STRUCTURAL TEARDOWN AND ANALYSIS: EVOLUTION OF THE TEARDOWN PROCESS

A Dissertation by

Melinda Laubach-Hock

Masters of Science, Wichita State University, 2003

Bachelors of Science, Wichita State University, 2002

Submitted to the Department of Aerospace Engineering and the faculty of the Graduate School of Wichita State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

December 2011
STRUCTURAL TEARDOWN AND ANALYSIS: EVOLUTION OF THE TEARDOWN PROCESS

The following faculty members have examined the final copy of this dissertation for form and content, and recommended that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy with a major in Aerospace Engineering.

________________________________________
John Tomblin, Committee Chair

________________________________________
Charles Yang, Committee Member

________________________________________
Suresh Keshavanarayana, Committee Member

________________________________________
Bob Minaie, Committee Member

________________________________________
Gregory Shoales, Committee Member

Accepted for the College of Engineering

________________________________________
Zulma Toro-Ramos, Dean

Accepted for the Graduate School

________________________________________
J. David McDonald, Dean
DEDICATION

To my loving husband, my kids, and the rest of my family
I am eternally grateful to all my family, friends, and colleagues that have provided guidance throughout my academic career. It was your continual support and encouragement that allowed me to complete my doctoral degree and continue to pursue my professional goals in the field of engineering.

I would like to thank Dr. John Tomblin for his guidance and never-ending support throughout my entire post secondary education as my advisor. Without his continual support and encouragement, I may not have survived this process. I would also like to thank members of my committee: Dr. Charles Yang, Dr. Suresh Keshavanarayana and Dr. Bob Minaie, for their time, effort, thoughts, and suggestions to improve this work. I am also grateful to Betty Woodrow and Jane Hatfield for providing proofreading and formatting assistance. Without your support this document would likely be a jumbled mess of ideas and misplaced commas.

I would particularly like to express my personal thanks and gratitude to Dr. Gregory Shoales for his guidance and encouragement. Dr. Shoales has served as my mentor and friend through this entire process and is single handedly responsible for maintaining my sanity over the past five years. From the late night, panicked phone calls to the moments I doubted myself the most, Greg has been there to calm me down and redirect my focus to making positive steps to accomplish my educational and professional goals.

I would like to thank my parents, Richard and Diane, for pushing me to pursue my dreams to become an engineer and forcing me to further my education. From the time I decided to be an engineer that “built airplanes” in grade school you have never doubted my ability to accomplish anything I set my mind to, regardless how crazy everyone else thought I was. I would also like to thank my sister, Tiffany, for setting the bar so high and forcing me to catch up.
Being four years younger than me and getting her PhD in genetics nearly two years ago motivated me to play catch up and complete this degree. I am so proud of everything you have accomplished. Your drive and perseverance continues to amaze me.

Finally, I would like to thank my loving husband, R.J., and my kids Reese, Madison, and Mason, for sticking with me through all the good times and bad, late nights, and frustrating days. R.J., you have supportively put up with so many times of me saying “just one more minute” only to be sitting patiently waiting for my attention hours later. I wholeheartedly appreciate all the sacrifices you have made for me to complete this degree. You have always lifted up my spirits and forced me to believe I can do anything no matter how impossible I felt the task was at the time.

Reese, Madison, and Mason, you have served as my drive to continually improve and make you proud. I appreciate you understanding (maybe in your own little ways) all the times that Mommy was busy and couldn’t play with you or give you attention exactly at the moment you wanted it. I am also thankful for all the times you “played quietly” so Mommy could finish this paper. Reese, thank you for being such a “big sister” by helping take care of your brother while I worked and setting a great example for your little sister. Madison, thank you for being a “big sister” by helping take care of your brother while I worked and understanding all the times Mommy had to work. Mason, my baby, thank you for not screaming to be held continually while Mommy tried to finish this paper. I love you all “big much.”
ABSTRACT

Due to current economic conditions, aircraft are being operated to their design life and often beyond. In order to assess the true condition of these aging aircraft structures, structural teardowns have become more common over the past decade. Teardown data fidelity is highly dependent on the processes developed and implemented to gather the data; therefore, improper procedure selection often results in the destruction or degradation of teardown findings. Incorrect implementation of procedures also occurs during teardown programs and frequently results in increased scatter in the teardown data, which leads to difficulty interpreting the data and applying the results to the fleet.

No detailed teardown planning process currently exists that incorporates lessons learned from previous programs. Common problems have occurred in recent teardown programs resulting in increased costs, schedule, and capacity requirements, and likely degradation or destruction of teardown data due to the lack of a defined process. A universally accepted teardown planning process would drastically reduce, or eliminate, these recurring problems.

This research provides a step-by-step process for planning and executing a structural teardown program with the goal of minimizing or eliminating problems encountered during past teardown programs. The developed process defines four steps to plan and three steps to execute a structural teardown. Each of these seven steps provides specific recommendations to avoid common pitfalls of previous teardown programs. Four case studies of previous and ongoing teardowns are discussed and the methods implemented are compared to the proposed teardown process to assess potential improvements when using the proposed method. Costs of the proposed process are also compared to costs of the case study teardown programs to weight technical benefit versus increased cost.
TABLE OF CONTENTS

Chapter | Page
--- | ---
1. INTRODUCTION AND BACKGROUND | 1
   1.1 Structural Teardown and Analysis Defined | 2
   1.2 Purpose of Structural Teardown and Analysis | 5
     1.2.1 Governing Documents for Structural Teardown | 5
     1.2.2 Engineering Motivations for Structural Teardown | 8
   1.3 Procedures Guidance | 20
     1.3.1 TTCP | 20
     1.3.2 PASTA | 21
   1.4 Issues Common to Past Teardowns | 21
     1.4.1 Lack of Definition in Goals and Objectives | 22
     1.4.2 Lack of Planning Prior to Execution | 22
     1.4.3 Flexible Requirement Definition | 23
     1.4.4 Incomplete Documentation of Teardown Processes | 23
   1.5 Proposed Process for Developing a Structural Teardown Program | 24
   1.6 C/KC-135 Teardown and Analysis Program | 27
   1.7 Research Goals and Objectives | 28

2. DEVELOPMENT OF GOALS AND OBJECTIVES FOR A TEARDOWN PROGRAM | 30
   2.1 Questions to Ask | 30
   2.2 Trade Offs | 46

3. TEARDOWN ARTICLE SELECTION | 49
   3.1 Typical Factors to Article Selection | 50
     3.1.1 Budget, Schedule and Teardown Article Availability | 50
     3.1.2 Teardown Article Depth vs. Breadth | 51
     3.1.3 Operational Article vs. Full Scale Test Article | 55
     3.1.4 Effect of Sample Size | 56
   3.2 Teardown Article Selection Process | 56
     3.2.1 Determine the Available Population | 57
     3.2.2 Determine the Selection Population | 58
     3.2.3 Teardown Article Selection Methods | 59
     3.2.4 Defining Areas of Interest (Teardown Subjects) from Selected Teardown Article(s) | 66

4. ESTABLISH DETAILED PROCEDURES | 68
   4.1 Administrative Teardown Tasks | 69
     4.1.1 Part Identification | 69
     4.1.2 Storage and Shipping Teardown Assets between Facilities | 75
     4.1.3 Data Documentation Requirements | 77
### TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>Field/Depot Inspections</td>
</tr>
<tr>
<td>4.3</td>
<td>Extraction</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Extraction Planning/Considerations</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Personnel Qualifications</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Pre-extraction Tasks</td>
</tr>
<tr>
<td>4.3.4</td>
<td>Extraction Task</td>
</tr>
<tr>
<td>4.3.5</td>
<td>Post-Extraction Tasks</td>
</tr>
<tr>
<td>4.4</td>
<td>Disassembly</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Pre-disassembly Visual Inspection</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Personnel Qualifications</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Part Removal</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Part Identification and Physical Marking</td>
</tr>
<tr>
<td>4.4.5</td>
<td>Part Inspection and Documentation</td>
</tr>
<tr>
<td>4.5</td>
<td>Coatings Removal</td>
</tr>
<tr>
<td>4.5.1</td>
<td>Qualifications</td>
</tr>
<tr>
<td>4.5.2</td>
<td>Pre-chemical Exposure</td>
</tr>
<tr>
<td>4.5.3</td>
<td>Exposure</td>
</tr>
<tr>
<td>4.5.4</td>
<td>Post Chemical Exposure</td>
</tr>
<tr>
<td>4.6</td>
<td>Nondestructive Inspection (NDI)</td>
</tr>
<tr>
<td>4.6.1</td>
<td>Qualifications</td>
</tr>
<tr>
<td>4.6.2</td>
<td>Determine Inspection Requirements</td>
</tr>
<tr>
<td>4.6.3</td>
<td>Part Inspection</td>
</tr>
<tr>
<td>4.6.4</td>
<td>Indication Documentation</td>
</tr>
<tr>
<td>4.7</td>
<td>Prioritization of NDI Indications</td>
</tr>
<tr>
<td>4.8</td>
<td>Failure Analysis</td>
</tr>
<tr>
<td>4.8.1</td>
<td>Qualifications</td>
</tr>
<tr>
<td>4.8.2</td>
<td>Visual Examination</td>
</tr>
<tr>
<td>4.8.3</td>
<td>Enhanced Visual Inspection (EVI)</td>
</tr>
<tr>
<td>4.8.4</td>
<td>Specimen Sectioning</td>
</tr>
<tr>
<td>4.8.5</td>
<td>Specimen Mounting</td>
</tr>
<tr>
<td>4.8.6</td>
<td>Specimen Polishing</td>
</tr>
<tr>
<td>4.8.7</td>
<td>Crack Opening</td>
</tr>
<tr>
<td>4.8.8</td>
<td>Fracture Surface Examination</td>
</tr>
<tr>
<td>4.8.9</td>
<td>Fracture Surface Characterization</td>
</tr>
<tr>
<td>4.8.10</td>
<td>Corrosion Type Identification</td>
</tr>
<tr>
<td>4.8.11</td>
<td>Corrosion Product Identification</td>
</tr>
<tr>
<td>4.8.12</td>
<td>Fracture Surface Corrosion Product Removal</td>
</tr>
<tr>
<td>4.8.13</td>
<td>Corrosion Grind Out Evaluation</td>
</tr>
<tr>
<td>4.8.14</td>
<td>Unusual Findings and Related Metallurgical Evaluation</td>
</tr>
</tbody>
</table>

5. **ESTABLISH DATA ANALYSIS PLAN** | 186
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.</td>
<td>EXECUTE ESTABLISHED PROCEDURES</td>
</tr>
<tr>
<td>6.1</td>
<td>Personnel Qualification</td>
</tr>
<tr>
<td>6.2</td>
<td>Facility Qualification</td>
</tr>
<tr>
<td>6.3</td>
<td>Audits of Teardown Assets</td>
</tr>
<tr>
<td>7.</td>
<td>CASE STUDIES</td>
</tr>
<tr>
<td>7.1</td>
<td>Evaluation of Airworthiness for Small Airplanes</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Development of Goals and Objectives</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Teardown Article Selection</td>
</tr>
<tr>
<td>7.1.3</td>
<td>Establish Detailed Procedures</td>
</tr>
<tr>
<td>7.1.4</td>
<td>Establish Data Analysis Plan</td>
</tr>
<tr>
<td>7.1.5</td>
<td>Execute Established Procedures</td>
</tr>
<tr>
<td>7.2</td>
<td>C-5A Structural Risk and Model Revalidation Program</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Development of Goals and Objectives</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Teardown Article Selection</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Establish Detailed Procedures</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Establish Data Analysis Plan</td>
</tr>
<tr>
<td>7.2.5</td>
<td>Execute Established Procedures</td>
</tr>
<tr>
<td>7.3</td>
<td>Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft Fuselage Structure</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Development of Goals and Objectives</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Teardown Article Selection</td>
</tr>
<tr>
<td>7.3.3</td>
<td>Establish Detailed Procedures</td>
</tr>
<tr>
<td>7.3.4</td>
<td>Establish Data Analysis Plan</td>
</tr>
<tr>
<td>7.3.5</td>
<td>Execute Established Procedures</td>
</tr>
<tr>
<td>7.4</td>
<td>C/KC-135 Teardown and Analysis Program</td>
</tr>
<tr>
<td>7.4.1</td>
<td>Development of Goals and Objectives</td>
</tr>
<tr>
<td>7.4.2</td>
<td>Teardown Article Selection</td>
</tr>
<tr>
<td>7.4.3</td>
<td>Establish Detailed Procedures</td>
</tr>
<tr>
<td>7.4.4</td>
<td>Establish Data Analysis Plan</td>
</tr>
<tr>
<td>7.4.5</td>
<td>Execute Established Procedures</td>
</tr>
<tr>
<td>8.</td>
<td>COMPARISON OF CASE STUDIES TO PROPOSED PROCESS</td>
</tr>
<tr>
<td>8.1</td>
<td>Development of Goals and Objectives</td>
</tr>
<tr>
<td>8.2</td>
<td>Teardown Article Selection</td>
</tr>
</tbody>
</table>
## TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.3</td>
<td>Establish Detailed Procedures</td>
</tr>
<tr>
<td>8.3.1</td>
<td>Field/Depot Inspections</td>
</tr>
<tr>
<td>8.3.2</td>
<td>Extraction</td>
</tr>
<tr>
<td>8.3.3</td>
<td>Disassembly</td>
</tr>
<tr>
<td>8.3.4</td>
<td>Coatings Removal</td>
</tr>
<tr>
<td>8.3.5</td>
<td>NDI</td>
</tr>
<tr>
<td>8.3.6</td>
<td>Prioritization of NDI Indications</td>
</tr>
<tr>
<td>8.3.7</td>
<td>Failure Analysis</td>
</tr>
<tr>
<td>8.4</td>
<td>Establish Data Analysis Plan</td>
</tr>
<tr>
<td>8.5</td>
<td>Execute Established Procedures</td>
</tr>
<tr>
<td>9.</td>
<td>CONCLUSIONS</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maximum True Field of View [25] Required to Meet KC-135 Program Requirements</td>
<td>78</td>
</tr>
<tr>
<td>2. Inspection Frequencies [33B-1-2]</td>
<td>126</td>
</tr>
<tr>
<td>3. Initial ECSS Settings [33B-1-2]</td>
<td>127</td>
</tr>
<tr>
<td>4. Flex Hone® Selection for Aluminum Alloys [28]</td>
<td>132</td>
</tr>
<tr>
<td>5. Initial BHEC Settings [32]</td>
<td>135</td>
</tr>
<tr>
<td>7. Filter Settings by Hole Diameter [32]</td>
<td>136</td>
</tr>
<tr>
<td>8. Steps for Polishing Aluminum Alloys Using the Struers Metalog System</td>
<td>168</td>
</tr>
<tr>
<td>9. Cost/Schedule/Man-Power Requirements for Teardown Article Section</td>
<td>243</td>
</tr>
<tr>
<td>10. Cost/Schedule/Man-Power Requirements for Field/Depot Inspection</td>
<td>246</td>
</tr>
<tr>
<td>11. Cost/Schedule/Man-Power Requirements for Extraction</td>
<td>249</td>
</tr>
<tr>
<td>12. Cost/Schedule/Man-Power Requirements for Disassembly</td>
<td>252</td>
</tr>
<tr>
<td>13. Cost/Schedule/Man-Power Requirements for Coatings Removal</td>
<td>255</td>
</tr>
<tr>
<td>14. Cost/Schedule/Man-Power Requirements for NDI</td>
<td>258</td>
</tr>
<tr>
<td>15. Cost/Schedule/Man-Power Requirements for Failure Analysis</td>
<td>261</td>
</tr>
<tr>
<td>16. Cost/Schedule/Man-Power Requirements for Establishing a Data Analysis Plan</td>
<td>262</td>
</tr>
<tr>
<td>17. Cost/Schedule/Man-Power Requirements for Execution of the Established Procedures</td>
<td>264</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Example of “typical” teardown structure.</td>
<td>4</td>
</tr>
<tr>
<td>2. Uses for structural teardown data from post-fatigue test articles.</td>
<td>9</td>
</tr>
<tr>
<td>3. Uses for structural teardown data from operational aircraft.</td>
<td>12</td>
</tr>
<tr>
<td>5. Example of stop drilling observed on the Cessna 402C [16].</td>
<td>19</td>
</tr>
<tr>
<td>6. Proposed steps to develop a structural teardown.</td>
<td>26</td>
</tr>
<tr>
<td>7. Proposed steps to execute a structural teardown.</td>
<td>27</td>
</tr>
<tr>
<td>8. Questions to ask during goals and objectives development.</td>
<td>31</td>
</tr>
<tr>
<td>9. Example of a double drilled hole.</td>
<td>33</td>
</tr>
<tr>
<td>10. Example of an out-of-round hole.</td>
<td>34</td>
</tr>
<tr>
<td>11. Example of a gouge.</td>
<td>34</td>
</tr>
<tr>
<td>12. Residual strength test setup for lap joint panel [18].</td>
<td>38</td>
</tr>
<tr>
<td>13. Disassembled lap joint to assess presence of CPC or corrosion [18].</td>
<td>39</td>
</tr>
<tr>
<td>14. Spotwelded structure.</td>
<td>40</td>
</tr>
<tr>
<td>17. Example of aircraft depth and breadth [11].</td>
<td>54</td>
</tr>
<tr>
<td>18. ESI damage versus flight hours for Fleet 1.</td>
<td>64</td>
</tr>
<tr>
<td>19. ESI damage versus flight hours for Fleet 2.</td>
<td>65</td>
</tr>
<tr>
<td>20. Teardown section selection.</td>
<td>67</td>
</tr>
<tr>
<td>21. Stamped metal hanging tag.</td>
<td>72</td>
</tr>
<tr>
<td>22. Adhesive bar code label.</td>
<td>73</td>
</tr>
</tbody>
</table>
List of Figures (continued)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>Part engraving.</td>
</tr>
<tr>
<td>24.</td>
<td>Sample overview photograph.</td>
</tr>
<tr>
<td>25.</td>
<td>Sample close-up photograph.</td>
</tr>
<tr>
<td>26.</td>
<td>Example of an orientation cube [25].</td>
</tr>
<tr>
<td>27.</td>
<td>Annotated pre-extraction overview photograph [26].</td>
</tr>
<tr>
<td>28.</td>
<td>Example of missing sealant [19].</td>
</tr>
<tr>
<td>29.</td>
<td>Example of a loose fastener [19].</td>
</tr>
<tr>
<td>30.</td>
<td>Example of exfoliation corrosion [19].</td>
</tr>
<tr>
<td>31.</td>
<td>Example of mechanically fastened patch [19].</td>
</tr>
<tr>
<td>32.</td>
<td>Example of a gouge [19].</td>
</tr>
<tr>
<td>33.</td>
<td>Example of a broken spotweld [19].</td>
</tr>
<tr>
<td>34.</td>
<td>Example of a multiple drilled hole [19].</td>
</tr>
<tr>
<td>35.</td>
<td>Diagram illustrating steps to remove a universal solid (button head) rivet [19].</td>
</tr>
<tr>
<td>36.</td>
<td>Typical rivet removal tool [19].</td>
</tr>
<tr>
<td>37.</td>
<td>Example of a hollow cutter on a pneumatic angle drill [19].</td>
</tr>
<tr>
<td>38.</td>
<td>Examples of locally fabricated non-metallic scrapers [19].</td>
</tr>
<tr>
<td>39.</td>
<td>Examples of effective commercially available non-metallic scrapers.</td>
</tr>
<tr>
<td>40.</td>
<td>Example of a damage overview photograph [19].</td>
</tr>
<tr>
<td>41.</td>
<td>Example of a damage close-up photograph [19].</td>
</tr>
<tr>
<td>42.</td>
<td>Example of a disassembly log [19].</td>
</tr>
<tr>
<td>43.</td>
<td>Example TSPB [19].</td>
</tr>
<tr>
<td>44.</td>
<td>Example of grouped gouges.</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES (continued)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>45. Method C – Too much residual penetrant remaining.</td>
<td>119</td>
</tr>
<tr>
<td>46. Method C – Part surface appropriately free of penetrant</td>
<td>119</td>
</tr>
<tr>
<td>47. Example of an excessive bleed-out indication</td>
<td>123</td>
</tr>
<tr>
<td>48. Results of re-evaluation technique for excessive bleed-out indications</td>
<td>124</td>
</tr>
<tr>
<td>49. Staveley Nortec® 2000 series with absolute bridge/shielded, 100-500 kHz probe and Eddy Current Reference Standard</td>
<td>125</td>
</tr>
<tr>
<td>50. Correct signal response from 0.020 inch notch in aluminum</td>
<td>128</td>
</tr>
<tr>
<td>51. Acceptable sensitivity check signal in aluminum</td>
<td>129</td>
</tr>
<tr>
<td>52. Staveley Nortec® 2000 series with differential/reflection, shielded, 200kHz-3MHz probe and Eddy Current Reference Standard</td>
<td>130</td>
</tr>
<tr>
<td>53. Example of a Flex Hone®</td>
<td>133</td>
</tr>
<tr>
<td>54. Lift-off response with phase adjusted correctly</td>
<td>137</td>
</tr>
<tr>
<td>55. Properly calibrated impedance display</td>
<td>137</td>
</tr>
<tr>
<td>56. Properly calibrated sweep display</td>
<td>138</td>
</tr>
<tr>
<td>57. Acceptable noise level</td>
<td>139</td>
</tr>
<tr>
<td>58. Magnaflux L-10 Coil</td>
<td>141</td>
</tr>
<tr>
<td>59. Overview of damage location</td>
<td>144</td>
</tr>
<tr>
<td>60. Damage photograph</td>
<td>145</td>
</tr>
<tr>
<td>61. Penetrant photograph</td>
<td>147</td>
</tr>
<tr>
<td>62. ECSS screen shot</td>
<td>148</td>
</tr>
<tr>
<td>63. ECSS phase angle definition</td>
<td>150</td>
</tr>
<tr>
<td>64. BHEC screen shot</td>
<td>151</td>
</tr>
<tr>
<td>65. BHEC phase angle definition</td>
<td>152</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>66</td>
<td>Edge crack in thin structure.</td>
</tr>
<tr>
<td>67</td>
<td>Cracks for fastener edge</td>
</tr>
<tr>
<td>68</td>
<td>Visual inspection photograph [34]</td>
</tr>
<tr>
<td>69</td>
<td>Corrosion damage identified during EVI [34]</td>
</tr>
<tr>
<td>70</td>
<td>Summary of EVI findings [34]</td>
</tr>
<tr>
<td>71</td>
<td>Close-up photograph [34]</td>
</tr>
<tr>
<td>72</td>
<td>Macro-photograph of the NDI indication [34]</td>
</tr>
<tr>
<td>73</td>
<td>Recommended section cuts for a visible crack near a fastener hole [34]</td>
</tr>
<tr>
<td>74</td>
<td>Recommended section cuts for a visible crack near a fastener hole in thicker parts [34]</td>
</tr>
<tr>
<td>75</td>
<td>Section cuts in the presence of multiple visible cracks near a fastener hole [34]</td>
</tr>
<tr>
<td>76</td>
<td>Multiple section cuts used to characterize corrosion area [34]</td>
</tr>
<tr>
<td>77</td>
<td>Sectioning method for multiple in-plane cracks inside a hole [34]</td>
</tr>
<tr>
<td>78</td>
<td>Standard three-point bend technique setup [34]</td>
</tr>
<tr>
<td>79</td>
<td>Modified three-point bend technique setup [34]</td>
</tr>
<tr>
<td>80</td>
<td>Standard V-notch technique setup [34]</td>
</tr>
<tr>
<td>81</td>
<td>Crack opening method for in-plane crack at the edge of thin structure [34]</td>
</tr>
<tr>
<td>82</td>
<td>Crack opening techniques for hole bore crack using three-point bend technique or V-notch method using a vise [34]</td>
</tr>
<tr>
<td>83</td>
<td>Crack opening options for edge cracks [34]</td>
</tr>
<tr>
<td>84</td>
<td>Crack opening options for SCC crack with slant profile considering thickness of sheet [34]</td>
</tr>
<tr>
<td>85</td>
<td>Crack opening options for a surface crack not through the thickness [34]</td>
</tr>
<tr>
<td>86</td>
<td>Crack opening procedure for through thickness surface crack [34]</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>87. Crack opening procedure for a spotweld crack without doubler and with doubler intact [34].</td>
<td>173</td>
</tr>
<tr>
<td>90. Example of beach marks on fracture face [11].</td>
<td>178</td>
</tr>
<tr>
<td>91. Example of pitting corrosion [19].</td>
<td>181</td>
</tr>
<tr>
<td>92. Example of exfoliation corrosion [19].</td>
<td>181</td>
</tr>
<tr>
<td>94. 1979 Cessna 402C, Tail #N780EA [16].</td>
<td>200</td>
</tr>
<tr>
<td>95. 1975 Piper Navajo Chieftain, Tail #N61510 [14].</td>
<td>201</td>
</tr>
<tr>
<td>96. 1993 Beechcraft 1900D, Tail #N856CA [23].</td>
<td>202</td>
</tr>
<tr>
<td>98. Example of a close-up photograph – crack in forward carry-through forward web (Figure 3-149 in Figure 97) [13].</td>
<td>207</td>
</tr>
<tr>
<td>99. C-5 Aircraft 69-0004.</td>
<td>211</td>
</tr>
<tr>
<td>100. Example of part numbering and critical hole numbering assignment [38].</td>
<td>214</td>
</tr>
<tr>
<td>101. Example of NDI requirements table [38].</td>
<td>215</td>
</tr>
<tr>
<td>102. Boeing 727 Tail Number N474DA [21].</td>
<td>218</td>
</tr>
<tr>
<td>103. Boeing 727 teardown process [21].</td>
<td>222</td>
</tr>
</tbody>
</table>
# LIST OF ABBREVIATIONS/NOMENCLATURE

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Advisory Circular</td>
</tr>
<tr>
<td>A &amp; P</td>
<td>Airframe and Powerplant</td>
</tr>
<tr>
<td>AFB</td>
<td>Air Force Base</td>
</tr>
<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
</tr>
<tr>
<td>AFT</td>
<td>Aft</td>
</tr>
<tr>
<td>AMOC</td>
<td>Alternate Means of Compliance</td>
</tr>
<tr>
<td>ASIP</td>
<td>Aircraft Structural Integrity Program</td>
</tr>
<tr>
<td>ASNT</td>
<td>American Society for Nondestructive Testing</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>BHEC</td>
<td>Bolt Hole Eddy Current</td>
</tr>
<tr>
<td>BL</td>
<td>Butt Line</td>
</tr>
<tr>
<td>BS</td>
<td>Body Station</td>
</tr>
<tr>
<td>CAR</td>
<td>Civil Air Regulation</td>
</tr>
<tr>
<td>CAStle</td>
<td>Center for Aircraft Structural Life Extension</td>
</tr>
<tr>
<td>CPC</td>
<td>Corrosion Preventative Compound</td>
</tr>
<tr>
<td>CVI</td>
<td>Close Visual Inspection</td>
</tr>
<tr>
<td>DTA</td>
<td>Damage Tolerance Assessment</td>
</tr>
<tr>
<td>DWN</td>
<td>Down</td>
</tr>
<tr>
<td>ECSS</td>
<td>Eddy Current Surface Scan</td>
</tr>
<tr>
<td>EDXS</td>
<td>Energy-dispersive X-ray Spectroscopy</td>
</tr>
<tr>
<td>EFH</td>
<td>Equivalent Flight Hours</td>
</tr>
<tr>
<td>EIFS</td>
<td>Equivalent Initial Flaw Size</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>ESI</td>
<td>Environmental Severity Index</td>
</tr>
<tr>
<td>EVI</td>
<td>Enhanced Visual Inspection</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FPI</td>
<td>Fluorescent Penetrant Inspection</td>
</tr>
<tr>
<td>FSH</td>
<td>Full Screen Height</td>
</tr>
<tr>
<td>FSMP</td>
<td>Force Structural Maintenance Plan</td>
</tr>
<tr>
<td>FSW</td>
<td>Full Screen Width</td>
</tr>
<tr>
<td>FWD</td>
<td>Forward</td>
</tr>
<tr>
<td>GAG</td>
<td>Ground Air Ground</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphic User Interfaces</td>
</tr>
<tr>
<td>H-GAIN</td>
<td>Horizontal Gain</td>
</tr>
<tr>
<td>I/B</td>
<td>Inbound</td>
</tr>
<tr>
<td>LBL</td>
<td>Left Butt Line</td>
</tr>
<tr>
<td>LHS</td>
<td>Left Hand Side</td>
</tr>
<tr>
<td>LOV</td>
<td>Limit of Validity</td>
</tr>
<tr>
<td>MIL-STD</td>
<td>Military Standard</td>
</tr>
<tr>
<td>MPI</td>
<td>Magnetic Particle Inspection</td>
</tr>
<tr>
<td>MSD/MED</td>
<td>Multiple Site/Element Damage</td>
</tr>
<tr>
<td>NAS</td>
<td>National Aerospace Standard</td>
</tr>
<tr>
<td>NDE</td>
<td>Nondestructive Evaluation</td>
</tr>
<tr>
<td>NDI</td>
<td>Nondestructive Inspection</td>
</tr>
<tr>
<td>NIAR</td>
<td>National Institute for Aviation Research</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>NSN</td>
<td>National Stock Number</td>
</tr>
<tr>
<td>NTIP</td>
<td>NDE Technical Initiatives Program</td>
</tr>
<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
</tr>
<tr>
<td>O/B</td>
<td>Outbound</td>
</tr>
<tr>
<td>OEMs</td>
<td>Original Equipment Manufacturers</td>
</tr>
<tr>
<td>PASTA</td>
<td>Procedures for Aircraft Structural Teardown Analysis</td>
</tr>
<tr>
<td>PTP</td>
<td>Peak-to-Peak</td>
</tr>
<tr>
<td>QQI</td>
<td>Quantitative Quality Indications</td>
</tr>
<tr>
<td>RBL</td>
<td>Right Butt Line</td>
</tr>
<tr>
<td>RHS</td>
<td>Right Hand Side</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions Per Minute</td>
</tr>
<tr>
<td>SCC</td>
<td>Stress Corrosion Crack</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscope</td>
</tr>
<tr>
<td>TDMS</td>
<td>Teardown Data Management System</td>
</tr>
<tr>
<td>TSPB</td>
<td>Teardown Section Parts Breakdown</td>
</tr>
<tr>
<td>TTCP</td>
<td>The Technical Cooperative Program</td>
</tr>
<tr>
<td>UP</td>
<td>Up</td>
</tr>
<tr>
<td>USAF</td>
<td>United States Air Force</td>
</tr>
<tr>
<td>UTC</td>
<td>Universal Technology Corporation</td>
</tr>
<tr>
<td>V-GAIN</td>
<td>Vertical Gain</td>
</tr>
<tr>
<td>WFD</td>
<td>Widespread Fatigue Damage</td>
</tr>
<tr>
<td>WL</td>
<td>Water Line</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>WS</td>
<td>Wing Station</td>
</tr>
<tr>
<td>WSU</td>
<td>Wichita State University</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION AND BACKGROUND

Due to current economic conditions, aircraft companies, owners, operators, and fleet managers are experiencing an increasing need for their fleets to maintain safe operations beyond their original design lives or service goals. This need results in a growing percentage of aging aircraft that must maintain their airworthiness and structural integrity by using standard methods of inspection and repair [1]. The aging concern exists for all types of aircraft including commercial, military, and general aviation airplanes.

The increase in the population of aging aircraft is a three-fold issue: (1) the number of aging aircraft fleets are increasing, (2) the size of aging aircraft fleets are increasing, and (3) the average age of aging aircraft fleets are increasing. Instead of only a handful of aging military, commercial, and general aviation fleets, the true number of aircraft platforms identified as “aging” easily reaches in the hundreds, if not thousands. For the purpose of this work, “aging” aircraft fleets are comprised of airframes that have reached their original design life from the perspective of flight hours or calendar age.

Managing aging aircraft fleets has also become more difficult as the average size of aging fleets is on the rise. Again, instead of addressing a handful of aircraft in each aging fleet, the number can often reach well into the hundreds of airframes. The aging KC-135 fleet, for example, is comprised of over four hundred airframes [2]. The average age of aircraft comprising aging fleets is also increasing. In 2001, the average age of the general aviation fleet as a whole was slightly greater than thirty years. By 2011, that number had risen to forty years [3].
In order to address structural and age-related concerns on a particular aircraft fleet, inspection and maintenance procedures are developed and implemented at the time the aircraft is introduced into service and modified throughout the service life of the fleet. As the fleet continues to age, the number of inspections and maintenance activities on each aircraft tend to increase due to historical knowledge and experience obtained from the operation of the fleet [4]. The primary concern, particularly with a high-time fleet, is how effective these inspection and maintenance programs are at maintaining the structural integrity and airworthiness of the airframe. Since the structural components targeted by these maintenance and inspection programs are identified through original design engineering analysis and often augmented by in-service experience, the question arises whether or not all areas of concern are being appropriately addressed and the risk of loss of structural integrity is effectively mitigated [5].

1.1 Structural Teardown and Analysis Defined

One way of assessing the effectiveness of inspection and maintenance programs for maintaining structural integrity is through a destructive teardown examination and analysis program [5]. A teardown examination allows targeted areas of concern to be removed from the surrounding structure, disassembled to gain full access, and inspected, while allowing the primary structure in the vicinity of the area of interest to also be inspected for damage. Performing a teardown examination is the only way to assess the actual condition of the fleet with respect to fatigue, corrosion, and other damage mechanisms [5].

Safely sustaining the ever-increasing numbers of aging aircraft in the commercial, general aviation, and military fleets has brought a correspondingly increased demand to determine the true condition, from a damage based perspective, of service-aged aircraft structural components and entire airframes. The only means available to precisely determine and quantify
the damage state of a given structure is by performing a “teardown inspection” of that structure [6].

Teardown inspection, as defined in Advisory Circular (AC) 25.571-1D, is “the term used for the process of disassembling structure and using destructive inspection techniques or visual (e.g., magnifying glass and dye penetrant) or other non-destructive (e.g., eddy current, ultrasound) inspection techniques to identify the extent of damage, within a structure, caused by fatigue, corrosion, and accidental damage [7].”

Part of planning and executing a teardown program is developing the program structure; defining all the tasks and processes to be implemented as part of that structural teardown. It is important to recognize that no one standard set of teardown processes or program structure will meet the goals and objectives, or requirements of every structural teardown. The structure of a teardown program and particularly teardown processes should be tailored to meet the specific requirements of the planned structural teardown. Often many program tasks will be common amongst different program structures, but the detailed processes may vary significantly. Figure 1 depicts a “typical” or “common” teardown program structure.
Prior to the late 1990s to early 2000s structural teardowns were primarily performed by original equipment manufacturers (OEMs). Therefore, the processes used and the data generated by these teardowns was held proprietary, making the information unavailable to the public. In
the early to mid 2000s structural teardowns performed by government agencies became more popular. Since then the demand for teardowns performed by government entities has continued to increase. Even with this trend, limited information is still available to the general public due to security restrictions on military teardowns. The Federal Aviation Administration (FAA) is the only government agency to fully disclose structural teardown processes and results to the general public.

1.2 Purpose of Structural Teardown and Analysis

Structural teardowns are performed on aging aircraft for two primary reasons: in order to comply with governmental requirements and/or to generate engineering data. FAA ACs and Military Standards (MIL-STD) provide guidance on when to perform structural teardowns and how to use the data, but fall short in providing information regarding recommended procedures for structural teardown. Engineering data generated from structural teardown is often used by engineers for structural management either as the aircraft enters operational service or towards the end of the original design life as a means to possibly extend service life.

1.2.1 Governing Documents for Structural Teardown

Three documents serve as the governing policy on structural teardown for all general, commercial, and military aviation. For the FAA, AC 23-13A [8] and 25.571-1D [7] address the uses of structural teardown, while MIL-STD-1530C [9] addresses teardown inspection and evaluation techniques for military aircraft. None of these documents prescribe a teardown inspection process or provide guidance specifically on the desired data to be captured from structural teardown. This lack of guidance has led to inconsistency between teardown programs, which have resulted in a wide variety of teardown processes and types and amounts of data captured from program to program. These governing documents do provide information on
when to perform structural teardowns and the desired end goals. However, cross-platform (or inter-agency) sharing of successful teardown procedures and other lessons learned is often lacking [6].

1.2.1.1 Advisory Circular AC 23-13A: Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes

This FAA AC recommends to “consider a teardown inspection of the structure after completion of a fatigue test. A teardown inspection often reveals unpredicted fatigue problems and can be valuable in addressing continued airworthiness issues in the future.” This document recommends including structural teardown as part of developing a full scale test plan [8].

1.2.1.2 Advisory Circular AC 25.571-1D: Damage Tolerance and Fatigue Evaluation of Structure

This FAA AC states that the teardown inspection results of high time in-service aircraft can be used to illustrate that Widespread Fatigue Damage (WFD) is unlikely to occur in that particular fleet up to the Limit of Validity (LOV) of the engineering data that supports the structural maintenance program. For certification purposes, applicants should identify WFD susceptible structure to support post-fatigue test teardown or residual strength testing to demonstrate that WFD will not occur in that fleet up to the LOV. These teardown inspections and/or residual strength tests must provide data that supports the determination of strength. In order to effectively evaluate structure identified as WFD susceptible, full scale testing followed by structural teardown inspections and failure analysis of any relevant findings or residual strength testing, or both must be performed.

Analytical estimates of residual strength may be made from teardown findings of “in-service aircraft” that augment full scale fatigue tests. These data may be used in determining or bounding the time to develop Multiple Site/Element Damage (MSD/MED) cracks of a
specific size, MSD/MED crack growth scenarios, and residual strength with MSD/MED cracks present in the structure. Residual strength may also be evaluated indirectly by using teardown inspection to quantify the size of MSD/MED cracks present in the structure, or to establish a lower bound on crack size based on the capability of the inspection methods employed. AC 25.571-1D notes that as a minimum, teardown inspection methods should be capable of detecting the minimum size of MDS/MED cracking that would result in WFD [7].

The AC also notes that it is important to document findings from the destructive teardown inspection of structure from in-service airplanes. This could include structure removed from aircraft that were subsequently returned to service or from retired airplanes. In order to establish and validate quality engineering models, it would also be necessary to have a credible record of the operational loading the teardown subject structure experienced while it was in service [7].

1.2.1.3 MIL-STD-1530C – Department of Defense Standard Practice Aircraft Structural Integrity Program (ASIP)

MIL-STD-1530C states that a destructive teardown program should be performed at the end of full scale testing. These teardown programs should be comprised of disassembly and laboratory-type inspections of critical areas identified during design, as well as critical structure identified during testing, and potential defect areas identified during close visual inspection during the disassembly process [9]. This standard also states that fractographic examinations (or failure analysis) shall be conducted to obtain crack growth data with the known applied fatigue spectrum and to assist in the assessment of the initial quality of the aircraft structure.

Equivalent Initial Flaw Size (EIFS) distribution should also be developed from the teardown inspection failure analysis results. EIFS methods and procedures are required by this standard to be delivered during aircraft acquisition to serve as a basis to validate future changes
in analytical methods as the airframe ages. This standard also recommends that prior to teardown; the effectiveness of anticipated nondestructive inspection (NDI) methods that may be applied to fielded aircraft should be evaluated. The Force Structural Maintenance Plan (FSMP) must be updated based on the teardown results according to the standard. The United States Air Force (USAF) derives the FSMP from an aircraft damage tolerance assessment (DTA). The FSMP prescribes for the maintainer how, when, and where to perform inspections to maintain safety of flight [9, 10].

This standard also states that “A structural teardown program may be required if an aircraft is expected to operate beyond its designed service life or if there is evidence of extensive damage that may jeopardize the aircraft’s structural integrity [9].” The standard also suggests that validation of the original EIFS distribution, by teardown inspection of aircraft or their major structural components with high levels of predicted damage, shall be considered [9].

1.2.2 Engineering Motivations for Structural Teardown

Structural teardowns are often performed post-fatigue test, prior to an airframe’s introduction into service. The loading spectrum applied during full scale fatigue and damage tolerance tests are always presumed spectra. Often, operational flight conditions vary significantly, resulting in different damage locations and damage extents. Also, full scale fatigue and damage tolerance tests fail to capture environmentally induced damage mechanisms, such as stress corrosion cracking and widespread surface corrosion. In some fleets, such as most Part 91 general aviation aircraft and particular military platforms, calendar/environmentally induced damage may be more detrimental to the structural integrity and continued airworthiness than flight-hour fatigue related damage. For these reasons, teardowns are also frequently performed on operational aircraft close to their original design service life. The data obtained from
structural teardown of an operational aircraft can often be used to update the information obtained from structural teardown following a full scale fatigue test.

1.2.2.1 Structural Teardown Post-Fatigue and Damage Tolerance Testing

Figure 2 illustrates multiple uses for data obtained from structural teardown, following the full scale test to simulate in-service loads.

![Diagram](https://via.placeholder.com/150)

**Figure 2.** Uses for structural teardown data from post-fatigue test articles.

Structural teardown following fatigue and damage tolerance testing allows engineers to validate critical structural details identified during the initial design and analysis phase. Teardown data also allows engineers to potentially identify new critical structural elements based on the nucleation and propagation of unanticipated cracks during the structural test.
Fractographic analysis, otherwise known as failure analysis, of fatigue cracks generated during fatigue testing may also be compared to analytical crack growth prediction models. Once validated against structural test data or fractographic data obtained from in-service aircraft with known flight spectra, these damage tolerance based models can be used to establish or modify inspection intervals. Part of establishing the inspection intervals are to determine the size of the flaw that must be detected to meet damage tolerant design criteria. Once this flaw size is determined, it can be compared to the detectable flaw sizes of specific inspection methods to determine which inspection procedures should be prescribed for operational aircraft.

Another use of the analytical crack growth prediction models is to predict the amount of damage that should be present at any operational point in the aircraft’s life. These data are often used by fleet managers to determine strategies to address concerns with their aging fleets. Fleet managers often update and attempt to validate these damage prediction models with structural teardown of operational aircraft. This teardown is often performed once the fleet-leading aircraft is near design service life or if evidence of extensive damage that may jeopardize the aircraft’s structural integrity or continued airworthiness is found in the fleet. This is particularly true if an aircraft may be required to operate beyond its original design service life. In almost all cases, these predictive damage models exist solely for the fatigue crack growth failure mechanism, so failures due to environmental or maintenance failure mechanisms cannot be addressed in this manner.

The likelihood of the onset of WFD may also be assessed using structural teardown post-fatigue test. Structural teardown after testing allows engineers to obtain the distribution of cracks in an airframe. Certification of Part 23 airplanes by the FAA, AC 25.571-1D requires the applicant to identify structure that is susceptible to WFD and demonstrate that it will not occur in
the airplane structure up to the LOV of the engineering data that support the structural maintenance programs [7]. This AC states that post-fatigue test teardown inspection or residual strength tests, must provide data that supports the determination of strength. The evaluation of WFD susceptible structure typically entails full scale fatigue testing, followed by teardown inspections, and a quantitative evaluation of any findings or residual strength testing, or both [7].

One final important use for data obtained through post-fatigue test structural teardown is the development of a risk assessment. One of the primary inputs to the USAF risk assessment approach is the distribution of cracks in the structure and the time to the onset of WFD [10]. Historically, the USAF has determined this distribution through teardown inspections of full scale fatigue articles or operational aircraft. The USAF believes this is the best method currently available to obtain the data required to derive the probability distribution function for EIFS of cracks in critical structure [10].

1.2.2.2 Structural Teardown of Operational (In-Service) Aircraft

Usage of data generated by structural teardowns from operations aircraft are illustrated in Figure 3.
The damage related data obtained during full scale fatigue testing is highly dependent on the assumed loading spectra. This spectrum is developed during aircraft design and is often the engineer’s “best guess” at the actual operational usage of the aircraft once in service. Typically, for commercial and general aviation aircraft, the operational usage does not differ substantially from the assumed spectra used in the fatigue test. Frequently; however, military aircraft missions deviate significantly from the designed usage spectrum and vary throughout the lifetime of a particular fleet [11]. Some examples of variable parameters over a platform’s service life include: variations in operational environment, gross weight, and operational altitude.

For example, many aircraft designed to withstand operation in a dry environment with flight-load driven damage are now being used for coastal surveillance, like the C-130, or are almost permanently stationed in hot, wet, salty environments, like the C-5A and KC-135R aircraft. Other aircraft, like the C-130, that were designed as mid-weight transport aircraft are
now being used in high gross weight special operation missions. Still other aircraft, designed for mid-altitude flight are being used for close air “gunship” support [11]. All of the changes in mission requirements cause deviations from the assumed loading spectrum used in the fatigue test; thus, changing the damage extents and sometimes even damage locations assumed in the design phase and validated or identified during the original fatigue test.

Structural teardown of operational aircraft with “known usage” allows for an understanding of the current condition of an aircraft to assess the validity of the damage prediction models typically developed during the original design or structural test. The distribution of crack sizes observed during an operational aircraft teardown can also be used to update the probability distribution function for EIFS in critical areas required to update the USAF and other risk models [10].

With the aging military, commercial and general aviation fleets, the aircraft’s complete usage history is infrequently fully known. With many of the aging aircraft fleets approaching forty-plus years of average service usage and the advent of loads monitoring systems much more contemporary than the manufacture dates of these aircraft, obtaining a full loads history over the life of the aircraft is unlikely. Since many of these aircraft were manufactured as early as the mid-1950s, loads monitoring systems were not required at the time of manufacture, nor were they invented, or in some cases, even theorized. Many older fleets were not retrofitted at the height of load monitoring system popularity as the systems are expensive, often precluding their implementation on aging fleets.

Often even more fundamental information, such as operational location, is unknown in many of the aging general aviation and military fleets. It is not uncommon for ten year gaps in operational basing location and other maintenance records for general aviation aircraft to exist
Operational basing location records may be incomplete for civilian aircraft due to poor record keeping or loss or destruction of paper records over the course of the aircraft’s service life. For military aircraft, masking the operational location of some aircraft may be necessary for security reasons. For example, during a maintenance review of the Cessna 402A subjected to structural teardown during the “Evaluation of Airworthiness for Small Airplanes” a seven year gap was identified in the maintenance logs from May 1991 to May 1998. It was also noted that no airframe hours were recorded in the logs from May 1984 to May 1998. A graph illustrating the frequency of recorded airframe hours is provided in Figure 4.

Aging aircraft fleets in general have service histories ranging from “excellent and complete” to “missing,” making the ability to correlate damage to flight history of service aircraft difficult if not impossible. One standard practice appears to be to use the information one knows from service records and infer the rest. While this is not a completely accurate representation of the flight operations of these aircraft from an engineering and damage...
reconstruction perspective, it is often the most complete assessment that can be done with the information available. This approach is often still more accurate than the spectra used during the full scale test.

With some military fleets expecting to operate aircraft to a service life of eighty plus years [14], understanding the condition of an aircraft from a damage perspective at or close to the original service life will allow engineers to assess if such lofty service life goals are even practical. Engineers will also be able to develop a list of fleet management decisions that must be made for continued structural integrity and fleet airworthiness once the actual condition of the airframe is known. Some options available to fleet managers are new inspections, a change in inspection frequency, repairs, and component replacement.

Another important issue that cannot be addressed using structural teardown of fatigue test articles that can be addressed with in-service aircraft teardowns is understanding environmentally driven damage scenarios. While teardowns performed post-fatigue test capture flight load damage, environmentally driven damage scenarios are often neglected during the design and certification stage and only addressed when they become problematic to the in-service fleet. Examples of these damage scenarios include widespread surface corrosion and stress corrosion cracking. Environmentally driven damage scenarios such as these may be more difficult to manage in the fleet than fatigue or other purely flight load driven damage scenarios. Fatigue damage initiation and progression can be modeled fairly accurately using validated damage prediction models from the design phase. No reliable method currently exists to predict stress corrosion cracking growth rates particularly in circumstances where the crack-driving stress is likely a fabrication induced stress that varies from location to location within a structural element [15].
Understanding the damage mechanisms and damage morphology for both flight load driven damage mechanisms, including fatigue and overload, and environmentally influenced damage mechanisms, such as corrosion, corrosion-fatigue, and stress corrosion cracking, is also crucial for employing an appropriate NDI in the field. Visual, fluorescent penetrant, eddy current, and ultrasonic inspection methods are capable of finding cracks in aircraft structure. Based on crack orientation and desired detectible crack length the inspection methods must be carefully selected.

Defining inspection fidelity often directs the program planners to appropriate inspection methods based on method capability. For instance, visual inspection is an effective means for finding larger, surface breaking cracks in metallic structure, but is often not capable of finding small fatigue cracks in critical structural members. Fluorescent penetrant inspection methods are often capable of finding smaller surface breaking cracks than a standard visual inspection, but are still unlikely to find the very small fatigue cracks in critical structure regions as reliably as eddy current techniques.

According to AC 25.571-1D, another use for teardown findings from “in-service aircraft” is to augment full scale fatigue test evidence to be used in determining or bounding the time to develop MSD/MED cracks of a certain size, MSD/MED crack growth scenarios, and residual strength capability in the presence of MSD/MED [7]. The residual strength capability of a structure may be evaluated indirectly by performing teardown inspections to quantify the size of any MSD/MED cracks that might be present, or to establish a lower bound on crack size based on the inspection method capability [7]. After this data has been obtained, an analytical estimate of residual strength can be performed. At a minimum, teardown inspection methods must be
capable of detecting crack sizes equivalent to the smallest size of MSD or MED cracking that would result in a WFD condition [7].

Yet another motivation or often a secondary goal of teardown inspection is to validate NDI procedures used in the field. NDI techniques are used across all aircraft platforms to determine the likelihood of damage in operational aircraft while minimizing the impact to the mission readiness of those aircraft. For this reason, it is desired that NDI indications be correlated to both damage mechanism and damage extent to support fleet management and operational readiness decisions [12].

While NDI validation is often not the sole reason for performing a structural teardown, validation of inspection procedures is often a “target of opportunity” during teardown programs [11]. Structural teardown of an in-service aircraft provides a unique opportunity to quantify the effectiveness of existing in-service inspection procedures on actual aircraft structure [6], compared to “representative structure with known damage.” Typically, prior to a structural teardown that is attempting to assess the effectiveness of field level NDI procedures; the structure is inspected by field or depot inspectors using the previously developed procedures and approved equipment. The results of these inspections are then compared to the findings of the structural teardown to assess the capabilities and limitations of the depot/field level inspection processes.

During teardown, the structure is disassembled into individual parts; cleaned to remove paint, primer, other coatings systems, and debris; and then inspected using part level NDI techniques. Part level NDI is significantly more accurate than assembly level NDI as the entire surface being inspected is accessible with no limitations to visibility. Another aspect making part level NDI more accurate than assembly level NDI is signals such as eddy current or
ultrasound are only required to penetrate the part being inspected, instead of potentially multiple layers at the assembly level. Although, part level NDI is significantly more accurate than assembly level NDI, false calls can still occur due to mechanical damage in the inspection area, inspection error, and other reasons. A false call is defined as a positive NDI indication whose root cause cannot be identified using failure analysis techniques. To rule out false calls, NDI indications of interest are often subjected to failure analysis, which is the only method available to accurately determine the root cause of the NDI indication and quantify any verified damage to the structure [6].

Another secondary motivation for structural teardown is the assessment of the effectiveness of field repairs. Like inspection, assessing field repairs is not a primary reason to perform structural teardown, but is a useful piece of information for engineers to gain while performing structural teardown. Occasionally, repairs are designed on aircraft as a “terminating action,” meaning that no follow up inspection of the area is required after the repair is installed. If subsequent inspections are not performed in the region of the repair, no assessment of the effectiveness of the repair to mitigate the pre-existing damage can be performed.

Since complete disassembly is almost always required during structural teardown, removal of the repair, inspection, and documentation of the damage existing beneath the repair is easily performed. The current extent of the damage beneath the repair can be determined and compared to the damage that existed at the time of the repair, if detailed records are available, to determine if the threat to structural integrity was mitigated. One commonly implemented temporary repair technique used to retard crack growth is stop drilling, where a hole is drilled at the end of the crack and left open in an effort to slow crack growth. While this frequently delays the propagation of existing cracks, often this temporary fix results in cracks growing out the
other side of the stop drill prior to permanent repair installation. Previous teardown inspections have commented on the widespread use of stop drilling techniques and warned that these techniques do not constitute a permanent or even long term repair [16], even though field mechanics often treat them as such.

An example of stop drilling was observed on the left wing inboard engine beam on the Cessna 402C torn down during the “Evaluation of Airworthiness for Small Airplanes” program. Crack A, shown in Figure 5, has been stop drilled twice, yet the crack continued to grow [16]. Crack B originated in one of the stop drilled holes and propagated due to fatigue loading.

Figure 5. Example of stop drilling observed on the Cessna 402C [16].

Structural teardowns can also identify regions of highly concentrated mechanical damage from the field, which often occur during original manufacture, or maintenance
activity/inspections of specific regions of the aircraft. Mechanical damage can include, but is not limited to, out-of-round holes, double drilled holes, surface or hole gouging, and drill starts. High concentrations of mechanical damage can indicate problems with a maintenance activity or inspection method. Mechanical damage can be indicative of lack of access or visibility for proper fastener removal, inadequate clearance for tools, and improper tool usage.

1.3 Procedures Guidance

Two handbooks currently exist that address structural teardown procedures, but neither are publicly available due to military content. In April of 2005, The Technical Cooperation Program (TTCP) between the Governments of Australia, New Zealand, Canada, the United Kingdom, and the United States published a handbook to document the best practices in teardown of aircraft structures [17]. The other procedures handbook was released in May 2008 by the Center for Aircraft Structural Life Extension (CAStLE) at the USAF Academy. The Procedures for Aircraft Structural Teardown Analysis (PASTA) combines the lessons learned from recent teardowns and the best practices for each of the tasks that typically comprise a structural teardown.

1.3.1 TTCP

The TTCP handbook addresses a number of economic and life cycle issues that could drive a program manager or engineering team to consider some level of teardown program. The document also provides some limited information on creating a work breakdown structure including project definition, task allocation, specimen assessment/selection, specimen preparation, detailed disassembly/examination, reporting, interpretation, and follow-up actions. The document also attempts to summarize lessons learned from previous teardown programs. The handbook discusses in detail all the financial reasons to perform or not to perform a
structural teardown and the projected economic impact on the fleet and provides a general task list for structural teardown. The document fails to provide guidance on appropriate procedures or methods to perform structural teardown. The document also fails to address in great detail the requirements to be considered during each task of a teardown program.

1.3.2 PASTA

PASTA is the most complete teardown information collection to date. This handbook does not discuss in detail the financial or managerial reasons to consider performing a structural teardown. It rather assumes the decision to perform a structural teardown has already been made, and provides recommendations on developing requirements and developing teardown procedures based on those requirements. PASTA discusses teardown processes at the top level providing recommendations on the content of detailed processes. This document does not provide step-by-step procedures or lessons learned on detailed procedures. While this handbook is a great start to developing appropriate procedures for structural teardown, the process has evolved significantly since its publication in 2008.

1.4 Issues Common to Past Teardowns

Due to the absence of specific recommendations/guidance on teardown planning and execution and limited information shared between government agencies, OEMs, and owners/operators, recurring problems with past teardown programs can be identified and continue to occur on teardown programs executed at this time. Without published processes and results, lessons learned cannot be ascertained and absorbed by the teardown community as a whole. Through literature survey of available data and personal experience performing teardown, the following recurring problems have been identified: lack of definition in goals and
objectives, lack of planning prior to execution, requirements not rigidly defined, and not all teardown processes fully documented.

1.4.1 Lack of Definition in Goals and Objectives

Defining goals and objectives is one of the most important tasks that must be performed at the onset of structural teardown development. Frequently, the time and resources required to define rigid goals and objectives are often allocated to focus on budget, schedule, and personnel management. Failure to define rigid goals and objectives for a teardown program results in and improper definition of the fidelity of teardown execution tasks [11]. The primary reason for developing rigid goals and objectives is to make sure the purpose of the teardown and the desired outcome is clearly defined. Without a defined purpose and clear understanding of the desired outcome, teardown programs lack focus and tend to generate significant amounts of irrelevant or useless data. This often results in the expenditure of more money for less useful data for engineers and program managers.

1.4.2 Lack of Planning Prior to Execution

The most common mistake that occurs during a structural teardown program is a lack of planning prior to program execution. Often during structural teardown programs, planning and development is rushed or even performed simultaneously with early program execution. This frequently occurs because money is often not available to sufficiently plan a teardown. Once the money becomes available, the desire to receive results of the teardown, often leads program managers to forgo the detailed development and planning stages and dive directly into acquisition of the teardown article and program execution. This leads to poor definition of the process requirements and fidelity of the findings. Instead of using the developed goals to define the fidelity of the desired results, often schedule and budget become the defining factor [11].
Using schedule and budget factors solely to define the fidelity requirements often results in the expenditure of more money for less useful data for engineers.

1.4.3 Flexible Requirement Definition

The single most important task performed when establishing goals and objectives is defining the finding fidelity, or the minimum damage extent required to be identified and characterized by the program to meet the program objectives [11]. It is imperative that this decision be made at the onset of planning the teardown since all subsequent teardown processes are dependent on the minimum required detectable flaw size. It is necessary that this damage extent becomes a rigid requirement to avoid scope growth and processes that produce results that drift away from the required goals and objectives.

Without a rigidly defined finding fidelity, tear downs often lose focus and irrelevant data is often collected. While the natural desire for engineers often is to find out all the possible information from a structural teardown, data relevance should be strongly considered to avoid flexible requirements. Flexible requirements often result in teardown programs that end up over budget and beyond schedule.

1.4.4 Incomplete Documentation of Teardown Processes

Another important aspect of planning a teardown that is often overlooked or diminished in priority, is deciding how to document the teardown processes selected for the teardown program. This step is vital to communicate effectively with personnel executing the teardown and to allow for reflection on “lessons learned” after teardown completion. In numerous cases with poor process documentation occurring during the planning stages of a teardown, valuable teardown data has been lost due to a misinterpretation of the processes by the teardown execution team. For this reason, step-by-step processes that have been previously validated on
representative aircraft structure are preferred [5]. In instances on specific structure where validated procedures are not available the conventional “best shop practices” are also acceptable as long as the program manager is made aware of the situation and accepts the substitution of procedures.

Another key advantage to step-by-step procedure documentation is the ability of others to analyze and repeat the processes years down the road. Like any scientific data collection activity, one expects the process to be repeatable and if performed again on a comparable teardown article or specimen the results to be repeatable within a prescribed scatter band. Without rigid definition of the processes used, the data collection activity is not completely repeatable and results in a more significant scatter.

The lack of step-by-step procedures does not always result in diminished quality of the results. If the teardown is small in scope and being performed in one facility with adequate oversight, inclusion of step-by-step detailed procedures may not be required. However, as program scope increases or the number of execution sites increase, step-by-step procedures become more necessary to minimize scatter on the teardown data collected. Even minor differences in the processes used to perform certain teardown tasks, often lead to different collected data. This is particularly true for NDI and failure analysis and less true for extraction, disassembly, and coatings removal. At times “best shop practices” are sufficient for these tasks.

1.5 Proposed Process for Developing a Structural Teardown Program

With structural teardowns becoming more frequent due to the large number of aging aircraft currently in service and the introduction of documents suggesting/requiring structural teardowns, the need to standardize the teardown program development process is becoming more urgent. The issue becomes even more complex since no single set of processes can be applied to
all teardown programs. Processes must be individually developed to meet the requirements of the specific teardown program.

Currently, every government agency, military platform, and OEM is using their own “standard practices,” with scarce sharing of information. This lack of information and process sharing results in no benefits to present or future teardowns from past “lessons learned.” The problem is further compounded by a limited number of personnel with experience developing and performing structural teardowns, particularly teardowns with diverse purposes, goals, and objectives.

The objective of this work is to develop a standard teardown planning process that incorporates lessons learned from multiple teardowns that can be applied to develop future teardowns regardless of budget, schedule, scope, or purpose. The desire is for this approach to be implemented during the planning of future teardowns to avoid repeated teardown pitfalls observed during the past decade. If these pitfalls can be minimized or avoided entirely, the teardown process will be more efficient, producing more quality product for less schedule and cost. To illustrate the benefits of the proposed process, case studies will be used to show how the proposed planning process could have affected the quality of the product of previous structural teardowns.

Based on this research, a structural teardown program can be divided into two phases: development and execution. A common issue for previous structural teardowns is a lack of concentration on the development phase with all the focus being placed on execution. The proposed process emphasizes the need for an appropriate level of development prior to program execution.
Based on the proposed process, the development of a structural teardown should consist of four steps, illustrated in Figure 6. The execution phase should be comprised of three steps shown in Figure 7. As one can observe from the steps shown in Figure 6 and Figure 7, a significant portion of the detailed work using the proposed process actually occurs during the development of the teardown with only “maintenance” and “fine tuning” performed during the execution phase.

![Figure 6. Proposed steps to develop a structural teardown.](image-url)
1.6 C/KC-135 Teardown and Analysis Program

In 2006 a unique opportunity to develop, implement, and refine the proposed structural teardown process on a large structural teardown presented itself in the form of the C/KC-135 Teardown and Analysis program. Funding for this teardown program would not be available until 2008 from the USAF, but planning/development funding, in the form of a congressional appropriation was made available to the National Institute for Aviation Research (NIAR) at Wichita State University (WSU) in 2006. The Nondestructive Evaluation (NDE) branch of the Air Force Research Laboratory (AFRL) sponsored this research program under the NDE Technology Initiatives Program II (NTIP II). The program was administered through Universal Technology Corporation (UTC) under Contract F33615-03-D-5204, for an effort entitled “Inspection and Analysis Methods in Aging Military Aircraft.”

The objective of this research program was to develop or plan the structural teardown prior to execution. A significant portion of the proposed process for developing a structural teardown was implemented on this teardown program. The development of the KC-135
teardown followed the proposed process by: (1) establishing goals and objectives, (2) selecting teardown articles, and (3) establishing detailed, step-by-step processes based on the teardown requirements. A detailed data analysis plan has yet to be developed for this particular structural teardown. Thought was also given to how the developed processes would be executed and the scatter reduced in the data by establishing quality assurance methods.

The teardown development team identified early in the development process that step-by-step documented processes would be required to support the goals and objectives of this teardown program due to both the large scope of the program as well as the anticipated large number of program participants located across the United States. Subsequent Chapters will discuss the implementation of the proposed teardown development process and provide specific examples of how the process was implemented on the C/KC-135 Teardown and Analysis Program.

1.7 Research Goals and Objectives

The use of structural teardown to assess the true condition of aging aircraft structures is becoming more and more common over the past decade. Structural teardown is now not only performed by manufacturers, but owners, operators, and type clubs, with a drastic increase in the number of teardowns being performed by the USAF and other branches of the US government. Since the fidelity of the data obtained from a structural teardown is highly dependent on the processes developed and implemented to gather the data, improper procedure selection often results in the destruction or degradation of teardown findings. Incorrect implementation of procedures also occurs during teardown programs and frequently results in atypically high scatter in the teardown data, which leads to difficulty interpreting the data and using it appropriately to manage the fleet of remaining aircraft.
The lack of a defined teardown planning process with specific recommendations based on lessons learned from previous teardown programs has resulted in a few common issues that have plagued multiple teardown programs. The four most common problems emerging from teardown programs of the recent past include: (1) lack of definition in goals and objectives, (2) lack of planning prior to execution, (3) flexible finding requirement, and (4) incomplete documentation of the teardown process. Recurrence of these issues results in increased costs, increased schedule and capacity requirements, and quite possibly a degradation or destruction of valuable teardown data. The recurrence of these issues could be drastically reduced, or even eliminated, if lessons learned from previous programs were shared within the teardown community and/or if a defined teardown planning process was developed with specific recommendations regarding process selection and implementation based on these lessons learned.

This research provides a step-by-step process for planning and executing a structural teardown program with the goal of minimizing or eliminating problems encountered during past teardown programs. The developed process defines four steps required to plan and three steps required to execute a structural teardown. Each of the developed seven steps provides specific recommendations to avoid common pitfalls of previous teardown programs. Four case studies of previous and ongoing teardowns are discussed and the methods implemented compared to the proposed teardown planning and execution process to assess potential improvements when using the proposed method.
Establishing goals and objectives is easily the single most important task in the development of a structural teardown. The time and resources to define these key parameters; however, are often overlooked in lieu of focusing on budget, schedule, and personnel resources. Without sufficiently developing the goals and objectives of the teardown program, the fidelity of the execution tasks that follow cannot be properly determined [11].

Often during structural teardown programs, planning and development is rushed or even performed simultaneously with early program execution. This frequently occurs because money is often not available to sufficiently plan a teardown. Once the money becomes available, the desire to receive results of the teardown, often leads program managers to forgo the detailed development and planning stages and dive directly into acquisition of the teardown article and program execution. This leads to poor definition of the process requirements and fidelity of the findings. Instead of using the developed goals to define the fidelity of the desired results, often schedule and budget become the defining factor [11]. Using schedule and budget factors solely to define the fidelity requirements often results in the expenditure of more money for less useful data for engineers.

2.1 Questions to Ask

The most critical step in any effective teardown program is defining the program goals and objectives. Figure 8 provides a list of questions that should be addressed prior to program execution during the development of goals and objectives:
Figure 8. Questions to ask during goals and objectives development.

What is the purpose of this structural teardown? Structural teardowns are seldom performed for a single purpose. Since one clear or primary purpose is often not defined, trade-offs during the planning phase of the teardown are common to make sure all purposes are adequately addressed by the processes selected and the damage mechanism/fidelity desired are achieved. If multiple purposes are identified for a structural teardown, prioritize all purposes in a
written document. Since some of these purposes may be competing with regard to resource allocation or other issues during process development, a prioritized list is critical prior to beginning the trade-off process.

Another motivation to clearly determining the purpose(s) of the structural teardown is to define how the data generated will be used by engineers and fleet managers during and at the conclusion of the teardown. An in-depth understanding of the future usage of the data often assists in developing the teardown processes and data storage requirements.

What damage mechanisms require identification and characterization during this program (i.e., cracks, corrosion, mechanical damage, etc.)? Determining which damage mechanisms should be identified and characterized is another important issue to decide when planning a structural teardown. Flight load driven damage such as fatigue cracks and overload failures, environmentally driven damage such as corrosion and stress corrosion cracking, and mechanical damage such as double drill holes, out-of-round holes, gouges, drill starts, etc. are common damage mechanisms of interest. Combinations of these damage mechanisms are often identified and characterized during structural teardowns.

Double drilled holes are defined as fastener holes that are not perfectly round due to mechanical damage. The extent of this type of damage can range from barely oblong to excessively double drilled, often referred to as a “figure eight hole” or a “snowman hole” as shown in Figure 9. Double drilled holes are of concern to engineers as the double drilled portion becomes larger, the stress concentration factor also becomes larger than the originally round fastener hole. The same rational is true for out-of-round holes, shown in Figure 10. The difference between double drilled and out-of-round holes is the mechanism causing the damage. Out-of-round holes are caused by fastener bearing while double drilled holes are caused by a
drilling operation either during manufacture or maintenance on the airframe. Gouges, like the one shown in Figure 11, typically occur from a metal punch contacting the surface or fastener bore of a part. This often results in an obvious indentation with displaced metal along the edges. Like double drilled and out-of-round holes, severe gouges do cause stress concentrations and based on the nominal stress in the location containing the gouge, could serve as prime crack starting locations.

Figure 9. Example of a double drilled hole.
Figure 10. Example of an out-of-round hole.

Figure 11. Example of a gouge.
Sometimes, particularly when the teardown is being conducted post full scale test, fatigue is the only damage mechanism of interest. In this case, the teardown article has not been subjected to harsh environments, so corrosion and stress corrosion cracking would not be considered. Also, mechanical damage that might exist on this particular type of teardown subject may not be representative of field damage. For structural teardowns of operational aircraft, typically a combination of flight load driven damage, environmentally driven damage, and mechanical damage are identified and characterized.

Referring back to the defined purpose(s) of the structural teardown should determine the types of damage mechanisms that should be identified and characterized on a structural teardown program. If desired damage mechanisms are unclear from the purpose(s) of the structural teardown, the purpose(s) must be redeveloped to include desired damage mechanism(s). Unnecessary scope growth with structural teardown tends to occur when the damage mechanisms are not clearly agreed upon in the earliest stages of teardown planning.

What is the minimum extent of damage required to be identified and characterized to meet the purpose of the structural teardown (finding fidelity)? Establishing a rigid value for finding fidelity, or the minimum damage extent required to be identified and characterized by the teardown to meet the program objectives [11] is the single most important task performed when establishing goals and objectives. It is imperative that this decision be made at the onset of planning the teardown since all subsequent teardown processes are dependent on the minimum required detectable flaw size. It is necessary to ensure this decision is based on what is “required” not just what is “desired.” From an engineering perspective, the desire always exists to obtain all possible data, relevant or irrelevant, during a structural teardown.
This natural desire makes the decision regarding required damage fidelity arguably one of the most difficult decisions to make when planning a teardown [11]. The obvious, although not advised, method is to identify the required fidelity as “whatever can be found by any NDI technique [11].” This often results in unnecessary NDI and failure analysis attempting to characterize very small defects. Although some NDI techniques exist that can find very small fatigue cracks, generally speaking the smaller the desired detectable crack length, the higher the false call rate. High false call rates lead to hours of unnecessary and expensive failure analysis, taking financial resources away from the rest of the teardown program.

In order to appropriately determine damage fidelity, the planners of structural teardowns must once again return to the purpose(s) of the structural teardown. If one of the primary goals is to validate the damage prediction models developed after the full scale structural tests, then consideration should be given to the minimum crack dimensions that would be useful for such validation. Since most damage tolerance analysis methodologies used by the USAF and FAA begin from the rouge flaw size of 0.050 inches for most structural elements, findings that are significantly smaller than this may be of no use to meet the objectives of the teardown program [11].

Although not typical, if the primary objective of the teardown program is to validate inspection methods on the aircraft, one must establish desired damage fidelity based on the fidelity of the field inspections being assessed. In this case yet again, damage drastically smaller than the minimum detectable size of the inspection methods being validated will be of little to no use to address the purpose of the teardown program. For instance, if visual inspection methods are desired to be validated on aircraft structure, the 0.050 inch damage fidelity discussed previously would be inappropriately small, where damage fidelity on the order of 0.100 inches or
0.250 inches might be more appropriate. On the other hand, if the primary objective is to develop or validate an EIFS to assist in the assessment of a structure’s susceptibility to WFD, crack sizes significantly smaller than 0.050 inches are appropriate. In this particular case, the highest fidelity NDI techniques are suggested and largest amounts of failure analysis are required.

If the purpose(s) of the structural teardown do not lead the planning committee to determine a rigid finding fidelity, they should be rewritten until finding fidelity becomes evident. Flexible finding fidelity definition leads to scope growth and unnecessary, irrelevant damage data collection, which often wastes schedule and budget. Teardown planning should not proceed until a rigid finding fidelity is agreed upon and formally documented.

Do unique structural elements exist on the teardown articles that required special attention (lap joint residual strength, corrosion preventative compound (CPC), spotwelded joints)? “Special structural features” require special consideration when developing a structural teardown with regard to how these features will affect standard extraction, disassembly, coatings removal, NDI, and failure analysis processes. Some examples include lap joints where residual strength properties are desired, assessment of CPC effectiveness, and spotwelded joints [18]. In past teardown programs where residual strength of lap joints has been desired, lap joint coupons have been extracted from the airframe at select locations and been subjected directly to residual strength testing [12]. Once failure occurs, these specimens are sent directly to failure analysis, forgoing the typical teardown steps of disassembly, coatings removal, and NDI. An example of a residual strength test setup for a lap joint is provided in Figure 12 [18].
One of the objectives of the KC-135 teardown program was to assess the effectiveness of CPCs utilized on the aircraft in the 1990s in lap joints [14]. To assess the effectiveness of CPCs, lap joint sections were extracted from the aircraft, disassembled to expose the overlapped region of the lap joint, and chemical measurements were taken within the lap joint to assess how far the CPC wicked into the lap joint. This effort also characterized the presence and amount of corrosion in the lap joint in an effort to assess the effectiveness of the CPC [14, 18]. A disassembled lap joint showing CPC or corrosion in the lap joint area is provided in Figure 13 [18].
Another challenge encountered in the teardown process is the presence of spotwelded structure [19]. Often disassembly of spotwelds is accomplished by either drilling into the spotweld and prying the two layers apart once the weld has been sufficiently weakened, or using a spotweld cutter to separate the two layers. Either of these two processes could easily cause incidental damage and mask any existing damage in the spotwelded region. Almost always, the program manager of the teardown facing this challenge, elected to leave the spotwelds intact, remove coatings, and perform NDI around the spotwelds instead of fully separating the two pieces of structure. An example of spotwelded structure is provided for reference in Figure 14.
If unique structural elements exist on the teardown article, program planners should make sure this is considered when establishing detailed processes based on requirements. It is imperative these issues be dealt with during program planning and not during program execution. Failure to address these types of issues prior to program execution could result in the degradation or destruction of teardown data.

How will engineers be able to compare results captured on this teardown program with previous programs (certification fatigue tests, previous teardown programs, previous fleet surveys, large scale component replacement programs, etc.)? Sometimes data from previous programs is incomplete, inaccurate, or missing all together. A survey of the existing data should be performed during the planning stages of a teardown to assure that additional objectives or goals should not be added to the new program based on “lessons learned” or data previously obtained during other programs. A typical example of past data effecting the planning of a
current teardown program is assuring that the locations of previous damage or repairs obtained from fleet history is incorporated into the areas being analyzed during the teardown.

Another example is CPC Figure 13. CPC effectiveness is typically not assessed during a teardown program. However, since such a large effort to protect the lap joints from corrosion was applied fleet-wide (and could be considered again during the life of the fleet to address corrosion issues in lap joints) this assessment was incorporated into the teardown program [14].

Prior to finalizing goals and objectives, a survey of results captured from past programs should be performed. A compilation of all historical fleet records with respect to damage might drive additional tasks/airframe locations to be added to the goals and objectives. This data is also useful for making fleet-wide projections from a small sample size teardown.

**How can this program assess field/depot inspection adequacy?** One of the secondary goals of many teardown programs executed recently is to assess the adequacy of field/depot level inspections. These inspections are designed for one reason which is to assure structural integrity and continued airworthiness of the airframe [11]. If damage is found by these inspection programs, maintenance activity must be conducted to repair the damage prior to continued operation in almost all cases. If the inspections are not of sufficient fidelity, risk is increased and safety can be compromised. However, if the inspection methods result in a high false call rate, mission readiness is compromised due to excessive, unnecessary maintenance activity [11]. While inspection procedures are not expected to be perfect, understanding their capabilities and limitations allow fleet managers to make more informed decisions regarding mission readiness. Structural teardown allows for a direct correlation of field/depot level inspection indications and damage identified and characterized during the teardown process.
How should teardown processes used be documented? Another important aspect of planning a teardown that is often overlooked or diminished in priority, is deciding how to document the teardown processes selected for the teardown program. This step is vital to communicate effectively with personnel executing the teardown and to allow for reflection on “lessons learned” after teardown completion. In numerous cases with poor process documentation occurring during the planning stages of a teardown, valuable teardown data has been lost due to a misinterpretation of the processes by the teardown execution team. For this reason, step-by-step processes that have been previously validated on representative aircraft structure are preferred [5]. In instances on specific structure where validated procedures are not available the conventional “best shop practices” are also acceptable as long as the program manager is made aware of the situation and accepts the substitution of procedures.

On programs where the process requirements are not clearly documented and communicated to the teardown execution team, miscommunications can occur and can be detrimental to the data obtained from the teardown. Even if step-by-step processes are not written in detail in a formal document, clear communication with the execution team is mandatory. Failure to clearly communicate processes and desired results jeopardizes the quality of the teardown data set obtained.

How should damage be documented so all important characteristics are captured and easily retrieved for future analysis? Data documentation and archival methods should be a primary consideration during any structural teardown. In earlier years during smaller structural teardown programs, reports containing tables and photos detailing damage mechanisms and extents were used for documentation. Spreadsheets in Microsoft® Excel® were also used regularly to document damage identified and characterized during teardown [11]. The trend in
recent years, particularly on larger programs, are custom designed databases that allow program/fleet managers to track the status of the teardown as well as archive data in a searchable format.

Two essential considerations when determining data storage techniques and desired database capability are budget and schedule. Even for simplistic databases, time and money must be set aside for development. For the more complex databases, such as the Teardown Data Management System (TDMS), developed for the KC-135 teardown and used now by multiple USAF platform teardowns, the development time was extensive and ongoing. A programmer has been assigned for the six year duration of the teardown to continually update, monitor, maintain, and improve the database during active data entry.

An example of a teardown program where databases were not utilized is during the teardown of the two T-34A wing sets [20]; where all damage characterization information was stored in tabular format. Overall part photographs and close-up damage photographs were taken of each NDI indication and failure analysis performed. This data was archived in a final report delivered to the FAA, and later published in the public domain. This documentation technique worked relatively well since this was a smaller scope teardown program with all teardown steps performed in one facility by one company. The downfall to this approach is the information is not easily searchable and higher level details such as crack size are not separated from very detailed information such as striation spacing.

Program management, from a communication and task completion standpoint, may also serve as the primary function of a database. Databases with program management as the primary objective are often lacking tools that query data for easy technical analysis. The C-5A teardown program database is an example of this type of database designed for the purpose of managing
participants performing teardown tasks and for easy communication between program management and participants. This database worked effectively for its purpose, but lacked the ability to analyze technical data effectively through the use of queries and other built-in data analysis tools [11].

Another purpose of database utilization during the structural teardown process is solely archival of technical data. One of the best examples of this type of database was the database used by the FAA and Delta Airlines during a joint teardown program of a Boeing 727. During this program, large fuselage panels were inspected by a large number of NDI techniques including commonly used field techniques and developmental methods [21]. High fidelity failure analysis was also performed [11]. The goal of the databases was to store both the details of the NDI indications identified by each inspection technique and the detailed results of the failure analysis performed. The FAA/Delta database that was generated to meet these requirements permitted easy access to volumes of inspection and damage data. Graphical user interfaces (GUI) further facilitated the generation of queries to perform virtually any imaginable data analysis [11, 21].

Most recently, databases have evolved to meet both the program management goal of the C-5A database and the data archival and analysis goal of the FAA/Delta database. Likely the most successful database developed with this combined goal approach is TDMS, which was designed and implemented to support the KC-135 teardown program [22]. Since its development and implementation, other teardown programs in the USAF have adopted versions of the KC-135 TDMS database. This database provides effective communication between all program team members including program management, vendor participants at multiple sites, Boeing engineers, and the C/KC-135 Sustainment Division in Oklahoma City through the use of
a status page. Reports can be generated based on any of the parameters entered into the status page including location of the parts, and the status including whether the work is completed or in work [22]. Start and completion dates for each task are also provided.

The technical data capacity of this database far surpasses that of any other teardown database [14]. The types of data stored include logs, photographs, parameters of NDI indications, and failure analysis information. All of this data is searchable using the built in report functions [22]. If unique reports are desired, beyond pre-designed reports, a custom reports function is also available, plus the database programmer is available if none of the other options produce the exact desired data subset. TDMS is a web based database, so multiple site usage is simple. All that is required is a connection to the internet and the correct credentials to access the database.

Prior to deciding on a data management philosophy, much thought should be given to how many people will be accessing the data and for how long during and after the completion of the teardown program this data will need to be accessible. Consideration should also be given to the time and budget required to develop the desired database and the costs associated with maintaining the database over the duration of its useful life. One of the most important aspects of designing a data storage system of any type is to grasp the amount of data that will be captured and needs to be stored using whichever philosophy is selected. Quite frequently, this is a potential Achilles heel to teardown databases. Often the amount of data is underestimated leaving a program in scramble mode to prevent running out of space to store data during the height of program execution.

Other aspects to consider during database development are security and how data backups will occur. In many cases, teardown data may be permanently lost if the data backup
system fails. Paper logs and backup copies of photographs at participating locations are often used as a failsafe to combat this issue; however, the risk of some data being lost or degraded even exists with this approach.

2.2 Trade Offs

As previously discussed, structural teardowns seldom have a single purpose. In the event of multiple purposes, trade-offs can be used to assure all purposes are adequately addressed by the selected teardown processes and the desired damage mechanisms/fidelity is achieved. One example of a common trade-off that occurs frequently on operational teardown articles is defining inspection methods for multiple desired damage mechanisms.

Often, in an effort to conserve budget, a primary damage mechanism may be identified for particular aircraft based on the fleet history. For example, if an airframe has operated primarily in a dry climate with very high flight hours, fatigue should be defined as the primary damage mechanism. In this case, more wide-spread fatigue driven inspection methods, such as eddy current, should be used over the entire airframe. Limited environmentally driven inspection methods, such as long dwell fluorescent liquid penetrant, should be used in locations where corrosion is most commonly found, such as lap joints.

On the other hand, if an airframe that has flown significantly lower flight hours than its design life, but has been operated and stationed in a harsh “corrosion friendly” environment one should designate corrosion and stress corrosion cracking as the primary damage mechanisms. Inspection methods would then be developed and implemented to find this damage mechanism over the entire airframe. If fatigue is a concern for this particular example, targeted inspections designed to detect fatigue cracks may be employed on a limited scope, like at the fatigue critical locations identified during design and certification testing.
Other examples of common trade-offs include:

- Defining a minimum damage extent for each damage mechanism to reduce inspection cost.
- Defining finding fidelity and inspection methods based on criticality of the location being inspected.
- Defining documentation requirements to minimize cost yet still capture most critical data.
- Defining the level of process documentation required for desired program quality.

Define a minimum damage extent for each damage mechanism to reduce inspection cost. Often the finding fidelity for the fatigue damage mechanism is significantly smaller than that of the environmentally driven damage scenarios. Inspection cost can often be minimized on a teardown program if reasonable minimum damage fidelities are selected based on damage type. For instance, fatigue damage fidelity might be selected at 0.050 inches and stress corrosion cracking damage fidelity might be selected at 0.100 or 0.250 inches. A larger stress corrosion cracking damage fidelity would allow less expensive inspection methods such as visual inspection or long dwell fluorescent penetrant inspection over more costly eddy current or ultrasonic inspection methods.

Define finding fidelity and inspection methods based on criticality of the location being inspected. If this type of trade-off occurs, commonly primary structure is inspected with a higher desired finding fidelity than secondary structure. Non-structural elements frequently are subjected to a visual inspection or are discarded as non-program structure. As with the previous trade-off the objective of this trade-off is to minimize cost while maximizing relevant teardown findings.
Define documentation requirements to minimize cost yet still capture the most critical data. When designing a structural teardown process, defining the data required to be captured and documented is very important. In some cases, particularly with large capacity databases in place, all parameters of any indication identified during structural teardown is stored with little thought as to relevancy. In some cases, where budget and/or storage space is tight, only the most relevant parameters are required to be obtained, documented, and stored.

Define the level of process documentation required for desired program quality. Detailed, step-by-step, processes of every teardown task are time consuming and expensive to generate. If a teardown process is small in scope and performed at a single location, detailed documented processes are not always required. Since structural teardown cannot be performed by one person, or in many cases even one team of people at a single site location, the absence of detailed documented processes increases the risk of process variability and scatter in the resulting data.
CHAPTER 3

TEARDOWN ARTICLE SELECTION

Once the teardown program goals and objectives are established, the next main consideration, when planning a teardown is identifying the teardown article(s). The teardown article selection process is usually based on cost, schedule, and teardown article availability. One important consideration is the impact of sample size on applicability of the findings. A sample size of one typically provides the teardown team a look at more areas from the airframe/component for a given budget. A larger sample size provides repeatability at a limited number of specific locations on the airframe/component and more confidence in repetitive findings being representative of the fleet. Once a sample size is decided, the planners need to determine if a full scale test article(s) or operational article(s) meet the goals and objectives of the teardown program. Teardown purpose, as discussed previously, may provide an answer to this question directly.

Over the past ten years, many methods have been used to select appropriate teardown article(s) from operational aircraft. Some methods include: random selection, a teardown article “volunteers” itself, or based on in-depth analysis of engineering parameters including flight hours, operational environment, presence of major repairs, etc. [2, 11, 13, 16, 20, 23]. The final major decision with regard to the teardown article(s) is identifying the area(s) of interest from the selected article(s). Many factors often influence area(s) of interest on a designated teardown article including: fatigue critical locations, locations with a history of damage in the fleet, areas with prescribed field/depot inspections, areas with known repairs, inaccessible areas, areas investigated in previous teardowns or fleet surveys, other areas of concern identified by program management.
3.1 Typical Factors to Article Selection

Selection of a structural teardown article typically occurs after consideration of a number of factors. These factors include both program management and technically based factors. Program management factors include budget, schedule, and teardown article availability. Technically based factors can include considerations for the desired type of teardown article; full scale test or operational article; teardown depth vs. breadth; and the effect of sample size on the teardown results.

3.1.1 Budget, Schedule and Teardown Article Availability

Structural teardowns are not immune to trade-offs between technical requirements and fiscal, program management based requirements. As with any large research based program, budget and schedule are always considerations during the planning stage. Frequently, the budget is a defined number prior to program planning. The goal then becomes getting the most relevant technical data with the money available. The cost of the acquiring a teardown article and shipping it to the teardown site(s) is often a non-negligible portion of any teardown program budget. If less expensive options in teardown article(s) become available these options are often explored, presuming minimal impact to the technical aspects of the planned teardown program.

Schedule is often another major consideration when planning a teardown program. Frequently, the money acquired to perform structural teardown is only valid for a specific period of time and is tied to a timeline requiring results by a specific point in the period of performance. If problems arise within the fleet, often the schedule must be revised to obtain a specific answer to a specific problem through the teardown program. This is often accomplished via reprioritization of teardown execution tasks. The final program management consideration is teardown article availability. If the desired schedule is tight, teardown article selection may be
altered because of specific article availability. For instance, if an ideal airframe is scheduled to be retired from the fleet in October, but the desired delivery date of the teardown article is May, the ideal article may be listed as unavailable because it does not support the program schedule goals. A less desirable teardown article may be selected in its place.

3.1.2 Teardown Article Depth vs. Breadth

For this discussion, “depth” refers to teardown of the same structural element on multiple teardown articles, while “breadth” refers to the amount of each teardown article subjected to in-depth teardown and analysis. Figure 15 [11] illustrates depth of teardown articles as the subject teardown focuses on one single structural element from multiple aircraft. Teardown breadth, illustrated in Figure 16 [11], shows the evaluation of as many structural elements as possible in a single aircraft. Ideally, a teardown with sufficient depth and breadth would be desired from an engineering perspective for a given budget, as illustrated in Figure 17 [11].
Figure 15. Example of aircraft depth [11].
Figure 16. Example of aircraft breadth [11].
Figure 17. Example of aircraft depth and breadth [11].

One key benefit to structural teardown is that if the breadth is sufficiently large, “unknown unknowns” may be captured [14]. This term refers to unexpected damage in areas that were not anticipated to have damage and are not accessible during normal inspection/maintenance processes. Structural teardown allows access to areas of airframes that have not been accessible since original manufacture. When considering the KC-135 is projected to have an average service life of eighty years when the fleet is fully retired, this becomes an often overlooked benefit to structural teardown. An unanticipated failure in a structural region not accessible during normal maintenance, falling in this “unknown unknowns” category, could significantly hamper mission readiness or result in a grounding of the fleet. Without a viable replacement for a critical mission, such as aerial refueling, this could result in a significant impact to USAF operations, both foreign and domestic.
3.1.3 Operational Article vs. Full Scale Test Article

Teardown data obtained from full scale test articles and operational articles are often used to accomplish different objectives and each has benefits over the other. The benefit to full scale test articles is that the flight spectrum is known and accurate. Teardown data from full scale fatigue tests is crucial to identification of critical structural details based on the applied fatigue spectrum. Often full scale fatigue tests are used to verify fatigue critical details identified during the design of an aircraft and to identify additional unanticipated fatigue details that arise during testing. This data is also vital to the validation of fatigue crack growth predictive models, generated during aircraft design. Once these models are validated with teardown data from the full scale test article, initial inspection intervals are developed using damage tolerance techniques.

Since the applied load spectra is known in full, the likelihood of the onset of WFD can be determined based on cracks found in the structural teardown post-test [7]. Risk models can also be developed from full scale test data as the probability distribution for EIFS in critical structural areas can be determined from post-test teardown data [9, 10]. Assessment of the likelihood of WFD and development of a risk model are required before the aircraft enters service.

The downfall of using full scale test data is the applied loading spectra is assumed and may often not be representative of fleet usage due to mission modification, increased gross weight operation, and the introduction of environmental factors. Once the aircraft has been operated a significant portion of its design life, structural teardown data can be used to:

- Assess the current condition of that particular aircraft and augment data already available to make fleet-wide predictions.
- Update the EIFS and risk models [9].
- Assess viability for continued operations to anticipated service retirement date.
- Consider the effect of environmental factors.
- Determine damage mechanisms and gear future inspections to distinguish them.
- Assess MSD/MED [7].
- Assess effectiveness of fleet management decisions to date (inspections, repairs, etc.).

A couple of the drawbacks to operational teardown data include a potentially unknown/incomplete loading spectra, including environmental exposure, and determining if the teardown article is representative of the rest of the fleet. Even without a complete load/environmental operation history, engineers can use the known information and presume operational history to fill in missing information. Any known usage is a benefit to engineers and decreases uncertainty/inaccuracy in predictive damage and risk models.

3.1.4 Effect of Sample Size

As with any data collection effort with a relatively small sample size, teardown data is not immune to significant “scatter” [11]. It is common to have a region identified by maintenance records as an area that commonly exhibits damage in the field, and find nothing in a structural teardown with a small sample size. Teardown data, regardless of the depth and breadth, should not be the sole source of data used for fleet management. Teardown data should be used to augment other available data, such as fatigue test data, data obtained from previous teardown programs, depot/field inspection/repair reports, previous fleet surveys, etc. [11]

3.2 Teardown Article Selection Process

Numerous selection methodologies have emerged over the past ten years for selection of an in-service or operational teardown article. The three primary methods used on recent teardowns include: random selection, teardown articles that “volunteer themselves,” and articles
selected by an in-depth engineering analysis of available history. The first step in executing any of the operational article selection methods is determining the available population. The available population is defined as all serial/tail numbers still in service that could be acquired for structural teardown. The next step is to develop the selection population by eliminating aircraft from the available population that do not meet the goals, objectives, and purpose of the teardown. The final step in selecting a teardown article is applying one of three selection criteria to determine the optimal teardown article. Insufficient attention is often given to identifying either the available or selection population of aircraft prior to final teardown article selection; however, this step is critical to selecting the optimal teardown article to meet the requirements of the program.

3.2.1 Determine the Available Population

In order to determine the available population, the planning committee should first perform a survey of all serial/tail numbers still in service to obtain a complete fleet population. The next step in determining an available population for teardown article selection is eliminating unavailable aircraft. For commercial and general aviation aircraft this step can be accomplished by contacting owners and operator to determine which serial numbers could be made available to support a teardown program. Salvage yards and used aircraft dealers may also be appropriate sources of airplanes to consider for general aviation aircraft. For military aircraft this step can be accomplished by contacting the Aircraft Structural Integrity Program (ASIP) Manager for the particular airframe. The ASIP manager should be able to survey the fleet, including recently retired aircraft, to determine a list of available aircraft.
3.2.2 Determine the Selection Population

Once the available population is determined and prior to implementing a teardown selection technique, a further reduction of the available population is possible by removing aircraft that will not meet the purpose of the teardown program. The aircraft remaining after this reduction would comprise the selection population.

In past programs, military aircraft that have been retired for more than a year have been removed from the population. The reasoning behind this decision is that these aircraft have likely been stored in the desert and have not been maintained at the same level as an operational aircraft. If assessing the representative condition of the fleet is an objective of the teardown program, due to the lack of continued maintenance, these aircraft are judged to be non-representative. Aircraft recently out of depot level maintenance were also removed from the population. Depot or heavy maintenance may repair or replace components containing vital damage mechanisms desired to be identified and characterized during the teardown process. Grinding out corrosion is also a typical practice at depot, meaning that information regarding the location and depth of widespread surface corrosion may be lost due to this common maintenance action.

Aircraft that have numerous major structural repairs are also often removed from the considered population as these aircraft may also not be representative of the fleet any longer. Often major structural repairs are unavoidable, particularly on the oldest fleets; however, a determination on whether or not the purpose of the teardown would be compromised due to the presence of the major structural repairs must be made prior to elimination or inclusion. Accident aircraft, particularly aircraft with widespread airframe damage in areas of interest, are also eliminated as the data in primary areas of interest for the teardown has likely been destroyed or
compromised at numerous locations on the airframe. If the purpose of the teardown is to assess the fleet, “hangar queens,” or aircraft with non-representative (low) usage are also typically eliminated from the selection population.

A list of elimination criteria, similar to those discussed above, should be generated at the onset of aircraft selection and applied to each available airframe on an individual basis to determine if that particular airframe should be included or excluded from the selection population. Any airframe remaining in the selection population at this point should serve as an acceptable teardown article. The next step in the process is to try to identify the optimal teardown article from this acceptable population. At this point in the process, an appropriate selection population has been developed and one of the three primary teardown article selection methods can be implemented.

3.2.3 Teardown Article Selection Methods

Many methods have been used to select an appropriate teardown article from an operational aircraft population throughout the history of structural teardown. Since aircraft damage, particularly environmental and mechanical damage, is so random and difficult to predict, no one selection method guarantees the optimal aircraft to be selected out of any selection population. For this reason, the random and the teardown article “volunteers itself” selection methods has been used quite frequently after a selection population has been developed. Only over the last few years has significant effort been placed on determining the optimal teardown article from a selection population using an in-depth engineering analysis of available history. The drawback to performing an in-depth engineering analysis of available history is that frequently, particularly on the oldest of airframes, significant fleet-wide engineering data is unavailable. Critics of this approach argue that significant time and budget
can be expended performing such analyses with little to no evidence of a more appropriate teardown article being selected compared to the other two selection methods. Proponents of the in-depth engineer approach are quick to point out that any further reduction in the selection population based on available engineering data statistically improve the chances of the selection of the optimal teardown article.

3.2.3.1 Random Selection Method

Random selection of a teardown article from the remaining selection population is obviously the easiest and most straightforward method for identifying a teardown article. The thought process behind using this method is that all remaining aircraft in the selection population at this point are representative of the fleet and meet the stated goals, objectives, and purpose of the teardown. The primary benefit of this methodology is that it is simple to execute, while the primary drawback is that no further effort is made to identify the optimal teardown article from the selection population.

3.2.3.2 Teardown Article “Volunteers Itself” Method

Another selection method occurs when the teardown article “volunteers itself.” This occurs when an airframe becomes readily available and it is present in the remaining selection population. An example of this method occurred during a follow on program to the FAA “Evaluation of Airworthiness for Small Airplanes [2, 13, 16, 23].” During the FAA teardown of the Piper Navajo Chieftain, a set of supplemental inspections were developed that provided the operator an idea of “where to look” on the airframe and “how to look.” Since only one Piper Navajo Chieftain airframe was assessed during the FAA Teardown [2], the FAA desired to inspect another high time Chieftain with the developed procedures. In February 2011, personnel flew to Alaska to inspect a high-time Chieftain, identified by the FAA for a limited teardown and
extensive inspection program. This particular Chieftain airframe slid off the end of a snow
packed runway and lodged into a snow bank, ripping off the landing gear and causing limited
damage to the belly of the fuselage. The airframe was of particular interest to the FAA as it had
approximately 45% more flight hours than the FAA teardown airframe.

3.2.3.3 In-depth Engineering Analysis of Available History Method

If teardown articles are not selected randomly and do not “volunteer themselves,”
selection often occurs by an in-depth engineering analysis of available history. Once the
selection population of aircraft has been established, engineering parameters which assess the
likelihood of flight load induced damage and environmental damage are often evaluated in an
attempt to identify the optimal teardown article. For flight load induced, or fatigue, damage, the
engineering parameters such as flight hours, severity of usage, or ground air ground (GAG)
cycles are often considered. In order to simplify comparisons, these parameters can be combined
into one, equivalent flight hours (EFH), which are the actual flight hours accumulated by an
aircraft adjusted for the actual usage severity compared to the design spectrum or to the baseline
spectrum [9, 24]. If the primary goal of the teardown is to assess fatigue damage on an airframe
then EFH should be calculated for critical structural components and compared. If the desired
teardown article is the worst aircraft in the fleet from a fatigue perspective the highest combined
EFH should be selected. If an average aircraft is desired from a fatigue perspective, then an
airframe toward the middle of this ranked EFH list should be selected.

Although engineers quite often consider fatigue first and foremost when assessing the
damage occurring due to service on an airframe, some of the older fleets have demonstrated
more susceptibility to corrosion. Many of the USAF older fleets including the C-5A, KC-135,
and B-52 are comprised of numerous aircraft that have accumulated flight hours far below their
original or service life extended design lives, making them more susceptible to environmental damage than flight induced damage. This is also true for Part 91 general aviation aircraft. The problem of environmentally induced damage is further compounded as predictive models for the initiation and growth of environmentally induced damage such as widespread surface corrosion and stress corrosion cracking either do not exist, or are not widely used and accepted. For these reasons, environmental damage mechanisms may be just as critical to the continued airworthiness and structural integrity as fatigue.

One method to assess corrosion susceptibility is to determine the environmental severity index (ESI) for each airframe in the fleet [24]. This task can be accomplished qualitatively or quantitatively. It seems logical that if an airframe is operated its entire service life in a costal environment and has flown a relatively low percentage of its fatigue based service life, corrosion based damage mechanisms are likely to be dominant. From a qualitative sense, if corrosion mechanisms are of primary concern, an aircraft operated in a primarily costal environment would be more desirable than one operated in a drier, less “corrosion friendly” environment.

During the selection process of the second and third airframe for the KC-135 teardown, quantification of the environmental effects on potential teardown articles was assessed. ESI was calculated based on the basing history of each aircraft [24]. Obviously, aircraft stationed a significant portion of their lives at bases such as Hickam Air Force Base (AFB) in Hawaii, Anderson AFB in Guam, and Kadena AFB in Japan would rank highest in this evaluation, whereas aircraft stationed at McConnell AFB in Kansas, for example, would rank significantly lower. As with the fatigue EFH metric, if the worst aircraft from a corrosion perspective were desired, the aircraft with the highest ESI should be selected. If an average aircraft were desired, an airframe toward the middle of a ranked ESI list should be targeted.
Quite frequently a compromise between fatigue and corrosion based damage mechanisms is desired to obtain a teardown aircraft with both a relatively high likelihood of fatigue and corrosion damage. When this occurs an averaging of the normalized EFH and ESI parameters can be utilized. For the selection of the third KC-135 teardown aircraft normalized values of wing EFH, weighted at 25%, fuselage EFH, weighted at 25%, and ESI, weighted at 50% was used to select the top aircraft of interest [24]. In this case, the in-depth engineering analysis further reduced the size of the population used to select the third KC-135 teardown article. A review of the aircraft configurations occurring within this reduced population, an in-depth review of all available maintenance data, and on-aircraft surveys were used to make the final teardown article selection [24].

If this, or a similar, approach is implemented, understanding the composition of the fleet from a flight hour vs. ESI damage perspective is important prior to selecting the teardown article(s). In some cases, the homogeneous nature of the fleet from a flight hour and ESI damage perspective leads the planning team to further reduce the selection population based on the data and then implement the random selection criteria to determine the final teardown article selected. For example, Figure 18 and Figure 19 show flight hour versus ESI damage data for two particular aging fleets. It is important to note that the proposed method for aircraft selection was not used in this case and the data collected and presented represents the entire fleet population, not the available or selection population.
Figure 18. ESI damage versus flight hours for Fleet 1.

Figure 18 illustrates a tightly clustered pack of airframes with similar ESI damage versus flight hours and a number of outliers. Using the in-depth engineering analysis selection method, this data would drive the teardown planning committee to select one of the outliers. If the purpose of the teardown was to assess the worst fatigue airframe in the fleet, the aircraft with the highest flight hours should be considered for final selection. If an airframe with a high likelihood of significant environmental damage is desired, airframes with the highest ESI damage rating should be considered. Teardown programs that wish to identify airframes with high likelihoods of both flight and environmentally driven damage scenarios should consider airframes that rank relatively high in both flight hours and ESI damage.
Figure 19 illustrates the ESI damage versus flight hours for a second fleet of aging aircraft. In this case, the fleet data is observed to be more homogeneous than the fleet data presented in Figure 18. Less outliers exist and the data is generally more tightly clustered. As mentioned previously, the problem with this data is that it represented the entire fleet, not just the selection population. Upon further review of this particular fleet data, all of the outliers were unavailable/undesirable as teardown articles. Many of the outliers were eliminated as they were not available for structural teardown due to their specific mission. Others were eliminated since the structure had been heavily modified to support special missions. With all of the outliers removed from the fleet population data shown in Figure 19, only a large, tightly clustered group of airframes remained. In this case, the in-depth engineering data analysis method did not provide a clear candidate for teardown. In this situation, random selection of airframes located in the tightly clustered data may be the only reasonable approach to identify a teardown airframe.
3.2.4 Defining Areas of Interest (Teardown Subjects) from Selected Teardown Article(s)

The identification of teardown subjects is nearly as important as setting the required finding fidelity. Proper finding fidelity requirements to address the program requirements will ensure the data acquired will meet the purpose, goals, and objectives of the teardown program. Appropriate selection of teardown subjects will address the utility of those data [11]. Some teardown programs select the entire airframe as the teardown subject. For example, the FAA general aviation teardown assessed the structure of the entire airframe for four general aviation airplanes [2, 13, 16, 23]. Other teardowns identify major structural components as the teardown subjects. Examples of this methodology are the T-34 and T-37 wing teardowns [11, 20]. In each of these teardown programs, only sets of wings were subjected to teardown analysis. Still other teardowns, such as the C-5 and KC-135 teardown programs, identified teardown sections, defined as table top sized pieces of structure.

Once a specific teardown article is identified, programs assessing the entire airframe or structural components such as wing sets, require no further action to determine areas of interest. Teardown programs targeting specific teardown sections on the other hand, require further extensive effort to define all areas of interest. For smaller airframes, such as general aviation or T-34/T-37, entire airframes or components might be a realistic scope for a teardown program. For larger airframes, like the C-5 and KC-135, selective sampling of regions of interest from the airframe may be more appropriate for a given budget/schedule. Teardown sections can be selected for various reasons as shown in Figure 20.
Figure 20. Teardown section selection.
CHAPTER 4

ESTABLISH DETAILED PROCEDURES

Establishing detailed procedures for each of the teardown tasks is often the most cumbersome activity required during the planning of any structural teardown. While step-by-step, validated, and fully documented procedures are preferred [5], they are not required for all teardown programs. Frequently, program budgets and schedules do not include formal documentation of step-by-step procedures. However, it is imperative that appropriately detailed procedures be provided to the teardown execution team. If a teardown program is small in scope and performed in a single execution site, formally documented, detailed procedures may not be required to minimize scatter in the teardown data. As either the scope or participating execution sites increase, the need for detailed, fully documented procedures also increases. For multiple aircraft, multiple participating site teardown programs, more formal, more detailed and documented processes are required for consistency of data collection and minimization of data scatter.

It is imperative to note that the development of these processes should be based on teardown program requirements, particularly finding fidelity, not budget and schedule. Teardown data can be compromised or destroyed if inappropriate processes are selected or if process requirements are not clearly communicated to the execution team. Since processes must be individually developed for specific teardown requirements, the following sections will provide recommendations based on requirements for process selection and data capture. Recommendations for each program task, in the common teardown program structure, will be presented for a medium to high fidelity teardown program. The processes presented may be scaled up or down, based on requirements of a specific teardown program.
4.1 Administrative Teardown Tasks

Although administrative teardown tasks are often overlooked during teardown planning and even execution, they are vital to assuring appropriate protection of teardown articles/parts, sufficient data documentation, and appropriate part identification/tracking. Without these requirements in place, teardown articles/parts may suffer damage or may be lost during shipping and storage activities; teardown data may be compromised, incomplete, or missing; and parts may be misidentified, resulting in inaccurate teardown information.

4.1.1 Part Identification

Part identification is one of the most critical administrative tasks associated with a teardown program. A unique naming scheme must be developed for all teardown assets to facilitate tracking, identification, and data collection. Teardown articles, sections or components, detail parts, NDI indications, and failure analysis samples all must have unique names. Once a naming convention is established, teardown assets must be permanently marked with the unique teardown asset name to prevent misidentification during the execution of all program tasks. Some acceptable methods of permanent part marking include use of: paint, permanent marker, hanging metal tags, adhesive bar code labels, and engraving [25].

4.1.1.1 Teardown Asset Naming Scheme

Each teardown asset should have a unique identifier/naming scheme for tracking, identification, and data capture purposes. For many programs, this means defining a naming scheme to include teardown article number, teardown section or component number, detail part number, NDI indication number, and failure analysis sample number. For example, during the KC-135 teardown program [25], teardown sections were identified by AAA-BBB where, AAA was the last three numbers of the aircraft serial number, and BBB was the three digit teardown
section number. Once detail parts were created another three digit number was added to the end of the teardown section level identifier to create AAA-BBB-CCC. An additional three digit extension was added to capture each NDI indication number. This method allowed traceability of each NDI indication to a specific part, parts to specific sections, and sections to a specific teardown article simply by using the prescribed naming convention.

For simplicity, all file names were also derived from the prescribed naming convention including photographs and logs. For example the first photograph of a specific part after disassembly was named AAA-BBB-CCC-DIS-A, easily identifying the serial number of the teardown article, the teardown section, the part number, the teardown task, and the unique photograph name. The first photograph of the first close visual inspection (CVI) indication would then be named AAA-BBB-CCC-CVI-001-A. This naming scheme resulted in a unique name for each piece of teardown data collected during the teardown program.

4.1.1.2 Physical Part Marking

Numerous permanent and semi-permanent physical marking schemes exist to identify teardown assets through all teardown tasks. Some examples of methods for physically marking teardown assets are: paint, permanent marker, hanging metal (dog) tags, adhesive bar code labels, and engraving [25]. Personnel initially identifying teardown assets should be qualified personnel knowledgeable in the established part identification procedures and teardown article structure. Initial identification mistakes at the teardown article level, can propagate clear through NDI and failure analysis if left undetected; therefore, the utmost care must be taken for correct teardown article level identification. Since many teardown processes degrade or remove permanent/semi-permanent physical markings other personnel may reapply the markings as needed throughout the teardown process. Typically, physical teardown asset marking includes
the part identification or name, orientation to the aircraft, and part extents in three dimensional aircraft coordinates, such as body station range, butt line range, water line range, etc.

Certain part marking techniques are more appropriate for specific teardown tasks, while other marking techniques are permanent and more appropriate for all tasks. Paint, for example, works well for identifying components or teardown sections prior to extraction. During and after disassembly, using paint to mark parts is no longer practical as many of the parts are too small and any marking made by paint is semi-permanent and will be removed during the coating removal process. Permanent marker is another example of a semi-permanent marking technique. During structural teardown, permanent marker is often used during extraction, disassembly and NDI as the markings show up well in photographs. One must remember that all marks made by permanent markers will be removed during the coating removal process and must be reapplied prior to NDI.

More permanent marking methods must be employed that will survive the coatings removal process, in order to maintain complete part identification control through all teardown tasks. Metal hanging or dog tags may be used during the coating removal process to maintain part identification. Aluminum composition, 0.040 inches thick, tags have been identified as preferable for many teardown programs [13, 14, 16, 20, 23, 25]. The tags should be attached by a 0.060 inch minimum diameter aluminum wire or 0.025 inch minimum diameter steel wire [25], as shown in Figure 21. The wire should be attached through a preexisting fastener hole and should be twisted a sufficient amount of times to ensure secure attachment. If possible, dog tags should be attached to both ends of the part for redundancy. Occasionally, one of these tags will become detached during the coating removal process. At a minimum, dog tags should be
stamped or engraved to include the complete part identification or name. It is strongly recommended that additional information should also be included on the dog tag including [19]:

- Part description – Use common aircraft terminology to describe the part such as stringer, bracket, skin, etc.
- Part coordinates – The three dimensional aircraft coordinates that pinpoint the location of a part in the aircraft.

Figure 21. Stamped metal hanging tag.

Another semi-permanent marking method that appears to be gaining popularity in structural teardown is the use of adhesive bar code labels, shown in Figure 22. These labels may either be directly applied to the teardown asset’s cleaned surface or attached via hanging tag. Bar code labeling is beneficial as a bar code reader can be used to automatically perform inventory, instead of performing this task manually. The drawback to using bar code labels is that they are easily damaged during the teardown process and they will be destroyed during the coatings
removal process. If hanging tags are used to attach the bar code, the wire attaching the tag to the part can be cut prior to coating removal and the tags stored and used to track parts in the coating removal process. Bar codes contain the part identification number and can include text. Examples of text on a bar code include, part identification number, teardown article name/number, part description, and part coordinates.

Figure 22. Adhesive bar code label.

Engraving, pictured in Figure 23, is another option for permanently marking the teardown asset’s surface. Information typically engraved directly on the part’s surface include part identification, orientation to the aircraft, and part extents in three dimensional aircraft coordinates. Engraving is a particularly attractive approach to part marking because if it is performed correctly, engraving will withstand the coating removal process, making it the most permanent marking method discussed in this section. While dog tags are also a permanent marking method, the possibility of the wire connecting the tag to the part breaking and the tag
separating from the part exists. Pneumatic engravers are recommended to be used because they are more powerful (i.e., creates a deep, more robust engraving), than an electronic tool [25]. All engraved characters should be clearly legible at a nominal distance of twelve inches from the surface of the part without the need for optical aid other than that required by the user to correct deficient vision [25].

Figure 23. Part engraving.

All part identification and orientation engraving marks should be located in an open region of the surface of the part far removed from visible damage locations, fastener holes, and other configurational areas of interest such as lap joints, radii, and spotwelds. Engraved coordinate labels should also be used to identify part extents with reference to the aircraft coordinate system. When permitted by the structural geometry, coordinate labels should be located in reference to well established datums such as fastener rows. When this is not possible, cut lines should serve as the reference datum. Two coordinates for each of the three aircraft reference axes should be engraved on parts greater than one inch in any coordinate direction.
For parts less than one inch in any coordinate direction, one coordinate for that particular aircraft axis will suffice. For very small parts, priority should be given to the part identification number, then aircraft orientation, then part extents. If any of the three pieces of identification information above is omitted from surface engraving, it must be included on hanging metal tags so all required information survives the coating removal process [25].

Teardown programs should use a combination of the permanent and semi-permanent part marking methods described above. Multiple marking methods are recommended for redundancy as each method has the opportunity to be destroyed or degraded during the teardown process. If all marking methods employed on a teardown were degraded by the teardown process to a point where part identification could be mistaken, one should rely on photographic and data log evidence to positively re-identify each part in question. Once re-identification occurs, parts should be remarked using the planned part identification scheme.

4.1.2 Storage and Shipping Teardown Assets between Facilities

Teardown assets; including complete teardown articles, teardown components, teardown sections, individual detail parts, and failure analysis samples may all require storage at some point during the teardown program. Inappropriate storage methods may result in damage of the teardown asset and lost or compromised, irreplaceable teardown data. From a security standpoint, care must be taken to assure all teardown assets are stored in a secure facility with limited access. Access to the teardown assets should be granted on an “as needed” basis. From a practical perspective, teardown storage methods should prevent further degradation to the teardown assets due to accidental damage or environmental exposure. Teardown assets should be stored, shipped and handled in a manner to prevent metal-to-metal contact and otherwise preclude the introduction of accidental damage [25]. Indoor storage facilities are preferable
during the teardown program. If indoor storage is not possible, packaging/wrapping methods should be implemented to prevent further environmental degradation.

Typically, detail parts are stored and/or shipped in crates, while larger teardown assets such as components or teardown sections are shipped/stored using pallets. The interior of wooden crates should be checked for nails, screws, and other metal fasteners that could damage teardown assets. If pallets are used, even more precautions should be taken. Not only is it recommended that pallets be surveyed for metal fasteners that could damage teardown assets, but personnel should be vigilant to assure teardown assets do not overhang pallets. Assets that overhang the pallets are more likely to be damaged during handling than assets confined to dimensions smaller than the pallet. Since pallets are often shipped or stored without covering, prolonged exposure to the elements is a concern. It is recommended, particularly if moisture is anticipated, to cover the pallets with plastic stretch wrap or tarps [25].

When storing or shipping parts, an inventory list is recommended to be included for each container. The inventory list should include a list of each teardown asset stored in each container and a total number of items per container or package. In an effort to minimize accidental damage to teardown assets, similarly sized assets should be packed together when possible. If different sized assets must be packed in the same container, it is recommended to pack smaller assets in a separate box within each crate to ensure larger parts will not damage smaller parts [25]. Segregation by part size also allows smaller parts to be found easier in large crates without having to unpack the entire crate.

When the bare metal is exposed to the surrounding environment, following coatings removal, it is recommended to wrap the exterior of each detail part/failure analysis specimen to prevent further environmental degradation. Acceptable wrapping methods include: flexible
Styrofoam sheets secured with packing tape, plastic wrap with padded corners to prevent sharp parts from breaking through, or zip top plastic bags for smaller teardown assets. If Styrofoam sheeting or any other non-moisture resistant method is used, it is recommended to package groups of these teardown assets in plastic trash bags to prevent moisture ingestion. Frequently, crates are shipped or stored in locations with moisture, such as on an open truck in a thunderstorm, in leaky warehouses, or in outdoor storage lots. Regardless of the packing method selected, aircraft assets should be easily identifiable without having to remove the packing material. Permanent markers or paint can be used to mark the outside of each crate and the outside of any acceptable wrapping method. Barcode labels have also been used on programs to simplify verification of the shipment inventory [25].

If parts are shipped or stored, it is important to notify the receiving facility and program management of the location of every part to make sure teardown assets are not misplaced. Some databases, such as TDMS, have a built in tracking feature that identify shipment and storage locations. If a database feature like this is not available to a specific teardown program, electronic communication including spreadsheets and e-mail will suffice.

### 4.1.3 Data Documentation Requirements

As a backup to all parts marking techniques and electronic data storage schemes, digital photographs and paper logs should be maintained documenting all required information for at least the duration of the teardown program. Teardown sections or components, their detail parts, all NDI indications, and all failure analysis findings should be photographed to provide a complete visual record of the assembled condition of each teardown section or component, individual part configuration, and part condition. Photographic records provide valuable information to failure analysis personnel regarding aircraft installation and condition which may
support failure analysis conclusions [25]. Moreover, photographic records serve an important role in recovering part identification and orientation information in the event of discrepancies or loss of data at any phase of the teardown program [25]. Paper logs should be stored for the duration of the program as well. These logs should include: shipping documents, extraction logs, disassembly logs, coating removal logs, NDI logs, and failure analysis logs.

4.1.3.1 Photograph Requirements

Even though in most teardown programs, a 100% quality assurance review of all data is performed by the on-site supervisor, only personnel familiar with the specific camera being used and knowledgeable of the photographic content and resolution requirements should serve as a photographer for the teardown program [25]. It is vital to make sure all photographs are of high enough resolution for engineers/program managers to obtain the required information from the photographs. Since numerous cameras exist and are acceptable for photographic documentation of structural teardowns, the KC-135 teardown program developed a Maximum True Field of View [25] for acceptable photographic fidelity based on mega-pixel capability of the desired camera, shown in Table 1. The maximum field of view numbers are based on a 4:3 frame aspect ratio and results in a photographic fidelity of 74 pixels per true-inch.

<table>
<thead>
<tr>
<th>Camera – Maximum Mega-Pixels</th>
<th>Maximum True Field of View (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>36 x 27</td>
</tr>
<tr>
<td>8</td>
<td>44 x 33</td>
</tr>
<tr>
<td>12</td>
<td>53 x 40</td>
</tr>
</tbody>
</table>

Since teardown assets can frequently exceed the maximum true field of view values presented in Table 1, segmented photographs can be taken of a teardown asset and then
combined in mosaic form to meet the fidelity requirements of the program while documenting the entire teardown asset. Mosaic photographs are created by reconstructing the overall asset from smaller photographs called mosaic source photographs. Each of the mosaic source photographs must meet the requirements in Table 1. Mosaic source photographs may be reassembled using software such as Microsoft® Publisher®.

In addition to field of view requirements, each photograph should be well illuminated to prevent shadows. Indirect, diffused lighting is preferred to minimize or eliminate surface reflections [25]. White-light sources should be used to prevent yellowing, and a monochromatic, non-reflective background of contrasting colors should be used to provide crisp color contrast between the edges of teardown assets and the background material [25]. All photographs should not be compressed, since compression frequently causes degradation in fidelity. JPEG File Interchange Format (.jpg) is the preferred file format for all digital photographs.

The final consideration for photographic requirements is content. During structural teardown programs, typically two primary types of photographs exist: overviews and close-ups. Overview photographs are typically used to document:

- Teardown section or component configuration prior to and post-extraction.
- The location of detail parts in the assembled condition.
- The configuration of individual detail parts after disassembly.
- The configuration of individual detail parts during NDI.
- The location of failure analysis samples prior to removal from the detail part.

Close-up photographs are used typically to document visual inspection findings identified during disassembly, NDI indications, and failure analysis findings. For overview photographs, a minimum of two scales, a part identification card, and an aircraft orientation card should be
included with each photograph, shown in Figure 24. For close-up photographs only the two scales are required, as illustrated in Figure 25.

Figure 24. Sample overview photograph.

Figure 25. Sample close-up photograph.
A minimum of two reference scales (inch units) should be visible in each overall and close-up photograph to provide a size reference to each teardown asset and each close-up photograph [25]. The scales should be placed perpendicular to each other, close to the edges of each part or close-up feature being photographed. Even though, permanent marker or other markings may be visible in overview photographs, a supplemental identification card should be included in each photograph. Teardown article identification, part identification number, part name, and part extents should be included and should be easily legible in each overview photograph. This identification card should be placed next to the teardown asset of interest, not directly over the top of it. For orientation reference, an orientation cube as shown in Figure 26 should be included with each overview to help facilitate quick identification of the orientation view of the photograph [25]. Identification cards and orientation cubes are not required for close-up photographs, provided the close-ups are taken in the same orientation as the overview photograph.
Figure 26. Example of an orientation cube [25].
4.1.3.2 Paper Documentation

Paper logs shall be stored for the duration of the program as well. These logs should include: shipping documents, extraction logs, disassembly logs, coating removal logs, NDI logs, and failure analysis logs. Typically, each of these logs document the information required to be gathered during each teardown task. For example, disassembly logs frequently contain information such as part number, part description, part extents, parts with common faying surfaces, and visual inspection findings during the disassembly process. NDI logs often identify relevant details of the NDI indications identified during inspection. Some examples of the information obtained during inspection include: indication type (crack, corrosion, double drill, etc.), estimated damage extent (length, width, surface area, etc.), percent full screen height for eddy current inspection, and phase angle for eddy current inspection.

4.2 Field/Depot Inspections

In an effort to assess inspection capability and limitations, field or depot level inspections can be performed on a teardown asset prior to component/teardown section extraction. New or emerging inspection techniques that have not been implemented in the field at the time of the teardown may also be assessed by this process. In an effort to characterize the capability of the inspection, one must consider the entire inspection including the capability of the inspection method, the prescribed equipment, the prescribed inspection process, and the capabilities of a field/depot level inspector familiar with the inspection technique. In other words, the particular inspection being assessed should mimic actual field/depot inspection as much as possible. Performing the inspection in a lab environment by inspectors with higher than average experience or training, would inappropriately skew the results of the capabilities of the inspection in an average field/depot setting with an average inspector.
Exact inspection indication parameters and extent should be thoroughly documented to assure accurate comparison with teardown findings. All indications should be fully characterized and located using the aircraft three dimensional coordinate system. If C-scans or other images that must be interpreted by the inspector can be stored and reviewed at a later date, limitations with the actual inspectors can be parsed out from the limitations of the inspection method. Detailed information regarding inspection performance can be vital in future fleet management decisions.

4.3 Extraction

After the teardown article has been selected for a teardown program, identification of teardown components or teardown sections must be performed and the components or teardown sections must be extracted from the remaining “non-teardown structure” or “residual structure.” A key consideration in the extraction of teardown assets is to avoid inducing incidental damage by the extraction process itself [11]. Such incidental damage could cloud the inspection results and waste program resources as it would ultimately need to be distinguished from damage that occurred as a result of the aircraft’s operational usage [11]. While the extraction process is often destructive in nature, and incidental damage can sometimes occur, it is imperative the likelihood of damage is minimized by selecting qualified personnel, appropriate equipment, and well-defined, validated procedures. Incidental damage should also be documented as soon as it occurs to prevent clouding of inspection results further into the teardown process.

Smaller aircraft components may be extracted directly from the teardown asset with minimal special provisions. For example, in the T-34A wing teardown, two wing sets were removed using the Hawker Beechcraft de-mate procedure [20]. Since this procedure was well-developed and validated through multiple previous executions and no cutting of structure was
involved, the risk for incidental damage was minimal. For larger airframes, often more destructive methods must be employed. The C-130 center wing teardown assets [11] were severed from the surrounding structure. The center wing was supported in a fashion similar to the procedure used during the center wing replacement program. This extraction procedure was designed to prevent incidental damage to the center wing teardown asset [11]. Even larger transport or bomber category airframes, including commercial airliners, might require additional considerations. For these sized airframes, the extracted component weights may be significantly higher and the reliance of one structure to support surrounding structure must be considered in detail prior to extraction [11]. In these cases, the aircraft OEM is often a useful resource to provide component weight data, support requirements, and plans to stabilize the remaining structure as components are extracted [11].

4.3.1 Extraction Planning/Considerations

Prior to any extraction efforts on the teardown asset, a detailed cut plan should be developed and approved by program management. The plan should address all stabilization methods planned to be employed during the extraction process and should ensure the inclusion of all teardown components or teardown sections. Considerations when defining cuts include [11]:

- Handling of removed pieces, or lots, in terms of size and weight.
- Cuts should be planned sufficiently far enough away from teardown components or teardown sections to prevent incidental damage to the areas of interest.
- Cutting though complex structure should be minimized or avoided all together.
- Combine a large number of teardown components or teardown sections in one lot to minimize the number of cuts required with the lot in place on the teardown asset.
Additional cuts, once the lot is removed from the airframe, result in less accidental damage.

- Preserve all residual structure for possible follow-on programs.

### 4.3.2 Personnel Qualifications

Extraction personnel must be able to read and interpret aircraft structural drawings/diagrams and understand three-dimensional aircraft coordinate systems. All extraction personnel must be able to distinguish typical types of aircraft structure [26]. All personnel must be familiar with the part identification and tracking plan as well as the required data captured during extraction. In addition, extraction personnel must be qualified to safely operate all equipment required to perform the specific extraction process and must have experience with performing removal of assemblies from similar sized aircraft [26]. For these reasons, aircraft structural mechanics, particularly those with experience on the selected fleet or similar airframes, are ideal.

### 4.3.3 Pre-extraction Tasks

Prior to extracting a component or teardown section from a lot, the boundary of each component or section must be appropriately defined and identified. It is important to locate the physical extents or boundaries of the teardown section on all visible surfaces and define preliminary cut lines to minimize damage and minimize the number of difficult cuts. Care should be taken not to cut through thick parts or complex geometries unless required. Preliminary marks should be placed on the lot to identify the location of each planned extraction. Care should also be taken not to encroach on the boundaries of other teardown sections or structural features of interest. If conflict arises from cut lines overlapping other areas of interest, promptly contact the program management to resolve this issue. One should also identify each
component or teardown section by its part identification number using permanent or semi-permanent marking methods described in Section 4.1.1.2.

Next, apply permanent cut line markings that meet the following requirements [26]:

- Use a contrasting paint or marker color such that all lines are clearly visible and sufficiently wide so both sides of the line can be seen during cutting operations.

- If final teardown section boundary cuts are difficult due to angle or limited access, rough cut at least three inches outside of the teardown section boundaries as long as these lines do not interfere with the definition of other teardown sections.

- Apply visible markings to all anticipated cut surfaces such that they are clearly visible to extraction personnel regardless of cut surface. For example, mark both the internal and external fuselage skins so that cut lines are clearly visible regardless of the position of the extraction personnel.

- Annotate boundaries on both sides of each cut line. Each boundary should be defined using the aircraft three-dimensional coordinate system (i.e., body station, butt line, water line, etc.). If one axis cannot be determined such as body station on a lot of extracted wing, distance from a known piece of structure will suffice. Examples of this type of coordinate system include distance aft of the front spar, or distance below the upper wing surface. NOTE: These coordinate systems should be used only in absence of the typical aircraft coordinate system.

Aircraft orientation arrows and reference coordinates should also be applied to the teardown section using semi-permanent marking methods. Prior to extraction, personnel should also perform a visual inspection and document any anomalous conditions identified on any surface of the teardown section. Such anomalies may include, but are not limited to: repairs,
loose fasteners, missing fasteners, missing fastener elements (such as collars), corrosion, paint/coating condition (such as flaking, scaling, or bubbling), gouges, chafing, and cracking. Overview photographs, meeting the recommendations in Section 4.1.3.1, should be taken of each visible surface of the teardown sections. If anomalous conditions are identified during the visual inspection, overviews should be annotated to locate the damage. All overviews and close-up photographs of the damage should be included in some form of pre-extraction report. An example of an annotated pre-extraction overview photograph is provided in Figure 27 [26].

Figure 27. Annotated pre-extraction overview photograph [26].

88
4.3.4 Extraction Task

The first step in performing extraction is to identify support points for the teardown section being extracted and the surrounding structure. Both the teardown section and the surrounding structure should not move undesirably either during or after extraction cuts are made. Safety of personnel and safety to the teardown asset are paramount during the extraction process. Next, extraction personnel should verify that all cut lines are completely visible and will remain visible during cutting operations. This step includes removing nonstructural elements and equipment which could hinder access to or viewing of the entire extraction cut line marks [26]. At this point, the cut lines should be re-verified to assure the entire teardown section is included within the planned extraction boundaries and that the boundaries do not infringe on other teardown sections. Personnel should also assure all cut lines are sufficiently wide to remain visible during all cutting operations.

Finally, the teardown section should be cut from the surrounding structure and moved to ground level using best shop practices. All teardown section markings should be checked to assure they remain legible during the cut process. If necessary, the teardown section should be remarked with part identification, orientation arrows, and teardown section extents in the three-dimensional aircraft coordinates. Personnel should assure the lot residual structure is stable and presents no safety hazard to extraction personnel [26].

4.3.5 Post-Extraction Tasks

Following the physical extraction of the teardown section, a visual inspection should be performed to report any additional anomalous conditions evident on the surfaces of the extracted teardown section. Such anomalies may include, but are not limited to, repairs, loose fasteners, missing fasteners, missing fastener elements (such as collars), corrosion, paint/coating condition
(such as flaking, scaling, or bubbling), gouges, chafing, and cracking [26]. Overview photographs, meeting the recommendations in Section 3.1.3.1, should be taken of each visible surface of the teardown sections.

If anomalous conditions are identified during the visual inspection that were not documented during the pre-extraction visual inspection, overviews should be annotated to locate the damage and close-up photographs of the damage should be included in some form of post-extraction report. If incidental damage occurred due to the extraction process this should be documented as well. Detailed documentation of incidental damage caused by the teardown process allows inspectors/failure analysts to not waste teardown resources on damage that is obviously not related to the aircraft’s service history.

4.4 Disassembly

Careful structural disassembly is a key aspect of any teardown program. In order to identify and characterize damage in aircraft structure, access to each layer of the structure must be obtained and examined [19]. The disassembly task of a structural teardown must be performed in a deliberate and organized manner to minimize non-service related damage to the aircraft structure. The presence of disassembly induced damage can often obscure damage resulting from the service of the aircraft. Deciphering whether damage is disassembly related or service related can waste valuable program resources.

It is important to note that a successful disassembly process involves more than just fastener removal and part separation [19]. Additional tasks such as part identification, part tracking systems, and photographic records also play a role in a successful disassembly process. Part cleaning to remove dirt, debris, and sealant allow for a proper environment to remove
critical components from surrounding structure while minimizing the likelihood of disassembly induced damage.

4.4.1 Pre-disassembly Visual Inspection

Prior to the start of any disassembly task, care should be taken to review teardown section identification markings made during the extraction process for completeness and accuracy. If inaccurate or missing information is observed, update the information prior to fastener removal. A detailed visual inspection should also be performed prior to and during fastener removal to identify in-service damage visible prior to detailed disassembly and coatings removal. Any damage identified during the visual inspection process should be documented with both an overview and close-up photograph as described in Section 4.1.3.1.

The types of visual inspection findings possibly present on the structure can be grouped into the following categories: coatings, fasteners, corrosion, repairs, and physical damage. Figure 28 [19] provides an example of missing sealant from the coatings damage category. Missing sealant can lead to moisture ingress between parts, which commonly cause corrosion. Other examples included in the coatings damage category are sealant damage, missing coatings, and damaged coatings.
Figure 28. Example of missing sealant [19].

An example of a loose fastener is provided in Figure 29 [19]. Other examples of fastener category findings include: missing fastener, damaged fastener, corroded fastener, and atypical fastener. Figure 30 [19] provides an example of exfoliation corrosion. Pillowing, corrosion product, pitting, and general surface corrosion represent other types of findings in the corrosion category.

Figure 29. Example of a loose fastener [19].
Figure 30. Example of exfoliation corrosion [19].

Figure 31 [19] provides an example of a mechanically fastened patch. Other repair category visual inspection findings include bonded patches, grind outs, or bushings. Crack, gouge, severed part, puncture, broken spotweld, bend, multiple drilled holes, drill start, out-of-round hole, short edge distance, dent, disbond, and accidental damage are all physical damage types that can be observed on aircraft. Figure 32 [19] provides an example of a gouge, while Figure 33 [19] provides an example of a broken spotweld. An example of a multiple drilled hole is provided in Figure 34 [19].
Figure 31. Example of mechanically fastened patch [19].

Figure 32. Example of a gouge [19].
Figure 33. Example of a broken spotweld [19].

Figure 34. Example of a multiple drilled hole [19].
4.4.2 Personnel Qualifications

Personnel involved in the disassembly process should be trained properly in sealant and fastener removal techniques, as well as appropriate part cleaning techniques. Any personnel involved with the disassembly process should also have a working knowledge of the part identification process, photographic, and documentation requirements for the program. Personnel involved in the disassembly process should be trained in proper sealant removal techniques. All applicable safety, hazardous material, and technical data requirements shall be adhered to during the sealant removal process [19]. Any personnel performing fastener removal shall also be properly trained to operate all power and non-powered hand tools required for part removal. Personnel performing fastener removal should be experienced in fastener type identification and proper techniques used to remove various types of fasteners.

4.4.3 Part Removal

All parts should be cleaned to remove loose particles, grease, or dirt prior to fastener removal. In order to minimize the likelihood of accidental damage, the entire surface of the fastener should be visible. Rags or non-metallic brushes are effective tools for cleaning aluminum aircraft parts to avoid scratching, gouging, or other accidental damage during the cleaning process. If heavy grease or other debris cannot be removed from the surface using these methods, non-metallic scrapers may be used to dislodge the debris. Under no circumstances are metallic scrapers acceptable during disassembly due to the high likelihood of accidental damage associated with their usage. If fastener heads are hidden by thick paint, localized coatings removal is permitted using approved coatings removal methods recommended in Section 4.5.

Another helpful tip to prevent accidental damage during disassembly is placing cardboard, rubber matting, or dense foam between the teardown asset and the hard work surface
to prevent scratches and other damage. Nylon washers can also be placed over fastener collars to protect the substrate material from gouges due to the use of metallic chisels and punches. Another method often used to avoid gouging when using chisels is to bevel the edges of the chisel prior to fastener removal.

For each type of fastener anticipated to be encountered during the disassembly process, detailed fastener removal techniques should be developed with the goal of minimizing accidental damage. One selected example, a solid rivet, is provided below [19].

**Solid Rivets – universal head:** Optimal removal steps, shown in Figure 35 [19] are as follows:

- File or grind a flat spot on the head of a universal rivet. This step is not required when drilling flush rivets.
- Center punch the newly filed flat area on the universal (button head) rivet to provide a starting point for the drill bit.
- Using a 1/16-inch drill bit and starting from the center punch dimple, drill a pilot hole though the rivet head and into the shank. This pilot hole will help keep subsequent drilling operations straighter, and aid with avoiding potential damage to the bore.
- Select a drill bit at least one size smaller than the shank diameter of the rivet being removed. If drill bit alignment is in question, select a smaller bit to avoid hole damage.
- Starting from the pilot hole, drill down into the head being careful not to proceed past rivet head depth. In some cases, a rivet removal tool, pictured in Figure 36 [19] may be used to set drilling depth when removing multiple universal head rivets on a flat surface.
- Insert a punch equal to or smaller than the diameter of the drill bit into the drilled hole and attempt to drive the rivet shank out. The rivet head should separate from the rivet
shank as it is driven out. If the rivet head does not come off, more drilling may be required to further weaken the rivet head. The separated rivet head will act as a cushion and help protect the top of the fastener hole from gouges caused by a punch. Care should be taken not to damage or remove material from the hole if further drilling is required to adequately weaken the rivet head.

- For thin parts, adequate support should also be used to prevent the part from deforming as a result of rivet removal.
- For parts that are thin (<0.060 inches) or have limited access, a sharp chisel may be used to shear the rivet head off after it has been weakened by the above process.
- When using the chisel to remove fastener heads, approach the rivet head as parallel with the part surface as the geometry allows. This helps prevent gouging the surface when the rivet head shears off. The placement of the chisel on the rivet head can also prevent potential accidental gouging. The chisel should contact the middle of the rivet head such that if the chisel slips off or is struck incorrectly the chisel bounces off the top of the rivet head not down and into the part surface. The chisel should not be placed at the bottom of the rivet head near the interface between the rivet and the part surface.
Figure 35. Diagram illustrating steps to remove a universal solid (button head) rivet [19].

1) File a flat on the manufactured head if required.
2) Center punch the filed flat.
3) Drill a pilot hole into the shank.
4) Use the pilot hole to drill into head (at least one drill size smaller than the rivet shank).
5) Drive out the rivet shank using a punch the same or smaller diameter than the drilled hole.

ONLY FOR VERY THIN OR LIMITED ACCESS PARTS: Remove weakened head with sharp chisel.

Figure 36. Typical rivet removal tool [19].
In conjunction with fastener removal, sealant removal is a critical portion of the part removal task. To facilitate post-disassembly visual inspection and coatings removal, all sealant must be removed from each part’s surface. Metallic scrapers and brushes are prohibited on teardown programs due to the frequent damage to the part associated with their use. Instead, non-metallic cutters, non-metallic scrapers, and blue Scotch-Brite™ are approved for sealant removal. Non-metallic cutters are typically available in two styles – solid and hollow. Hollow cutters, shown in Figure 37 [19] are generally used to remove sealant around fastener heads, pins, bolts, etc. Solid cutters are frequently used where access is limited such as in corners and between fasteners. Both of these types of cutters can be used on the ends of drills with a threaded extension or on a threaded angle drill. A limit of 2,000 revolutions per minute is recommended [19].

Figure 37. Example of a hollow cutter on a pneumatic angle drill [19].

Non-metallic scrapers can either be purchased or locally fabricated based on the sealant removal requirements. An example of locally fabricated scrapers is provided in Figure 38, while
the orange scrapers pictured in Figure 39 have been proven the most effective commercially available scrapers on a variety of teardown program structures. Blue 622 Scotch-Brite™ may also be used to remove coatings and sealant to expose hidden fasteners. Studies have shown that all other types of adhesive pads, including other varieties of Scotch-Brite™ can mar the surface of teardown assets [19].

Figure 38. Examples of locally fabricated non-metallic scrapers [19].
4.4.4 Part Identification and Physical Marking

After each part is removed from the teardown asset, an assessment on whether or not the part is a program part or a residual non-program part must be performed. Specific guidance should be provided as to the types of parts that should be maintained as program assets and which may be disregarded. Typical examples of disregarded parts include: washers, shims, non-metallic structure, hoses, and systems components. Non-program or residual parts should be discarded and not subjected to further teardown program steps. Parts determined to be program assets should be identified per the part identification system recommended in Section 4.1.1.1 and physically marked based on the recommended methods in Section 4.1.1.2.

Care should be taken to make sure all teardown physical part markings do not obscure obvious damage. On smaller teardown parts, permanent markings should not obscure engraved part markings. For visibility in teardown photographs, use permanent marker on each and every visible surface of the part with the following information:
• Complete Part Number (AAA-BBB-CCC) where:
  o AAA is the last three digits of the serial number.
  o BBB is the three digit teardown section number.
  o CCC is the three digit part number.

• Aircraft Orientation Arrows and Directions where:
  o FWD is forward.
  o AFT is aft.
  o RHS is right hand side.
  o LHS is left hand side.
  o UP is up.
  o DWN is down.
  o I/B is inboard.
  o O/B is outboard.

• Reference Datums where:
  o BS is body station.
  o WL is water line.
  o RBL is right butt line.
  o LBL is left butt line.

  Part naming systems different than the method described above are acceptable; however, regardless of the part naming system, the entire part name should be documented on each surface of the teardown part for visibility in all disassembly photographs. If the orientation cube, recommended in Figure 26 is used abbreviations used on the cube (FWD, RHS, and UP) are preferred to the other acceptable abbreviations above to prevent orientation confusion. If the
reference datums listed above are not available or are unsure, due to specific teardown asset geometry or airframe location, other reference datums are acceptable. Examples of such datums may include, distance aft of the front spar or distance above the lower wing skin.

Since permanent marker is a semi-permanent marking method incapable of surviving the coating removal process, one surface of each teardown part should be engraved with the following information:

- Complete Part Number.
- Aircraft Orientation Arrows and Directions.
- Reference Datums.

It is critical to ensure the engraving is deep enough to penetrate the coatings and reach the substrate material. If the engraving is not deep enough, the engraving will be illegible after coatings removal and part identification could be in question.

A minimum of two metal tags should be attached to every program part, each through pre-existing, undamaged holes on opposite ends of the part for redundancy with stainless steel safety wire with a minimum diameter of 0.025 inches. At least one of these tags should be a stamped dog tag with information similar to the one provided in Figure 21 and one should have similar information to Figure 22 if bar code tags are desired. If bar codes are not desired, a minimum of two dog tags should be utilized. Dog tags are considered permanent markings since the information stamped on them can withstand the coating removal process. The bar code tags will not withstand coating removal and should be removed prior to that operation. These tags provide a way to double check that all parts subjected to the coating removal process are accounted for after the process is complete. Either way, two tags are recommended as
sometimes the wires affixing the tags to the parts become tangled or broken during the teardown process.

4.4.5 Part Inspection and Documentation

Once the part is removed from the teardown asset assembly and is identified and physically marked, perform a visual inspection using the same methods discussed in Section 4.4.1. The types of visual inspection findings possible on the structure include the same groups as the pre-disassembly visual inspection: coatings, fasteners, corrosion, repairs, and physical damage. Since the part has been removed and cleaned free of dirt, grease, and sealant, all sides of the part should be visually accessible; therefore, a comprehensive visual inspection can be performed to identify the finding categories listed above.

In order to document configuration and condition of each part removed from the assembly, overview pictures of each visible plane, or orientation cube face shown in Figure 26, should be taken that meet the requirements provided in Section 4.1.3.1. If findings from the post-disassembly visual inspection are identified, a damage overview photograph consisting of an overview photograph annotated to show the location of the visual inspection finding should be taken. An example of a damage overview photograph is provided in Figure 40 [19]. A damage close-up that meets the requirements of Section 4.1.3.1 should also be taken that clearly shows the visual inspection findings. An example of a damage close-up photograph is provided in Figure 41 [19]. If similar findings are identified at multiple locations on the same overview photograph, annotate the location of each finding and provide a damage close-up photograph that is representative of the worst damage observed.
Following the completion of the photographic documentation of all the detail parts, a disassembly log should be generated. An example of a typical disassembly log is provided in Figure 42 [19]. At a minimum, a disassembly log should contain the following information for each teardown section/asset:
- Each individual part number.
- Each individual part name (using generic aircraft terminology such as stringer, frame, web, bracket, etc.).
- The three dimensional part extents (body station, butt line, water line, distance from a known reference point, etc.).
- Visual inspection finding types (cracks, surface corrosion, out-of-round holes, etc.).
- Faying part numbers.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Name</th>
<th>Coordinate Boundaries</th>
<th>Visual Inspection Results</th>
<th>Faying Parts</th>
<th>Tags Prepared &amp; Attached</th>
<th>Engraved</th>
<th>Bar Code</th>
<th>Engraved</th>
<th>Pictures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Axis 1</td>
<td>Axis 2</td>
<td>Axis 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 42. Example of a disassembly log [19].

Next, the teardown section parts breakdown (TSPB) photograph should be created. An example of a single view TSPB is provided in Figure 43 [19]. The purpose of the TSPB is to illustrate the location and condition of all parts in the assembled condition. When creating a TSPB it is important to make sure the location of each detail part can be easily identified. If one view is insufficient to illustrate this, then multiple views should be provided.
4.5 Coatings Removal

The coating removal process encompasses all tasks required to transform each part from its post-disassembly condition to a part that is prepared for part level NDI. For this to be successful, all parts must be completely free of paint and other coatings. A part entirely free of paint and other coatings allows for proper NDI. Chemical coatings removal is almost always preferred. Coatings removal via chemical emersion is the preferred method. Brush on chemical coating removal may also be used, but the process is tedious and often results in incomplete coating removal.

Other mechanical techniques, such as dry media blasting, can smear substrate metal causing surface damage that could obscure critical teardown findings such as cracks, corrosion,
etc. Historically to prevent obscuring findings, the dry media blasting process has been accompanied by a light surface etch. This etching removes a thin coat of surface material which could destroy or damage evidence of light surface corrosion. Also, if cracks are sufficiently open, striations or other crack face markings can be degraded or obliterated by the acid etching process. This can also occur with chemical coating removal systems; therefore, it is important to perform detailed studies and select a chemical system that does not degrade teardown findings.

A proper coating removal system should include coating removal chemicals, holding containers, part removal tools, possibly heating and circulation elements, and rinsing equipment. It is imperative that all systems work per any instructions, technical memoranda, and data sheets provided with the coating removal system and chemicals in use [27]. Deviations from prescribed specification coatings removal processes could result in teardown asset damage and possible loss of critical findings.

4.5.1 Qualifications

Personnel performing tasks within the coating removal process should be familiar with the part identification and tracking system as well as the part naming convention. Ideally personnel should have previous experience with the specific coating removal process implemented, particularly on aluminum aircraft parts. All personnel should also have an understanding of the expected results of the process and knowledge on how to use and dispose of the chemicals safely [27].

4.5.2 Pre-chemical Exposure

Once the parts are received from the disassembly process, personnel should verify that all permanent and semi-permanent markings required during disassembly are in place and legible. Next, each part should be assessed to determine whether the part is of a size and shape to fit into
any vats or containers, as well any baskets or other items used for coating removal [27]. If the selected coating removal techniques do not support the part geometry in question, sub-sectioning of the part must be considered and proposed to program management. When proposing sub-sectioning, make sure the cut lines avoid geometrical areas of interest and areas with known damage.

Prior to exposing any teardown assets to chemicals, personnel should make sure all components of the coating removal system are functioning properly. If required by the technical data sheets, testing of the chemicals may also need to be performed at specific intervals to check properties such as the acidity or basicity, or pH, of the chemicals. The temperature of the chemicals should also be compared to the technical data sheets to assure that it falls in an acceptable operating range.

4.5.3 Exposure

After assuring the correct functionality of the coating removal system, parts should be prepared for chemical exposure. Make sure the part is free of sealant, dirt, grease and any other material that might be detrimental to the coating removal system. If bar code tags were attached prior to coating removal, remove them from the parts prior to chemical exposure. When beginning the emersion process, one should make sure the parts are completely covered by the chemical remover. Make sure the system is not overloaded preventing all surfaces of each part to have complete contact with the chemical coating remover.

Regardless of the chemical coatings removal method selected, parts should be checked regularly so that they are not exposed longer than required to adequately remove the coatings. Based on experience, an initial check thirty minutes after initial chemical exposure is recommended with subsequent checks occurring every hour at a minimum. Once flaking or
bubbling of the coatings is observed, the parts should be removed from the chemical and scraped using non-metallic scrapers, similar to those pictured in Figure 39. Once the loose coatings are removed by the scraping process, the parts should be re-exposed to the chemical coating remover to loosen any remaining coatings. This process should be repeated until all coatings are removed. Each time the part is removed from the chemical coating remover, the parts should be visually inspected for remaining coatings. Special attention should be paid to specific geometric features such as tight radii and bore holes [27] which tend to trap coatings longer than free surfaces. Nylon bristled pipe cleaning brushes may be useful for removing residual coatings in these limited access regions of parts.

If parts seem to take an unusually long time, based on previous experience with coating removal of this type, to remove coatings, photograph the parts periodically and contact Program Management. Do not subject parts to the chemical coating remover selected for longer durations than the product’s specific maximum exposure time to avoid potential damage to the substrate material. After all coatings have been completely removed from the part, rinse each part with water or steam as required in the technical data for the chemical coatings remover to deactivate any residual remover on the part surface.

4.5.4 Post Chemical Exposure

Inspect all permanent marking systems for legibility and secure attachment. If engraving marks are illegible, re-engrave. If dog tags became detached during the coating removal process, either reattach the detached tags or make new tags and attach them to the parts. Following coatings removal, all parts should be handled and stored to prevent environmental damage due to corrosion. Ideal part storage is indoors, in cool, dry areas [27].
4.6 Nondestructive Inspection (NDI)

NDI processes are employed to interrogate structures and materials for discontinuities, defects, and damage without causing damage to a component or resulting in a loss of vital metallographic evidence [28]. NDI processes should be implemented in an efficient fashion to maximize inspection fidelity for critical structures while minimizing the inspection cost of non-critical or secondary structures, while ensuring the resulting teardown analysis is sufficiently robust to support sound program management decisions [28]. NDI indications should guide failure analysts to specific damage types at critical areas on the airframe.

4.6.1 Qualifications

Personnel performing tasks within the NDI process should be familiar with the part identification and tracking system as well as the part naming convention. Close visual inspection (CVI) should be performed by individuals with sufficient experience to accurately identify and classify damage types [28]. Individuals with previous aircraft inspection or aircraft maintenance experience, particularly those possessing an Airframe and Powerplant (A&P) license are desirable. All individuals conducting CVIs must possess sufficient visual acuity to successfully perform inspections. Therefore, it is recommended that the near vision acuity of all inspectors (not just inspectors performing CVI) be tested to ensure near vision in equivalent to Snellan20/25 or Jaeger No. 1, at not less than 30 centimeters or 12 inches, in at least one eye, naturally or corrected.

All personnel performing Eddy Current Surface Scan (ECSS), Bolt Hole Eddy Current (BHEC), Fluorescent Penetrant Inspection (FPI), and Magnetic Particle Inspection (MPI) must be qualified and certified to the current National Aerospace Standard (NAS) 410 [29], Certification and Qualification of Nondestructive Test Personnel [28]. Only individuals certified
to Level II or Level III in each method may perform inspections using that particular inspection method. In order to perform teardown inspections, each individual inspector must demonstrate previous experience performing inspections using the required equipment and techniques defined in the detailed procedures for each specific teardown program. It is recommended that each teardown organization have a Level III on staff to review inspection results and maintain certification requirements. Typically, certification in accordance with the American Society for Nondestructive Testing (ASNT) SNT-TC-1A [30] is considered equivalent to NAS 410 certification.

4.6.2 Determine Inspection Requirements

Inspection requirements must be determined based on the individual purposes, goals, objectives, budgets, and schedules of each teardown program. The information provided in this section is based on requirements commonly used on mid-to-high fidelity teardown programs. Recently, most teardown programs have used a minimum of two of the inspection types discussed in this section for all teardown program parts. Critical parts, particularly fatigue critical parts are typically inspected with more than two inspection techniques presented in this section.

CVI is typically used for all program parts. This inspection method is a relatively inexpensive way to assess the condition of all program parts. The CVI method is capable of finding cracks, corrosion, and mechanical damage. Finding fidelity is the limiting factor to this inspection method. Typically very small cracks under 0.100 inches, and light surface corrosion cannot be reliably detected using this inspection method.

FPI is also typically used for all program parts. FPI is typically divided into two separate inspections, short dwell FPI and long dwell FPI. Long dwell, a minimum of four hours, is
typically used for parts where stress corrosion cracking is possible. The use of short dwell, one hour FPI, is becoming less and less frequent during teardown programs, particularly on the oldest airframes.

Stress corrosion cracking occurs most frequently in 7XXX series aluminum parts. Prior to the mid-2000s, stress corrosion cracking was thought to occur only in thick forgings and not occur in thin sheet material, such as that used in most fuselage skins. Recent teardown programs have determined that stress corrosion cracking can even occur in thin 7XXX series aluminum skins, as thin as 0.040 inches. Since the exact aluminum alloy used in many locations on the oldest airframes are frequently unknown, long dwell FPI use is more widespread. At a minimum formed parts, or parts with thicknesses greater than 0.250 inches with unknown alloy type should be subjected to long dwell penetrant. FPI, either long dwell or short dwell, is capable of detecting cracks and corrosion. While the finding fidelity is typically better than CVI, cracks under 0.100 inches can still not be reliably identified. FPI offers a relatively quick and inexpensive way to inspect large surface areas.

ECSS/BHEC is typically used in regions where small cracks, typically fatigue, are expected. ECSS/BHEC can often reliably find cracks in the vicinity of 0.050 inches in length and sometimes much smaller given ideal part geometries. The drawback to ECSS/BHEC is cost. The equipment and personnel requirements for ECSS/BHEC are significantly higher than the previous methods. The amount of time required to scan a large area is significantly more than either CVI or FPI. It is recommended to use ECSS/BHEC for fatigue critical locations in addition to CVI/FPI with challenging geometric features including fastener holes, cut outs, and tight radii.
MPI is used primarily on steel structure to identify cracks and corrosion. Parts subjected to MPI must be magnetic. Finding fidelity for MPI is comparable to FPI. Since steel parts are seldom in critical locations on aging aircraft, this inspection method is used infrequently.

4.6.3 Part Inspection

Development of step-by-step inspection processes must be based on specific program requirements. These processes must take into account part geometry, specific material alloy, and the size and type of damage required to be detected by the process. Recommendations in this section are based on a mid-to-high finding fidelity program, with typical aircraft geometries, and typical aging aircraft aluminum alloys. For a program of this nature, both CVI and FPI are recommended for all parts, while eddy current inspections should be used to target specific regions of concern on the airframe.

4.6.3.1 CVI

All CVIs must be performed with the parts in the completely disassembled condition, with all sealant and coatings removed, and all surfaces clean of dirt and grease. If the part condition does not meet the cleanliness requirements, perform additional cleaning as necessary prior to CVI. All CVIs should be performed using proper lighting, a minimum of 100 foot-candles, and proper inspection distance, eye to part of twenty-four inches or less [28].

If part geometry obscures a portion of the inspection area, or if the naked eye is insufficient to judge the condition of the part, visual aids such as mirrors, videoscopes, or borescopes may be used to aid in the inspection. Grouping damage of the same type and approximate severity is allowed. An example of acceptable grouping would be small gouges of approximately the same severity at different locations on the same side of a part. This grouped damage may be recorded as one indication instead of multiple indications. A photographic
example of such grouping is provided in Figure 44. During the inspection, mark the location and extent of all damage on the surface of the part using a permanent marker and document each indication per Section 4.6.4.

![Image of grouped gouges](image)

Figure 44. Example of grouped gouges.

Non-detrimental indications such as scratches shall be identified based on the inspector’s discretion. As a rule of thumb, any indications that contact a geometric stress concentration or area of interest, such as fastener holes, cut outs, and radii, should be documented. Extremely light, barely visible regions of corrosion, very shallow scratches, and shallow isolated gouges are typically not reported as findings in CVI based on inspector discretion. Shallow gouges are loosely defined as gouges whose depth cannot be felt by running your fingers at a reasonable pace over the surface of the part. However, a tight cluster of shallow gouges should be documented.
4.6.3.2 FPI

All FPI equipment and processes must meet the requirements of ASTM E-1417 [31]. The equipment listed below is recommended for FPI [28]:

- Penetrant – Met-L-Chek® FP-95A, Type 1 (fluorescent), Level 3.
- Solvent Remover - Met-L-Chek® R-504, Class 2 Solvent Remover.
- Developer - Met-L-Chek® D-70, form d (non-aqueous).
- Clean, Lint-free Rags.
- Black Light – 1000 µW/cm² at a distance of 15 inches from the part surface and ambient light conditions shall not exceed two foot-candles.

All part surfaces should be pre-cleaned prior to penetrant application. Pre-cleaning should be accomplished by first applying a liberal amount of solvent remover directly onto the part surface. Next, remove the excess solvent and contaminants from the part surface using a dry, lint-free cloth or paper towels. Repeat this process until a clean surface is obtained. Make sure no residual cloth or paper towel material is left on the surface of the clean part. Prior to applying penetrant, make sure to leave a sufficient period of time for any residual solvent to evaporate prior to penetrant application.

Assure the part surface temperature is between 60°F and 120°F prior to applying penetrant. Penetrant may be applied by dipping, brushing, swabbing, or spraying. Make sure to reapply penetrant as necessary to prevent the penetrant from drying on the part surface during the dwell period. Double check the inspection requirements to determine whether a one hour or four hour dwell is required for each part. If the longer dwell penetrant inspection is required, reapply penetrant each hour to prevent penetrant from drying or becoming tacky on the surface of the part.
part. If for some reason, the penetrant does become dry or tacky, the part must be completely reprocessed including pre-cleaning and penetrant reapplication [28].

Three acceptable methods exist for removing excess penetrant after the dwell time. It is important to note that concentrated solvent remover should never be applied directly onto the inspection area. Excess solvent will remove or dilute entrapped penetrant resulting in a degradation of the indication or a complete failure to produce an indication.

Method C, or the solvent wipe method, can be used by wiping the surface of the part with a dry lint-free rag or paper towel to remove most of the surface penetrant. The only acceptable process is to make only one pass, then fold the rag or towel over to provide a clean surface for each successive wipe.

Once the surface penetrant has been minimized, remove any residual surface penetrant with a fresh, lint-free rag or towel moistened with solvent. It is critical to pay attention to the amount of solvent applied to the towel. The cloth or towel should only be lightly moistened with the application of a fine spray of solvent to the cloth. Do not saturate the cloth by pouring, immersion, or excessive spraying.

Examine the part under black light illumination during the wiping stages. Make sure to examine the surface of the rag also under black light after the final solvent wipe. If the rag shows more than just a trace of residual penetrant, the part must be wiped again. After the rag shows little to no trace of penetrant, wipe the part with a dry rag to remove any residual solvent on the surface. Figure 45 shows the surface of a part that has too much residual penetrant to be considered clean; therefore, it must be wiped again. Figure 46 illustrates a part surface appropriately free of surface penetrant.
Another approved method for penetrant removal is Method D or hydrophilic remover immersion. This removal process using hydrophilic remover is accomplished by immersion of
the part in the remover. For this technique the rinse spray temperature must stay between 50°F and 100°F and a maximum pressure of 40 pounds per square inch [28].

Following the penetrant dwell time, rinse the surface of the part with water to remove a majority of the excess penetrant from the surface. While the part is still wet from the pre-rinse, immerse the part in the approved concentration of hydrophilic remover to eliminate any residual surface penetrant. Make sure the immersion hydrophilic remover concentration does not exceed 20% and the immersion time does not exceed two minutes. Any higher concentrations or immersion times may remove entrapped penetrant, which would degrade or eliminate any FPI indications.

Agitating the solution to bring fresh solution in contact with the inspection surface is highly recommended. Solution agitation may be accomplished by manually moving the part through the solution, but is most often produced by an air manifold at the bottom of the tank [28]. Typical immersion of parts is between thirty seconds and two minutes, with two minutes seldom required to complete the task. Make sure to use only the minimum exposure time required to remove the surface penetrant. Finally, spray clean water over the part to remove the hydrophilic remover from the surface. Perform this task under black light illumination. If excess background penetrant is still observed under black light illumination, reapply hydrophilic remover provided the total remover contact time does not exceed two minutes.

The final surface penetrant removal process is a modified version of Method D, which allows for spraying on hydrophilic remover instead of using the immersion technique. After the penetrant dwell time, rinse the part with water to remove most of the residual surface penetrant. Next, using a garden spray nozzle, rinse the part with a 5% concentration of hydrophilic remover to eliminate any remaining surface penetrant. Make sure the concentration does not exceed 5%
when using the spray application method. Higher concentrations may result in the removal of entrapped penetrant, which would result in the degradation or destruction of the FPI indication.

Perform the remover application under black light illumination to ensure residual surface penetrant removal. Spray remover on the part for no more than two minutes, using the minimum time required to remove the penetrant from the surface of the part. After the residual surface penetrant is removed, spray water over the part to remove the hydrophilic remover from the surface of the part.

The next step in performing any FPI is to dry the part. Make sure to rotate and visually inspect the part to prevent pooling of water. If available, place the part in a 110°F to 140°F oven/dryer until the part is completely dry. If an oven is not available or impractical due to part size/configuration, air drying is acceptable. Make sure the part is completely dry before the initial inspection and application of developer.

During the initial inspection, examine the part surface under black light illumination prior to developer application. Evaluate all indications (typically cracks and corrosion) under 10X magnification. Mark all indications with a permanent marker and document them per Section 4.6.4.

The final steps in the FPI process are developer application and final inspection. Prior to applying developer on the part, shake the spray can thoroughly and test the spray pattern on something other than the surface of the part to ensure a uniform, smooth, light coating can be applied. If the test spray is not smooth, light, and uniform, select another spray can. Once an appropriate test spray pattern is achieved, apply a very light, uniform coat of developer to the surface of the part.
Make sure to examine the inspection surface throughout the initial ten minutes of the dwell period looking for small indications that could be masked by excessive bleed-out from adjacent structure. Excessive bleed-out of surrounding structure can result in interpretation errors. Re-examine the part after a thirty minute developer dwell time has passed to detect small flaws that might have gone undetected during the initial ten minute dwell. If the long dwell penetrant method is used, perform a final examination of the part after a developer dwell time of 120 minutes [28]. Examine the part surface under black light illumination for linear indications. Make sure to evaluate all indications under 10X magnification. Mark all findings with permanent marker and document them per Section 4.6.4.

If excessive bleed-out occurs, an indication can be indistinct and blurred while still highly visible. An example of an excessive bleed-out indication is provided in Figure 47. The following method may be used to verify and evaluate this type of indication [28]. The results of using this method are shown in Figure 48. Begin by lightly dampening a cotton swab with solvent. Carefully wipe the indication area only once with the solvent dampened swab. After the solvent has evaporated, examine the bare surface. Next, watch the indication as it begins and continues to develop without additional developer applied. Evaluate the indication with the developer removed, as developer will blur and enlarge the indication.

Conduct the initial evaluation at lower magnification (3X to 5X) and with higher magnification (10X) after the indication has been located. If the indication cannot be located with this method, spray a very light coat of developer over the area and watch the indication as it begins and continues to re-develop. Examine the part surface throughout the initial ten minutes of the developer dwell period to look for small indications. Re-evaluate the indication at low magnification (3X to 5X) and with higher magnification (10X) after the indication has been located.
located. If the indication is repeatable, document the indication per Section 4.6.4. If no indication can be seen after a thirty minute dwell, consider the indication non-relevant and do not document.

Figure 47. Example of an excessive bleed-out indication.
As with CVI, grouping of similar indications on the same part surface is allowed as long as the indications are similar in severity. For example, light corrosion scattered over the surface of a part can be grouped across the entire surface of the part instead of being documented as a large number of small cluster locations of light corrosion.

4.6.3.3 ECSS

The equipment listed below is recommended for performing ECSS, as shown in Figure 49:

- Probe(s) – Absolute bridge/shielded, 100-500kHz probe, probes shall be self-balanced (i.e., reference coil in the housing).
- Connectivity – shall connect directly to the Nortec® 2000 series using a 16-pin Lemo® connector. Balancing adaptors are not permitted.


![Staveley Nortec® 2000 series with absolute bridge/shielded, 100-500 kHz probe and Eddy Current Reference Standard.](image)

Figure 49. Staveley Nortec® 2000 series with absolute bridge/shielded, 100-500 kHz probe and Eddy Current Reference Standard.

All ECSS should be performed with the parts completely disassembled, with all coatings removed, and all surfaces cleaned free of dirt and grease. Since most aircraft parts inspected
with eddy current techniques are aluminum or titanium, only recommendations for those materials will be presented in this section. For other materials, Air Force Technical Order 3B-1-2 [32] provides valuable information regarding equipment setup and inspection processes.

Table 2 provides inspection frequencies for aluminum, titanium and other materials, while Table 3 provides initial machine settings for all materials presented in Table 2.

### TABLE 2

INSPECTION FREQUENCIES [33B-1-2]

<table>
<thead>
<tr>
<th>Material Alloy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Titanium</td>
<td>2 MHz</td>
</tr>
<tr>
<td>Inconel Alloys</td>
<td>1-2 MHz</td>
</tr>
<tr>
<td>Nickel Alloys</td>
<td>1-2 MHz</td>
</tr>
<tr>
<td>300 and 400 Series Stainless</td>
<td>500 kHz – 1 MHz</td>
</tr>
</tbody>
</table>
TABLE 3
INITIAL ECSS SETTINGS [33B-1-2]

<table>
<thead>
<tr>
<th>Soft Key</th>
<th>Description/Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIN MENU</strong></td>
<td></td>
</tr>
<tr>
<td>FREQ</td>
<td>FREQUENCY 1 / SEE TABLE 2</td>
</tr>
<tr>
<td>FREQ</td>
<td>FREQUENCY 2 / OFF</td>
</tr>
<tr>
<td>H-GAIN</td>
<td>HORZ GAIN / 60.0 Db</td>
</tr>
<tr>
<td>V-GAIN</td>
<td>VERT GAIN / 75.0 Db</td>
</tr>
<tr>
<td>ANGLE</td>
<td>ANGLE / 70°</td>
</tr>
<tr>
<td><strong>FILTER MENU</strong></td>
<td></td>
</tr>
<tr>
<td>LFP</td>
<td>LP FILTER / 100</td>
</tr>
<tr>
<td>HPF</td>
<td>HP FILTER / OFF</td>
</tr>
<tr>
<td>CONT</td>
<td>CONT NULL / OFF</td>
</tr>
<tr>
<td><strong>DISPLAY MENU</strong></td>
<td></td>
</tr>
<tr>
<td>SWEEP</td>
<td>SWEEP OFF</td>
</tr>
<tr>
<td>V-POS</td>
<td>V-POS / 10%</td>
</tr>
<tr>
<td>H-POS</td>
<td>H-POS / 80%</td>
</tr>
<tr>
<td>PERSIST</td>
<td>PERSIST / OFF</td>
</tr>
<tr>
<td>DISP ERS</td>
<td>DIS ERASE / 2-5 SEC</td>
</tr>
<tr>
<td>GRATICLE</td>
<td>ON</td>
</tr>
<tr>
<td>DOT/BOX</td>
<td>DOT</td>
</tr>
<tr>
<td><strong>SETUP MENU</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>FREQ / SINGLE</td>
</tr>
<tr>
<td>4</td>
<td>PRB DR / MID</td>
</tr>
</tbody>
</table>

All equipment and the parts being inspected should be allowed to reach ambient temperature prior to inspection to ensure valid, repeatable inspection results. Place the probe on the reference standard a minimum of twice the probe diameter from all notches and edges and press the null key to null the probe. Tap the probe on the reference standard away from notches and edges to generate a lift-off response. Adjust the phase angle until a horizontal, right-to-left-liftoff signal is achieved. While repeatedly scanning across the 0.020 inch deep notch adjust the V-GAIN and H-GAIN independently until a signal trace of 80% Full Screen Height (FSH)
deflection is obtained from the notch, as shown in Figure 50. If the signal from this notch goes off the left side of the display, decrease the H-GAIN.

Figure 50. Correct signal response from 0.020 inch notch in aluminum.

Next, check the sensitivity of the inspection set-up by scanning over the 0.005, 0.010, and 0.020 inch deep notches. The responses should be similar to those illustrated in Figure 51. It is important that the response from the 0.005 inch notch should produce a minimum of 5% FSH vertical response (one-half of one division) and should be clearly distinguishable from the baseline noise. If these responses are not obtained, perform the set-up again until these results are achieved.
Figure 51. Acceptable sensitivity check signal in aluminum.

Prior to scanning parts, apply Teflon tape to the end of the probe to reduce wear and prevent damage to the probe from rough surfaces. Place the probe on the part to be inspected away from the edge or any known defects. Ensure good contact between the coil and the part. Null the probe. In order to maintain the baseline at 10% FSH and 80% full screen width (FSW), frequent nulling might be required during the inspection. Finally, scan the inspection area using the same speed used during calibration and assure the probe remains perpendicular to the inspection surface. Mark with permanent marker all repeatable crack-like indications equal to or greater than 15% vertical screen deflection over the baseline/null point. These indications should be documented per Section 4.6.4.
4.6.3.4 BHEC

The equipment listed below is recommended for performing BHEC, shown in Figure 52:

- **Probe(s)** – Differential/reflection, shielded, 200 kHz – 3MHz, 4-pin Fischer connector.
- **Scanner(s)** - Nortec® MiniMite.

![Figure 52. Staveley Nortec® 2000 series with differential/reflection, shielded, 200kHz-3MHz probe and Eddy Current Reference Standard.](image)

All BHEC should be performed with the parts completely disassembled, with all coatings removed, and all surfaces cleaned free of dirt and grease. Since most aircraft parts inspected
with eddy current techniques are aluminum, only recommendations for this material will be presented in this section. For other materials, Air Force Technical Order 3B-1-2 [32] provides valuable information regarding equipment setup and inspection processes.

The flex honing process may be used to ensure holes that are clean and free of nicks, burrs, and gouges. First determine the material type of the part containing the hole to be honed. Next, select the hone that best matches the size of hole being honed from Table 4. Make sure to pre-clean all holes to be honed using a cotton swab and isopropyl alcohol. Next, chuck the hone, shown in Figure 53, in a drill. Test the flex hone in the drill. If wobbling occurs, shorten the shaft of the flex hone. If desired, lightly coat the hone with LUB MED BLUE PASTE (lubricant) by inserting the spinning hone in the lubricant. The use of hone lubrication will extend the life of the hone. Prior to honing holes, make sure appropriate safety material, such as safety glasses, are being used. Next, align the hone perpendicular to the hole. Start the drill, but do not exceed 1000 revolutions per minute (rpm) Insert the rotating hone into the hole and use no more than three consecutive in and out passes to clean the hole. Finally, clean any honed hole with isopropyl alcohol on a cotton swab to remove any residual material from the honing process.
<table>
<thead>
<tr>
<th>Hole Diameter (inch)</th>
<th>Description</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.177</td>
<td>BC 4.5 mm (0.177 inch) 320AO Flex Hone</td>
<td>BC45M320AO</td>
</tr>
<tr>
<td>0.197</td>
<td>BC 5 mm (0.197 inch) 320AO Flex Hone</td>
<td>BC5M320AO</td>
</tr>
<tr>
<td>0.250</td>
<td>BC 6.4mm (0.250 inch) 320AO Flex Hone</td>
<td>BC64M320AO</td>
</tr>
<tr>
<td>0.315</td>
<td>BC 8 mm (0.315 inch) 320AO Flex Hone</td>
<td>BC8M320AO</td>
</tr>
<tr>
<td>0.375</td>
<td>BC 9.5 mm (0.375 inch) 320AO Flex Hone</td>
<td>BC95M320AO</td>
</tr>
<tr>
<td>0.394</td>
<td>BC 10 mm (0.394 inch) 320AO Flex Hone</td>
<td>BC10M320AO</td>
</tr>
<tr>
<td>0.433</td>
<td>BC 11 mm (0.433 inch) 320AO Flex Hone</td>
<td>BC11M320AO</td>
</tr>
<tr>
<td>0.472</td>
<td>BC 12 mm (0.472 inch) 320AO Flex Hone</td>
<td>BC12M320AO</td>
</tr>
<tr>
<td>0.500</td>
<td>BC 12.7 mm (0.500 inch) 320AO Flex Hone</td>
<td>BC13M320AO</td>
</tr>
<tr>
<td>0.552</td>
<td>BC 14 mm (0.552 inch) 320AO Flex Hone</td>
<td>BC14M320AO</td>
</tr>
<tr>
<td>0.625</td>
<td>BC 16mm (0.625 inch) 320AO Flex Hone</td>
<td>BC16M320AO</td>
</tr>
<tr>
<td>0.709</td>
<td>BC 18 mm (0.709 inch) 320AO Flex Hone</td>
<td>BC18M320AO</td>
</tr>
<tr>
<td>0.750</td>
<td>BC 19 mm (0.750 inch) 320AO Flex Hone</td>
<td>BC19M320AO</td>
</tr>
</tbody>
</table>
During the BHEC inspection process, if a gouge or other anomaly is observed visually and cannot be blended out using the flex hone procedure, and it could potentially cause damage to the eddy current probe, DO NOT insert the probe into the hole. Instead, perform ECSS around the circumference of the hole and document that BHEC could not be performed due to excessive damage in the hole. For very thin parts, generally less than 0.050 inch thick with countersunk holes where knifed edge effects preclude meaningful BHEC inspection, scan both sides using ECSS and document that BHEC could not be performed due to a knifed edge condition [28]. As with the other inspection methods, grouping of similar damage is also permitted for the BHEC inspection technique. Grouping is most commonly used for holes that could not be inspected due to the reasons above or residual gouges that do not pose a threat to damage the BHEC probe.
Prior to inspection, make sure all parts and equipment have reached ambient temperature to ensure valid, repeatable inspection results [32]. Choose the probe for the best fit in the hole to be inspected. Apply Teflon tape to the end of the probe to reduce probe wear and signal noise that may occur from scanning rough surfaces and hole edges. Make sure tape, if used, is wrapped over the coils and through the split in the probe. Do not wrap tape completely around the probe split. Check the probe for good fit, which means the probe should be in close contact with the hole surface, but still rotate easily. Use the settings listed in Table 5 for initial instrument setup. Table 6 provides the frequency settings for fastener hole scanning based on material type, while Table 7 provides filter settings based on hole diameter. The filters may be adjusted ±50 Hz to improve symmetry of the notch response [32].
TABLE 5
INITIAL BHEC SETTINGS [32]

<table>
<thead>
<tr>
<th>Soft Key</th>
<th>Description/Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIN MENU</strong></td>
<td></td>
</tr>
<tr>
<td>FREQ</td>
<td>FREQUENCY 1 / SEE TABLE 6</td>
</tr>
<tr>
<td>FREQ</td>
<td>FREQUENCY 2 / OFF</td>
</tr>
<tr>
<td>H-GAIN</td>
<td>HORIZ GAIN / 65.0 Db</td>
</tr>
<tr>
<td>V-GAIN</td>
<td>VERT GAIN / 65.0 Db</td>
</tr>
<tr>
<td>ANGLE</td>
<td>ANGLE / 0°</td>
</tr>
<tr>
<td><strong>FILTER MENU</strong></td>
<td></td>
</tr>
<tr>
<td>CONT</td>
<td>CONT NULL / OFF</td>
</tr>
<tr>
<td><strong>DISPLAY MENU</strong></td>
<td></td>
</tr>
<tr>
<td>SWEEP</td>
<td>SWEEP OFF</td>
</tr>
<tr>
<td>V-POS</td>
<td>V-POS / 50%</td>
</tr>
<tr>
<td>H-POS</td>
<td>H-POS / 50%</td>
</tr>
<tr>
<td>PERSIST</td>
<td>PERSIST / OFF</td>
</tr>
<tr>
<td>DISP ERS</td>
<td>DIS ERASE / 0.2 SEC</td>
</tr>
<tr>
<td>GRATICLE</td>
<td>ON</td>
</tr>
<tr>
<td>DOT/BOX</td>
<td>DOT</td>
</tr>
<tr>
<td><strong>SETUP MENU</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>FREQ / SINGLE</td>
</tr>
<tr>
<td>4</td>
<td>PRB DR / HIGH</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>RPM</td>
<td>SCAN RPM / 1500 R/A</td>
</tr>
<tr>
<td>SYNC ANG</td>
<td>0</td>
</tr>
</tbody>
</table>

TABLE 6
FREQUENCY SETTING FOR BHEC SCANNING [32]

<table>
<thead>
<tr>
<th>Material Alloy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>200 kHz – 500 kHz</td>
</tr>
<tr>
<td>Inconel Alloys</td>
<td>1-2 MHz</td>
</tr>
<tr>
<td>Nickel Alloys</td>
<td>1-2 MHz</td>
</tr>
<tr>
<td>300 and 400 Series Stainless</td>
<td>500 kHz – 1 MHz</td>
</tr>
</tbody>
</table>
TABLE 7
FILTER SETTINGS BY HOLE DIAMETER [32]

<table>
<thead>
<tr>
<th>Filter</th>
<th>Probe Diameter</th>
<th>Probe Diameter</th>
<th>Probe Diameter</th>
<th>Probe Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.156 inch –</td>
<td>0.219 inch –</td>
<td>0.312 inch –</td>
<td>0.437 inch –</td>
</tr>
<tr>
<td></td>
<td>0.219 inch</td>
<td>0.312 inch</td>
<td>0.437 inch</td>
<td>0.750 inch</td>
</tr>
<tr>
<td>LPF (Hz)</td>
<td>500</td>
<td>500</td>
<td>700</td>
<td>1500</td>
</tr>
<tr>
<td>HPF (Hz)</td>
<td>150</td>
<td>200</td>
<td>300</td>
<td>500</td>
</tr>
</tbody>
</table>

With the scanner turned off, null the probe without it contacting the part surface or any other surface. Make sure the sweep is turned off and hold the scanner so that the probe is parallel to the reference standard. Place the coil in contact with a flat region of the standard away from all notches, holes, and edges. Turn the scanner on when the coil makes contact with the standard to generate a lift-off signal. Adjust the phase rotation by pressing the ANGLE key and rotating the Smartknob to achieve a substantially horizontal lift-off signal. An example of an appropriate lift-off signal is provided in Figure 54. Insert the rotating probe into the appropriate size hole in the reference standard and locate the 0.030 inch corner notch located at the interface of the first and second layers. Maximize the reference notch signal. Adjust the vertical gain (V-GAIN) and Horizontal Gain (H-Gain) independently to position the entire notch response on the screen at a 1:1 slope or 45 degree angle, spanning 80% FSH and 80% FSW, as illustrated in Figure 55. The lift-off may not be visible. Do not adjust the phase angle at this point.
Figure 54. Lift-off response with phase adjusted correctly.

Figure 55. Properly calibrated impedance display.
Next, return to the DISPLAY MENU and press the SWEEP key to enter the “SWEEP EXTERN” mode to place the instrument in sweep mode. If the sweep is not centered at 50% FSH null the probe again without it contacting any surface. Reinsert the rotating probe in the appropriately sized reference hole and maximize the signal from the 0.030 inch interface notch. Push the GAIN button to adjust the horizontal and vertical gain simultaneously as necessary to obtain an 80% vertical Peak-to-Peak (PTP) signal from the reference notch. The signal should now appear narrow and nearly symmetric above and below the baseline as shown in Figure 56.

![Figure 56. Properly calibrated sweep display.](image)

In order to assess the noise levels of the particular setup, an inspector must ensure the signal response from good areas of the hole is relatively smooth across the sweep display. Noise levels in undamaged areas should be less than 20% vertical PTP [32]. If higher noise levels are observed, repeat the setup procedure. Pay particular attention to probe and filter settings. An example of an acceptable noise level is provided in Figure 57. The maximum speed that the
probe can be moved through the hole bore is the rate of probe travel that always identifies the notch and does not cause a reduction of the peak in signal height from 80% vertical PTP [32].

![Image showing a graph with noise level](image)

**Figure 57. Acceptable noise level.**

When determining the scanner zero or origin, visually locate the notch on the top surface of the reference standard. Insert the probe into the appropriate sized hole in the reference standard and rotate the scanner housing until the red LED alarm indicator on the side of the scanner housing is pointed at the physical position of the notch on the standard [32]. Then turn on the scanner and adjust the SYNC ANGLE in the SPECIAL menu until the trailing edge of the notch indication is displayed on the left side of the screen with the leading edge of the indication positioned on the right side of the screen [32].

With the SWEEP mode OFF, turn on the scanner and insert the probe in the hole of the part to be inspected. Inspect the hole by slowly pushing the probe through the entire hole then pulling the probe back slowly through the hole. Be sure to keep the probe perpendicular to the
part surface during scanning. Repeat this process a minimum of two times for each hole being inspected.

Any repeatable indication above the noise level, which exhibits a vertical response greater than 40% vertical PTP and appears to be similar in shape to the signal obtained from the reference standard, shall be considered a possible crack. To verify, closely examine the bore and bore edge surface for evidence of cracking using 10X magnification or greater. Look for evidence of gouges, scratches, or nicks that might result in a non-relevant indication. If these causes for a non-relevant indication are observed carefully blend out the disturbed metal using 400 to 600 grit emery cloth and repeat the BHEC inspection. If the indication does not reoccur, the indication was non-relevant and should not be documented. If non-relevant indication causes were not observed during the initial inspection, or the indication persists after the emery cloth step, document the indication per Section 4.6.4.

If the indication occurs at the edge of a hole, no crack is visually identified under 10X or greater magnification, and there is no evidence of disturbed metal from gouges, scratches, or nicks, perform ECSS inspection around the hole. Use of an edge template is highly recommended [28]. If an indication is verified using ECSS, document the indication as an ECSS indication per Section 4.6.4. If holes are excessively out-of-round or un-inspectable due either to excessive damage or a knifed edge condition, document the holes as un-inspectable using BHEC and perform an ECSS inspection on both sides of the part.

4.6.3.5 MPI

All MPI processes should meet the requirements of ASTM E-1444 [33]. The equipment listed below is recommended for performing MPI:

- Stationary Multidirectional Magnetic Particle Bench.
- Contour Probe – Parker Research, DA-400 Contour Probe.
- Coil – Magnaflux, L-10 Coil, shown in Figure 58.
- Prepared Bath – Magnaflux, 14AM, Prepared Bath.
- Solvent Cleaner - Met-L-Chek® R-504, Class 2 Solvent Remover.
- Field Indicator.
- Black Light.

Figure 58. Magnaflux L-10 Coil.

Prior to performing MPI, all parts must be pre-cleaned by applying a liberal amount of solvent cleaner on the part surface. Remove the excess solvent and contaminants from the surface with a dry, lint-free cloth or paper towels. Repeat this process until a clean surface is obtained. Make sure all solvent has evaporated prior to performing MPI inspection. MPI
processes must be established based on the part’s magnetic properties and part geometry [28]. Guidance can be found in Technical Order 33B-1-2 [32] Work Package 300 and 301. The following requirements also apply [28]:

- All MPI shall be performed in accordance with ASTM E-1444-05 [33].
- Only the wet continuous, fluorescent particle method shall be used.
- Alternating current magnetization shall be the preferred method.
- Particle concentration shall be between 0.2ml and 0.4ml per 100ml.
- Prods SHALL NOT be used.
- Type C shims, quantitative quality indications (QQIs) shall be used to establish effective field strength and direction. Use of a Gauss meter to establish field strength is strongly recommended.
  Evaluate all indications under black light illumination using 10X magnification.

Document all indications in accordance with Section 4.6.4.

4.6.4 Indication Documentation

All relevant NDI indications must be documented. The documentation recommendations discussed in this section are provided for mid-to-high fidelity documentation requirements. If lower fidelity documentation requirements are desired, the recommendations can be modified to meet specific program requirements.

4.6.4.1 Hole Numbering

Hole numbering methods shall be consistent between inspection types for the same part to allow correlation between NDI indications obtained using different NDI methods. Each hole on a plane containing an NDI indication should be numbered. If no indications occur on a specific plane of a specific part, hole numbering should not be required. If indications are found
on a plane that did not require hole numbering based on no indication being found using previous
inspection methods, continue numbering holes sequentially from the highest hole number used
on the part previously. Failure to use consistent hole numbering between inspection methods
may preclude accurate correlation of indications and inhibit efficient NDI indication
prioritization.

While no specific hole numbering pattern should be required, a hole numbering technique
that makes sense should be selected based on part geometry. Holes should be numbered
sequentially along fastener rows on a part. Do not randomly number holes across the surface of
the part. Make sure all numbers are written legibly in permanent marker and that the pattern is
easily distinguishable in all overview pictures. Also make sure the same hole has the same
number on both thru thickness planes. For example hole 15 on plane 1A should still be hole 15
on plane 1B.

4.6.4.2 CVI Indication Documentation

Circle the indication on the surface of the part and identify the type of indication (crack,
corrosion, out-of-round hole, double drill, etc.) in the immediate area of the indication using a
permanent marker. Make sure these markings do not obscure the hole numbering markings if the
CVI indication is in or near a fastener hole. Next, photograph the indication. One overview
photograph and one close-up photograph of each indication are required. If similar damage is
observed, indication grouping can be performed. Annotate all damage locations on the overview
and take one close-up of the most severe damage observed. At a minimum each overview
photograph shall include:

- Two reference scales with units in inches.
- Part Identification card.
• Orientation cube.

Damage close-ups only required the two reference scales, provided the photographs are taken in the same orientation as the overview photograph. All photographs should meet the requirements provided in Section 4.1.3. An example of an overview photograph is provided in Figure 59, while the corresponding close-up is provided in Figure 60.

Figure 59. Overview of damage location.
All CVI indications should also be documented in hard-copy log format by part number. Each part should have a corresponding CVI log. If no indications were found on a particular part, the log should clearly state the part number and “No Indications.” If indications were identified on a specific part number, the following information should be recorded at a minimum:

- **Indication Number** – Indications on the same part shall be numbered sequentially starting with 001 so each indication has a unique identifier.

- **Observation** – This field should contain the type of indication observed including: crack, corrosion, out-of-round hole, double drilled hole, etc.

- **Indication Location** – This field should contain the location of the indication: surface, hole, edge, etc.
• Hole Number Affected – If the location was a hole or holes, provide the hole number(s) containing the NDI indications.

• Surface/Edge Location – Provide the location of the NDI indication in the aircraft three dimensional coordinates (BS, WS, BL, WL, distance from a reference point, etc.).

• Length – Provide the length of the indication in inches.

• Width – Provide the width of the indication in inches. If a linear indication was observed, enter “0” for the width dimension.

• Surface Area – Provide the surface area of the indication in square inches. If only a linear indication is reported, record “0” for the surface area.

4.6.4.3 FPI Indication Documentation

Documentation of FPI indications is very similar to CVI indications. As with CVI, circle FPI indications on the surface of the part and identify the type of indication observed. In addition to the required overview and close-up photograph, take a penetrant photograph under black light to document the visual FPI indication. Unlike the damage photograph, scales are not required in the penetrant photograph. The penetrant photograph should also be taken in the same orientation as the overview and damage photograph. An example of a penetrant photograph is provided in Figure 61. As with CVI indications, all FPI indications should also be documented in hard copy format. The same parameters that were recorded for CVI should also be recorded for each part subjected to FPI.
4.6.4.4 ECSS Indication Documentation

All ECSS indications should be circled on the surface of the part and the type of defect should be identified as crack, corrosion, gouge, out-of-round hole, etc. in the immediate vicinity of the indication using permanent marker. Also, make sure to write the percent full screen height and indication phase angle in degrees next to the circled indication. All of this information must be visible in both the required overview and close-up photographs. Overview and close-up photographs should meet the same requirements as described in Section 4.6.4.2. In addition to
An overview and close-up photograph, an ECSS screen shot should be stored of the indication. An example of an ECSS screen shot is provided in Figure 62.

![Figure 62. ECSS screen shot.](image)

All ECSS indications should also be documented in hard-copy log format by part number. Each part should have a corresponding ECSS log. If no indications were found on a particular part that required ECSS, the log should clearly state the part number and “No Indications.” If indications were identified on a specific part number, the following information should be recorded at a minimum:

- Indication Number - Indications on the same part shall be numbered sequentially starting with 001 so each indication has a unique identifier.
• Observation – This field should contain the type of indication observed including: crack, corrosion, out-of-round hole, double drilled hole, etc.

• Indication Location – This field should contain the location of the indication: surface, hole, edge, etc.

• Hole Number Affected – If the location was a hole or holes, provide the hole number(s) containing the NDI indications.

• Surface/Edge Location – Provide the location of the NDI indication in the aircraft three dimensional coordinates (BS, WS, BL, WL, distance from a reference point, etc.).

• % Full Screen Height – Provide the percent full screen height of the indication.

• Indication Phase Angle – Provide the phase angle of each indication in degrees. For ECSS, the phase angle is defined as the tangent angle at the defect tip signal [28], as illustrated in Figure 63.

• Length – Provide the length of the indication in inches.

• Width – Provide the width of the indication in inches. If a linear indication was observed, enter “0” for the width dimension.

• Surface Area – Provide the surface area of the indication in square inches. If only a linear indication is reported, record “0” for the surface area.
4.6.4.5 BHEC Indication Documentation

Like ECSS indications, all BHEC indications should be documented by circling all indications and writing the type of indication, percent full screen height, and indication phase angle near the hole containing the indication. An overview and close-up photograph should be provided for all BHEC indications as well as a BHEC screen shot. An example of a BHEC screen shot is provided for reference in Figure 64.
All BHEC indications should also be documented in hard copy. Each part should have a corresponding BHEC log. If no indications were found on a particular part that required BHEC, the log should clearly state the part number and “No Indications.” If indications were identified on a specific part number, the following information should be recorded at a minimum:

- Indication Number – Indications on the same part shall be numbered sequentially starting with 001 so each indication has a unique identifier.
- Observation – This field should contain the type of indication observed including: crack, corrosion, out-of-round hole, double drilled hole, etc.
- Hole Number Affected – If the location was a hole or holes, provide the hole number(s) containing the NDI indications.
- % Full Screen Height – Provide the percent full screen height of the indication.
• Indication Phase Angle – Provide the phase angle of each indication in degrees. For BHEC, the phase angle is defined as the slope of the straight line joining the end points [28], as illustrated in Figure 65.

• Clock Position – Provide the clock position of the indication.

• Point of Reference – Provide the coordinate system used to reference clock position. The face of the orientation cube used to reference clock position is typically used.

Figure 65. BHEC phase angle definition.
4.6.4.6 MPI Indication Documentation

Documentation of an MPI indication is exactly the same as the FPI documentation process. Circle the indication on the part and identify the type of indication. Provide an overview, close-up, and black light photograph of the indication. Document the exact same parameters as the FPI hard copy recommendations.

4.7 Prioritization of NDI Indications

Depending on the findings fidelity requirement and the scope of the particular teardown program, tens of thousands of NDI indications can be identified during a mid fidelity teardown program on each teardown article. It is imperative to identify a prioritization plan during the teardown planning phase, not as results become available during program execution. The planning team should consider what types of NDI indications are possible on a given structure and what types of indications best support the program analysis requirements [11]. Since priorities may change over the duration of a long term teardown program, it is important that while guidelines regarding prioritization of indications are set prior to program execution, the process remains flexible and can evolve during the program as data becomes available.

The question then becomes, which NDI indications should be validated through failure analysis? Program requirements, goals, and objectives often serve as the basis to prioritize indication for failure analysis. If one of the primary goals of a teardown is to assess the accuracy of damage predication models, the primary focus of the prioritization should be in the vicinity of critical aircraft structure with developed damage models. Typically, these models consist of fatigue models, which are used to predict damage progression at fatigue critical locations. Corrosion damage models, if they exist, would be used to predict and track corrosion damage progression at corrosion critical locations on the airframe [11]. Due to the widespread use of the
fatigue damage models, a majority of the indications prioritized for failure analysis are cracks for teardowns with this objective. Limited areas of severe corrosion damage are also sometimes subjected to the failure analysis process. Another prioritization scheme for teardowns with model validation is to survey cracks in other regions of the teardown article to assure the correct set of fatigue critical locations have been identified [11].

For teardowns where the primary objective is to assess the condition of the teardown article without comparison to models; cracks, corrosion, and sometimes even mechanical damage are all assessed and prioritized by severity of the NDI indication and the location on the airframe structure. Commonly the primary objective of these teardown programs is to determine the current condition of the airframe and determine the maintenance/inspection actions required to keep the airframe flying until a desired service date. In order to provide solid recommendations, damage in critical areas where damage is expected should be sampled, while unusual, unpredicted damage should be studied in depth. An understanding of the presence of damage at unanticipated locations on the airframe can often lead to anticipating fleet problems years in the future and having a solution prepared prior to encountering the problem. This often increases mission readiness and aircraft availability.

If validation of field/depot level inspections is an objective of the teardown program, NDI indications in the inspection regions should be prioritized, particularly if the indications were found at the part level, but not at the assembly or field level. The characterization of these defects will allow program managers to begin to assess the capabilities and limitations of the inspection being performed in the field/depot.

Regardless of purpose, another subset of NDI indications that should be considered for failure analysis prioritization is damage that occurs commonly in the fleet. Understanding the
failure mechanism of damage that frequently occurs in the field could help develop inspections/repairs to address that particular damage type at a specific airframe location. Within the entire prioritization plan it is important to realize that if similar damage types occur multiple times in the airframe, sampling of this damage at the failure analysis level may be acceptable. Based on similarity in structural element, damage severity, and damage orientation, one may be able to draw conclusions about similar damage by sampling a portion of the damage.

One should also rule out obvious causes of damage that are not service related. Edge cracks existing in thin structure, as shown in Figure 66, can often be ruled as overload/tearing cracks occurring during the teardown process. Fastener locations in thin structure that are distorted through the thickness with small tearing cracks emanating from fastener edges, pictured in Figure 67, can also be assumed to result from the disassembly process by not properly backing up thin structure when driving out rivet shanks.

Figure 66. Edge crack in thin structure.
4.8 Failure Analysis

Failure analysis encompasses all activity that occurs after NDI is complete for a given part. The primary objective of performing failure analysis is to determine the root cause of select NDI indications and to characterize any confirmed damage. It is important to note that no NDI indication is considered damage until it is confirmed by the failure analysis process. Also, no attempts to characterize the NDI indication prior to failure analysis are valid. Lengths and widths of NDI indications are only estimations of the NDI indication, not an actual characterization or confirmation of damage. The only way to accurately measure and characterize damage is with the failure analysis process. Prior to initiating any failure analysis tasks, it is recommended to review the NDI indication data thoroughly to make sure the parameters of the indication and the location of the indication are clearly documented.
4.8.1 Qualifications

The failure analysis engineer must have a technical degree in metallurgy, material science, materials engineering, mechanical engineering, or a related field [34]. The failure analyst shall also have demonstrated competency in each task to the program management prior to being allowed to perform a specific task on the teardown program. For more advanced failure analysis tasks including: identification of corrosion product, unusual findings and related metallurgical evaluation, and review of findings from failure analysis engineers, a senior analyst should perform the tasks. Senior failure analysts shall have a technical degree in metallurgy, material science, material engineering, mechanical engineering, or a related field, with some coursework on physical and mechanical metallurgy [34]. The senior analyst should also have undergone a recognized failure analysis course offered by an accredited university or similar institution, and have at least two years experience working on failure analysis of aircraft structures during the previous five years [34].

4.8.2 Visual Examination

Begin by performing a visual inspection of the part without magnification. For more obvious damage, a potential root cause may be hypothesized [34]. Note the orientation of the damage, the location on the aircraft in three dimensional aircraft coordinates and the surrounding structural features. The full extent of all damage should be noted, whether it was recorded as an NDI indication or not. Next, take a photograph of the part including a single scale in inches and the orientation cube. Figure 68 provides an example of an acceptable visual inspection photograph [34]. In this photograph, the black circle indications the location of the indication on the part, while the red dash shows the approximate orientation of the suspected damage.
4.8.3 

**Enhanced Visual Inspection (EVI)**

EVI can be performed to support two purposes: (1) identify the root cause of an NDI indication, and (2) to perform secondary NDI of a given indication as a further assessment of a previously entered NDI indication in order to support an indication disposition decision [34]. If the purpose is to identify the root cause of the NDI indication, EVI is performed to visually confirm a previously documented NDI indication. Visual identification during EVI directs the subsequent tasks required to complete the failure analysis. EVI can also be used for secondary NDI. For instance, if locations requiring ECSS or BHEC are un-inspectable or the results could be questioned for some reason, EVI using a stereomicroscope may be able to aid in inspection and assessment of such locations [34]. In some cases, EVI is sufficient to meet the failure analysis required for selected NDI indications. Other times, EVI results direct the remaining tasks required to complete a full failure analysis. This decision is based on the discretion of the program management.
Begin by inspecting the fastener hole bores and part surfaces, paying close attention to the region near the NDI indication. Rotate and tilt the part and use both downward and upward incidents of lighting to appropriately observe all features as small or tightly closed flaws might be difficult to identify. Try different types of lighting including, halogen, fluorescent, and high intensity lights [34]. Mirrors may also be useful. If damage is identified, document the damage dimensions and attempt to locate the origin. Also include the part number and the location with respect to hole number and/or the three dimensional aircraft coordinate system. Photograph the damage in its entirety, as shown in Figure 69 [34]. Use image capturing software to overlay a color-contrasting scale and include identifying labels to clearly identify structural features of interest.

Figure 69. Corrosion damage identified during EVI [34].
If EVI is performed for secondary NDI, the goal is to provide the level of information required for indication disposition. The information required will likely include [34]:

- Stereomicrograph(s) of the damage site to identify the damage location.
- Annotated image(s) produced from the stereomicrograph(s) which includes a brief description of the indication, magnification, and recommended disposition, provided in Figure 70 [34].
- Document with specific details about previous NDI attempts.

Figure 70. Summary of EVI findings [34].
4.8.4 Specimen Sectioning

Prior to sectioning a specimen, make sure overview photographs of the entire part, similar to Figure 68, close-up photographs, similar to Figure 71, and macro-photographs of the NDI indication, similar to Figure 72, are taken. Make sure all relevant documentation steps from EVI are complete and accurate. Also make sure all relevant part identification markings and orientations are transferred from the parent part to the planned excised specimen with an engraver [34].

Figure 71. Close-up photograph [34].
For an indication with a clearly observable visual crack in a fastener hole, make section cuts as shown in Figure 73 [34]. The first section cut should occur through the diameter of the fastener hole containing the visual crack, perpendicular to the crack. The second section cut should be parallel to the first less than 0.010 inches beyond the extent of the visible crack tip. If the specimen is relatively thick, cut a notch instead of the second parallel cut as shown in Figure 74 [34]. A notch of this type allows for loading along the axis of the notch which will prevent damaging loading to the fracture surface. If more than one crack is observed at the indication site, treat the cracks as a single crack when sectioning the specimen. Figure 75 [34] provides a schematic illustrating how to section a specimen with multiple cracks occurring in the same vicinity near a fastener hole. If multiple cracks occur at different orientations around the fastener
hole and section of one will prevent the sectioning of others, prioritize specimen sectioning by the longest visible crack observed.

Figure 73. Recommended section cuts for a visible crack near a fastener hole [34].

Figure 74. Recommended section cuts for a visible crack near a fastener hole in thicker parts [34].

Figure 75. Section cuts in the presence of multiple visible cracks near a fastener hole [34].
For an indication with clearly visible corrosion, first identify the corrosion type. Corrosion types typically investigated during failure analysis include: exfoliation, stress corrosion cracks, and in-plane cracks [34]. Exfoliation corrosion, a severe form of intergranular corrosion, is typically assessed by sectioning and characterizing the specimen to determine the thickness of the corrosion region. In order to characterize the depth of the corrosion region, a small specimen is excised outside the corroded region. Figure 76 shows a part excised from a specimen and sectioned to characterize the corrosion. Sectioning the specimen along multiple angles provides detailed information regarding the spread of corrosion damage. A full three-dimensional reconstruction of the corrosion region can be performed if desired from the information obtained from this three section cut method.

Figure 76. Multiple section cuts used to characterize corrosion area [34].
For stress corrosion cracks, extract the specimen from the part outside the corrosion region, then follow the steps for opening a visual crack at a fastener hole. For in-plane cracks, which are unique and often occur at the edge of a panel or inside a fastener hole, the primary interest is to estimate the lengths of the cracks, corrosion products if any, and the mode of crack propagation [34]. Since these cracks do not often break the surface, choosing a distance to initially cut is difficult. The recommendation is to first attempt to extract a specimen outside the corrosion damage leaving ample clearance as shown in Figure 77 [34]. Next take subsequent sections at known locations to characterize the extent of the damage.

Figure 77. Sectioning method for multiple in-plane cracks inside a hole [34].

If damage is not confirmed visually or microscopically, cut a section about 0.08 inches from the bore wall [31]. If the actual damage is further away from the hole than this, cutting at this distance allows the initiation and other important crack face feature to be preserved. The full extent of the damage can be found by performing subsequent sectioning. Following the physical sectioning of the specimen, clean the specimen in an ultrasonic bath of acetone to remove residual debris from sectioning. Next, polish the section cut to determine if cracks are present, and then take macroscopic photographs of each specimen. Finally, engrave the identification of each of the sectioned pieces.
4.8.5 Specimen Mounting

For easy of handling during grinding and polishing tasks, specimens should be mounted in a polymer or epoxy. Polymeric mounting is performed in a hot compression mounting press, while epoxy mounting is performed at room temperature by mixing resin and a hardening compound in a mold. Hot mounting is preferred and should be used except in temperature sensitive situations [34]. Either thermoplastic or thermoset polymers can be used for hot mounting. To perform hot mounting, begin by cleaning the surface of the specimen using acetone in an ultrasonic cleaner. Next, coat the ram, mold cavity, and plunger with the mold release spray to assure clean removal of the mount and prevent damage to the press [34]. Follow the press manufacturer’s procedure for loading the polymer in the mold cavity. Make sure the surface of the specimen to be polished is placed upside down on the ram [34]. Preheat the press. For thermoplastic polymers, preheating without pressure helps to soften the polymer and fills up the mold cavity completely resulting in better mounts [34]. Only five to ten minutes of heating under pressure is sufficient for most polymers. For thermoplastic polymers, cooling under pressure is recommended to prevent bulging of the mold [34]. Remove the mold from the press.

For cold mounting, clean the surface with an acetone bath in an ultrasonic cleaner. Coat the mold surfaces with mold release agent to prevent the mount sticking to the mold. Mix the resin and the hardening compounds together and pour into the mold. Make sure to use freshly mixed compound because resins have a limited pot life [34]. Remove the mounted specimen from the mold.
4.8.6 Specimen Polishing

Specimen polishing creates a smooth surface required for high magnification investigation. Polishing begins with a grinding operation, which removes the maximum material during specimen polishing with abrasive coated papers or discs. This material removal is required for three reasons [31]:

- It makes the surface between the mount and the specimen level and exposes the complete specimen surface in case some of it was obscured by the mounting process.
- It removes large scratches and other damage from the surface of the specimen.
- It removes sub-surface damage to soft materials.

Specimen polishing removes significantly less material than grinding, as a finer abrasive is selected. Polishing is used to remove very fine surface protrusions only. The grinding option should be minimized to prevent removal of too much surface material. For specimens sectioned with metallographic saws, 240 grit silicon carbide paper can be a good starting point [34]. The specimen can then be ground with 400 and 600 grit silicon carbide papers sequentially. If manually grinding the specimen, turn the specimen at each sequential step to grind away scratches left by the previous grit. The grinding step is complete when all scratches are removed. Make sure to thoroughly wash the specimen and ones hands before switching grit size. After 600 grit grinding is complete, chamfer the specimen edges to prevent damage to mapped cloths used for polishing. Complete a final polishing by colloidal silica or colloidal alumina suspension if require for a mirror finish [34]. Table 8 provides the steps used for polishing aluminum using the Struers Metalog System [34].
4.8.7 Crack Opening

Prior to crack opening, make sure specimen sectioning cuts have been performed. The three-point bend method and the V-notch method are the two most common crack opening methods. Either one of these methods prevent fracture surface rubbing, which is required to prevent smearing of the crack surface features. The three-point bend method is executed by applying three-point forces on a specimen to produce a bending moment on the specimen that opens the fracture surface, as illustrated in Figure 78 [34]. Before applying the three-point bend crack opening technique, make sure the specimen sectioning cuts are correct and correctly setup the fixture with the focus on proper loading of the specimen. Insert the specimen and check to make sure that compressive loading will not occur. If compression occurs near the crack origin, smearing of the fracture faces could result in deteriorating or destroying vital crack face features. Next, apply an increasing load to the specimen until it fractures. Make sure to protect the opened fracture surfaces from damage and do not allow the two surfaces to contact each other after opening. Contact can often result in smearing of crack face features. If specimens are very small, the alternate three-point bend technique illustrated in Figure 79 [34] is acceptable.
The second common crack opening technique is the V-notch method, illustrated in Figure 80 [34]. The V-notch method is particularly useful for large cracks and cracks with abrupt changes in direction. If the three-point bend method was used for either of these crack geometries, crack face rubbing and smearing would likely occur [34]. Before applying the V-notch method, make sure the correct specimen sectioning cuts have been performed. Next, insert the specimen into a bench vise to apply a compressive force to the bottom of the notch. Continue to increase the compressive load until the specimen fractures. After fracture, make sure the two fracture surfaces do not come into contact with one another after opening. Protect the opened fracture faces from damage.
Opening in-plane cracks is an even more difficult situation. In cases of severe cracking, the material can be split, almost delaminated, to form two pieces. For severe cracking scenarios, it is acceptable to attempt to open the crack as long as the fracture surface is not damaged during the process. For in-plane cracks near holes, it is advisable to open the in-plane cracks assuming a radial crack emanating from the hole bore [34]. For in-plane cracks at or near the edge of a thin structure, begin by marking the precise location where the crack terminates on the free edge [34]. Clamp the specimen near the end of the crack and apply a load on the opposite side, as illustrated in Figure 81 [34]. Other detailed guidelines on opening other types of cracks are provided in Figure 82 to Figure 87.
Figure 82. Crack opening techniques for hole bore crack using three-point bend technique or V-notch method using a vise [34].

Figure 83. Crack opening options for edge cracks [34].
Figure 84. Crack opening options for SCC crack with slant profile considering thickness of sheet [34].

Figure 85. Crack opening options for a surface crack not through the thickness [34].
Figure 86. Crack opening procedure for through thickness surface crack [34].

Figure 87. Crack opening procedure for a spotweld crack without doubler and with doubler intact [34].

4.8.8 Fracture Surface Examination

Fracture surface examination can be accomplished with stereo microscopic observation, scanning electron microscope (SEM) observation, or a combination of both. For most failure analysis efforts, stereo microscopy is used to determine the type and severity of damage as well as the origin. SEM is used for more advanced analysis. Stereomicroscopic observation provides
the macroscopic signature of different failure mechanisms [34] and is used to determine the dimensions of the damage.

The stereo microscopic observation begins by preparing the specimen for inspection. Once the fracture surface is opened it should require no further cleaning unless the surface is covered with corrosion or other environmental products [34]. If the surface is covered with deposits, take a macroscopic photograph prior to cleaning. Cleaning using an ultrasonic wash in acetone or ethanol for approximately twenty minutes should be sufficient for stereo microscopic inspection [34]. Identify the region of interest and mark the region using a fine point permanent marker or engraver for SEM observation if required.

Observe the fracture surface at magnification levels between 5X and 60X [34]. Document the indication both at low and high magnification with photographs. Make sure the lighting and contrast are appropriate. Characterize the observed damage on the fracture face. Document failure modes including: fatigue, corrosion, overload, mechanical damage, localized melting, porosity, etc. [34]. If the damage is not clear at this point, document the fact that no damage could be identified at this point and proceed to SEM analysis. Locate and classify the origin and severity of each observed damage feature. Attempt to measure each damage feature observed on the fracture surface. Capture images of all damage features observed.

Next move on to SEM analysis by re-cleaning the specimen using the gentle acetone wash process that is allowed to be used prior to stereo microscopic observation. Re-mark the area to be analyzed by the SEM by marking the specimen with an engraver sufficiently far away from the indication [34]. Use conductive tape to adhere the specimen to the SEM stage so the specimen will not move under vacuum [34]. One can also clamp the specimen in place if a suitable fixture is available. Locate the indication using low magnification. Increase the
magnification and scan the area on multiple planes, looking for defects or other fracture face features. Normally 5,000X magnification is sufficient [34]. Any surface damage including corrosion and mechanical damage should be noted.

Often gouges may appear to be cracks prior to failure analysis. At high magnification, a crack may appear to be very deep, and the bottom may not be visible, while a gouge will have a smooth bottom feature [34]. Mechanical damage or scratches may appear to be cracks. Commonly scratches have a very straight appearance micro structurally, while cracks are more jagged at high magnification [34]. Locate and classify the origin and the severity of each damage feature observed. If a crack is identified, measure its length along each plane in which it is visible. Also measure other relevant damage features [34]. Capture images of each part of the damage in its entirety.

4.8.9 Fracture Surface Characterization

Based on the fracture surface examination, assign the results to one of the following categories [34]:

- **No Finding** – No root cause could be determined for the NDI indication.
- **Overstress** – In aluminum, a dimpled pattern will be present. No obvious other phases of crack growth will be present and the surface will look uniform across the fracture face. An example of overstress failure is shown in Figure 88 [11].
- **Mechanical Damage** – The fracture surface will have the microscopic features of overstress, but the cause of the NDI indication will be clearly mechanical damage from installation, maintenance, or disassembly.
- **Corrosion** – The fracture surface will be rough. Analyze the composition of the surface with Energy-Dispersive X-ray Spectroscopy (EDXS).
• **Corrosion – Fatigue** – This type of finding is characterized as a corrosion defect initiating a fatigue failure. In corrosion-fatigue, the fatigue and corrosion are processes occurring at the same time. Analyze this failure as a fatigue failure. If the nucleation is a corrosion pit, make sure to measure the pit and record it as the nucleation site. Also, perform EDXS analysis on the fracture surface.

• **Corrosion/Fatigue** – This type of finding occurs when corrosion and fatigue alternate as the crack growth mechanism. GAG cycles often lead to corrosion/fatigue. Record both the characteristics of fatigue and corrosion.

• **Stress Corrosion Cracking (SCC)** – The fracture surface of stress corrosion cracking will have typical initiation, slow crack growth, and final rupture zones. In aircraft aluminum, stress corrosion cracking is often verified by observing branched, intergranual cracking in specimens. Sometimes branching does not occur. For further confirmation on the mode of crack propagation, the crack should be opened and observed under the SEM. An example of a stress corrosion crack, showing deposit, charging around deposit, and leaves of the fracture surface is provided in Figure 89 [11].

• **Fatigue** – A fatigue fracture surface is often easy to distinguish even without SEM analysis. The nucleation site for fatigue can be identified by following the path of the radial and converging “river marks.” Often bands associated with crack arrest or change in crack growth behavior or environment, known as beach marks, may also be visible at no to low magnification. Striations should be visible at higher magnifications. A photograph illustrating beach marks is provided for reference in Figure 90 [11].
Figure 88. Example of overstress fracture face [11].

Figure 89. Example of stress corrosion cracking [11].
To characterize fatigue findings, identify fatigue striations near the nucleation site. At some magnification, one can no longer find crack growth striations. At this magnification, it may be assumed that the area encompassed by the field of view is the extent of the nucleation site. Measure two planar dimensions and report the size of the nucleation site. Next, locate three clear sets of striations and measure the distance from each set to the nucleation site. Next, locate a set of striations where at least a few are clearly visible, measure the distance from the first to the last and divide by the number of striations to identify average spacing.

For all damage types, try and identify the originating feature and the severity of each observed damage feature. If a crack is found, measure the length along each plane in which it is visible. Any other relevant damage features should also be measured. If cracks are identified,
characterize the appearance as single, branching, etc. and measure the lengths [34]. Finally, photograph all damage observed.

4.8.10 Corrosion Type Identification

Ten typical types of corrosion are often identified and categorized during failure analysis. All of the corrosion types discussed in this Section are easily identified with the assistance of visual and/or optical aides. Failure analysis engineers should use the corrosion type guidelines presented below to classify corrosion into one of the ten types presented in this Section [34].

- **Uniform Corrosion** – Common on all metals regardless of their corrosion potential. This type of corrosion results from a direct chemical attack on a metal surface and is not common on aircraft structure.

- **Galvanic Corrosion** – One of the most common types of corrosion found on aircraft structures. This type of corrosion occurs when dissimilar metals are in contact in the presence of an electrolyte. It is usually found along the interface between the dissimilar metals.

- **Pitting Corrosion** – Most common type of corrosion on aluminum alloys. This type of corrosion is often observed as white or gray powder, similar to dust on the surface of a part. When the powdery substance is removed, tiny pits can be seen across the surface of the part. Pits often serve as crack starters due to the stress concentration they create. An example of pitting corrosion is provided for reference in Figure 91 [19].

- **Intergranular Corrosion** – Easily identified by cracks prorogating along the grain boundaries. This type of corrosion occurs when there is an attack on the grain boundaries of the metal.
- **Exfoliation Corrosion** – Severe type of intergranular corrosion. This type of corrosion can be easily identified by flaking layers of metal near the surface of the part. An example of exfoliation corrosion is provided in Figure 92 [19].

- **Filiform Corrosion** – Occurs on metal surfaces with an organic coating system. This type of corrosion exhibits the presence of worm-like traces of corrosion product beneath paint film.

- **Crevice Corrosion** – Occurs near riveted lap joints where electrolytes have a different concentration than in adjacent locations [34].

- **Corrosion Fatigue** – Occurs due to a combination of corrosion and fatigue.

- **Stress Corrosion Cracking** – Occurs primarily due to the combined effects of constant tensile stress and corrosion. Stress Corrosion Cracking occurs intergranularly or transgranularly.

- **Fretting Corrosion** – Occurs due to a combination of wear and corrosion. This corrosion occurs on the faying surface of moving joints.
Figure 91. Example of pitting corrosion [19].

Figure 92. Example of exfoliation corrosion [19].
4.8.11 Corrosion Product Identification

It is often necessary to analyze the chemical composition of corrosion product to determine the cause of observed corrosion. The elements identified during the assessment of chemical composition can point to the environment, or possibly dissimilar materials, responsible for the corrosion [34]. EDXS on the SEM is the most common method for elemental analysis in most failure analysis laboratories.

Begin by calibrating the EDXS system. Calibration can be performed with a single crystal silicon wafer and/or a sample of high purity copper in accordance with the EDXS system manual [34]. Make sure the EDXS system is calibrated at the same acceleration voltage and beam current planned for SEM observation of the specific specimen. Clean the sample using compressed air. Observe the fracture surfaces with the corrosion deposits. If excessive charging of the specimen is observed, remove the specimen and sputter coat with 3-5 nanometers thick gold or gold/palladium film [34]. The working distance for the area to be analyzed is commonly 0.4 inches to 0.6 inches, but should be maintained according to the EDXS system requirements. Make sure no protrusion exists on the specimen that could block the path of x-rays from the specimen to the detector.

Turn off the chamber viewing infra-red camera if the SEM is equipped with one [34]. Acquire and check a sample spectrum to see if prominent elements of the specimen show up with a high signal-to-noise ratio. Ensure the dead time for specimen acquisition is below 20-40% [34]. Element identification is typically preferred over elemental mapping due to the amount of time required to complete the task. Remove the coating element from the quantification matrix [34].
4.8.12 Fracture Surface Corrosion Product Removal

In order to appropriately examine the fracture faces, the surfaces must be free of dirt, grease, corrosion and other products that could mask fracture face details. To clean the fracture face, start with a dry air blast to remove all dirt and debris. Next, clean with an acetone bath in an ultrasonic cleaner for 15-20 minutes. If oil or greasy residue persists, clean 15 minutes in an ultrasonic cleaner with each of the following sequentially: ethanol, methanol, acetone, and isopropanol bath in that order [34]. Next, apply cellulose acetate replica tape, press the tape on the surface, and then lift the tape of the surface [34]. Continue this process until no products are removed with the tape. View the fracture surface under a microscope. If the previous techniques fail to produce a clean fracture surface, more aggressive techniques can be applied for no more than twenty minutes. If necessary, aggressively clean the surface using the following procedure [34]:

- Dissolve 15 grams of Alconox detergent in 350 milliliters of deionized water at 194°F.
- Heat in an ultrasonic bath to 158°F.
- Wash the part in the detergent for five minutes at 158°F.
- Collect and strain liquids to recover the corrosion products for further analysis.

Observe the fracture faces under a microscope again to check for acceptable cleanliness. If deposits still exist, repeat the above procedure for a total maximum time of 20 minutes. Take photographs of the fracture surface conditions at each stage to document change. If the maximum time limit is met and the surface is still not clean, it is very unlikely that the deposits can be removed without significant damage to the substrate material [34]. Use the photographs taken between cleaning steps to document and assess any damage to the fracture surface caused
by the cleaning operation. A final resort for cleaning fracture surfaces is acid pickling, but surface analysis after this technique can be very complicated and difficult [34].

4.8.13 Corrosion Grind Out Evaluation

One method used to assess the thickness loss and effected surface area of corrosion is to perform a corrosion grind out evaluation. Grinding on areas of corrosion can generate toxic airborne particles; therefore, eye protection, adequate ventilation, and respirator are required from a safety perspective. To perform a corrosion grind out evaluation begin by double checking the location of the region of corrosion to be assessed. Document the condition of the corrosion location prior to grinding by measuring and documenting the area affected by the corrosion using calipers. Also make sure to measure the thickness of the unaffected region with calipers. Make sure to take photographs during each step of the grind out process to assure adequate documentation.

Begin the grind out process with fine grit abrasive paper, approximately 400# to assess the depth and severity of corrosion [34]. Pneumatic drill motors are recommended for removing heavy corrosion or reworking large surface areas. Recommended abrasive wheels and discs for aluminum include: 3M Scotch-Brite® flap wheel and spindle mount, 3M Radial Bristle™ disc, and 3M Roloc™ discs [34]. Slowly and carefully grind away corrosion until no visible pits remain. Finish the process by using Scotch-Brite® or buffing wheels. Next, etch the surface using dilute etchant to make sure all corrosion products have been removed from the surface. If no pits are observed, use Scotch-Brite® to finish the surface [34].

If pits are still observed continue to grind away the corrosion and repeat the etching process until a pit-free surface is achieved. To document the thickness lost, measure the thickness of the part at the lowest point of the grind out. Use a micrometer, dial gauge, or a test
indicator to perform this measurement. Make sure micrometers and dial gauges have a ball anvil with a diameter less than that of the grinding tool [34]. Compare this thickness measurement to the thickness of the part in a region near the ground out location that was not affected by corrosion. Calculate and record the thickness lost.

4.8.14 Unusual Findings and Related Metallurgical Evaluation

If unusual findings are recorded an in depth metallurgical evaluation may be performed to determine the root cause of unusual cracks and other anomalies associated with particular findings. Begin the metallurgical evaluation by removing sections at three different orientations away from the specific indication. Mount and polish the specimens, then etch the specimens prior to viewing them under the microscope. Next, identify microstructural features of interest including partially recrystallized grains, recrystallized grains and growth features [34]. Next identify processing signatures such as extrusion and forging, by polishing and observing an extracted cross-section and identifying certain processing condition features. Finally, identify the microstructure according to observed features and document the data.
CHAPTER 5

ESTABLISH DATA ANALYSIS PLAN

Establishing a data analysis plan is often the most overlooked portion of planning any teardown program. The focus of most teardown programs is executing the detailed processes and obtaining damage state and other teardown data. This methodology often results in a large volume of data with no plan on how to compile or analyze it. The first step in generating a data analysis plan based on the proposed method is to answer two fundamental questions:

- Is the data valid and representative of the fleet?
- How will the data be compiled, reduced, and analyzed to meet the program purpose, goals, and objectives?

For damage identified during the teardown program; the OEM engineers, fleet managers, field engineers, etc., must understand the nature of the teardown findings in order to provide fleet management recommendations. For example, the following questions need to be assessed in order to determine the applicability of the teardown data to the fleet:

- Were instances of fatigue cracking isolated to the fatigue critical locations?
- Were damage types/locations consistent with fleet damage history?
- Were damage types/locations consistent with areas investigated in previous teardowns or in fleet surveys?
- Were damage types/locations identified in other areas of concern highlighted by program management?

If the answer to these questions is consistently no, then one must question if the teardown findings were representative of the entire fleet or if the teardown article was atypical of the fleet due to aircraft basing, load history, mission mix, maintenance history, structural configuration, or
manufacturing quality [6]. If the answer to a majority of the questions presented is yes, then it is safe to assume that the findings are representative of the fleet. Keep in mind that not all findings from fleet aircraft will likely be found in the teardown article and vice versa. This is particularly true if inaccessible areas on the airframe were scrutinized by the teardown process. Since these areas are inaccessible during routine maintenance activities, there are likely few to no fleet findings in these regions.

As discussed in Section 1.2.2, many purposes exist for structural teardown. With the wealth of damage/findings data generated from the teardown program, it may be difficult to determine how to reduce and analyze all the data obtained to meet the purpose of the teardown program. For instance, much thought would be required on how to interpret the teardown data to understand the current condition of the airframe/fleet to determine steps to meet the service life goals.

If the purpose of the teardown program was to assess the effectiveness of inspection procedures, the data reduction process becomes more straightforward. The entire data set should be reduced to focus only on the areas of the airframe that had field/depot level inspections performed prior to the teardown process. Care should be taken to compare all indications from the field/depot level inspections to the teardown findings and vice versa. If indications were identified during the inspections prior to teardown, one must review the teardown program data carefully to look for other causes for the indications such as atypical sub-structure, missing or deteriorated sealant, or other structural anomalies that could have caused the inspection false call.

One should also look into the teardown findings data generated through part level NDI and verified with failure analysis to determine possible causes for indications being missed by
the field/depot inspections. The result of this comparison process allows for the capabilities and limitations of the field/depot level inspections to be determined. Once the capabilities and limitations of each inspection process are thoroughly understood the inspection can be applied in appropriate situations and the results of the inspections can be interpreted and appropriately applied to manage field/depot aircraft.

The same thought process can be applied when assessing the validity of damage prediction models. The data set can again be reduced only to contain locations with damage prediction models. Cracks (or other damage if applicable) can be compared to the existing damage prediction models to determine if the models are over predicting or under predicting the damage state of the fleet. Presuming intact and discernable fracture face features and a known usage history, damage progression models can be compared at numerous times during the operational history of the teardown article to actual operational damage. An assessment of the quality of the damage prediction model can then be made based on these comparisons.

If the purpose of the teardown is to understand environmentally driven damage, the teardown data set can be limited to environmentally driven damage types. Once the data is reduced, it can be organized based on airframe location to identify critical environmentally induced damage locations on the airframe. Inspections can then be used to monitor, and repairs developed to fix, environmentally induced damage scenarios in the most common structural regions of the airframe. If understanding the damage mechanisms on the airframe is a purpose for conducting a structural teardown, the data can be sorted into two groups: load driven damage and environmentally driven damage. These damage types can again be analyzed based on aircraft location and inspections can be developed for each damage method to identify the
specific type of damage anticipated at that location, based on the teardown findings and fleet history.

As this section has shown, teardown data may be sorted numerous ways to address many teardown purposes. It is critical; however, that the data sorting methodology and how the data will be analyzed prior to teardown data generation be determined. Quite frequently, the data is collected and then a data sorting/analysis method is determined based on the type of damage observed. This method can be misleading and result in improper data sorting, which frequently leads to less objective data analysis methods and potentially poor conclusions.
The execution of a well-planned structural teardown is one of the most straightforward aspects of the proposed process. However, much attention should be paid to assure the teardown program is actually be executed as planned and every effort is made to mitigate scatter in the teardown data collected. The only way to accomplish this is extensive oversight during the program execution. This oversight should come in the form of personnel qualification, facility qualification, and regular audits of teardown assets after each process, as most frequently the personnel that planned the teardown are not the personnel executing the teardown process.

6.1 Personnel Qualification

Execution personnel selection, or participant selection as it is often referred to as, during a teardown program, is most frequently influenced by the schedule and budget of a teardown program. Schedule effects the selection of participants/number of participating sites, from a capacity standpoint. If a large scope teardown is desired in a relatively short timeframe, a larger number of program participants are required. If a small teardown is desired or if the timeframe allotted for the teardown is generous, the potential exists for a single participating site.

The larger the number of participants/participating sites involved in a structural teardown, the more likely inconsistencies in the results will occur. This is the primary reason detailed step-by-step procedures are strongly recommended for large scope teardowns with multiple participating sites. If a multiple site team is established, a qualified, experienced program integrator is highly recommended to assure program coordination between participants, clear communication of requirements, appropriate quality of the product, and minimal scatter in the
teardown data generated [6]. Budget effects the selection of possible teardown participants as costly participants may be less desirable if the budget is tight.

The selection of experienced, qualified participants is key to the successful execution of any teardown program regardless of scope, budget or schedule. Some of the primary factors to consider when selecting a teardown team are: previous experience in the desired tasks, proper facilities and equipment, possession of appropriate qualifications/certifications, retention rate, proficiency, and lastly cost [6]. If performed incorrectly, teardown tasks can result in the degradation or complete destruction of critical information. Improper disassembly, coating removal, polishing of failure analysis specimens, and crack opening are just a few example of teardown tasks that, if performed incorrectly, can result in the loss of one-of-a-kind data with no way to recover the data[6].

For this reason, participants considered for qualification on a teardown program must demonstrate previous success conducting similar tasks, preferably on a large scale teardown program. If previous teardown task execution has not been performed by a participant, personnel with extensive disassembly/maintenance experience, non-production NDI experience, and detailed failure analysis experience may suffice. All past experience should be extensively documented. At a minimum, detailed resumes of personnel and applicable qualifications/certification should be provided.

Based upon experience from previous teardowns, often personnel lacking a sufficient level of individual certification/experience can perform specific teardown tasks, including disassembly and coating removal/cleaning, under the direct supervision of highly qualified personnel with sufficient certification/experience. This is an absolutely inappropriate approach for NDI and failure analysis. For this reason, it is important to consider if the required past
performance should be individual-based or site-based by task. Teardown programs must consider whether each task of the teardown program requires experience in the individuals performing the task or the participating site’s management structure, or both [6].

Often overlooked during the assessment of personnel at a participating site is a strong vendor supervisor. Typically during structural teardown programs, on-site supervisors oversee all teardown activities. Previous experience in this particular position is vital to the success of the vendor site. Engineers, mechanics with extensive experience, and NDI Level III inspectors with previous teardown experience are desired to fill this position. Previous large scale teardown experience is preferred in this case. It is also critical the vendor supervisor has the “big picture” from a total teardown program perspective. Inclusion of the vendor supervisors in the planning, execution, and program progress reviews strengthens the entire teardown team.

Many types of certifications are available to augment work experience for the assessment of the qualification of personnel for the disassembly and NDI tasks. Personnel seeking to perform disassembly should have recent experience with aircraft structural maintenance, disassembly, or repair [6]. This experience is even more valuable to a teardown program when it involves structural components of a similar aircraft type and scale. Possessing additional certifications, such as an Airframe and Powerplant (A&P) license further assures the teardown planning committee of a participant’s capability/competency to perform the disassembly task.

Participating sites seeking to perform NDI tasks must have a written practice as well as a training and certification program meeting the requirements of NAS 410 or ASNT SNT-TC-1A [6]. Recent experience and technical skill are vital to a robust inspection execution; all individuals conducting NDI must be certified to Level II or Level III in the method to be performed and must have performed the specific method and technique in the past six months.
Due to stringent inspection requirements, yearly audits of inspection personnel are recommended. These audits may be composed of a paper work review of credentials and/or a practical “trial” inspection of parts to determine competency. While no formal certifications exist for failure analysis sites, it is recommended all failure analysis techniques be performed under the supervision of a senior failure analyst who possesses significant experience with the type of materials being analyzed and the processes being used [6].

A participating site’s retention rate is also important to maintain consistency during a long duration teardown program. Although this metric may be more difficult to quantitatively assess, it should be carefully considered. Poor retention rate at a participating site leads to a lack of confidence in the site to provide an appropriately trained/experienced teardown staff over the duration of the teardown program. The potential inconsistency in teardown data that results from workforce variability is another program problem that emerges from low employee retention rates. High turnover may also be indicative of a management problem, including low employee morale or employee under-compensation. Strain is also placed on program management to assess the qualifications of new individuals on a frequent basis. These problems may result in unacceptable technical, financial, and schedule risk to the program [6].

6.2 Facility Qualification

Participating sites must have the appropriate facilities, tools, instrumentation, and analytical equipment, as described in Chapter 4, to perform the teardown task assigned [6]. For sites desiring to perform extraction, sufficient space, adequate heavy equipment, and appropriate extraction tools must be available to store, move, support, and perform large scale extraction to meet program requirements. Disassembly participants must have adequate space to manage large components, sufficient workbench space to identify and catalog detail parts, sufficient lighting,
and the required tools to perform disassembly. Coatings removal sites must demonstrate the capability to safely handle, store, and dispose of hazardous or waste materials generated by the paint stripping process.

NDI participants must have the required equipment, sufficient space to perform the inspection process, and sufficient lighting. Required equipment would be based on the inspection methods planned for the particular participant. At a minimum, all NDI participants should have hand-held magnifiers, calipers, and low-power (~45X) microscopes to perform any NDI tasks. Regardless of the inspection methods, all equipment should maintain calibration as required. Sites performing failure analysis evaluations of NDI indications must have laboratory quality facilities with the appropriate laboratory space and equipment to successfully and competently perform photographic documentation of samples, sample preparation, macro and micro optical examination, compositional analysis, micro examination by SEM, and appropriate reporting of all findings [6].

6.3 Audits of Teardown Assets

Another method used to assess participant qualification is proficiency in performing potential teardown tasks. Proficiency can be demonstrated by reports detailing past performance on similar programs, or often more valuably on representative aircraft structure or specimens. A proficiency demonstration must evaluate the quality, completeness, and accuracy of the participant’s capability to accomplish a specific teardown task [6]. Audits of in-process or completed samples over the duration of the teardown program are also useful to assess the continued competency of a participants. The highest audit/review effort should occur at the beginning of the teardown program to correct any unacceptable practices before they become widespread. It is also recommended to perform “no-notice” audits of a participating facility [6].
CHAPTER 7

CASE STUDIES

In an effort to illustrate the evolution of the teardown process, four case studies will be presented and assessed in Chapter 7 and Chapter 8. Three of these prior teardown programs were executed in the early to mid 2000s by governmental agencies with industry and academic partners. The fourth case study, the C/KC-135 Teardown and Analysis Program, was developed from 2006 to 2008 and is currently being executed. This teardown program used a significant portion of the proposed teardown development processes and many of the recommendations provided by this work. The goal of assessing these four case studies is not to critique the efforts of any of these teardown programs, but to show the evolution of the teardown process from the early 2000s to present day.

Chapter 7 will detail the processes implemented to plan and execute each teardown program, while Chapter 8 will compare these processes to the proposed teardown process. Differences between the implemented and proposed processes will be highlighted and the effects of the implemented processes on the final product will be assessed. Cost, schedule, and man-power requirements for all four programs will be assessed and compared to the proposed process in Chapter 8.

7.1 Evaluation of Airworthiness for Small Airplanes

The FAA general aviation teardown was performed from 2002 to 2007 to determine the “typical” condition of general aviation airframes. Four complete general aviation airframes were subjected to the teardown process at a single teardown facility. Due to the small number of participants, detailed procedures were not developed for any of the teardown tasks. Instead, “best shop practices” were commonly used instead of step-by-step validated procedures. All
results were published in tabular and photographic form in a final report that was made available to the general public.

7.1.1 Development of Goals and Objectives

The purpose of establishing goals and objectives on this teardown program was to ensure the data obtained answered relevant questions regarding the quality of current maintenance programs on general aviation aircraft. Concerns for the specific make/model would also be addressed, if observed, during the teardown. Assessment of prescribed, OEM developed; supplemental inspections were also desired as the FAA considered the possibility of mandating these inspections through regulations and rule making actions.

The process of developing goals and objectives on this research program began by brainstorming all possible reasons to perform structural teardown, possible obstacles during execution, and the possible desired outcomes. Extremely limited public data was available in 2002 regarding the development of other structural teardowns and only limited experience with teardown existed in the planning team. These brainstormed ideas were narrowed down and prioritized to the final published list of goals and objectives.

The short term objective of the research program was to determine if potential continuing airworthiness problems exist for the general aviation fleet as a function of the aging process. The long term objective was to establish guidance to ensure current maintenance programs of small general aviation airplanes are providing acceptable levels of continued airworthiness [1]. Achievement of the short term objective should determine if generic degradation indicators exist in the small airplane fleet. These indicators would likely include structure (corrosion/cracking); electrical systems or wiring; aircraft systems, such as fuel, hydraulic, pneumatic, mechanical,
and flight control; and maintenance, service, and inspection quality. Determination of generic indicators would assist in providing initial generic inspection guidance such as [1]:

- Do maintenance inspection programs address all areas of concern appropriately?
- What was found in areas that normal maintenance would not see?
- Are additional inspection criteria required for aged airplanes?
- Should specialized one-time inspections at some age be required?
- Should inspections and maintenance programs become more extensive as the airplane ages?

7.1.2 Teardown Article Selection

Four general aviation airframes were selected to meet the goals and objectives of the FAA/NIAR teardown program. The entire structure of the airframe was assessed as part of this comprehensive structural teardown. Since many Part 91 general aviation aircraft have lower flight hours than similar aircraft used in passenger service, both environmental and flight driven damage scenarios had to be identified and characterized as part of this teardown program.

Goals and objectives existed regarding the condition of each specific make/model as well as generalizations to the typical condition of the entire general aviation fleet. Efforts to assess the effect of operational environment and the effect of maintenance quality on the condition of the airframe were also desired. To meet these goals for individual makes/models as well as the general aviation fleet as a whole, airframes with diverse operational environments were desired. In order to characterize the typical condition of the general aviation fleet, at least one airframe should have been operated in a high-fatigue environment, one in a highly corrosive environment, and at least one with a wide variety of operational environments. Varying qualities of maintenance programs were also desirable to meet the goals and objectives. Effort was made to
select at least one aircraft with a basic, “at-home” maintenance program and at least one from a highly reputable maintenance program.

During this timeframe the FAA was also considering mandating supplemental inspection programs for small twin commuter aircraft used in passenger service. Many of the larger OEMs including Cessna Aircraft Company and Hawker Beechcraft had developed damage tolerance based supplemental inspections for twin commuter aircraft, while many other smaller OEMs did not have the funds available to develop such a costly inspection program to support their smaller remaining fleets. Therefore, the FAA desired to select airframes from Cessna and Hawker Beechcraft with OEM developed supplemental inspection programs and at least one airframe that did not have a supplemental inspection program.

The process used to select each of the four airframes for this teardown program was different. The first airframe selected for teardown on this program was an example of an aircraft that “volunteered itself.” The FAA was contacted about a twin engine Cessna that was owned by a company, that has recently become bankrupt, that would meet some of the goals and objectives of the teardown program. The Cessna 402A, shown in Figure 93, [13]:

- Had an OEM developed supplemental inspection program.
- Was operated in a fatigue-driven environment, flying low profile tourist flights over the Grand Canyon most of its operational life.
- Was in the upper 75% of the 402A fleet with regard to flight hours.
- Was not maintained in a formal, reputable maintenance program during the latter portion of its service life.
The second airframe selected for teardown on this program was selected using a modified version of the in-depth analysis of available engineering data method. The FAA contacted a major operator of Cessna 402C aircraft on the East Coast with the hopes of obtaining one of their higher time airframes. The selected Cessna 402C, shown in Figure 94, [16]:

- Had an OEM developed supplemental inspection program.
- Was operated in a corrosion-driven environment, flying coastal passenger service flights in the Caribbean around Cape Cod/East Coast.
- Was in the upper 90% of all the 402C fleet with regard to flight hours.
- Was maintained in one of the most reputable maintenance programs in the country for twin engine aircraft.
The third airframe selected for teardown on this program was selected using a random selection method. FAA personnel shopped used aircraft dealers and identified a Piper Navajo Chieftain for aircraft number three. The selected Chieftain, shown in Figure 95, [14]:

- Did not have an OEM developed supplemental inspection program.
- Was operated all over the United States including Alaska.
- Was in the upper 50% of all Chieftains with regard to flight hours.
- Was maintained in both formal and non-formal maintenance programs during its service life.
- Was operated in passenger service part of its life and Part 91 general aviation the remainder.
The fourth and final airframe selected for teardown on this program was another example of an aircraft that “volunteered itself.” The Beechcraft 1900D was selected since it had been retired for corrosion issues. The aircraft, shown in Figure 96, [23]:

- Had a pressurized cabin (the only teardown article with a pressurized cabin on this program).
- Had an OEM developed supplemental inspection program.
- Was operated in a corrosion-driven environment with low flight hours, flying coastal passenger service on the East Coast.
- Was part of a reputable maintenance program.
The first teardown examination was performed on a 1969 Cessna 402A model, which had accumulated 19,699 airframe hours [1]. This aircraft was most recently operated in commuter service by Sunshine Airlines for tourism flights from Las Vegas to the Grand Canyon. The second airplane selected was a 1979 Cessna 402C model. This aircraft has 25,547 total airframe hours and was most recently used by Cape Air/Nantucket Airlines of Hyannis, Massachusetts, flying in and around Cape Cod, the Florida Keys, and the Caribbean Islands [1]. The third aircraft selected for destructive evaluation was a 1975 Piper Navajo Chieftain PA31-350 model with 17,270 total airframe hours [1]. The Piper aircraft was operated all across the United States with the majority of its time spent on the West Coast and Alaska. The final aircraft selected for teardown examination was a 1993 Beechcraft 1900D airliner. This airframe had accumulated 15,203 total airframe hours and was operated on the East Coast.

The two Cessna 402s and Piper Navajo models were selected because they represent a large portion of the small airplane commuter fleet. These aircraft models share many design commonalities with other small twin class airplanes. The structural design concepts (layout and
materials) are similar model-to-model and manufacturer-to-manufacturer [1]. Therefore, findings from the destructive evaluation of these aircraft models would be applicable to all general aviation models regardless of manufacturer. The Beechcraft 1900D was selected since it was a larger commuter aircraft with a pressurized cabin.

7.1.3 Establish Detailed Procedures

The only detailed procedures used on this teardown program were the annual inspections developed and released by each OEM in the respective aircraft’s maintenance manual, and the supplemental inspection programs developed by the OEMs for the Cessna 402s [13, 16] and the Beechcraft 1900D [23]. Supplemental inspection procedures were developed by the participating site and the FAA based on engineering judgment and maintenance history for the Piper Navajo Chieftain [14]. These procedures were well documented in the final report. All other procedures implemented on this teardown program were “best shop practices.”

7.1.3.1 Field/Depot Inspections

Prior to extraction, all four aircraft were inspected based on the published inspections in each aircraft’s OEM developed maintenance manual [13, 14, 16, 23]. These inspections consisted almost exclusively of visual inspections that would be performed annually as part of the aircraft’s normal maintenance cycle. Prior to detailed disassembly, the supplemental inspection programs, developed either by the OEM or by the participating site in the case of the Navajo, were performed. These inspections consisted of visual inspections, fluorescent penetrant inspections, surface and bolt hole eddy current inspections, and magnetic particle inspections at critical locations on each airframe [13, 14, 23]. All supplemental inspections were performed by certified inspectors and the indication data obtained from these inspections were compared to the
teardown findings in the inspection area to assess the quality of the supplemental inspection program.

Prior to disassembly, select regions of each airframe were subjected to advanced NDI inspections. The inspection methods selected for these regions were considered “emerging” inspection methods at the time and included magneto-optic imaging, sliding probe, and spot probe to identify cracks and corrosion in the second or third layer of a structural stackup. These inspection methods were concentrated on the front and rear spars of the wings, horizontal, and vertical stabilizers. While these methods were being explored for research purposes on this structure, the desire was not to implement these methods in the field on these particular airframes, rather to gather information on their performance on thin skinned aircraft structure.

7.1.3.2 Extraction

Since the entire airframe for each of the teardown articles on this program were subjected to the teardown process, extraction was performed by separating the airframe into its major structural sections, using production breaks and designed attachment points, rather than cutting pieces from the airframe [13, 14, 16, 23]. To facilitate disassembly, the wings were removed from each airframe at the wing attachment fittings. Next, the horizontal and vertical stabilizers were removed from the empennage using their respective attachment fittings. The landing gear and engines were also removed. Finally, each fuselage was separated at the aircraft production breaks by removing the skins and separating the longerons. Since each major section was still identifiable, as it was separated at designed production breaks/attachment fittings, minimal documentation was required during this process. Demating of the wings and stabilizers was performed per the maintenance manual procedures.
7.1.3.3 Disassembly

Disassembly was performed using “best shop practices” and standard sheet metal techniques [13, 14, 16, 23]. No procedures for fastener removal were documented and no qualification standards were developed for personnel performing disassembly tasks. Following fastener removal, all parts were subjected to a visual inspection. Only parts with obvious visible damage were photographed and documented at this stage. Metal tags were affixed to the parts for identification purposes. The metal tag contained the original part number obtained from the illustrated parts breakdown.

7.1.3.4 Coatings Removal

Dry media blasting using plastic beads was used to mechanically remove the paint and primer on each of the parts [13, 14, 16, 23]. Since evidence exists that surface material smearing can occur, resulting in smeared material potentially obscuring open cracks, a light acid etch was used to remove a thin layer of surface material. No documentation was performed during the coating removal process.

7.1.3.5 NDI

Following the coating removal process, suspect regions were subjected to short dwell FPI and low magnification microscopic examination to identify and characterize cracks and corrosion [13, 14, 16, 23]. Mechanical damage was not assessed during this process. Suspect regions were defined as all regions inspected using the “emerging” NDI techniques prior to disassembly, visible damage identified during the visual inspections after disassembly, and all critical structural details. No detailed procedures were documented for the FPI or microscopic examinations. No minimum qualifications were provided for personnel performing the microscopic examinations.
Cracks identified during either of these inspection processes were recorded if the measured length was greater than 0.01 inches. Crack position, hole diameter, part thickness, and basic geometry were recorded for each crack identified [13, 14, 16, 23]. The affected surface area for each region of corrosion was documented as well as maximum pit depth and nominal part thickness near the corroded area. Corrosion was classified based on thickness loss using the following categories [13, 14, 16, 23]:

- Light (0%-2%).
- Light-to-Moderate (2%-5%).
- Moderate (5%-7%).
- Moderate-to-Severe (7%-10%).
- Severe (>10%).

Each crack/region of corrosion identified during the microscopic examination was documented and included in tabular and photographic format in the final report. Photographic documentation included a close-up of the damage oriented to the aircraft. The location of each close-up photograph was identified on the illustrated parts breakdown photograph. Examples of this documentation are provided in Figure 97 and Figure 98 [13].
Figure 97. Example of a illustrated parts breakdown photograph – forward carry-through structure aft and forward web – Cessna 402A [13].

Figure 98. Example of a close-up photograph – crack in forward carry-through forward web (Figure 3-149 in Figure 97) [13].
7.1.3.6 Prioritization of NDI Indications

Team members from the FAA reviewed all NDI indications and selected a small number of cracks and corrosion for failure analysis. No prioritization criterion was documented in the final report.

7.1.3.7 Failure Analysis

Failure analysis performed by the contractor was limited to origin location and failure mode. SEM photographs were provided, illustrating fracture face features to support failure mode determination such as fatigue striations or ductile dimples, typical of overload failures. Corrosion characterization and documentation was limited to identifying corrosion type and taking photographs illustrating features to support the corrosion type characterization. No information regarding processes used to open or prepare fracture surfaces were provided. “Best shop practices” are assumed to be the methods used.

7.1.4 Establish Data Analysis Plan

No data analysis plan was established for this teardown. All results were published in tabular and photographic form in a final report that was made available to the general public.

7.1.5 Execute Established Procedures

No formal effort was made during program execution to mitigate scatter in the resulting teardown data. No quality assurance programs were developed and no audits were conducted. The FAA reviewed the participating site’s data periodically and provided feedback on the findings, but not the teardown procedures used to obtain the findings.

7.2 C-5A Structural Risk and Model Revalidation Program

The C-5A Teardown was performed by the USAF from 2004 to 2005. The primary focus of the teardown was to determine the damage state of the airframe and to validate and adjust the
aircraft structural models [12]. Select regions from one aircraft were subjected to the structural teardown process. Multiple teardown participants were used to execute the structural teardown due to the large scope of the program and tight schedule. Detailed procedures were not developed and documented for extraction, disassembly, and coating removal, but extensive time and effort was contributed by the OEM to develop part identification and inspection requirements, which were well documented. All results were stored in a web-based database.

7.2.1 Development of Goals and Objectives

The purpose of developing goals and objectives was to ensure the appropriate data set at the end of the structural teardown. Since crack growth model validation was one of the objectives of the teardown program, solidly defining goals and objectives, particularly finding fidelity was extremely important to the success of the teardown program. Well defined goals and objectives also kept the planning team focused on collecting relevant data regarding the damage state. The process of developing goals and objectives was not made publicly available for this teardown program.

The primary objective of the C-5A aircraft teardown was to determine the damage state of this aircraft and use this data to validate and adjust, if required, the aircraft’s structural models [12]. When operational loading spectra were compared to the original design spectra for ground handling, it was determined that ground operations in the fleet were significantly less severe than previously predicted. Once the usage was corrected to current operational usage, a significant increase in fatigue life was predicted. The structural teardown of select locations on the airframe was used to validate these predictions.

Also, during the operation of the fleet, environmentally driven damage scenarios were occurring more frequently than presumed in the fleet. Stress corrosion cracks were being
observed in the crown skin regions. These cracks often occurred at random orientations in regions of relatively low stress [35]. Due to the random nature of location and orientation, inspection procedures currently used in this region of the aircraft needed to be assessed for capability and limitations to assure protection of the fleet. It was also desired to understand the frequency of this type of cracking in the crown skin region.

7.2.2 Teardown Article Selection

The purpose of the aircraft selection process implemented was to identify the optimal airframe to meet the purposes, goals, and objectives of this structural teardown program. This teardown had two main objectives of validating structural damage models and identifying and characterizing environmental damage. An aircraft with typical usage was desired instead of identifying the most likely “worst case” aircraft from a damage perspective.

The aircraft selection method implemented on this teardown was based on a modified version of the in-depth analysis of engineering data method. An available population of fourteen candidate aircraft was identified as these airframes were slated for retirement. A selection population of only three aircraft resulted from the available population. The other eleven aircraft were dismissed due to structural configuration differences, as initial production aircraft compared to the later serial number production aircraft [36]. The airframes remaining in the selection population were identified as “high maintenance aircraft” [36]. The most suitable teardown article was chosen from the selection population based on criteria such as “age of aircraft, number of flights, accumulated flight hours, and number of pressure cycles” [36].

Aircraft tail number 69-0004 was selected for structural teardown in support of this program. This airframe had 18,306 flight hours, 12,257 landings, and 3,549 cumulative pressure
cycles over its service life [36]. Of the fourteen candidate aircraft, the selected airframe had the second highest flight hours and sixth highest landings.

The airframe selected for structural teardown, 69-0004, also had an added advantage of being instrumented with Loads/Environment Spectra Survey (L/ESS). The L/ESS instrumentation provided more information on fleet usage data in support of fleet management. If major flaws or defects were found during the structural teardown of this aircraft, the L/ESS data could provide valuable information which could be used to correlate the findings to specific events or types of aircraft usage [36]. Figure 99 is a photograph of 69-0004 for reference.

![Figure 99. C-5 Aircraft 69-0004.](image)

### 7.2.3 Establish Detailed Procedures

Detailed procedures for extraction, disassembly, and coatings removal were not developed for this teardown program. “Best shop practices” augmented with minimal additional guidance were provided for these teardown tasks. Extensive effort; however, was expended to develop detailed procedures for all part identification and inspection tasks. More in-depth guidance was also provided for failure analysis tasks, but this guidance was not in the form of detailed, step-by-step procedures [37].

#### 7.2.3.1 Field/Depot Inspections

Validation of field/depot inspections was not a goal or objective of this teardown program; therefore, no inspections were performed prior to teardown activities for this purpose.
Emerging NDI techniques were used on select locations of the aircraft prior to teardown tasks in an effort to assess the limitations and capabilities of such technologies for possible future implementation. The results of the emerging technology assessment were not provided as part of this teardown program.

7.2.3.2 Extraction

Select regions of the aircraft were identified for teardown analysis. The aircraft was jacked and shored prior to the onset of the extraction process to assure stability of the aircraft for the duration of the extraction process. Teardown regions were cut from the surrounding aircraft structure. Pre-extraction and post-extraction photographs of the critical portions of the teardown regions were documented. Detailed procedures were not developed for the extraction process. Instead “best shop practices” were used.

7.2.3.3 Disassembly

Detailed disassembly procedures were not developed for this teardown program. “Best shop practices” and guidance from specific technical orders were provided in lieu of step-by-step documented procedures. Program participants were required to retain all fasteners regardless of condition [37]. After parts were removed from the teardown region, any residual sealant was required to be removed using a non-metallic scraper and the parts were required to be cleaned to remove dirt, oil, and grease. Once the parts were free of grease and debris, a detailed visual inspection was performed using well-defined visual inspection procedures and all findings were thoroughly documented.
7.2.3.4 Coatings Removal

Limited guidance was provided for chemical coatings removal on this teardown program. Mechanical methods for coatings removal were prohibited and only nylon brushes, abrasive pads and non-metallic scrapers were approved to facilitate coating removal [37]. No information was provided regarding preferred or approved coating removal chemicals.

7.2.3.5 NDI

In order to prioritize inspection requirements based on part criticality to reduce budget and inspection schedule, parts were placed into categories as follows [37]:

- Category 1 – Primary structure that is the central focus of the teardown region. All holes that fall within the defined critical area shall receive eddy current inspection.
- Category 2 – Remaining primary structure that generally mates with Category 1 parts. Holes may or may not require eddy current inspection.
- Category 3 – Least significant structural components. These parts are not considered critical for teardown inspection. These parts shall only require the standard visual inspection unless visual results require further investigation.
- Category 4 – Non-structural components. These parts do not require any inspections and may be discarded.

Visual inspection, according to a fully developed, documented procedure, was required for all parts in Category 1, 2, and 3. Photographs of the “as inspected” condition of all sides of Category 1 and Category 2 parts were required and a single view of all Category 3 parts was required. Any defects identified during the visual inspection process were required to be documented on a form capturing all relevant parameters of the indication and all indications were photographed.
As with visual inspection, detailed procedures were developed for FPI, ECSS, BHEC and MPI. Detailed documentation requirements were also developed, which included recording all relevant indication parameters as well as photographic documentation of all indications. OEM engineers assigned sequential part numbers to each visible part in the post extraction photographs and hole numbers to critical holes requiring eddy current inspection. These sequential part numbers were then correlated to the manufacturing part number, where possible. A table of all sequential part numbers was then developed which provided the execution participant with the inspection requirements. An example of one of the photographs illustrating sequential part numbers and critical hole numbers is provided in Figure 100 [38]. An example of the corresponding inspection requirements table is provided in Figure 101 [38].

Figure 100. Example of part numbering and critical hole numbering assignment [38].
7.2.3.6 Prioritization of NDI Indications

All NDI indications were prioritized for failure analysis by OEM engineers and government personnel. No defined prioritization criterion was made public from this program.

7.2.3.7 Failure Analysis

Detailed, step-by-step procedures were not developed for failure analysis on this research program. Standard techniques for failure analysis were augmented by detailed technical information and additional reference standards/procedures. Qualifications standards for failure analysis consisted primarily of formal education and previous demonstrated proficiency. Detailed documentation formatting requirements were also provided.
7.2.4 Establish Data Analysis Plan

No formal data analysis plan was provided for this program prior to the execution of the teardown. All teardown results were stored in a database to be reviewed by government and OEM personnel. Validation of the existing damage models was performed by OEM engineers, while the end usage of other data was not publicized.

7.2.5 Execute Established Procedures

The C-5A teardown program was one of the first teardown programs to qualify facilities and individuals to perform teardown tasks and audit the results to assure the desired data fidelity was being obtained using the implemented teardown processes and qualified personnel. Most of the qualification requirements consisted of demonstrated performance or previous performance history. All qualifications were maintained at the facility level, not the individual performance level.

7.3 Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft Fuselage Structure

The FAA/Delta Teardown was performed from 2003 to 2005 to characterize the state of MSD in the fuselage structure using detailed NDI and destructive inspection, in an effort to assess the likelihood of WFD [21]. During this teardown program, nine lap spliced panels, identified as susceptible to WFD, were removed from a retired Boeing 727 near its design service goal. Field inspections were performed prior to the removal of the teardown sections to assess MSD using a wide variety of NDI techniques.

Five of these panels were immediately subjected to the teardown process, while an additional four were subjected to extended fatigue testing to advance the state of MSD which initiated in the panels due to operational loading. This testing provided a unique opportunity for the teardown team to measure the incremental development of WFD from cracks that initiated as
a result of commercial service [21]. All teardown processes were conducted by a single facility, yet step-by-step procedures were documented for disassembly and failure analysis with less detailed procedures documented for all of the inspection methods used on the program. All results were stored in a database, developed with high level technical data query and analysis capabilities.

7.3.1 Development of Goals and Objectives

The purpose of establishing goals and objectives on this teardown program was to ensure the data obtained answered relevant questions regarding the initiation and growth of MSD/MED in fuselage panel structure. When inspecting for small MSD/MED cracks well defined inspection and failure analysis procedures will reduce scatter in the data. Also, well defined goals and objectives keep planning teams focused on the desired end result avoiding potential scope growth in the teardown program. The process of developing goals and objectives was not made publicly available for this teardown program.

The primary focus of this structural teardown was to characterize the state of MSD in the fuselage structure using detailed NDI and destructive inspection in an effort to assess the likelihood of WFD [21]. Another goal of this teardown program was for the FAA to obtain first-hand knowledge of teardown procedures that may be conducted in support of applications for continued airworthiness certification [21]. The desire was for the firsthand experience the FAA gained while participating in this teardown would enable the FAA to issue rules, policies, and ACs pertaining to the prevention of WFD.

7.3.2 Teardown Article Selection

The purpose of the aircraft selection process implemented was to identify nine large sections from a Boeing 727 aircraft representative of fuselage structure susceptible to WFD [21].
The desire was to identify an aircraft at or near its design service life with areas of fuselage structure that likely contained naturally occurring WFD. The aircraft was selected from a large number of retired 727 aircraft; however, no detailed information regarding the aircraft selection method was provided. The aircraft selected was a Boeing 727-232, serial number 20751, line number 1000, and registration number N474DA, shown in Figure 102. This aircraft was operated by Delta Airlines during its entire service life. It was well maintained and stored, and has a well documented and accessible service history.

The aircraft was placed into service in 1974 and was retired in 1998. During its service history, the aircraft accumulated 59,497 flight cycles and 66,412 flight hours, which is near its design service life [21]. The aircraft was retired prior to an advisory directive mandating inspection and repairs for inner layer cracking of the lap joints on the 727 fuselage [21]. From its introduction in the fleet until 1993, this aircraft was used in mainline routes where its average was 1.4 hours per flight and 8.3 hours per day. In 1993, the aircraft was modified and used from that point until retirement as a shuttle mission aircraft, reducing its average flight duration to 0.7 hours and average daily usage to 3.7 hours [21]. Average operating pressure was 8.6 pounds per square inch over the life of the aircraft, which is typical for the fleet.

![Figure 102. Boeing 727 Tail Number N474DA [21].](image-url)
7.3.3 Establish Detailed Procedures

In order to meet the goals, objectives, and required finding fidelity of this teardown program, an atypical program structure was required. Inspections were performed prior to fuselage panel extraction. Then the panels were extracted from the aircraft and the inspections were repeated in a laboratory environment to assure no defects were missed during the field inspections. Five of the extracted fuselage panels were immediately subjected to the teardown process, while four panels were subjected to extended fatigue testing to propagate existing damage, after which these panels were also subjected to the teardown process.

Sites containing a single fastener location with a crack indication identified during the inspection process were extracted from the panel. Crack locations were verified using a visual inspection of the hole via stereo microscopy. Disassembly/crack opening was performed on verified crack locations and a detailed failure analysis was performed at all locations opened for analysis [21]. Detailed procedures were documented for each of the steps in the atypical teardown program structure.

7.3.3.1 Field/Depot Inspections

Detailed inspections using both conventional and newer emerging NDI methods were used both before and after fuselage panel extraction. The purpose of these inspections was to catalog the condition of the aircraft and target structure [21]. Detailed visual inspections, mid-frequency eddy current, and external low frequency eddy current were the traditional inspection techniques implemented on this teardown program. All traditional inspections were performed per standard industry practices, OEM specifications, mandated service bulletins, and advisory directives [21]. These traditional NDI methods were repeated after the panels were extracted as well.
Several newly emerging NDI technologies were also used post-extraction including magneto optical imaging, self-nulling rotating eddy current probe, time varying eddy current arrays, pulsed eddy current, phased eddy current, eddy current rotating C-scan, thru-transmission eddy current, ultrasonic systems, digital radiography, and acoustically excited laser vibrometry [21]. The magneto optical imaging, self-nulling rotating eddy current probes, and time varying eddy current array sensors were used to track damage progression during the extended fatigue testing. All NDI data was collected so that the signal response data could be analyzed at a later time [21].

7.3.3.2 Extraction

Nine fuselage lap joint regions, each approximately 8 feet by 12 feet, were removed from the aircraft. Five of these regions were immediately subjected to the teardown process, while four were first subjected to extended fatigue testing to propagate existing data and to the teardown process after the testing was complete [21]. Detailed guidance, not step-by-step procedures, was provided for component extraction. Prior to panel removal, all panels were labeled with boundaries and identification marks to indicate the location and orientation of the section with respect to the aircraft coordinate system. Prior to the onset of the extraction process, weight and balance analyses were conducted in order to properly support the structure as well as to properly define the cutting sequence [21].

7.3.3.3 Disassembly

The pre-extraction and post-extraction NDI results were used to identify fastener locations that likely contained cracks of interest. One inch square pieces containing a single fastener site were extracted from the center of the joint with the fastener remaining in place [21]. In order to preserve very small cracks, fasteners were not removed using standard disassembly
techniques. Using standard fastener removal techniques with trained teardown personnel creates a low risk situation where small cracks or portions of them could be destroyed.

7.3.3.4 Coatings Removal

Coatings removal tasks were not performed during this teardown.

7.3.3.5 NDI

After removing the one inch square pieces containing the single fastener, the pre-disassembly NDI crack indications were verified using stereo microscopy. Once visually verified using this process, the fracture faces were opened for failure analysis. Each crack was thoroughly documented prior to failure analysis.

7.3.3.6 Prioritization of NDI Indications

No prioritization scheme was provided as part of this teardown program.

7.3.3.7 Failure Analysis

Following the visual verification of small cracks surrounding a fastener site, the region around the base of the fastener that could be removed without destroying the existing cracks was identified. Two machine cuts were installed though the fastener-hole interface to remove the fastener. The pieces were then soaked in D-limonene to soften any sealant so the layers could be more easily separated. Next, a slot was cut in the plane of the crack leaving a 0.05 inch ligament to the crack tip. The specimen was then cooled using liquid nitrogen. Finally, the ligament was broken to expose the fracture surfaces of the crack [21]. This entire process is shown pictorially in Figure 103. Detailed documentation was performed at each step during the teardown process.
7.3.4 Establish Data Analysis Plan

A detailed data analysis plan was generated prior to program execution on this teardown program. The crack data (patterns, distributions, sizes, and shapes) generated were analyzed and used to characterize MSD crack initiation, crack detection, crack linkup, residual strength, and the WFD average behavior in the removed structures [21]. Analysis methods were developed to correlate the state of MSD at any point in time. The following analysis steps were planned [21]:

- **Generate Stress Spectra:** A procedure to generate stress spectra representative of prior operation and usage for each structure removed is planned to be developed. The basic aircraft usage (e.g., flight types, flight mix, and flight hours actually flow) will be used to generate the spectra.
• **Crack Initiation and Initial Damage Scenario:** A procedure will be generated to estimate the number of cycles to crack initiation and to estimate the size, extent, and distribution of cracks characterizing MSD initiation.

• **Residual Strength and Final Damage Scenario:** The size, extent, and distribution of MSD that reduces the residual strength below predefined levels for the structure removed will be determined.

• **Conduct Crack Growth Analysis:** Fatigue crack growth analysis will be conducted from the initial damage scenario to the final damage scenario. Calculations will include the number of cycles to crack detection, to crack linkup, and to the final damage scenario.

### 7.3.5 Execute Established Procedures

No information was provided regarding personnel qualification, audits, or other data scatter reduction techniques implemented on this program.

### 7.4 C/KC-135 Teardown and Analysis Program

The C/KC-135 Teardown and Analysis Program was planned from 2006 to 2008 and is currently being executed. This teardown program was developed as a multiple year, multiple aircraft structural teardown program to address fleet concerns and assure the practicality of an average desired service life of eighty years for the remaining fleet. Teardown activities were planned for over three-hundred sections each from three aircraft. The program was desired to be a large scope teardown program with a high likelihood of multiple participating teardown sites. Step-by-step procedures were developed for all teardown tasks. Results are being stored in a state-of-the-art database with high end data analysis capability as well as communication functions to support program management.
7.4.1 Development of Goals and Objectives

The purpose of developing goals and objectives was to ensure the appropriate data set at the end of the structural teardown. Solidly defining goals and objectives is the first step in minimizing scatter in the resulting data as well. Also, well defined goals and objectives keep planning teams on target and avoid the potential growth in desired data that naturally occurs with teardown programs. The focus is kept on what is “required” not simply what is “desired.”

The process of defining goals and objectives for this teardown began by developing a list of questions to ask, similar to those listed in Section 2.1. Answering these questions allowed the teardown planning team to address many potential issues that typically arise while performing structural teardowns during the planning stage instead of the execution stage. Once these questions were considered or even answered, trade-offs could be executed to deliver a final list of defined goals and objectives, as well as requirements, such as finding fidelity and desired inspection method.

The published objectives of the KC-135 teardown are as follows [24]:

- Meet the requirements of MIL-STD-1530C, Section 5.4.3.3.2.
- Determine the condition of the C/KC-135 fleet in order to assess its viability for continued operations.
- Determine the effectiveness of actions taken to mitigate corrosion following the 1990s hidden corrosion teardown program.
- Confirm ASIP inspection adequacy.
- Look for cracks in locations where cracking was found after the 1967 and 1972 fatigue tests.
- Compare to results of previous teardown programs.
• Make fleet management recommendations.

7.4.2 Teardown Article Selection

The purpose of the aircraft selection process implemented was to identify the optimal airframes to meet the purposes, goals, and objectives of this structural teardown program. Since this program was a multiple objective, multiple aircraft teardown, trade-offs had to be made in the selection of each airframe. The teardown planning team anticipated some scrutiny over the aircraft selection process, so the implemented process was well documented and decisions made were well defended.

In September 2010, the remainder of the KC-135E model fleet was retired, leaving only KC-135R model aircraft and special mission KC-135 aircraft left in the operational fleet. The small percentage of special mission KC-135 aircraft have all been heavily modified or reconfigured to support special operations and do not structurally represent the remaining KC-135R fleet. Since KC-135R models comprise a large majority of the remaining fleet, acquiring at least one aircraft with the exact KC-135R model structural configuration was desirable for this teardown program, but removing an active KC-135R model from an already small KC-135 operational fleet was not considered likely. Since the remaining operational fleet had a desired service retirement date of 2040, both flight and environmentally driven damage scenarios were desired to be identified and characterized. The goal was to identify an aircraft with fatigue as the primary damage mechanism for the second aircraft and an aircraft with a mixture of fatigue and corrosion damage for the third aircraft [2].

The process used to select the first aircraft was substantially different than the process used to select the second and third aircraft. As mentioned previously, a KC-135R model was desired for the teardown program since this configuration is prevalent in the remaining
operational fleet. Prior to conducting a fleet survey of all existing aircraft, a KC-135R model aircraft was identified as available for structural teardown as it was involved in a mishap overseas. Due to program management concerns such as schedule, quick selection and execution of the first aircraft was desired. Therefore, the KC-135R model mishap aircraft was selected for the first aircraft of the structural teardown program. This is an example of the aircraft “volunteering itself.”

The selection of the second and third aircraft was significantly more time consuming as an in-depth engineering analysis approach was planned. Contrary to the aircraft selection method proposed by this paper, the KC-135 planning team began this process by acquiring data to calculate EFH and ESI damage for all aircraft remaining in the fleet prior to determining the available and selection population. Since time was required to determine the available and selection populations it was determined that the in-depth engineering analysis approach would be performed in parallel with the EFH/ESI data calculations.

After EFH/ESI data was calculated for each airframe in the entire fleet, data from unavailable aircraft was discarded. The objective for the second aircraft was to concentrate on fatigue as the primary damage mechanism, while the objective for the third aircraft was to concentrate on both fatigue and corrosion jointly [24]. The second aircraft weighted wing EFH and fuselage EFH at 50% each and a list of the top five aircraft using this ranking scheme was obtained. The third aircraft was weighted as 25% wing EFH, 25% fuselage EFH and 50% ESI [24]. The top five aircraft were identified using this selection technique as well. The selection pool consisted of 70 KC-135E model airframes retired in fiscal years 2008 and 2009. The final selection was performed after reviewing aircraft configurations, completing an in-depth review
of maintenance records, and conducting an on-aircraft survey looking at major structural repairs and corrosion prone areas.

The first aircraft selected using the aircraft “volunteers itself” method for structural teardown was a 1963 KC-135R model aircraft that was involved in a mishap. The last two aircraft selected were both 1957 KC-135E model aircraft, which were selected using a modified version of the in-depth engineering analysis approach.

### 7.4.3 Establish Detailed Procedures

Extensively detailed, step-by-step procedures were developed for part tracking and identification, extraction, disassembly, coatings removal, NDI, and failure analysis [5, 18, 19, 22, 25, 26, 27, 28, 34] as part of this teardown program. All procedures addressed the technical portion of each teardown task as well as the part identification and data documentation requirements. This teardown program also has quality assurance and control steps built into the teardown process to reduce scatter and minimize data capture errors to assure a higher quality data set at the end of the teardown program.

#### 7.4.3.1 Field/Depot Inspections

Select field/depot inspections were performed by field/depot inspectors prior to the onset of the teardown program. Results from these inspections will be compared to the teardown results in an effort to assess the capabilities and limitations of the field/depot inspections. The inspections were performed in a warehouse environment with standard inspection equipment. All inspections were performed according to the current inspection procedures utilized in the field/depot.
7.4.3.2 Extraction

The extraction process consists of more than just physically cutting a section from the aircraft. Step-by-step procedures for teardown section extraction were developed which address the following extraction tasks [26]:

- Locate Teardown Section – reference documents to appropriately define the boundaries of each teardown section and perform preliminary markings.
- Mark Teardown Section – mark cut lines per the reference documents, label teardown section reference coordinates, photographically document the teardown section prior to extraction, visually inspect the teardown section and documented any anomalies, and submit the extraction plan for approval.
- Enter Pre-extraction Data in the Database – upload photographs and logs as required to the database based on provided detailed instructions.
- Extract Teardown Section – support the teardown section, remove unnecessary structure, verify the extraction cut lines, and cut the section free from the surrounding structure.
- Document the Teardown Section – complete the teardown section identification and tagging, photographically document the teardown section after extraction, and visually inspect the teardown section and document any anomalies.
- Enter Post-extraction Data in the Database – upload photographs and logs as required to the database based on provided detailed instructions.

7.4.3.3 Disassembly

The disassembly teardown task consists of more than just removing mechanical fasteners and sealant. Step-by-step procedures for teardown section disassembly were developed which address the following disassembly tasks [19]:
- Receive Teardown Section – verify teardown section identification and photographic documentation in the database, review the previous incidental/shipping damage record, perform a visual inspection of the entire section, record and photograph new incidental damage in the database, and update the status in the database.

- Remove a Part from the Teardown Section – clean parts as required, perform a visual inspection, removal all mechanical fasteners, and remove all sealant.

- Identify and Physically Mark Parts – create new part identification in the database and physically mark the part.

- Inspect Part and Document Observations – perform a visual inspection of the part, photograph each part and any new observations, record all parts and new observations, complete accidental damage report (if required) and document in the database, complete the teardown section disassembly log, and create a teardown section parts breakdown photograph.

- Transfer Parts to Coating Removal – complete disassembly quality assurance log, finalize database disassembly entries, and update status in the database.

7.4.3.4 Coatings Removal

Step-by-step procedures for part coating removal were developed which address the following coating removal tasks [27]:

- Receive Parts – verify identification and photographic documentation in the database, review previous incidental/shipping damage records in the database, record and photograph any new incidental/shipping damage in the database, update status in the database, and assess specific part coating removal requirements relative to material and size.
• Coating Removal System Set-up and Preparation – verify operational status of coating removal system and complete coating removal system quality control steps.

• Part Exposure – expose parts in coating removal system per provided guidance.

• Part Removal and Rinsing – remove parts prior to reaching exposure limit, rinse parts per provided Chemical Technical Sheet guidance, inspect parts particularly holes and radii, use approved scrapers/brushes as required, expose parts as needed up to limit, and upload process log in the database.

7.4.3.5 NDI

Step-by-step procedures for NDI were developed which address the following inspection tasks [28]:

• Receive Part – verify identification and photographic documentation in database, review previous damage record, record and photograph obvious new incidental damage in database as required, and update status in the database.

• Inspect Part – determine the inspection requirements in the database, perform CVI, ECSS, BHEC, FPI, MPI, and/or ultrasonic thickness measurement based on the developed procedures.

• Document Relevant Indications – number holes based on the developed procedure, mark indications, photographically document all relevant indications, document all indication in hard copy (backup) format, document all relevant indications in the database per provided procedures.

• Identify Parts for Failure Analysis – complete the NDI quality assurance log, finalize all database entries, update part status in database, and transfer parts to failure analysis as required.
7.4.3.6 Prioritization of NDI Indications

No official NDI prioritization criteria were disclosed on this teardown program.

7.4.3.7 Failure Analysis

Step-by-step procedures for failure analysis were developed which address the following tasks [34]:

- Receive NDI Report – make an initial assessment of the part, verify the identity and source of the part, verify the source of the NDI report, and verify the existence and documentation of each part indication.

- Visual Examination – perform a visual inspection of the part and take a digital image of the part.

- Enhanced Visual Inspection – inspect fastener hole bores and part surfaces, document the damage dimensions, photograph the damage, and document the results.

- Specimen Sectioning – take macroscopic photographs of the entire part as received and the resulting specimen both prior to and after excising, perform enhanced visual and microscopic observation, ensure all part identification markings and orientation are properly transferred from the parent part with an engraver, section outside the crack, sectioning outside a corrosion region, and sectioning outside indication region in the absence of visible damage.

- Specimen Mounting – hot mounting or cold mounting.

- Specimen Polishing – wash the specimen, chamfer the specimen edges, and final polishing by colloidal silica or colloidal alumina suspension.

- Crack Opening – prepare the specimen and apply the appropriate opening method.
Fracture Surface Examination – prepare the specimen for inspection, mark the area to be analyzed, observe the indication at different magnifications, ensure proper lighting and contrast, characterize the observed damage, find the origin of the damage feature, measure the damage, and photograph the damage.

Electron Microscopy – clean the sample, mark the area to be analyzed, affix the specimen to the stage, find the indication at low magnification, identify the source of the indication at successively higher magnifications as required, characterize the observed damage, find the origin of the damage feature, measure the damage, and photograph the damage.

Fracture Surface Characterization – categorize the damage as ‘no finding’, ‘overstressed’, ‘mechanical damage’, ‘corrosion’, ‘corrosion-fatigue’, ‘corrosion/fatigue’, ‘stress corrosion cracking’, or ‘fatigue’; find the origin of the damage feature; measure the damage; document the damage characteristics and dimensions; and photograph the damage.

Corrosion Type Identification – identify the corrosion type based on provided guidance.

Corrosion Product Identification – calibrate the EDXS system, clean the sample, perform SEM observation of the fracture surface with corrosion deposits, turn off the chamber viewing infra-red camera, acquire and check a sample spectrum, select the proper option for the product evaluation requirement, and remove the coating element.

Fracture Surface Corrosion Product Removal – clean the fracture surface with a dry air blast, clean the fracture surface in an acetone bath, strip the fracture surface with cellulose acetate replica tape, observe the fracture surface, aggressively clean the surface if necessary, collect and strain clean liquids, observe the fracture surface, and identify the damage caused by the cleaning process.
• Corrosion Grind Out Evaluation – identify part and part coordinates, review all data in the database, take macroscopic photographs at various stages, measure and record the area affected by corrosion, start the removal process with abrasive mats or pads, carefully grind away corrosion, finish using buffing wheels, if no residue or pits found finish the surface, measure the thickness part closest to the affected area, measure the thickness of the part at the lowest point of the grind out, and calculate and record thickness lost.

• Unusual Findings and Related Metallurgical Evaluation – review all data in the database, take sections from the part at three different orientations, mount and polish specimens, etch the specimen, identify the microstructural features, identify processing signatures, and identify microstructure.

7.4.4 Establish Data Analysis Plan

No formal data analysis plan was developed prior to program execution.

7.4.5 Execute Established Procedures

This teardown program defined qualification requirements for each step of the teardown process. The requirements consisted of a combination of demonstrated past performance, individual qualifications/certifications, and on-site competency testing on specific tasks. Some qualifications were facility based, including extraction, disassembly and coating removal. NDI and failure analysis task certifications were individually based since results must be interpreted by individual technicians/engineers. Appropriate equipment/facilities were also assessed in the qualification of teardown facilities.

Audits were also used extensively to assure that processes were being implemented correctly and that the desired data was being obtained using the developed processes. Audits consisted of watching personnel perform teardown tasks to assure accurate execution, reviewing
the results after completing teardown processes to assure desired results are achieved using the process, and auditing data to assure correct data collection and documentation. Audits were scheduled annually and occurred more frequently toward the beginning of the teardown program to correct problems before a significant amount of teardown data was collected.

Quality control programs for data documentation were also implemented. An approved on-site supervisor was designated for each facility. This person was typically an engineer, Level III NDI inspector, or a senior mechanic, typically with prior teardown experience, whose responsibility was to review every piece of teardown data for quality prior to finalization in the database. The data review consisted of reviewing all logs and photographs to assure these pieces of data met the minimum standards outlined in the requirements documents.

The qualification requirements, audits, and quality control programs were designed and implemented to minimize error and scatter in the resulting teardown data set. Data and process reviews were also conducted by members of the planning and execution management teams on primarily a spot check basis. If common discrepancies or problems with the data or quality of the product from the teardown task were identified, corrective action, frequently additional training, was required by the participating facility to maintain program qualification.
CHAPTER 8

COMPARISON OF CASE STUDIES TO PROPOSED PROCESS

The processes and results of the four case studies discussed in detail in Chapter 7 are compared in this Chapter to the proposed teardown process. The goal of the comparison is not to critique the efforts of any of these teardown programs, but to show the evolution of the teardown process form the early 2000s to present day. Differences between the processes implemented in the case study teardowns and the proposed teardown process are highlighted and the effect of the differences on the final product is assessed. Cost, schedule, and man-power requirements for all programs are compared to the proposed process. Note the cost, schedule, and man-power requirements are not based on actual program cost figures, rather are estimates based on experience.

8.1 Development of Goals and Objectives

Evaluation of Airworthiness for Small Airplanes – The method of brainstorming all possible reasons to perform structural teardown, possible obstacles during execution, and the possible desired outcomes is similar to the proposed method of developing a list of questions regarding purpose, finding fidelity, desired damage mechanisms, etc. The shortcoming on this program existed with the experience level of the teardown planning team. Few, if any, of the teardown team had participated in large scale structural teardowns so the ability to foresee problems and perform trade-offs required to prioritize and accommodate completing objectives did not exist on this teardown program.

The primary goals of the teardown program were to determine if potential continuing airworthiness problems exist for the general aviation fleet in general as a function of the aging process and determine if generic degradation indicators exist in the small airplane fleet. The
ability to correlate maintenance quality and condition of the aircraft was also desired. This resulted in too many variables defined in the goals and objectives to be successfully decoupled and analyzed. Some of the variables included: manufacturer, make/model, calendar age, environmental operating environment, flight hours/loading environment, and quality of maintenance over the operational life of the airframe. Some of these variables, particularly the quality of the maintenance over the operational life of the airframe, were difficult if not impossible to quantify, particularly for aircraft with a high number of owners/operators.

Finding fidelity was also not solidly defined for this teardown program. Inspection techniques were selected based on common industry practice, budget, and schedule, not desired finding fidelity. Besides eddy current requirements from the supplemental inspections, the inspection techniques were also applied globally to the airframes, not target locations based on desired finding type/size. This flexible/undefined finding requirement could have resulted in a loss of focus on the goals and objectives and resulted in a “find everything one can possibly find regardless of relevance” approach. This is particularly dangerous for teardown programs with a defined scope and budget.

The development of goals and objectives on this teardown program could have been improved by using trade-offs to prioritize competing objectives and to reduce the number of variables in the operational and maintenance histories. A rigidly defined finding fidelity would also reduce the teardown data set to only data relevant to answer questions posed in the goals and objectives. A reduction or prioritization in variables and a rigid finding fidelity would have resulted in easier data interpretation and a more direct application of the results of the teardowns.

C-5A Structural Risk and Model Revalidation Program – While the process used to develop the program goals and objectives was not publicized on this teardown program, the
results still may be assessed and critiqued. The primary objective of the C-5A teardown was to
determine the damage state of this aircraft and use this data to validate and adjust the aircraft’s
structural models. An additional objective to characterize environmental damage mechanisms on
the airframe was also defined. In this case, the aircraft structural models are presumed to be
fatigue models that exist only in critical structural areas. Since fatigue findings are desired only
in a small number of locations on the airframe and environmental damage mechanisms are
desired to be identified and characterized in a general sense, minimal competition exists between
the two objectives.

While no formal finding fidelity was explicitly provided for this teardown program, the
desired fidelity could be estimated from the provided goals and objectives and selected
inspection methods. Since the fatigue findings would be used for structural model verification,
one can assume a finding fidelity on the order of 0.050 inches as this is a typical initial flaw size
for USAF damage tolerance models. No finding fidelity can be assessed for the environmental
damage mechanisms from the provided goals and objectives; however, with the visual and FPI
requirements, one can infer a finding fidelity in the range of 0.100 inches to 0.250 inches.

The development of goals and objectives could have been improved on this program by
solidly defining finding fidelities for both failure modes of interest. Using a list of questions
similar to that provided in the proposed process may have also resulted in additional secondary
goals, which would have provided different uses for available teardown data.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – While no
detailed information exists for the steps used to develop the goals and objectives on this
teardown program, the goals and objectives can still be assessed and improvements suggested
based on the proposed method. The primary goal of the teardown program was to characterize
the state of MSD in the fuselage structure using detailed NDI and destructive inspection in an effort to assess the likelihood of WFD. A secondary, non-competing goal of the teardown program was for the FAA to obtain first-hand knowledge of teardown procedures that may be conducted in support of applications for continued airworthiness certification. Since no data requirements or process changes were required to meet the knowledge objective, the two objectives were completely decoupled objectives so no trade-offs were required. While no formal finding fidelity was documented, one could presume that very small defects on the order of 0.010 inches were desired to meet the goal of assessing MSD in fuselage structure.

The goals and objectives on this program could have been improved by defining a solid finding fidelity and potentially defining additional secondary goals to improve the value of the teardown by obtaining data to address additional issues without significant increases in cost/schedule.

C/KC-135 Teardown and Analysis Program – This teardown program used a version of the proposed process to develop goals and objectives. A list of questions was developed and the answers to these questions were used to develop the goals and objectives. Minimum flaw sizes were defined by desired damage type, but this information was never publicly disclosed. Based on the prescribed inspection types and published goals and objectives, one can estimate the value for fatigue flaws at approximately 0.050 inches and environmentally induced damage scenarios in a range of 0.100 inches to 0.250 inches, similar to the C-5A teardown program.

Multiple goals and objectives were developed using the selected process and trade-offs were performed to prioritize competing objectives. The development of goals and objectives could have been improved on this teardown program by publishing the developed finding fidelity by damage mechanism.
Cost/Schedule/Man-power Assessment – No significant changes in cost, schedule, or man-power would have resulted from using the proposed method over each of the methods used to develop goals and objectives in the case studies. Goal and objective development typically consists of a single planning committee meeting, regardless of the development method selected.

8.2 Teardown Article Selection

Evaluation of Airworthiness for Small Airplanes – Four different teardown articles were selected to meet the goals and objectives of this teardown program. Variations of each of the three aircraft selection methods included in the proposed process were used on this teardown program. Each will be independently assessed and compared to the proposed method to identify potential improvement. The Cessna 402A and the Beechcraft 1900D were selected based on the aircraft “volunteering itself”. The Cessna 402C was selected based on a modified version of the engineering data analysis method, while the Piper Navajo was chosen based on random selection.

During the selection process for the Cessna 402A, no effort was made to determine the available or selection population of this make/model of aircraft. The airframe selected, was made available to the FAA due to the bankruptcy of the owner/operator. No formal effort was made to assess how the flight hours/flight environment compared to the remainder of the fleet as this demographic data was not conveniently accessible for review for the general aging fleet at the time. Members of the FAA with “tribal knowledge” of the fleet felt this aircraft was fairly typical of the 402A fleet.

The selection of this teardown article could have been improved by developing the selection population as described by the proposed process and collecting accurate demographic data to assess how typical this aircraft truly was to the Cessna 402A fleet. One of the primary
reasons this aircraft was selected for teardown was that it was operated in a fatigue environment, flying tourists over the Grand Canyon, yet little fatigue damage was actually found on the aircraft. If a fatigue likely aircraft was desired, a more likely candidate aircraft may have been identified through a review of the fleet demographic data.

The Cessna 402C was selected using a modified engineering data approach. The available population was determined to be all Cessna 402C aircraft owned/operated by Cape Air, one of the largest operators of Cessna 402C aircraft on the East Coast. An aircraft from this operator was desired due to the high quality of the maintenance operations, high flight hours, and almost exclusive operation in “corrosion friendly” environment. The selection population was defined as the available population minus a few aircraft with significant major repairs, not typical to the Cessna 402C fleet. The tail number selected was chosen based on the high number of flight hours/flight cycles and the small number of major repairs/modifications. The selection of this teardown article may have been improved by considering a larger available population, not just aircraft owned/operated by Cape Air.

The Piper Navajo Chieftain was selected using a random selection method. No available or selection population were ever formalized. The only selection criterion was a typical Piper Navajo Chieftain. The selected aircraft was identified through a used aircraft trading company and purchased from a private individual. As with the Cessna 402A, the flight hours/operating environment was discussed with the FAA and was determined to be “typical” with no formal demographic data review. After the aircraft was acquired, it was determined that although no formal accident/incident occurred with the aircraft, the airframe had been subjected to a gear up landing, which resulted in significant damage and repair to the belly structure and lower wing skins of the airplane.
The selection process for this airframe could have been significantly improved by performing a more thorough maintenance record and demographic data review. Due to the extensive repairs of the lower portion of the airframe, any teardown findings in this region are questionable and likely not applicable to the fleet. A demographic data review of all Navajos and a large selection population might have also yielded an aircraft with higher flight hours and more severe usage that could have forecasted issues with this make/model in the future. The selected Navajo was also used all over the US so correlating operating environment to aircraft condition was impossible.

The Beechcraft 1900D was another example of an aircraft that volunteered itself. This particular airframe was retired from passenger service due to a significant corrosion problem. The aircraft had very low flight hours compared to the general knowledge of the condition of the fleet. As with the Cessna 402A, more information regarding the fleet demographics might have led the planning committee to identify a different airframe that may have better met the goals and objectives of this research program.

**C-5A Structural Risk and Model Revalidation Program** – The selection of the teardown article for this program was based on the engineering data analysis process described in the proposed process. The available population consisted of fourteen C-5A airframes being retired by the USAF. The selection population was narrowed to three aircraft from the fourteen available due to atypical structural configurations on eleven airframes. The airframe identified for structural teardown was selected based on aircraft age, number of flights, accumulated flight hours, and the number of pressure cycles. The only improvement to the teardown article selection process recommended would be to increase the available/selection population if possible. It is also recommended to review similar operations data for the remaining fleet to
determine if the airframe selected truly represents a “typical C5-A” as desired or if one of the other aircraft in the selection population is actually more representative of the typical aircraft remaining in the fleet.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – No detailed information regarding the selection method of this teardown article was provided. The aircraft was selected from Boeing 727 retired aircraft near their design service goal. To assure the WFD damage required to meet the goals and objectives, four of the test panels were subjected to extended fatigue testing. Since the details of the airframe selection process were not disclosed, no recommendations for improvement or assessment of the process can be made.

**C/KC-135 Teardown and Analysis Program** – The first teardown article was an example of the aircraft “volunteering itself,” while the remaining two aircraft were selected based on the in-depth engineering data analysis method. Since the remaining fleet of KC-135 aircraft is comprised of all R models, the first airplane was desirable due to configuration, with less regard for the flight hours and operational environment. The remaining two aircraft were selected from an available population of retired E model aircraft. The entire available population was assessed based on EFH and ESI, prior to determining the selection population. The most desirable aircraft based on the analysis of the EFH and ESI engineering data were then surveyed to determine if these airframes should be included in the selection population.

The recommended improvement to the teardown article selection process would be to develop the selection population prior to performing the engineering analysis. This would be more cost effective as the data and analysis would not be required for aircraft that do not meet the program goals and objectives.
Cost/Schedule/Man-power Assessment – Table 9 provides a comparison of the estimated cost/schedule/man-power required to perform the teardown article selection process implemented on each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process. Cost/schedule/man-power is presented as a single number since all three values are directly related for planning activities. Since no selection process was outlined for the Destructive Evaluation and Extended Fatigue testing of Retired Aircraft Fuselage Structure (Boeing 727), no estimation of cost could be provided in Table 9. Since four different aircraft were selected during the Evaluation of Airworthiness for Small Airplanes using different selection techniques, each is evaluated independently in Table 9.

TABLE 9
COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR TEARDOWN ARTICLE SECTION

<table>
<thead>
<tr>
<th>Proposed Process</th>
<th>Cessna 402A</th>
<th>Cessna 402C</th>
<th>Piper Navajo Chieftain</th>
<th>Beechcraft 1900D</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>70</td>
<td>5</td>
<td>15</td>
<td>80</td>
<td>N/A</td>
<td>110</td>
</tr>
</tbody>
</table>

The values assigned in Table 9 to the Cessna 402A, Piper Navajo Chieftain, and Beechcraft 1900D are evaluated significantly lower than the proposed process as no effort was made to assess the available or selection population or to review data to assure the optimal aircraft was selected to meet the goals and objectives of this teardown program. The values for the Cessna 402C and C-5A were also lower than the proposed process, but significantly higher than the other general aviation teardown aircraft since effort was made to identify the optimal aircraft. For these two airframes assessing a larger available population might have resulted in a different airframe selection. The KC-135 teardown was ranked higher than the proposed process.
as more effort was made to identify the optimal airframe to meet the goals and objectives for the second and third airframe, particularly, including on-site visits to assess visible damage and repairs.

8.3 Establish Detailed Procedures

Detailed procedures, particularly for large scope teardown programs with multiple participating locations/sites, were recommended in the proposed process. The four case studies used varying degrees of detailed procedures for each of the teardown tasks. Each teardown task for each case study was compared to the proposed process to identify potential improvements in data collection and teardown task execution. Cost/schedule/man-power is presented as a single number since all three values are directly related for this step in the teardown process. Separate assessments are made for planning and execution as the cost of the two is not directly related.

8.3.1 Field/Depot Inspections

Evaluation of Airworthiness for Small Airplanes – Visual inspections were performed prior to extraction based on the typical annual inspection required in the aircraft maintenance manuals. The inspection processes were well developed and documented in the maintenance manual. Supplemental inspections, consisting of visual, FPI, and limited eddy current inspections were preformed prior to detailed disassembly. Well documented supplemental inspection procedures were developed by the OEMs for every aircraft except the Piper Navajo Chieftain. Detailed, step-by-step supplemental inspection procedures were developed by the contractor on the Piper Navajo Chieftain. Detailed procedures were not documented for the advanced NDI inspections performed on the spars of the wings, horizontal and vertical stabilizers.
While step-by-step procedures were implemented for the annual inspections and the supplemental inspections, the process could have been improved using the proposed process by retaining all inspection signals/data for later interpretation. Photographs of all visual findings were taken and stored, but no fluorescent photographs of the FPI indications, screen shots of the eddy current responses, or inspection data from the advanced NDI techniques were stored for review. Storing this type of inspection data that requires interpretation allows others to review the data and assure no errors occurred in interpreting the signal response data.

**C-5A Structural Risk and Model Revalidation Program** – Emerging NDI techniques were investigated on select regions of the airframe; however, documented procedures or stored inspection results data was not available on this program. Inspection technique assessment was not a goal or objective developed on this program, so little work was performed in this area. This process could be improved, as suggested in the proposed process, by performing field/depot inspections prior to structural teardown tasks to assess the capabilities and limitations of the inspection procedures or investigate more emerging NDI techniques that may be implemented in the field in the future.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – Conventional and newly emerging NDI methods were performed prior to extraction to assess the damage state of the fuselage panels to be assessed during the structural teardown. All inspections were performed per standard industry practices, OEM specifications, mandated service bulletins, and advisory directives. All NDI data was collected so that signal response data could be analyzed at a later date. Even though the goal was not to assess NDI procedures used in the field/depot, this program made effective use of existing and newly emerging inspection techniques to
characterize the state of damage on the teardown regions of interest. No improvements to this process are suggested based on the proposed teardown process.

C/KC-135 Teardown and Analysis Program – The field/depot inspections performed on this teardown program were performed based on the proposed process. All inspections were performed by field/depot inspectors, using field/depot equipment in a warehouse setting. All NDI data was archived for later interpretation and review. No improvements are recommended based on the proposed process.

Cost/Schedule/Man-Power Assessment - Table 10 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the field/depot inspections for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>80</td>
<td>30</td>
<td>175</td>
<td>100</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>90</td>
<td>75</td>
<td>175</td>
<td>100</td>
</tr>
</tbody>
</table>

The values assigned in Table 10 to the C-5A teardown planning phase and execution phase are lower than the proposed process as only limited emerging NDI was performed on this teardown article. No detailed procedures were developed and documented for the inspections performed and the results were not shared as part of this teardown program. The planning phase of the general aviation teardown was also rated lower than the proposed process as advanced NDI procedures were not developed in detail and documented. The execution phase was also evaluated lower than the proposed process, as inspection signal response data was not retained.
for later evaluation and interpretation assessment. The Boeing 727 teardown program was evaluated higher than the proposed process in both planning and execution as a significantly higher number of conventional and emerging NDI techniques were planned and executed. All NDI signal data was retained for later evaluation on this program as well.

8.3.2 Extraction

Evaluation of Airworthiness for Small Airplanes – Extraction for all four airframes consisted of separating the airframe into major structural components using the demating procedures in the maintenance manual. These procedures are step-by-step and well documented. Since no cutting is required for extraction of this type, just separating the airframe at designed attachment points, the likelihood of accidental damage is even further minimized. The only recommendation for extraction on this teardown program based on the proposed process is to photograph the extraction process before and after the demating process and physically mark the major aircraft sections with orientations and three dimensional aircraft coordinates on the extremities of each major aircraft section. The addition of extremity coordinates is recommended so that three dimensional aircraft coordinates are transferred correctly to the part level during the disassembly process.

C-5A Structural Risk and Model Revalidation Program – Detailed planning was performed to assure the aircraft was jacked and shorted prior to the onset of the cutting operations. Photographs were also taken before and after the cutting operations to document the condition and locations of each of the teardown regions. Detailed procedures were not developed for the extraction process, but instead “best shop practices” were used.

While “best shop practices” for the cutting portion of the extraction process are typically sufficient, appropriate care needs to be taken to minimize accidental damage due to the cutting
operation and removing the region from the surrounding structure. Two recommendations are made on this process from the proposed process. First, make sure the cut lines are visible on all surfaces of the region being extracted to assure, regardless of the locations/orientation of the person performing extraction, the cut lines remain visible. Second, make sure aircraft coordinates are labeled on the extremities of all regions extracted from the airframe. Sometimes some of these markings become illegible during the cutting process, particularly if the cuts are imprecise or the cut lines have to be moved during the actual cutting operations. Also, make sure these markings are visible and legible in all photographs both before and after extraction.

Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft – Prior to cutting operations, weight and balance analyses were performed to assure proper aircraft support and determine the appropriate cutting sequence to assure stability of the remaining airframe. All panels were labeled with boundaries and identification marks to indicate the location and orientation of the section with respect to the aircraft prior to panel extraction. Detailed guidance, in lieu of step-by-step procedures, was provided for the cutting operation and photographs were taken of the panels before and after the extraction process. No recommendations for extraction process improvement are made based on the proposed process.

C/KC-135 Teardown and Analysis Program – Step-by-step procedures were developed for the extraction process of this teardown program. Weight and balance calculations were also performed to assure stability of the airframe during the cutting process and cutting sequence. Significant care was taken in developing the detailed procedures to assure safety during the cutting operations. Teardown section extents and orientation markings were well defined during this program and the photographic documentation prior to and after extraction was extensive. No recommendations are made regarding this program based on the teardown proposed process.
Cost/Schedule/Man-power Assessment - Table 11 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the extraction process for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

TABLE 11

COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR EXTRACTION

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>20</td>
<td>90</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>50</td>
<td>90</td>
<td>90</td>
<td>120</td>
</tr>
</tbody>
</table>

The assessment of the extraction process for the general aviation teardown articles in Table 11 is lower than the proposed process in both planning and execution as no cutting was required on this program and all demating procedures were previously developed by the OEM. Also, limited photographic documentation before and after was performed and the amount of part marking during the extraction process could have been improved significantly. Both the C-5A and Boeing 727 teardown programs lacked some of the documentation requirements in the proposed process, so both programs were assessed slightly lower than the proposed process in both planning and execution. The KC-135 program was rated higher than the proposed process in both planning and execution as the developed processes were significantly more detailed and the documentation requirements were more extensive.

8.3.3 Disassembly

Evaluation of Airworthiness for Small Airplanes – “Best shop practices” and standard sheet metal techniques were used in lieu of detailed disassembly procedures or teardown specific guidance. Part marking was minimal and photographic documentation was limited only to parts
with obvious visual damage. Also, no minimum qualification standards were developed for personnel performing disassembly. These practices coupled together, while typical of teardown programs of this time, cause significant concern for the integrity of the data set developed from the teardown program. A lack of specific procedures coupled with no minimum qualification standards frequently leads to a significant amount of disassembly induced damage at fastener site locations.

If the finding fidelity for cracks on a teardown program is rather large, on the order of 0.150 inches to 0.250 inches at fastener locations, the risk to teardown data obtained from cracks at fastener sites becomes a loss of origination feature for the crack and loss of crack face data at shorter crack lengths. If disassembly damage occurs in critical regions with small desired crack lengths on the order of 0.050 inches, the risk becomes loss of the entire crack indication. If the fastener removal operation causes gouging in the fastener hole or out-of-round fastener holes, BHEC techniques, designed to detect small cracks, become completely unusable or the fidelity of the results significantly degraded at a minimum. Typically in the field, if out-of-round holes or gouging are observed, the fastener site is simply oversized and no harm is done to the aircraft, which is why standard disassembly techniques are acceptable for field repair. During teardown, however, one-of-a-kind, irreplaceable teardown data is lost or degraded. The lack of detailed part marking is also problematic as parts can be misidentified or lost with no record of the “as installed” configuration or condition.

Establishing a minimum qualification for disassembly is recommended based on the proposed process. If personnel are new to structural teardown, it is recommended that if detailed fastener removal procedures are not developed, disassembly personnel are subjected to teardown training. This training should highlight the potential risks to the teardown data associated with
standard disassembly practices and provide a global view of the teardown process. The interdependency of one teardown tasks on all the other tasks should also be highlighted. For example, if damage occurs in disassembly the quality of the NDI and failure analysis at that location is degraded or destroyed.

At a minimum it is recommended that, parts should be identified with part number, orientation to the aircraft, and three dimensional aircraft coordinates at the extremities of the part. Photographs of parts obtained from critical structural regions should be photographed once removed from the airframe even if damage is not visible during disassembly.

**C-5A Structural Risk and Model Revalidation Program** – This teardown program used “best shop practices” and guidance from specific technical orders, which provide guidance on techniques used to perform sheet metal tasks in the field, to guide disassembly personnel. Unlike the previous program, minimum qualification standards were developed to primarily include previous sheet-metal experience. In this teardown; however, all structural components removed from the teardown regions, were required to be photographed in the “as removed” condition. All structural parts were also subjected to a detailed visual inspection, following a specific procedure.

As with the previous case study, the risk to data generated using teardown tasks downstream of disassembly exists from using standard disassembly techniques when personnel without previous teardown experience or training are performing fastener removal tasks. In order to mitigate this risk, teardown training is recommended for all disassembly personnel on this teardown program without previous teardown experience.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – Atypical disassembly techniques were used on this teardown program to remove the risk of damage or
destruction to the desired small cracks due to standard fastener removal techniques. Detailed documentation including photographs of all locations selected for disassembly were taken and stored on this teardown program. No process changes are recommended based on the proposed teardown process for disassembly on this teardown program.

C/KC-135 Teardown and Analysis Program – Step-by-step disassembly procedures were developed and implemented on this teardown program. Qualification requirements based on previous experience and training/certifications were developed to assess disassembly personnel. Detailed part marking and photographic documentation requirements were developed as part of the disassembly process. As with other case studies, teardown training is recommended for personnel without previous teardown experience.

Cost/Schedule/Man-power Assessment – Table 12 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the disassembly process for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>10</td>
<td>25</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>60</td>
<td>90</td>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>

The assessment of the disassembly planning process for both the general aviation and C-5A teardown are significantly lower than the proposed process as only standard practices were prescribed for both programs with additional technical order guidance provided for the C-5A teardown. The execution cost assessment for the general aviation teardown was also
significantly lower as the documentation and part marking requirements were also significantly less than any other teardown program assessed in the case studies. The KC-135 planning and execution cost assessments are higher than the proposed process as the step-by-step procedures, part marking requirements and data documentation requirements are more significant than the proposed process.

8.3.4 Coatings Removal

Evaluation of Airworthiness for Small Airplanes – The dry media blasting with acid etching technique was used on this teardown program. Since the time of this teardown program, evidence has surfaced that this mechanical coating removal technique introduces the possibility of smearing metal over open cracks. If metal smearing occurs over the entire surface of a crack, visual and FPI techniques would be rendered useless as both methods are only effective in identifying surface breaking discontinuities. Acid etch was used to minimize the likelihood of this problem occurring. Acid etch removes between 0.003 inches and 0.005 inches of the surface material. Due to the amount of material removed across the entire surface of the part, the possibility exists that light surface corrosion would be eaten away by the etching process. Also, if cracks faces are open to the surface, fracture face details may also be degraded or destroyed by the acid etch, reducing or destroying the ability of failure analysis to obtain information regarding origin and propagation mode of the crack.

Based on the proposed process, chemical coatings removal techniques are recommended. Care should be taken to identify a chemical coating removal system that does not remove surface material or destroy crack face features. Exposure limits should be carefully developed to assure complete coating removal and no damage to the substrate material.
C-5A Structural Risk and Model Revalidation Program – Limited guidance was provided for chemical coatings removal on this teardown program. No information was provided regarding preferred or approved coating removal chemicals and no studies were performed on maximum exposure times. The lack of well controlled coating removal parameters, such as approved coating removal systems and maximum exposure times, may have resulted in damage to the substrate material due to improper chemical selection or over exposure or incomplete removal of coatings. On this program, incomplete coatings removal occurred resulting in a residual film over the surface of the part. The presence of the film significantly degraded the quality of the FPI method causing excessive fluorescent background which may mask cracks and regions of corrosion.

Based on the proposed process, extensive coatings removal chemical studies are recommended. These studies should identify chemical systems that do not damage the substrate material or result in incomplete coatings removal for specified windows of exposure times. Parameters should also be developed to monitor the acidity of the system throughout the life of the chemical to assure no substrate damage as the chemical coatings systems age due to time or usage.

Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft – No coatings removal was performed on this program; therefore, no recommendations based on the proposed process can be made.

C/KC-135 Teardown and Analysis Program – Detailed studies were performed on multiple coatings removal systems to identify systems that do no damage the substrate material and completely remove the specific coatings system on the teardown article. Two systems were approved for use on this program. Maximum exposure times were set based on the results of
extensive exposure studies. Chemical tests were also identified to assess the breakdown of the chemical coatings system with time to determine when chemicals need to be replaced. No suggested improvements are recommended based on the proposed process.

Cost/Schedule/Man-power Assessment - Table 13 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the coating removal process for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>80</td>
<td>30</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>80</td>
<td>80</td>
<td>0</td>
<td>120</td>
</tr>
</tbody>
</table>

The assessment of the coatings removal planning and executing process costs resulted in the general aviation, C-5A, and the Boeing 727 teardown being estimated lower than the proposed process. While the dry media blasting and etching process was well developed, limited quality control steps were developed to minimize over exposure risk. On the C-5A program, no guidance was provided regarding coatings removal other than the fact that mechanical methods were not allowed.

Coating removal was not performed on the Boeing 727 teardown; therefore, no cost was assigned to this teardown program. Execution of the general aviation and C-5A teardown were estimated less expensive than the proposed process as quality control was not performed and no efforts were made to assess the degradation of the process with age/usage. The KC-135 teardown program was estimate more costly than the proposed process as more research was
performed to approve chemical systems and establish maximum exposure times. Also quality checks were established and efforts were made to assess the degradation of the coatings over time.

8.3.5 NDI

**Evaluation of Airworthiness for Small Airplanes** – Suspect regions were subjected to short dwell FPI and low magnification visual examination to identify and characterize cracks and regions of corrosion. Suspect regions were defined as all regions inspected using “emerging” NDI techniques prior to disassembly, visible damage identified during the visual inspections after disassembly, and all critical structural details. No detailed procedures were documented for the FPI or low magnification visual examination and no qualification requirements were provided for the microscopic examination. Documentation procedures for findings identified by either inspection process were detailed and all findings were documented in tabular and photographic format.

Improvements recommended based on the proposed process include, detailed procedures for all inspection requirements and qualification requirements for visual inspectors. Extensive amounts of teardown data are acquired during the NDI task. In order to assure repeatability and minimize scatter in this data, detailed processes and qualified personnel are required. Qualification of NDI personnel should be based on previous experience, general knowledge of NDI and aircraft, and hands-on competency tasks at the individual level since indication interpretation is performed independently by inspectors. It is also recommended that all NDI data, such as FPI photographs be captured and retained so interpretation of results can be independently verified if questionable.
**C-5A Structural Risk and Model Revalidation Program** – Inspection requirements were based on part criticality for this teardown program, which if performed correctly, is an excellent way to conserve and efficiently use limited inspection budget. Extensive efforts, similar to those prescribed by the proposed procedures, were expended to develop step-by-step detailed inspection procedures for CVI, FPI, ECSS, BHEC, and MPI. Detailed documentation requirements were also developed, which included recording all relevant indication parameters as well as photographing all indications.

The additional step of correlating arbitrary disassembly generated part numbers to OEM part numbers was performed by the OEM to make inspection data more easily applicable/comparable to the field data. As mentioned previously, the quality of the FPI process was significantly degraded due to the failure of the coatings removal process to completely remove all coatings. ECSS was used as a substitute inspection method on a limited number of parts. Besides an improved coating removal process, no recommendations are made for NDI based on the proposed process.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – Post-disassembly NDI on this program consisted of visually verifying crack indications obtained using other NDI methods using stereo microscopy. Each crack was thoroughly documented prior to failure analysis. Qualifications for personnel performing stereo microscopy to verify cracks are recommended based on the proposed process.

**C/KC-135 Teardown and Analysis Program** – Step-by-step, detailed procedures were developed for CVI, FPI, ECSS, BHEC, MPI, and ultrasonic thickness measurements. Detailed documentation requirements were also generated for all relevant indications. Indication parameters such as length, width, surface area, clock position, etc. were recorded. Overview and
damage photographs, as well as NDI interpretation photographs such as FPI and eddy current screen shots were captured for additional interpretation as required. No process changes are recommended based on the proposed process.

Cost/Schedule/Man-power Assessment - Table 14 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the NDI process for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

TABLE 14
COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR NDI

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>25</td>
<td>175</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>80</td>
<td>100</td>
<td>90</td>
<td>100</td>
</tr>
</tbody>
</table>

The cost assessment of the case studies shows the general aviation planning phase significantly lower than the proposed process since no detailed procedures were developed for the low magnification visual inspection or FPI. Also, no qualification requirements were developed for personnel performing visual inspection. The execution phase of the general aviation teardown was also lower as the documentation requirements were not as stringent as the proposed method. The C-5A planning cost was estimated significantly higher than the proposed method as the inspection requirements were based on part criticality and the arbitrary part numbers were correlated to OEM part number. No minimum qualifications for personnel performing stereo microscopy on the Boeing 727 teardown resulted in a cost estimate below the proposed method.
8.3.6 Prioritization of NDI Indications

Evaluation of Airworthiness for Small Airplanes – No formal process for prioritization of NDI indications was developed; therefore, the process could not be analyzed. It is recommended that prioritization schemes be thoroughly documented.

C-5A Structural Risk and Model Revalidation Program – No formal process for prioritization of NDI indications was provided on this program; therefore, the process could not be analyzed. It is recommended that any prioritization schemes be documented and shared with the rest of the teardown data/results.

Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft – No formal process for prioritization of NDI indications was provided on this program; therefore, the process could not be analyzed. It is recommended that any prioritization schemes be documented and shared with the rest of the teardown data/results.

C/KC-135 Teardown and Analysis Program - No formal process for prioritization of NDI indications was provided on this program; therefore, the process could not be analyzed. It is recommended that any prioritization schemes be documented and shared with the rest of the teardown data/results.

Cost/Schedule/Man-power Assessment – Since no prioritization schemes were made available for assessment, no cost assessment could be performed for this activity.

8.3.7 Failure Analysis

Evaluation of Airworthiness for Small Airplanes – Failure analysis on this program consisted of documenting origin location and failure mode of select cracks with SEM photographs providing fracture face features to support the failure mode determination. Corrosion was categorized by type with photographs supporting the characterization. “Best
practices” are assumed to be the method used. Based on the proposed process, detailed processes are recommended to assure appropriate techniques are used to obtain all failure analysis data without destroying or degrading data. Stringent, individual qualifications are recommended to assure appropriate conclusions regarding failure are determined from the obtained data.

**C-5A Structural Risk and Model Revalidation Program** – Standard practices supplemented by detailed technical information and additional reference standards/procedures were used on this teardown program. Individual qualifications for failure analysis personnel were developed based on formal education and previous demonstrated proficiency. Detailed documentation requirements were also provided. No improvements are recommended based on the proposed process.

**Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft** – Detailed procedures for failure analysis tasks, including documentation, were developed on this teardown program. Qualification standards for personnel are recommended to be developed based on the proposed process.

**C/KC-135 Teardown and Analysis Program** – Step-by-step procedures were developed for all failure analysis tasks, including documentation. Qualification standards were developed for personnel performing failure analysis based on formal education and past proficiency performing similar tasks. No process modifications are recommended based on the proposed process.

**Cost/Schedule/Man-power Assessment** - Table 15 provides a comparison of the estimated cost/schedule/man-power required to plan and execute the failure analysis process for each of the case studies and the proposed teardown process. The proposed process was assigned a value of
100 and all processes implemented in the case studies are evaluated compared to the proposed process.

TABLE 15
COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR FAILURE ANALYSIS

<table>
<thead>
<tr>
<th>Teardown Phase</th>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Execution</td>
<td>100</td>
<td>25</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

The cost assessment of the general aviation teardown was significantly lower than the other case studies and proposed process. The planning portion was significantly lower due to the use of standard practices with no additional guidance and no qualification requirements developed for personnel. The execution cost was estimated lower as the only information provided on each failure analysis was origin and failure mode/corrosion type. This is significantly less information than obtained per failure analysis on any other case study or using the proposed process.

8.4 Establish Data Analysis Plan

Evaluation of Airworthiness for Small Airplanes – No formal data analysis plan was developed or documented as part of this teardown program. It is recommended that a formal analysis plan be generated prior to the start of teardown tasks.

C-5A Structural Risk and Model Revalidation Program – No formal data analysis plan was publicized as part of this teardown program. All data was planned to be reviewed by the OEM and USAF. It is recommended that a formal analysis plan be generated prior to the start of teardown tasks.

Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft – A detailed formal data plan was provided for this teardown program that outlined exactly how the data
would be used to meet the goals and objectives of the program. Based on the proposed process, no changes to the process implemented are recommended.

C/KC-135 Teardown and Analysis Program - No formal data analysis plan was developed or documented as part of this teardown program prior to program execution. It is recommended that a formal analysis plan be generated prior to the start of teardown tasks.

Cost/Schedule/Man-power Assessment - Table 16 provides a comparison of the estimated cost/schedule/man-power required to establish the data analysis plan for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.

| TABLE 16 |
| COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR ESTABLISHING A DATA ANALYSIS PLAN |

<table>
<thead>
<tr>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

No assessment of cost was made on the general aviation, C-5A, or KC-135 teardown programs as no data analysis plan was available for review.

8.5 Execute Established Procedures

Evaluation of Airworthiness for Small Airplanes – No formal effort was made during the program execution to mitigate scatter in the resulting teardown data. Quality assurance programs were not developed and audits were not conducted. The FAA reviewed the participating personnel’s data periodically and provided feedback on the findings, but not the procedures used to obtain the findings. Both qualification standards and audits are recommended based on the proposed process to reduce scatter in the teardown data.
C-5A Structural Risk and Model Revalidation Program – This program was one of the first teardown programs to qualify facilities to perform teardown tasks and audit the results to assure the desired data fidelity was obtained using the developed processes and qualified personnel. Many of the qualification requirements consisted of demonstrated previous performance. All qualifications were maintained at the facility level, not the individual level. Qualifications in NDI and failure analysis are recommended to be on the individual level, instead of the facility level, due to the independent interpretation of data required by these tasks. On-site competency testing on specific tasks is also recommended, particularly for NDI.

Destructive Evaluation and Extended Fatigue Testing of Retired Aircraft – No information regarding personnel qualification, audits, or other data scatter reduction techniques were implemented on this program. All of the above data scatter techniques are recommended based on the proposed process.

C/KC-135 Teardown and Analysis Program – Individual and site level qualifications, audits of processes and the resulting data, and quality control programs were all implemented on this teardown program in an effort to minimize scatter in the teardown data. If common discrepancies or problems with the data or quality of the product from the teardown task were identified corrective action, frequently, additional training, was required by the participating facility to maintain program qualifications. No process changes are recommended based on the proposed process.

Cost/Schedule/Man-power Assessment - Table 17 provides a comparison of the estimated cost/schedule/man-power required to execute established procedures for each of the case studies and the proposed teardown process. The proposed process was assigned a value of 100 and all processes implemented in the case studies are evaluated compared to the proposed process.
TABLE 17
COST/SCHEDULE/MAN-POWER REQUIREMENTS FOR EXECUTION OF THE ESTABLISHED PROCEDURES

<table>
<thead>
<tr>
<th>Proposed Process</th>
<th>General Aviation</th>
<th>C-5A</th>
<th>Boeing 727</th>
<th>KC-135</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>5</td>
<td>80</td>
<td>0</td>
<td>120</td>
</tr>
</tbody>
</table>

Little to no effort in error mitigation through qualification requirements, audits and quality control programs was expended on the general aviation and Boeing 727 teardowns, which is the reason the cost estimates for these programs are significantly lower than the proposed process. Qualification and audits were implemented on the C-5A program, but only at the facility level for all teardown tasks. The KC-135 teardown program implemented all of the scatter reduction techniques discussed in the proposed plan and performed the audits more frequently than recommended; therefore, it was assessed at a higher cost than the proposed process.
CHAPTER 9

CONCLUSIONS

The lack of a defined teardown planning process has resulted in a number of repeatable pitfalls that have resulted in increased teardown cost, increased schedule and capacity requirements, and degradation in fidelity or destruction of valuable teardown data. The recurrence of these problems could be drastically reduced or even eliminated if a universally accepted structural teardown process was adopted that provided recommendations based on lessons learned from previous teardown programs. Structural teardown is a technical data collection process; therefore, a defined, repeatable process is desired to minimize errors and scatter in the resulting data set.

This research provides a step-by-step process for planning and executing a structural teardown program with the goal of minimizing or eliminating problems encountered during past teardown programs. The developed process defines four steps required to plan and three steps required to execute a structural teardown. Each of the developed seven steps provides specific recommendations to avoid common pitfalls of previous teardown programs. Four case studies of previous and ongoing teardowns were discussed and the methods implemented compared to the proposed teardown planning and execution process to assess potential improvements when using the proposed method. Cost/schedule/man-power requirements of each of the case studies and the proposed process were estimated to assess the economical impact versus the technical benefit of implementing the proposed process.

The developed teardown planning process addresses every step of a structural teardown and provides managers/engineers with a step-by-step, repeatable solution to harvest required engineering data to support fleet management activities for any type of aging aircraft platform.
The developed process allows persons not familiar with structural teardown to navigate the planning and execution process, steering them away from program pitfalls common to many recent teardown programs. The proposed process provides a scientific data collection method to assure teardown data is captured in a repeatable way with effort made to reduce error and scatter in the resulting data set.
REFERENCES
REFERENCES


REFERENCES (continued)


REFERENCES (continued)


[30] ASNT, “Recommended Practice No. SNT-TC-1A”


REFERENCES (continued)


