AIR FORCE STRUCTURES

Structures Bulletin

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Number: EZ-SB-16-001

Date: 3 February 2016

Subject: Aircraft Structure Service Life Extension Program (SLEP) Planning, Development, and Implementation

References:

1. AFI 62-601, "USAF Airworthiness", 11 June 2010
2. Department of Defense Standard Practice, MIL-STD-1530C, "Aircraft Structural Integrity Program", 1 November 2005
3. EN-SB-09-001, "Methodology for Determination of Equivalent Flight Hours and Approaches to Communicate Usage Severity", 15 June 2009
4. EN-SB-11-001, "Guidance on Correlating Finite Element Models to Measurements from Structural Ground Tests", 24 June 2011
5. EZ-SB-15-001, "Aircraft Structure Teardown Inspection and Evaluation Program Protocols", 30 January 2015
6. EZ-SB-13-002, "Correlating Durability Analysis to Unanticipated Fatigue Cracks in Metallic Structure", 26 February 2013
7. EZ-SB-14-003, "Durability Test Programs to Validate Aircraft Structure Service Life Capability for Repairs, Modifications, and Materials & Processes Changes, 9 April 2014
8. JSSG-2006, "Joint Service Specification Guide Aircraft Structures", 30 October 1998

Background:

Reference 1 states that each aircraft type design shall have a service life limit (SLL) established, approved and documented in the Military Type Certificate (MTC) and that the SLL shall be included in the Military Certificate of Airworthiness (MCA) issued for each individual aircraft within a type design. The efforts required to increase the SLL are typically referred to as a SLEP and Reference 1 states that SLEPs shall be considered reportable modifications for purposes of airworthiness certification. The SLL documented in the MTC and MCA has been simplified to certified service life (CSL) for use throughout this document.

Discussion:
Many factors must be considered when establishing a SLEP requirement. As a minimum, a SLEP requires engineering investigation to:

1. Determine the scope and feasibility; to include structures, mechanical systems, propulsion, avionics, wiring, etc.
2. Establish the foundation for modifying the airworthiness certification.
3. Execute the methods of compliance for each applicable airworthiness criterion.

For aircraft structures, Reference 2 states that the SLEP effort should consider all Aircraft Structural Integrity Program (ASIP) tasks and elements and may require an additional full-scale static and/or durability test. The minimum requirement for SLEP evaluation is to conduct a comprehensive durability and damage tolerance analysis (DADTA) and corrosion assessment that accounts for the desired CSL increase.

To validate the DADTA, there are many factors that must be considered to determine if durability testing at any level (coupon, element subcomponent, component, and full-scale), flight testing and/or teardown inspections of high-time aircraft are necessary. The factors include:

1. Percent service life increase in terms of flights, flight hours and years in service.
2. Projected aircraft equivalent flight hours (EFH) per Reference 3 at desired CSL increase compared to most recent full-scale durability test (FSDT).
3. Damage discoveries in service compared to analysis and test predictions.
4. Others that are explained in further detail below.

The DADTA and testing results may establish the requirement for fleet-wide aircraft changes such as repairs, modifications, part replacements, and/or component replacements to extend the CSL. The aircraft changes require additional engineering activities as well as all other disciplines becoming involved in change development, verification, manufacturing, implementation and sustainment. In addition, aircraft changes (other than aircraft structure) may be necessary to ensure the aircraft is suitable and effective throughout the SLEP period.

Some possible SLEP scenarios include:

1. DADTA and corrosion assessment demonstrates that the CSL can be increased without the need to implement aircraft changes and it is concluded that testing is not required to validate the DADTA.
2. DADTA and/or corrosion assessment demonstrates that aircraft changes are required to increase the CSL and it is concluded that testing is not required to validate the DADTA or design changes.
3. FSDT is required to evaluate CSL increase potential and demonstrates that aircraft changes are required to increase the CSL and it is concluded that additional testing is not required to validate the DADTA or design changes.
4. FSDT is required to evaluate CSL increase potential and demonstrates that aircraft changes are required to increase the CSL and it is concluded that additional testing is also required to validate the DADTA and/or design and associated manufacturing changes.

Therefore, SLEP planning and development may involve several phases spanning many years. Example tasks are described below and typical timelines associated with some of the SLEP scenarios described above are shown in the figures that follow:

1. Generate a baseline operational loads/environment spectrum update to include any planned future mission or usage changes.
2. Perform a corrosion assessment update and a comprehensive DADTA update, to include revised FEM development and validation per Reference 4, to identify additional critical locations.
3. Develop initial design changes based on what is already known from updated DADTA, service experience, and past durability testing with supporting DADTA, static strength analysis, etc.
4. Perform FSDT planning which includes: test article selection and acquisition, installation of instrumentation, development of test loads spectrum, verification of test loads spectrum, procurement of load control & data acquisition system, design and production of test fixture to include load application system, installation of test loading system and system checkouts.
5. Conduct FSDT cycling and periodic inspections, collect and correlate strain gage and deflection data, obtain crack growth data when practical, and install repairs representative of fleet dispositions wherever practical, etc. as needed.
6. Conduct FSDT residual strength tests and perform teardown inspection and evaluation per Reference 5 which includes: disassembly, visual inspections of all structure, NDI of all safety-of-flight structure and other locations based on analyses, fleet history, etc., and failure analyses.
7. Perform DADTA correlations with FSDT results per Reference 6 to include development of Equivalent Initial Flaw Size (EIFS) values for all cracks discovered to support risk analyses.
8. Develop additional design changes based on test & updated DADTA results with supporting DADTA, static strength analysis, etc. Consider combining discrete design changes into larger integrated design changes when beneficial.
9. Perform ground tests of SLEP designs as necessary to validate the analyses such as static testing, durability testing (considering Reference 7), damage tolerance testing, ground vibration testing, etc.
10. Perform flight tests of SLEP designs as necessary to validate the analyses such as flight loads, ground loads, flutter, etc.
11. Iterate SLEP designs as required based on ground and/or flight tests of the design changes, if conducted.
12. Complete all change development tasks necessary to implement the design changes to include: acquisition strategy, installation strategy, tooling (development, acquisition, manufacturing, sustainment, etc.), manufacturing instructions (planning, work control documents, technical orders, etc.), kits (development, acquisition, manufacturing, etc.) consumables, kit prototyping, kit proofing, installation training and spares provisioning.
13. Update ASIP Master Plan, Force Structural Maintenance Plan (FSMP), etc.
14. Obtain MTC for the SLEP design.
15. Implement the changes and increase the SLL documented in the MCA for each aircraft when completed.

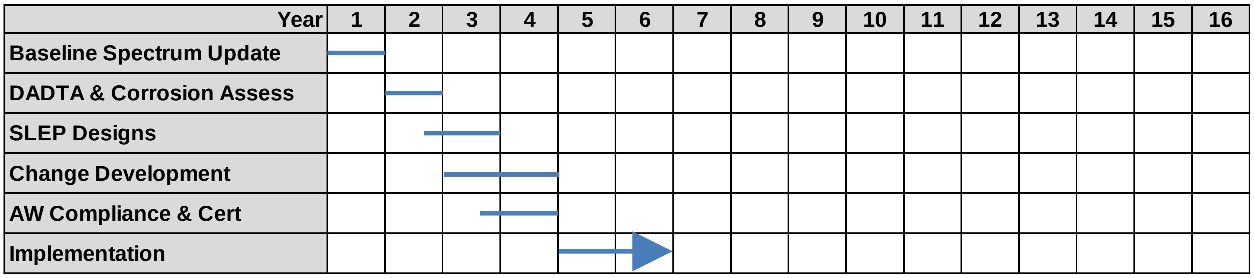

Figure 1. SLEP Scenario 2

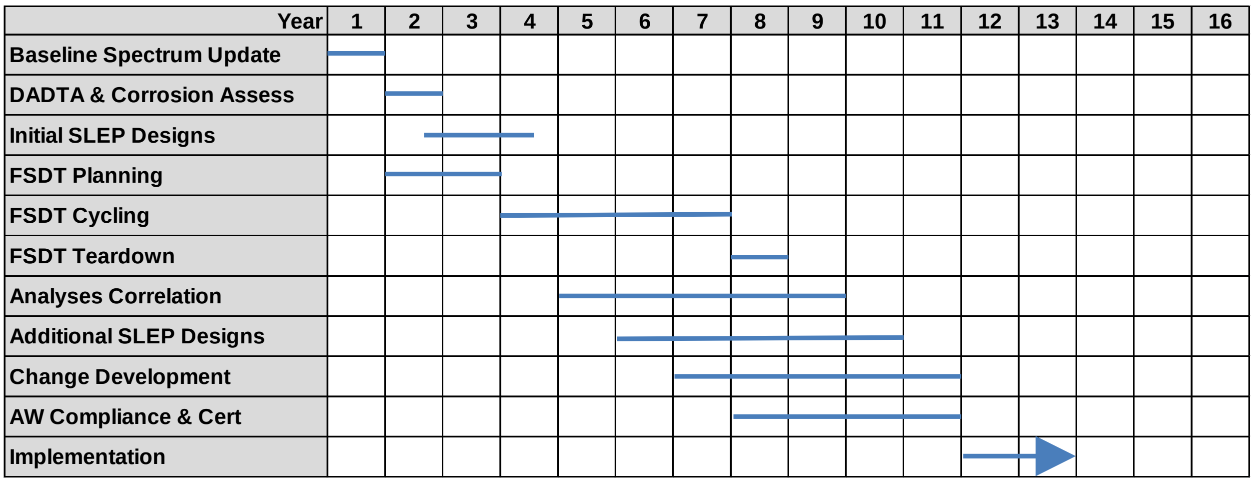

Figure 2. SLEP Scenario 3

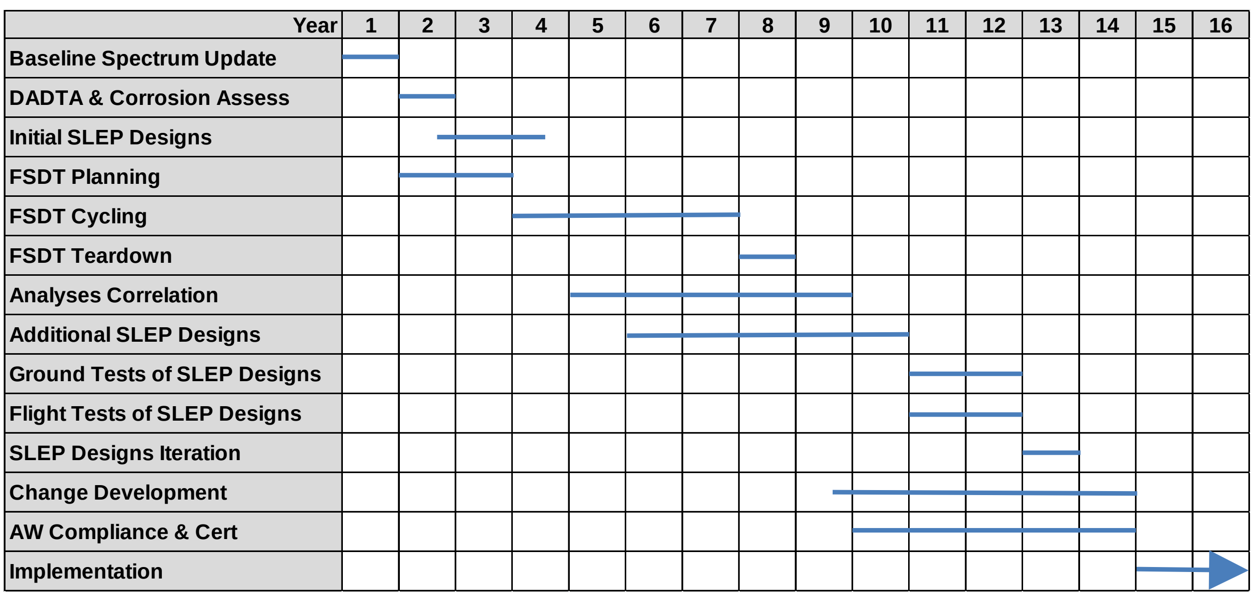

Figure 3. SLEP Scenario 4

One of the most significant challenges associated with a SLEP is determining whether or not a FSDT is required to validate the DADTA and to demonstrate the durability life for the extended service life. A FSDT can add 5 to 7 years or more to the schedule and cost $50M or more to execute, so this is not a trivial decision. In addition, unanticipated failures in the FSDT can lead to further cost and schedule increases. However, not performing the FSDT could lead to unanticipated safety issues as well as adverse economic and mission critical impacts. The following are the initial questions to determine the overall scope of the SLEP that should be asked and answered by those involved in force structure planning:

1. What % increase in flights and flight hours (fatigue consideration)?
2. What % increase in years (corrosion consideration)?
3. Confidence level that further service life extensions will not be required?
4. Are there new mission types?
5. Are there new mission profiles?
6. Is there a new mission mix?
7. Is the new spectrum more/less severe than the baseline?
8. Are there any changes to the aircraft weight?
9. Are there new configurations (e.g., stores, payload)?
10. Are there planned modifications that may affect aircraft performance and therefore the aircraft loads/environment?
11. Does fleet history indicate a SLEP is required?

Once the overall scope of the SLEP is determined, the structures team must consider many factors to determine if FSDT is required; and if so, to convince the decision makers to provide the funds and schedule necessary to plan and execute the test. These factors include:

1. How well is aircraft usage on each aircraft known?
2. How stable is past usage for the fleet?
3. What is the IAT capture rate?
4. What is the L/ESS capture rate?
5. What is the projected EFH of each aircraft for the proposed service life extension compared to the current CSL?
6. What was the previous full-scale durability test experience (e.g., significant cracks found late in test that did not result in changes, testing limitations) and how does it compare to the current or planned aircraft configurations and usage?
7. Is damage found in service consistent with DADTA and test results?
8. What does the existing DADTA and corrosion assessment indicate for service life extension potential?
9. When does the onset of WFD occur?
10. What are the results of durability test and/or fleet teardown inspections?

There is no prescribed set of answers to the questions above that leads to a simple conclusion that a FSDT is required or not. The intent is that the questions be answered as fully as possible and that the structures team consisting of the ASIP Manager, other structures personnel in the SPO, and the ASIP Technical Advisor carefully evaluates the data to formulate a conclusion and recommendation.

A SLEP of an aircraft that utilizes composite structures poses additional challenges. Reference 8 contains specific guidance for composite structures from which requirements during a SLEP can be inferred. Some pertinent extracts from Reference 8 relative to aircraft service life follow:

> From Reference 8 paragraph A.3.11.1 (requirement guidance for durability), "It should be demonstrated that damage not readily visible on the surface will not result in subsequent degradation of the part, impair function, or require maintenance actions. Visible damage is defined as damage that is visible to the unaided eye from a distance of 5 feet (dent depths of 0.10 inch). … To accomplish this goal, the structure is to be divided into two types of regions. The first type is one where there is a relatively high likelihood of damage from maintenance or other sources. The second type of region is one where there is a relatively low probability of the structure being damaged in service. The specific requirements for these two areas are given in table VII. There are two other threats to the structure that may cause an economic burden. These threats are hail damage to the aircraft when parked and runway debris damage to the aircraft from ground operations. … The details of the hail and runway debris requirements are shown in table VIII. The structure should be designed such that the above sources will not incur damage of sufficient magnitude to require inspection or repair throughout two times of design service life usage at the critical environmental condition. The loading spectrum and environmental conditioning for the testing associated with the table VII and table VIII requirements will be the same as that described for the durability tests."

TABLE VII. Low Energy Impact (Tool Impact)

Zone	Damage Source	Damage Level	Requirements in addition to Paragraph 3.11.1
1 High Probability of Impact	* 0.5 in. dia. solid impactor * low velocity * normal to surface	Impact energy smaller of 6 ft-lbs or visible damage (0.1 in. deep) with min. of 4 ft-lbs.	* no funcitional impairment or structural repair required for two design lifetimes and no water intrusion * no visible damage from a single 4 ft-lb impact
2 Low Probability of Impact	Same as Zone 1	Impact energy smaller of 6 ft-lbs or visible damage (0.1 in. deep)	* no functional impairment after two design lifetimes and no water intrusion after field repair if damage is visible

TABLE VIII. Low Energy Impact (Hail and Runway Debris)

Zone	Damage Source	Damage Level	Requirements in addition to Paragraph 3.11.1
All vertical and upward facing horizontal surfaces	Hail: * 0.8 in. dia. * sp. Gr. = 0.9 * 90 ft/sec * normal to horizontal surfaces * 45 deg. angle to vertical surfaces	Uniform density 0.8 in. on center	* no functional impairment or structural repair required for two design lifetimes * no visible damage
Structure in path of debris	Runway debris: * 0.5 in. dia. * sp. Gr. = 3.0 * velocity appropriate to system	N/A	* no functional impairment after two design lifetimes and no water intrusion after field repair if damage is visible

From Reference 8 paragraph A.4.11.1.2.1 (verification guidance for durability), “For durability test of composite components, the success criteria is somewhat more complicated by the relatively large scatter in fatigue test results and the potential of fatigue damage from large spectrum loads. It has been demonstrated, however, that the durability performance of composites is generally excellent when the structure is adequate to meet its strength requirements. Therefore, the thrust of the durability test must be to locate detrimental stress concentration areas that were not found in the static tests. An approach to achieve this goal is to test the durability components to two lifetimes with a spectrum whose severity accommodates these concerns. When the effects are judged to be significant, durability tests for design development shall be moisture conditioned.”

From Reference 8 paragraph A.3.12.1 (flaw sizes for composite structures), “The design missions must be adequately defined such that the potentially damaging high load cases are properly represented. … safety of flight structure must be designed to meet other damage threats. These threats are those associated with manufacturing and inservice damage from adverse usage and battle damage. The initial flaw/damage assumptions are described in table IX for manufacturing initial flaws and in-service damage. The 100 ft-lb of energy required to cause a dent 0.10 inch deep may be reduced if the structure is not exposed to the external impact or maintenance damage threats and the part is thoroughly inspected before closing up. To qualify the structure under this reduced impact energy criteria, the proposed impact energy of _______ shall be approved by the procuring agency and the damage resulting from the impact which will grow to critical sizes in two lifetimes of spectrum loadings shall be detectable by industry standards or special demonstrated NDI techniques. The design development tests to demonstrate that the structure can tolerate these defects for its design life without in-service inspections shall utilize the unclipped upper bound spectrum loading and the environmental conditioning developed for the durability tests. These two lifetime tests must show with high confidence that the flawed structure meets the residual strength requirements in table X. These residual strength requirements are the same for the metallic structures except the Pxx is not limited to 1.2 times the maximum load in one lifetime. To obtain the desired high confidence in the composite components it is necessary to show that either the growth of the initial flaws arrests and is insignificant, or the damage/flaw will not grow to critical size in two design lifetimes by analysis and the analysis methods could be verified by component testing. As for the durability tests there shall be a program to assess the sensitivity to changes in the baseline design usage spectrum.”

TABLE IX. Initial Flaw/Damage Assumptions.

Flaw/Damage Type	Flaw/Damage Size
Scratches	Surface scratch 4.0" long and 0.02" deep
Delamination	Interply delamination equivalent to a 2.0" diameter circle with dimensions most critical to its location
Impact Damage	Damage from a 1.0" diameter hemispherical impactor with 100 ft-lbs of kinetic energy or with that kinetic energy required to cause a dent 0.10" deep, whichever is less.

In summary, verification of durability and damage tolerance requirements for composite structures is based on two lifetimes of testing, with explicit emphasis on including potentially damaging high load cases. The empirical data is required because validated analysis methods have not yet been developed to determine service life capability and to evaluate aircraft loads/environment differences. The challenge for a SLEP of an aircraft with composite structures is to determine what building-block durability and damage tolerance testing must be repeated and to translate existing and/or additional testing results into maintenance requirements that will ensure continued airworthiness.

Recommendations:
The need for an aircraft SLEP to increase the SLL in the MTC and MCA should be established far enough in advance to allow all of the necessary engineering activities to be sufficiently planned, funded and accomplished. The lead time required could range from 2 years to 14 years or more dependent on the extent of the planning, analysis, testing, design changes and certification activities required and the associated programmatic requirements and funding availability. All stakeholders involved in the decision making process on whether or not to extend the service life of an aircraft, and if so by how much, should carefully consider the potential engineering tasks and outcomes described above when planning for an aircraft SLEP.

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