint peeling off</td>
</tr>
<tr>
<td>Peeled</td>
</tr>
<tr>
<td>Peeling</td>
</tr>
<tr>
<td>Pitted</td>
</tr>
<tr>
<td>Pitting corrosion</td>
</tr>
<tr>
<td>Rusty</td>
</tr>
<tr>
<td>Salt water damage</td>
</tr>
<tr>
<td>Stress corrosion</td>
</tr>
</tbody>
</table>
◆ **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

<table>
<thead>
<tr>
<th>Army aircraft mishap descriptive text fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCIDENT_DESCRIPTION</td>
</tr>
<tr>
<td>ANALYSIS</td>
</tr>
<tr>
<td>FINDINGS</td>
</tr>
<tr>
<td>RECOMMENDATIONS</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>Investigative terms</th>
<th>Text description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>Cause</td>
<td>Corrosion</td>
<td>Fracture</td>
</tr>
<tr>
<td>Factor</td>
<td>Corrosion</td>
<td>Stress</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>Investigative terms</th>
<th>Text description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not corrosion-related</td>
<td>Corrosion</td>
<td>…The bearing races appeared to be in good serviceable condition. No corrosion pitting &amp; progressive type failures were noted…</td>
</tr>
<tr>
<td></td>
<td>Pitting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bearing</td>
<td></td>
</tr>
<tr>
<td>Not corrosion-related</td>
<td>Corrosion</td>
<td>…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…</td>
</tr>
<tr>
<td></td>
<td>Decaying</td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Fixed-wing aircraft</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
</tr>
<tr>
<td>M</td>
<td>Missiles</td>
</tr>
<tr>
<td>E</td>
<td>Engines</td>
</tr>
<tr>
<td>X</td>
<td>Common use across aircraft types</td>
</tr>
</tbody>
</table>

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**

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

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

<table>
<thead>
<tr>
<th>Class</th>
<th>Mishaps in which corrosion was the cause or a factor</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>29</td>
<td>33%</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>15%</td>
</tr>
<tr>
<td>C</td>
<td>45</td>
<td>52%</td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
<td>100%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Aircraft total losses</th>
<th>Corrosion-related cost (in millions)</th>
<th>Percentage of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>AH-64</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>$20.394</td>
</tr>
<tr>
<td>UH-60</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>$0.011</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>$20.405</td>
</tr>
</tbody>
</table>
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.
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.

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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related mishap cost (in millions)</th>
<th>Percentage of total corrosion-related cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R</td>
<td>45</td>
<td>33</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>6</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R</td>
<td>45</td>
<td>33</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>6</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>AWBS 3rd/4th character</th>
<th>System description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Engines</td>
<td></td>
<td>14</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>03 Landing gear</td>
<td></td>
<td>9</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>05 Rotor and propeller system</td>
<td></td>
<td>5</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>02 Airframe</td>
<td></td>
<td>7</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>20 Consumables and toolbox hardware</td>
<td></td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
Table 2-14. Systems with the Highest Number of Corrosion-Related Mishaps, FY1983–FY2013

<table>
<thead>
<tr>
<th>AWBS 3rd/4th character</th>
<th>System description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>Power distribution and electrical</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>07</td>
<td>Hydraulics/pneudraulics</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>35</td>
<td>Armament</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Fuel System</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>06</td>
<td>Drive System</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>All other systems</td>
<td></td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total for all systems</td>
<td></td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Landing gear</td>
<td>8</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Engine bearing</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Gas turbine engine</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Rotor blade</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Turboshaft engine</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>All other objects</td>
<td>32</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Total for all objects</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related mishap cost (in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Circuit breaker</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rotor blade</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Engine bearing</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Servocylinder</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Hanger bearing</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>All other objects</td>
<td>43</td>
<td>28</td>
<td>71</td>
</tr>
<tr>
<td>Total for all objects</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Engine bearing</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Gas turbine engine</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Rotary compressor</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Rotor blade</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Nuts and bolts</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Pneumatic components</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Gearshaft</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hanger bearing</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hinge</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Driveshaft</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Engine compressor</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Clevis</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Compressor</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Servocylinder</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2-20. Corrosion-Related Failed Objects Associated with Army Aviation Mishaps that Resulted in Total Loss of Aircraft, FY1983–FY2013

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Structural support</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Washer</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Circuit breaker</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Blade</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Engine fuel system</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Main rotor</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>All other objects</td>
<td>29</td>
<td>20</td>
<td>49</td>
</tr>
<tr>
<td>Total for all objects</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Washer</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Circuit breaker</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Clevis</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Engine bearing</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Servocylinder</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Hinge</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Blade</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gearshaft</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Structural support</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>All other objects</td>
<td>41</td>
<td>29</td>
<td>70</td>
</tr>
<tr>
<td>Total for all objects</td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>OH-58</td>
<td>R</td>
<td>11</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>AH-64</td>
<td>R</td>
<td>7</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>UH-1</td>
<td>R</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>CH-47</td>
<td>R</td>
<td>7</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>UH-60</td>
<td>R</td>
<td>6</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>AH-1</td>
<td>R</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>MH-6</td>
<td>R</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>MH-47</td>
<td>R</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Q-7</td>
<td>F</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>OH-6</td>
<td>R</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>All others</td>
<td></td>
<td>10</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>51</td>
<td>36</td>
<td>87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>UH-60</td>
<td>R</td>
<td>6</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>MH-47</td>
<td>R</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>OH-58</td>
<td>R</td>
<td>11</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>UH-1</td>
<td>R</td>
<td>7</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>AH-64</td>
<td>R</td>
<td>7</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>All others</td>
<td></td>
<td>20</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>Total of all EITMs</td>
<td></td>
<td>51</td>
<td>87</td>
<td>23</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH-58</td>
<td>R</td>
<td>11</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>AH-64</td>
<td>R</td>
<td>7</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>UH-1</td>
<td>R</td>
<td>7</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>UH-60</td>
<td>R</td>
<td>6</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>CH-47</td>
<td>R</td>
<td>7</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>All others</td>
<td></td>
<td>13</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>Total for all EITMs</td>
<td></td>
<td>51</td>
<td>87</td>
<td>25</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Class</th>
<th>AFCPCO Air Force study</th>
<th>Army aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mishaps</td>
<td>Percentage of total mishaps</td>
</tr>
<tr>
<td>A + B</td>
<td>5,749</td>
<td>4%</td>
</tr>
<tr>
<td>C</td>
<td>124,319</td>
<td>96%</td>
</tr>
<tr>
<td>Total</td>
<td>130,068</td>
<td>100%</td>
</tr>
</tbody>
</table>

The large proportion of Air Force Class C mishaps (compared to Army aviation mishaps) led us to assume 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

<table>
<thead>
<tr>
<th>Class</th>
<th>AFCPCO Air Force study</th>
<th>Army aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corrosion-related mishaps</td>
<td>Total mishaps</td>
</tr>
<tr>
<td>A + B</td>
<td>90</td>
<td>5,749</td>
</tr>
<tr>
<td>C</td>
<td>233</td>
<td>124,319</td>
</tr>
<tr>
<td>Total</td>
<td>323</td>
<td>130,068</td>
</tr>
</tbody>
</table>

\(^a\) 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

<table>
<thead>
<tr>
<th>Class</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Total mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td>27</td>
</tr>
<tr>
<td>A</td>
<td>14</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>B</td>
<td>19</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>C</td>
<td>76</td>
<td>49</td>
<td>125</td>
</tr>
<tr>
<td>Total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

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 “Corrosion” and “Corroded.” 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>
<thead>
<tr>
<th>DON aviation mishap descriptive text fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVENT_SHORT_NARRATIVE</td>
</tr>
<tr>
<td>EVENT_NARR</td>
</tr>
<tr>
<td>DMG_CMTS</td>
</tr>
<tr>
<td>HFACS_EVENT_CMTS</td>
</tr>
<tr>
<td>INVLVD_FAC_NARR</td>
</tr>
<tr>
<td>PRIV-MISHAP_ANALYSIS_NARR</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>1st investigative term</th>
<th>2nd investigative term</th>
<th>3rd investigative term</th>
<th>Phrase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause</td>
<td>Corrosion</td>
<td>Intergranular</td>
<td>Cracking</td>
<td>...Cause factor: Material failure - engine first stage turbine airseal/second stage vane positioning lugs failed due to stress corrosion and intergranular cracking...</td>
</tr>
<tr>
<td>Factor</td>
<td>Corrosion</td>
<td>Deterioration</td>
<td>Intergranular</td>
<td>...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...</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>1st investigative term</th>
<th>2nd investigative term</th>
<th>3rd investigative term</th>
<th>Phrase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not corrosion-related</td>
<td>Corrosion</td>
<td>Fracture</td>
<td>Stress</td>
<td>...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....</td>
</tr>
<tr>
<td>Not corrosion-related</td>
<td>Corrosion</td>
<td>Fracture</td>
<td>Cracking</td>
<td>...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...</td>
</tr>
</tbody>
</table>
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. 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>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Fixed wing aircraft</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
</tr>
<tr>
<td>M</td>
<td>Missiles</td>
</tr>
<tr>
<td>E</td>
<td>Engines</td>
</tr>
<tr>
<td>X</td>
<td>Common use across aircraft types</td>
</tr>
</tbody>
</table>

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.

---

Table 3-6. AWBS System Codes

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

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

<table>
<thead>
<tr>
<th>Class</th>
<th>Mishaps in which corrosion was the cause or a factor</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>27</td>
<td>15%</td>
</tr>
<tr>
<td>B</td>
<td>27</td>
<td>15%</td>
</tr>
<tr>
<td>C</td>
<td>125</td>
<td>70%</td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td>100%</td>
</tr>
</tbody>
</table>
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, non-destructive 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.
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 ($49.7 million) 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.
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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Mishaps in which corrosion was a factor</th>
<th>Corrosion-related mishaps</th>
<th>Aircraft total losses</th>
<th>Corrosion-related cost (in millions)</th>
<th>Percentage of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-18</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>$20.961</td>
<td>42%</td>
</tr>
<tr>
<td>P-3</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>$13.929</td>
<td>28%</td>
</tr>
<tr>
<td>T-45</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>$11.558</td>
<td>23%</td>
</tr>
<tr>
<td>KC-130</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>$3.042</td>
<td>6%</td>
</tr>
<tr>
<td>CH-53</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>$.049</td>
<td>0%</td>
</tr>
<tr>
<td>T-34</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>$.045</td>
<td>0%</td>
</tr>
<tr>
<td>S-3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>$.043</td>
<td>0%</td>
</tr>
<tr>
<td>SH-60</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>$.027</td>
<td>0%</td>
</tr>
<tr>
<td>E-2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>$.008</td>
<td>0%</td>
</tr>
</tbody>
</table>
Table 3-8. DON Aviation Corrosion-Related Mishaps, Aircraft Total Losses, and Costs by TMS for FY1998

<table>
<thead>
<tr>
<th>End item type</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Aircraft total losses</th>
<th>Corrosion-related cost (in millions)</th>
<th>Percentage of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>8</td>
<td>5</td>
<td>13</td>
<td>3</td>
<td>$49.663</td>
</tr>
</tbody>
</table>

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, 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
Effects of Corrosion on DON Aviation Mishaps

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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td>total</td>
</tr>
<tr>
<td>F</td>
<td>Fixed-wing aircraft</td>
<td>77</td>
<td>55</td>
<td>132</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
<td>32</td>
<td>15</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

To understand the high percentage of corrosion-related fixed-wing mishaps, we used the equipment list inventory gathered from other corrosion reports3, 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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Average annual inventory</th>
<th>Percentage of total average annual inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Fixed-wing aircraft</td>
<td>3,202</td>
<td>69%</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
<td>1,425</td>
<td>31%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3,627</td>
<td>100%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related mishap cost (in millions)</th>
<th>Percentage of total corrosion-related cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Fixed-wing</td>
<td>77</td>
<td>55</td>
<td>132</td>
<td>$236</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
<td>32</td>
<td>15</td>
<td>47</td>
<td>$28</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
<td>$264</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>End item type</th>
<th>Description</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Fixed-wing</td>
<td>77</td>
<td>55</td>
<td>132</td>
<td>15</td>
</tr>
<tr>
<td>R</td>
<td>Rotary aircraft</td>
<td>32</td>
<td>15</td>
<td>47</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
<td>19</td>
</tr>
</tbody>
</table>

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

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

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 Mispah Costs by AWBS Major System Character, FY1983–FY2013

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

<table>
<thead>
<tr>
<th>AWBS character</th>
<th>System description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>03</td>
<td>Landing gear</td>
<td>39</td>
<td>18</td>
<td>57</td>
</tr>
<tr>
<td>02</td>
<td>Airframe</td>
<td>21</td>
<td>13</td>
<td>34</td>
</tr>
<tr>
<td>09</td>
<td>Miscellaneous aircraft</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>20</td>
<td>Consumables and toolbox hardware</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>01</td>
<td>Engines</td>
<td>7</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>All other systems</td>
<td>31</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>AWBS character</th>
<th>System description</th>
<th>Mishaps in which corrosion was the cause</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>Airframe</td>
<td>21</td>
<td>13</td>
<td>34</td>
</tr>
<tr>
<td>11</td>
<td>Flight control</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Fuel system</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>03</td>
<td>Landing gear</td>
<td>39</td>
<td>18</td>
<td>57</td>
</tr>
<tr>
<td>09</td>
<td>Miscellaneous aircraft</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>All other systems</td>
<td>34</td>
<td>29</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was…</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Landing gear</td>
<td>11</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Nose landing gear</td>
<td>13</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Bearing</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Body, frame, or hull</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Landing gear strut</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>All other objects</td>
<td>76</td>
<td>48</td>
<td>124</td>
</tr>
<tr>
<td>Total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Failed object</th>
<th>Mishaps in which corrosion was…</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related mishap cost ($ in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Nose landing gear</td>
<td>13</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Actuator</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reservoir</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Landing gear</td>
<td>11</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Conduit</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>All other objects</td>
<td>84</td>
<td>51</td>
<td>135</td>
</tr>
<tr>
<td>Total</td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>
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

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

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.
### 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**

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Percentage of total corrosion-related mishaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>F-18</td>
<td>F</td>
<td>13</td>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>F-14</td>
<td>F</td>
<td>3</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>S-3</td>
<td>F</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>SH-60</td>
<td>R</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>P-3</td>
<td>F</td>
<td>7</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>AV-8</td>
<td>F</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>E-2</td>
<td>F</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>CH-53</td>
<td>R</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>SH-3</td>
<td>R</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>KC-130</td>
<td>F</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>All others</td>
<td></td>
<td>45</td>
<td>24</td>
<td>69</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

---

*Effects of Corrosion on DON Aviation Mishaps*
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*

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>CH-53</td>
<td>R</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>UH-46</td>
<td>R</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AH-1</td>
<td>R</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>F-14</td>
<td>F</td>
<td>3</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>All others</td>
<td>100</td>
<td>56</td>
<td>156</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>

**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*

<table>
<thead>
<tr>
<th>EITM</th>
<th>End item type</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related aircraft total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>F-18</td>
<td>F</td>
<td>13</td>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>F-14</td>
<td>F</td>
<td>3</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>P-3</td>
<td>F</td>
<td>7</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>T-45</td>
<td>F</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>AV-8</td>
<td>F</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>All others</td>
<td>78</td>
<td>37</td>
<td>115</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>109</td>
<td>70</td>
<td>179</td>
</tr>
</tbody>
</table>
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*

<table>
<thead>
<tr>
<th>Class</th>
<th>AFCPCO Air Force study</th>
<th>DON aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mishaps</td>
<td>Percentage of total</td>
</tr>
<tr>
<td>A + B</td>
<td>5,749</td>
<td>4%</td>
</tr>
<tr>
<td>C</td>
<td>124,319</td>
<td>96%</td>
</tr>
<tr>
<td>Total</td>
<td>130,068</td>
<td>100%</td>
</tr>
</tbody>
</table>

The large proportion of Air Force Class C mishaps (compared to DON aviation mishaps) led us to assume 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*

<table>
<thead>
<tr>
<th>Class</th>
<th>AFCPCO Air Force study</th>
<th>DON aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corrosion-related mishaps</td>
<td>Total mishaps</td>
</tr>
<tr>
<td>A + B</td>
<td>90</td>
<td>5,749</td>
</tr>
<tr>
<td>C</td>
<td>233</td>
<td>124,319</td>
</tr>
<tr>
<td>Total</td>
<td>323</td>
<td>130,068</td>
</tr>
</tbody>
</table>

*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.
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

<table>
<thead>
<tr>
<th>Service</th>
<th>Aviation mishaps</th>
<th>Corrosion-related aviation mishaps</th>
<th>Corrosion-related mishaps as a percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Army</td>
<td>4,664</td>
<td>87</td>
<td>1.9%</td>
</tr>
<tr>
<td>DON</td>
<td>8,445</td>
<td>179</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

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 cause 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

<table>
<thead>
<tr>
<th>Service</th>
<th>Mishaps in which corrosion was...</th>
<th>Corrosion-related mishaps</th>
<th>Corrosion-related fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the cause</td>
<td>a factor</td>
<td></td>
</tr>
<tr>
<td>Army</td>
<td>17</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>DON</td>
<td>14</td>
<td>13</td>
<td>27</td>
</tr>
</tbody>
</table>
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

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

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.”

Understanding this definition will help investigators identify mishaps related to corrosion.

---

Table A-1 and 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

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

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

<table>
<thead>
<tr>
<th>Start Date</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 August 1982</td>
<td>≥ $200,000</td>
<td>$50,000–$199,999</td>
<td>$700–$49,999</td>
</tr>
<tr>
<td>1 October 1983</td>
<td>≥ $500,000</td>
<td>$100,000–$499,999</td>
<td>$10,000–$99,999</td>
</tr>
<tr>
<td>1 October 1988</td>
<td>≥ $1,000,000</td>
<td>$200,000–$999,999</td>
<td>$10,000–$99,999</td>
</tr>
<tr>
<td>1 October 2001</td>
<td>≥ $1,000,000</td>
<td>$200,000–$999,999</td>
<td>$20,000–$199,999</td>
</tr>
<tr>
<td>1 October 2009</td>
<td>≥ $2,000,000</td>
<td>$500,000–$1,999,999</td>
<td>$50,000–$499,999</td>
</tr>
</tbody>
</table>

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*

<table>
<thead>
<tr>
<th>Date</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY1983–FY2013</td>
<td>Fatal, permanent total disability, missing and presumed dead</td>
<td>Permanent partial disability(^a)</td>
<td>Lost workday case–days away from work</td>
</tr>
</tbody>
</table>

\(^a\) 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

<table>
<thead>
<tr>
<th>Start Date</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 October 1982</td>
<td>$\geq 200,000$</td>
<td>$50,000–$199,999$</td>
<td>$300–$49,999$</td>
</tr>
<tr>
<td>30 November 1982</td>
<td>$\geq 500,000$</td>
<td>$100,000–$499,999$</td>
<td>$10,000–$99,999$</td>
</tr>
<tr>
<td>27 February 1986</td>
<td>$\geq 1,000,000$</td>
<td>$200,000–$999,999$</td>
<td>$10,000–$199,999$</td>
</tr>
<tr>
<td>1 March 2001</td>
<td>$\geq 1,000,000$</td>
<td>$200,000–$999,999$</td>
<td>$20,000–$199,999$</td>
</tr>
<tr>
<td>1 October 2009</td>
<td>$\geq 2,000,000$</td>
<td>$500,000–$1,999,999$</td>
<td>$50,000–$499,999$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY1983–FY2013</td>
<td>Fatal, permanent total disability, missing and presumed dead</td>
<td>Permanent partial disability</td>
<td>Lost workday case—days away from work</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cause/type of failure</th>
<th>Corrosion-related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corroded</td>
<td>Yes</td>
</tr>
<tr>
<td>Fretting corrosion</td>
<td>Yes</td>
</tr>
<tr>
<td>Galvanic corrosion</td>
<td>Yes</td>
</tr>
<tr>
<td>Hot corrosion (sulfidation)</td>
<td>Yes</td>
</tr>
<tr>
<td>Hydrogen embrittlement</td>
<td>Yes</td>
</tr>
<tr>
<td>Insufficient protection from moisture</td>
<td>Yes</td>
</tr>
<tr>
<td>Intergranular corrosion</td>
<td>Yes</td>
</tr>
<tr>
<td>Moisture saturation</td>
<td>Yes</td>
</tr>
<tr>
<td>Paint peeling off</td>
<td>Yes</td>
</tr>
<tr>
<td>Peeled</td>
<td>Yes</td>
</tr>
<tr>
<td>Peeling</td>
<td>Yes</td>
</tr>
<tr>
<td>Pitted</td>
<td>Yes</td>
</tr>
<tr>
<td>Pitting corrosion</td>
<td>Yes</td>
</tr>
<tr>
<td>Rusty</td>
<td>Yes</td>
</tr>
<tr>
<td>Salt water damage</td>
<td>Yes</td>
</tr>
<tr>
<td>Stress corrosion</td>
<td>Yes</td>
</tr>
<tr>
<td>Sunlight damage</td>
<td>Yes</td>
</tr>
<tr>
<td>Weather damage</td>
<td>Maybe</td>
</tr>
<tr>
<td>A/C elec. power loss</td>
<td>No</td>
</tr>
<tr>
<td>A/C elec. system faulty</td>
<td>No</td>
</tr>
<tr>
<td>A/C fire warning light</td>
<td>No</td>
</tr>
<tr>
<td>A/C fuel system faulty</td>
<td>No</td>
</tr>
<tr>
<td>A/C oil system faulty</td>
<td>No</td>
</tr>
<tr>
<td>A/C temp. indication error</td>
<td>No</td>
</tr>
<tr>
<td>Abraded</td>
<td>No</td>
</tr>
<tr>
<td>Accepted as is</td>
<td>No</td>
</tr>
<tr>
<td>Activates incorrectly</td>
<td>No</td>
</tr>
<tr>
<td>Adjusted</td>
<td>No</td>
</tr>
<tr>
<td>Adjustment improper</td>
<td>No</td>
</tr>
<tr>
<td>Admits dust</td>
<td>No</td>
</tr>
<tr>
<td>Air leak</td>
<td>No</td>
</tr>
<tr>
<td>Air leak A/C system</td>
<td>No</td>
</tr>
<tr>
<td>Air leak closed bleed</td>
<td>No</td>
</tr>
<tr>
<td>Air leak open bleed</td>
<td>No</td>
</tr>
</tbody>
</table>
## Table C-1. Army Aviation Mishap Cause or Type of Failure

<table>
<thead>
<tr>
<th>Cause/type of failure</th>
<th>Corrosion-related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air leak, faulty gasket</td>
<td>No</td>
</tr>
<tr>
<td>Air start failure</td>
<td>No</td>
</tr>
<tr>
<td>Alignment improper</td>
<td>No</td>
</tr>
<tr>
<td>Ammeter pegged</td>
<td>No</td>
</tr>
<tr>
<td>Arcing, arced</td>
<td>No</td>
</tr>
<tr>
<td>Arithmetic error</td>
<td>No</td>
</tr>
<tr>
<td>Armature dirty</td>
<td>No</td>
</tr>
<tr>
<td>Attack display malfunction</td>
<td>No</td>
</tr>
<tr>
<td>Audio and video faulty</td>
<td>No</td>
</tr>
<tr>
<td>Audio faulty</td>
<td>No</td>
</tr>
<tr>
<td>Backed off (or out)</td>
<td>No</td>
</tr>
<tr>
<td>Backfiring</td>
<td>No</td>
</tr>
<tr>
<td>Base-to-collector, short</td>
<td>No</td>
</tr>
<tr>
<td>Base-to-emitter, open</td>
<td>No</td>
</tr>
<tr>
<td>Battered</td>
<td>No</td>
</tr>
<tr>
<td>Bearing failure</td>
<td>No</td>
</tr>
<tr>
<td>Bent</td>
<td>No</td>
</tr>
<tr>
<td>Beyond specified tolerance</td>
<td>No</td>
</tr>
<tr>
<td>Binding</td>
<td>No</td>
</tr>
<tr>
<td>Blistered</td>
<td>No</td>
</tr>
<tr>
<td>Blown</td>
<td>No</td>
</tr>
<tr>
<td>Bolts-nuts-screws loose</td>
<td>No</td>
</tr>
<tr>
<td>Bosses not cast in proper location</td>
<td>No</td>
</tr>
<tr>
<td>Bound together</td>
<td>No</td>
</tr>
<tr>
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### Table C-1. Army Aviation Mishap Cause or Type of Failure

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<td>Cloudy</td>
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Table C-1. Army Aviation Mishap Cause or Type of Failure

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

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<th>Cause/type of failure</th>
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### Table C-1. Army Aviation Mishap Cause or Type of Failure

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

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

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

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

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<td>Tachometer out</td>
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<td>Temperature incorrect</td>
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<td>Temperature indication faulty</td>
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<td>Temperature none</td>
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<td>Temperature too high</td>
<td>No</td>
</tr>
<tr>
<td>Temperature too low</td>
<td>No</td>
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<tr>
<td>Tension incorrect</td>
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</tr>
<tr>
<td>Tension under minimum (sprgs. and rings)</td>
<td>No</td>
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<tr>
<td>Tight</td>
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<tr>
<td>Timing, incorrect</td>
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<td>Timing, off</td>
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<tr>
<td>Timing, too fast</td>
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</tr>
<tr>
<td>Tire failure</td>
<td>No</td>
</tr>
<tr>
<td>Tooth broken on gear</td>
<td>No</td>
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<tr>
<td>Torching</td>
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<tr>
<td>Tom</td>
<td>No</td>
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<td>Torque calibration a not obtained</td>
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</tr>
<tr>
<td>Torque incorrect</td>
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<tr>
<td>Torque oil pressure, erratic</td>
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<tr>
<td>Torque unbalance, incorrect</td>
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</tr>
<tr>
<td>Torque, low</td>
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</tr>
<tr>
<td>Transportation damage</td>
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<tr>
<td>Twisted</td>
<td>No</td>
</tr>
<tr>
<td>Unable to adjust to limits</td>
<td>No</td>
</tr>
<tr>
<td>Unbalanced</td>
<td>No</td>
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<tr>
<td>Undersize</td>
<td>No</td>
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<td>Undetermined</td>
<td>No</td>
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<td>Unfeather slow</td>
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<td>Unknown</td>
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<td>Unstable</td>
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<td>Unstable flight characteristics</td>
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<td>Values, improper</td>
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### Table C-1. Army Aviation Mishap Cause or Type of Failure

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

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<tr>
<th>Investigative term from AFCPCO study</th>
<th>Investigative term from AFCPCO study</th>
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<tbody>
<tr>
<td>Bearing Failure</td>
<td>Flake</td>
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<tr>
<td>Binding</td>
<td>Fogged Metal</td>
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<tr>
<td>Blistered</td>
<td>Fouling</td>
</tr>
<tr>
<td>Blush</td>
<td>Fracture</td>
</tr>
<tr>
<td>Cass</td>
<td>Fretting</td>
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<tr>
<td>Caustic Cracking</td>
<td>Gallling</td>
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<tr>
<td>Caustic Embrittlement</td>
<td>Galvanic (Couple)</td>
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<tr>
<td>Corrosion</td>
<td>Grain Drop</td>
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<td>Hot Crack</td>
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<td>Crateri</td>
<td>Hydration</td>
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<td>Crevice</td>
<td>Hydroly</td>
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<tr>
<td>Cure</td>
<td>Induced Cracking</td>
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<td>Decay</td>
<td>Interdentic</td>
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<tr>
<td>Decomposition</td>
<td>Intergranular</td>
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<td>Degeneration</td>
<td>Lapping</td>
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<tr>
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<td>Matte</td>
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<tr>
<td>Deposition</td>
<td>Mechanical Binding</td>
</tr>
<tr>
<td>Deterio</td>
<td>Mechanical Bond</td>
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<tr>
<td>Deterioration</td>
<td>Moisture</td>
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<tr>
<td>Disbond</td>
<td>Mottle</td>
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<td>Disintegration</td>
<td>Oxidat</td>
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<tr>
<td>Embrittlement</td>
<td>Oxidation</td>
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<td>Environmental Crack</td>
<td>Oxide</td>
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<td>Environmental Stress Fracture</td>
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<td>Environmentally Assisted Cracking</td>
<td>Ozone</td>
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<td>Exfoliate</td>
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<td>Spalling</td>
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<td>Potentio</td>
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<td>Rot</td>
<td>Terne</td>
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<td>Rust</td>
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<td>Scale</td>
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<td>Selective Leaching</td>
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## Table D-2. Additional Investigative Search Terms

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<td>Fatigue Cracking</td>
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<td>Intrusion</td>
<td>Vibrapeened</td>
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<td>Microcracks</td>
<td>Warp</td>
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<td>Moist</td>
<td>Warpage</td>
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<td>Oxidization</td>
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<td>Wetness</td>
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<td>Pitt</td>
<td>Wrinkle</td>
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## Appendix E
### Abbreviations

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