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AIR VEHICLE INTEGRATION AND TECHNOLOGY RESEARCH (AVIATR)

Delivery Order 0003: Condition-Based Maintenance Plus Structural Integrity (CBM+SI) Demonstration (September 2008 to March 2008)

LeRoy Fitzwater, Y.T. "Tony" Torng, and Christopher Davis

The Boeing Company

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Interim Report

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AIR FORCE RESEARCH LABORATORY
AEROSPACE SYSTEMS DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

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*//Signature//
ERIC J. TUEGEL, Project Engineer
Structures Technology Branch
Aerospace Vehicles Division

//Signature//
MICHAEL J. SHEPARD, Acting Chief
Structures Technology Branch
Aerospace Vehicles Division

//Signature//
FRANK C. WITZEMAN
Acting Chief
Aerospace Vehicles Division
Aerospace Systems Directorate

*Disseminated copies will show “//Signature//” stamped or typed above the signature blocks.

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The Boeing Company
Engineering, Operations and Technology
Boeing Research and Technology
5301 Bolsa Avenue
Huntington Beach, CA 92647-2048

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14. ABSTRACT
This report summarizes recent progress made on the AVIATR contract Task Order 3, Condition Based Maintenance plus Structural Integrity – Basic Phase. The organization of the report follows the agreed to Work Breakdown Structure, and specifically documents the progress to date on the Strategy Development task (WBS 1.1.1).

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Table of Contents

List of Figures

List of Tables

Summary of March Bi-Annual Report

This report summarizes recent progress made on the AVIATR contract Task Order 3, Condition Based Maintenance plus Structural Integrity – Basic Phase. The organization of the report follows the agreed to Work Breakdown Structure, and specifically documents the progress to date on the Strategy Development task (WBS 1.1.1) which contains the following key sub-sections:

1.1.1 Strategy
- 1.1.1.1 Requirements
- 1.1.1.2 Architecture Prototype
- 1.1.1.3 Data Flow
- 1.1.1.4 Beta Testing

The content of this document follows the Work Breakdown Structure to report progress on this project to date. Most of the effort has been focused on sub-section Requirements (1.1.1.1). The other sub-sections (1.1.1.2 and 1.1.1.3 and 1.1.1.4) will include a brief summary of the task objective and plan for each of the remaining tasks.

In the Requirements sub-section (1.1.1.1), the goals, objectives, and business needs for ASIP, CBM+, and CBM+SI have been identified and illustrated. To demonstrate the CBM+SI benefit on the selected structural component, several key CBM+SI technologies have been identified and the associated requirements definition is in work. At present, the SHM requirements have received the most attention and a draft requirements document is provided for review in Appendix D. The technology requirements for all the identified technologies will be drafted and continuously updated as the project continues.

In addition to the above mentioned progress, a special effort has been made to conduct a detailed data comparison of the two F-15 structural components, frame station 626 Bulkhead and Intermediate Wing Spar, using three key criteria, listed below, to down-select the structural component. The objective is to select the component which will engender the most comprehensive business case analysis.

- *What are the data requirements for the Technical Performance Measurement (TPM) analysis?* TPMs will be used to develop a comprehensive CBM+SI strategy. A report on TPM data requirements has been completed and shown in Appendix A.
- *Can the F-15 program provide all the necessary data for TPM analysis for the two structural components under consideration?* A detailed report on the assessment of data availability is included in Appendix B. A majority of this effort has been completed; however, there are a few data categories which are outstanding. We are working with Warner-Robins to collect information on the availability of mission profile, maintenance, equipment and labor costs data. We expect to have the final information/data availability assessments completed by the end of April.
- *Are both components suitable to apply currently available advanced SHM technology?* The application of SHM technology will be necessary to demonstrate a compelling benefit of CBM+SI; therefore, it is critical to determine which SHM technologies will be

suitable for each of the two structural components. A report on the suitability and capability of the currently available SHM technology for the two F-15 structural components has been completed and included in Appendix C.

From the above three criteria, one structural component will be selected after data availability issue has been resolved by the F-15 program. We anticipate making the final component selection by the end of April. In the subsequent tasks of this project, the selected structural component will be evaluated using the developed CBM+SI architecture prototype and its associated reliability and risk assessment strategy to perform a feasibility study with several maintenance approach options. The most cost effective maintenance option will finally be selected.

The Strategy Development phase is planned to be completed at the end of September. We are on schedule to meet this date and start the Demonstration phase of the program the beginning of October. At the present time, there are no major issues to report. The project is expected to be completed on schedule and on budget.

1.1.1 Strategy

1.1.1.1 Requirements

The main objective of this task is to document the requirements for both CBM+ and ASIP related technologies based upon the selected candidate structure. Three major steps are used to achieve the main objective. At present, Step 1 for ASIP, and Step 2 for CBM+, have been studied and documented. Step 3 for CBM+SI has been initiated and the required technologies have been identified. A CBM+SI Continuous Process Improvement (CPI) process will be developed to continuously update the technology needs. It is anticipated that the majority of the requirements for these technologies will be understood and documented by the end of June, however, as the Strategy Development continues, new requirements may become apparent and they will be incorporated accordingly. To give visibility to this improvement process the current task will not be closed out until the Strategy Development is completed at the end of September. In addition, a special effort has been made to compare the two F-15 structural components, under consideration, using three key criteria (TPM data requirement, F-15 data availability, and SHM suitability). The results from this effort also supported this Requirements task by providing TPM data requirements and its relationship to TLCSM, the F-15 data availability, and its current CBM+ technology usage status, and SHM capability assessment for the selected structural component.

Step 1. Study and document SI (ASIP) technology requirements and needs, identify and leverage Boeing past experience in reliability and risk assessment to meet ASIP's needs

The team studied and found the following ASIP goals, objectives, and business needs [1, 2, 3] that will guide us in developing a CBM+SI strategy. How the team plans to incorporate these goals, objectives, and business needs will be discussed in Step 3, below.

ASIP Goals and Objectives

In Summary, the goal of ASIP is to ensure the desired level of structural safety, performance, durability, and supportability with the least possible economic burden throughout an aircraft's service life.

USAF ASIP Standard (MIL-STD-1530) Objectives:

- Define the structural integrity requirements associated with meeting Operational Safety, Suitability and Effectiveness (OSS&E) requirements
- Establish, evaluate, substantiate, and certify structural integrity
- Acquire, evaluate, and apply usage and maintenance data to ensure the continued structural integrity of operational aircraft
- Provide quantitative information for decisions on force structure planning, inspection and modification priorities, risk management, expected life cycle costs and related operational and support decisions
- Provide a basis to improve structural criteria and methods of design, evaluation, and substantiation for future aircraft systems and modifications

ASIP Business Needs

- The means to determine air vehicle risk and reliability for changes from legacy approaches during development such as:

    - Requirements/criteria tailoring
    - Limited analyses
    - Reduced verification testing
- Improved risk and reliability methods for sustainment related issues
    - Service life extension programs
    - Potential for missing damage during inspections
    - Unanticipated air vehicle damage
- ASIP community support to ensure structural safety record is at least preserved, if not improved, as USAF fleet continues to age

Boeing Past Experience In Reliability and Risk Assessment

The team studied several ASIP related projects (C-17, KC-135, and B-1) and identified several important reliability and risk assessment methodologies and tools that may be used as reference for this project. Three key tools have been developed for different purposes including: FEBREL (Finite Element Based RELiability) – a general purpose probabilistic analysis tool [4], RELDOT (RELiability Based Design Optimization Tool) – a reliability based design optimization tool [5], and Risk-Based Design and Maintenance System (RBDMS) – a risk assessment code for ASIP which estimates structural risk and is used to identify optimal maintenance schedules based on MIL-STD-1530C requirements [6, 7, 8]. These methodologies and tools will be applied to develop an advanced CBM+SI risk-based method to estimate the risk and to identify optimal maintenance options.

Step 2. Study and document CBM+ definition, identify CBM+ business needs, study and document CBM+ 10 enabling technologies and concepts

For this step, the team studied and found the following CBM+ definition, CBM+ business needs, and key CBM+ technologies/concepts [9-15] that will guide us in developing the best CBM+SI strategy. Much of the text below was incorporated as part of the proposal, however, it is presented again for completeness of the discussion. More specific details of CBM+ can be found in the cited references. Again, the planned approach to incorporate these goals, objectives, and business needs are with those of ASIP will be discussed in Step 3, below.

CBM+ Definition

Condition-Based Maintenance (CBM) can be defined as a set of maintenance processes and capabilities derived from real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measurements using portable equipment. The goal of CBM is to perform maintenance only upon evidence of need.

CBM+ expands on these basic concepts, encompassing other technologies, processes, and procedures that enable improved maintenance and logistics practices. These future and existing technologies, processes, and procedures will be addressed during the capabilities planning, acquisition, sustainment, and disposal of a weapon system.

CBM+ Business Needs

Recognizing several fundamental business needs will assist in guiding the transition to a CBM+ oriented business environment.

- Need to predict equipment failures
- Need for a holistic view of equipment condition

- Need for greater accuracy in failure prediction
- Need to reduce the cost of ownership
- Need to improve equipment and component reliability
- Need to reduce equipment mean down time (logistics responsiveness).
- Need to optimize equipment performance.

10 Key CBM+ Technologies and Concepts
The 10 enabling technologies and concepts identified below constitute an acceptable initial Air Force baseline for achieving the DoD vision for CBM+ implementation [10]. These technologies and concepts are:

Technologies
- Prognostics
- Diagnostics
- Portable Maintenance Aids
- Interactive Electronic Technical Manuals (IETMs)
- Interactive Training
- Data Analysis
- Integrated Information Systems
- Automatic Identification Technology

Concepts
- Reliability Centered Maintenance (RCM)
- Joint Total Asset Visibility

Step 3. Study and document CBM+SI goals and objectives, study and document CBM+SI business needs, study and document requirements for the CBM+SI technologies required to demonstrate the CBM+SI benefits on the selected structural component
For the CBM+SI goals and objective, the team first summarized key CBM+SI goals and objectives keeping in mind for CBM+SI approach to achieve level 4 of the U.S. Air Force CBM+SI pyramid. These goals and objectives will be used to guide the team in developing the most appropriate CBM+SI strategy. For the CBM+SI business needs, the team integrated both ASIP needs (Step 1) and CBM+ (Step 2) to form a general CBM+SI business needs. To satisfy both the goals and objectives and the business needs, the team identified the CBM+SI technologies required to demonstrate the benefit CBM+SI as applied to the selected structural component. The team has started to define and collect the requirements for these technologies, however, at present, only the SHM technology requirements have made significant progress, the remainder of the technology requirements will be studied and documented in the next report. Again, following our continuous improvement model, the majority of this effort will be completed in June but the task will not be closed out until the Strategy Development is completed at the end of September.

CBM+SI Goals and Objectives
The objective of the baseline task is to develop and demonstrate a CBM+SI strategy for at least one structural application on a USAF weapons platform. Again, most of the text below was a part of the proposal and is included here for completeness of the discussion. As part of this demonstration, the benefits to the Air Force as result of employing this CBM+SI strategy shall be determined in terms of:

- Total cost of ownership
- Aircraft availability rates
- Maintenance hours per flight hour

Develop and demonstrate CBM+SI Strategies for structural Applications on a USAF weapon platform to include:

- Developing integrated, predictive maintenance approaches, which minimize unscheduled repairs, eliminate unnecessary maintenance, and employ the most cost-effective maintenance health management approaches.
- Determining an optimum mix of maintenance technologies.
- Identifying the optimum opportunity to perform required maintenance.
- Providing real-time maintenance information and accurate technical data to technicians and logisticians.

In addition, the developed CBM+SI must be able to achieve the level 4 of the CBM+ pyramid as shown in the Figure below. It is important to recognize the requirement in order to identify required CBM+SI technologies to demonstrate this level of benefit on the selected structural component.

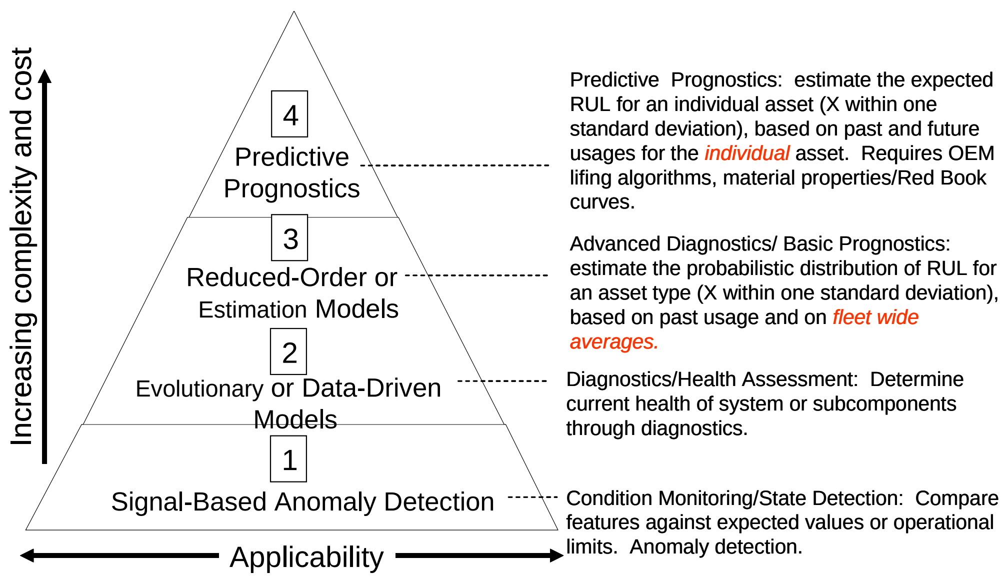

Figure 1. CBM+SI Pyramid chart

CBM+SI Business Needs

CBM+SI business needs are developed and summarized by considering and integrating both ASIP and CBM+ business needs as follows:

1. For the initial Basic Phase of this contract, the following CBM+SI business needs will be considered and demonstrated:
    a. ASIP side: Improved risk and reliability methods for sustainment related issues (service life extension programs, potential for missing damage during inspections, and unanticipated air vehicle damage). ASIP community support to ensure structural safety record is at least preserved, if not improved, as USAF fleet continues to age.

    b. CBM+ side: Need to predict equipment failures, need for a holistic view of equipment condition, need for greater accuracy in failure prediction, need to reduce the cost of ownership, need to improve equipment and component reliability, need to reduce equipment mean down time (logistics responsiveness), and need to optimize equipment performance.
2. For the option phase of this contract, only one business needs from the ASIP side remains to be addressed.
    a. The means to determine air vehicle risk and reliability for changes from legacy approaches during development.
    b. This business needs will be considered in only a very limited sense during the forward looking assessment step of the Demonstration task.

Identify Technology Needs to Meet CBM+SI Business Needs

To meet all of the business needs mentioned above, as well as the goals and objectives defined earlier, the team identified technologies that need to be incorporated into a comprehensive CBM+SI strategy. For the basic phase of this contract, the main objective is to provide a business case assessment of the application of the developed CBM+SI Strategy on the selected structural component. Therefore, for the Requirements development, we will focus on the technologies needed for the selected structural component.

1. ASIP risk assessment capability
    a. MIL-STD-1530C
    b. Additional requirements for risk assessment. For example, how do the requirements change in performing the risk assessment in the presence of SHM data?
2. Prognostic
    a. Structural Health Monitoring (SHm)
    b. ASIP risk assessment process
3. Diagnostic
    a. ASIP: Individual Aircraft Tracking, Loads/Environment Spectra Survey, Forced Structural Maintenance Plan
4. Information tool – Portable Maintenance Aid, Interactive Electronic Technical Manuals
5. Advanced NDI
6. Reliability Center Maintenance
7. TLCSM - TPM

Notice that CBM+ is a Continuous Process Improvement (CPI) strategy so is CBM+SI. Under CPI principle, it is envisioned that the elements of CBM+SI should be revisited as the life cycle progresses, conditions change, and technologies advance. The developed CBM+SI strategy includes fully developed technologies and processes that can be implemented now as well as yet-to-be developed capabilities. CBM+SI also use proof-of-concept and prototype activities that can be applied incrementally, not waiting for a single solution package. To maintain consistency, CBM+SI development should be based on a broad architecture and an enterprise framework that is open to modification and can be easily adjusted.

In order to develop a CBM+SI strategy which meets the defined business needs for the selected historical ASIP application, the team will be considering the basic steps outlined below, which is taken from the CBM+ guidebook [11]:

1. Understand that CBM+SI is a continuous improvement initiative over the life cycle of a weapon system or equipment.
2. Ensure full understanding of the planning, implementation and operations phases of CBM+SI by the implementation team, functional managers, stakeholders and customers.
3. Initiate the CBM+SI planning phase and complete the processes needed to develop the CBM+SI strategy and to begin the selection of applicable technologies.
4. Build on planning phase actions by managing the implementation phase as a time-phased execution of process changes, technology insertion, organizational realignments, and equipment changes.
    a. Although, this step here is more closely related to the option phase of this task order program, it may be briefly addressed in the forward looking step of the Demonstration task.
5. In the operations phase, incrementally deploy CBM+SI capabilities to operational user locations and continue through full execution of required CBM+SI capabilities.
6. Continuously assess CBM+SI progress and overcome barriers to successful execution as they occur.
7. Discontinue or modify CBM+SI capabilities for specific weapon systems and equipment as requirements evolve with the cessation of use or replacement of those capabilities.

The above CBM+SI CPI process will be defined in more detail and completed in June and will be used to continuously improve the developed CBM+SI strategy with needed technologies.

CBM+SI Requirements for the Selected Structural Component
For the selected structural component, by applying developed CBM+SI planning phase process, it is envisioned that the key technologies, referenced above, must be applied in order to achieve the CBM+SI goals & objectives, and demonstrate a benefit.

The requirements for these identified key technologies will be documented. Initial work has focused on SHM technology requirements. A detailed requirements document is in work and a draft of the document is included as Appendix D. The document is evolving as we learn more about the requirements. The first release will be at the conclusion of Strategy Development of this program. Included below is a list of topics covered in the document.

Section	Topic
1.0	Introduction
2.0	Scope
3.0	Safety
4.0	System Function and Performance
5.0	Interfaces
6.0	Design Life
7.0	Reliability
8.0	Mass
9.0	Electromagnetic Effects
10.0	Repairability
11.0	Redundancy and Fault Tolerance
12.0	Degradation of Structural Capability
13.0	Contamination by Fluids
14.0	Allowable Damage Limits
15.0	Inspection Requirements
16.0	Integration with Airplane Systems
17.0	Data Bus Requirements
18.0	Portable Maintenance Aids
19.0	Open System Architecture
20.0	Ease of Use
21.0	Energy Sources
22.0	System Power Requirements
23.0	Testing
24.0	Ground (Off-Board) Systems
25.0	Workmanship
26.0	Interchangeability
27.0	Labeling and Marking
28.0	Information Control Requirements
29.0	Security
30.0	Document Maintenance

Table 1. Outline of Draft SHm Requirements Document

Additional effort for the Requirements task is required and the majority of this work will be completed by the end of June but will be updated as necessary through the end of the Strategy Development in September.

Additional Requirement Task: Down-Select the F-15 Structural Components
In order to compare the two F-15 structural components, the team developed three key criteria (TPM data requirement, F-15 data availability, and SHM suitability) to down-select the structural component that will be able to demonstrate the most benefits by using the developed CBM+SI strategy. The results from this effort also supported this requirements task by providing TPM data requirements and its relationship to TLCSM, the F-15 data availability and its current CBM+ technology usage status, and SHM capability assessment for the selected structural component. These three key criteria are shown as follows,

- *What are the data requirements for the Technical Performance Measurement (TPM) analysis?* TPMs will be used to develop a comprehensive CBM+SI strategy. A report on TPM data requirements has been completed and shown in Appendix A.
- *Can the F-15 program provide all the necessary data for TPM analysis for the two structural components under consideration?* A detailed report on the assessment of data availability is included in Appendix B. A majority of this effort has been completed; however, there are a few data categories which are outstanding. We are working with Warner-Robins to collect information on the availability of mission profile, maintenance, equipment, and labor costs data. We expect to have the final information/data availability assessments completed by the end of April.
- *Are both components suitable to apply currently available advanced SHM technology?* The application of SHM technology will be necessary to demonstrate a compelling benefit of CBM+SI; therefore, it is critical to determine which SHM technologies will be suitable for the each of the two structural components. A report on the suitability and capability of the currently available SHM technology on the two F-15 structural components has been completed and included in Appendix C.

From the above three criteria, one structural component will be selected, after data availability issue has been resolved by the F-15 program. It is anticipated that this issue will be resolved and a final selection between the two components will be made by the end of April. In the subsequent tasks of this project, the selected structural component will be evaluated using the developed CBM+SI architecture prototype and its associated reliability and risk assessment strategy to perform a feasibility study with several maintenance approach options The most cost effective maintenance option will finally be selected.

1.1.1.2 Architecture Prototype

The main objective of this task is to develop an integrated, predictive maintenance CBM+SI architecture prototype for an identified F-15 platform structural component. Four major steps are required to achieve this objective. The team has started an initial study of ASIP and CBM+ engineering analysis processes (Steps 1 and 2) but there is no significant progress to report at this time. Development on this task will commence after the CBM+SI key technologies are identified in the Requirements (1.1.1.1) task. In is anticipated that the majority of this work will be completed before the end of June but will be updated as necessary and completed at the end of September.

Step 1. Evaluate Current ASIP Engineering Analysis Process

Planned effort: Study and document the current ASIP engineering analysis process with special attention to any established risk assessment process.

This Step is anticipated to be completed before the end of April.

Step 2. Evaluate Analysis Process for the CBM+ 10 Enabling Technologies and Concepts

Planned effort: Study and document the CBM+ analysis process especially the 10 most important technologies and concepts. Compare with ASIP engineering process and identify similarity and difference for developing of a CBM+SI engineering analysis process especially the risk assessment data requirements.

This Step is anticipated to be completed before the end of April.

Step 3. Develop a Preliminary CBM+SI Architecture Prototype for the selected demonstration example

Planned efforts: Develop a preliminary Architecture Prototype for the selected demonstration example based on identified ASIP and CBM+ analysis processes from Steps 1 and 2. Identify technologies required to implement the Architecture Prototype.

This Step is anticipated to be completed before the end of June and may be updated as necessary through the end of the Strategy Development to be completed in September.

Step 4. Develop a Compliance Matrix for the Proposed CBM+SI Architecture and finalize CBM+SI Architecture Prototype

Planned effort: With the developed CBM+SI Architecture Prototype from Step 3, developed a compliance matrix to check if all the key CBM+SI elements have been considered and included: integrated individual tracking data with IVHM/SHM data, diagnostic and prognostic capabilities, enhanced maintenance quality, information tools, and Total Life Cycle Systems Management (TLCSM).

This Step is anticipated to be completed by the end of June and may be updated as necessary through the end of the Strategy Development task to be completed in September.

1.1.1.3 Data Flow

The main objective of this task is to define the data flow of the developed architecture prototype. All the data shall be collected and stored within the historical database for further decision making cycles and future designs. To implement the task, ASIP reliability and risk assessment data flow and data requirement will be studied first and used as a reference for CBM+SI reliability and risk assessment data flow.

At present, this task has not initiated and will start in July and be completed in September.

Step 1. Study current ASIP reliability and risk assessment data flow and its data requirements

Planned effort: Study current ASIP reliability and risk assessment process used to determine the maintenance schedule based on the MIL-STD-1530C. Study and define the data flow for he risk computational strategy based on IAT, Load Spectrum data, material data, NDE POD, EIFS, etc.

This Step will start in July and be completed in September.

Step 2. Define CBM+SI data flow for reliability and risk assessment

Planned effort: Study and define the CBM+SI data flow for reliability and risk assessment based on the ASIP's data flow (from Step 1) with consideration of SHM data impact, advanced NDI data impact, information tools (AIT, PMA, IETM) data impact, and data requirement for TLCSM. From the above, define an updated risk computation strategy with consideration of additional SHM sensor data, advanced NDI, information tools, and others.

This Step will start in July and be completed in September.

1.1.1.4 Beta Testing

The main objective of this task is to develop a beta testing plan based on the developed CBM+SI architecture prototype to demonstrate CBM+SI benefits on the selected structural component. From the down-select process, feasibility of CBM+SI process has already been studied and shall be implemented accordingly based on the developed CBM+SI architecture prototype. In addition, technology shortcomings and gaps needed for a successful demonstration will be identified. Two steps are developed to meet the objective.

At present, this task has not been initiated yet and will start in July and be completed in September.

Step 1. Based on the selected structural component, apply the proposed CBM+SI architecture prototype and its reliability and risk assessment strategy to perform a feasibility study for several maintenance options and select the most cost effective maintenance optimization.

Planned efforts: Perform a feasibility study by considering the following maintenance options:

- Baseline (deterministic)
- Baseline (risk based)
- SHM on board or off-board data extraction
- SHM with advanced NDI checkup or not?
- SHM with advanced NDI and additional IETM/IFM development

This Step will start in July and be completed in September.

Step 2. From step 1 results, identify CBM+SI technology shortcomings and gaps needed to be resolved for a successful CBM+SI technology demonstration.

Planned efforts: Based on the results from the feasibility study in Step 1, identify technology shortcoming or gaps that are needed to perform a successful CBM+SIU technology demonstration. Some technology gaps identified:

- Robust embedded sensors (SHM)
- High fidelity data reasoners (SHM)
- SHM real-time data acquisition and fusion techniques
- Risk assessment with SHM data, PMA data, Advanced NDE POD data
- TLCSM data accuracy and source (Availability, Cost, and Maintenance Hours per Flight Hour)

Additional efforts required and will be initiated in July and completed in September.

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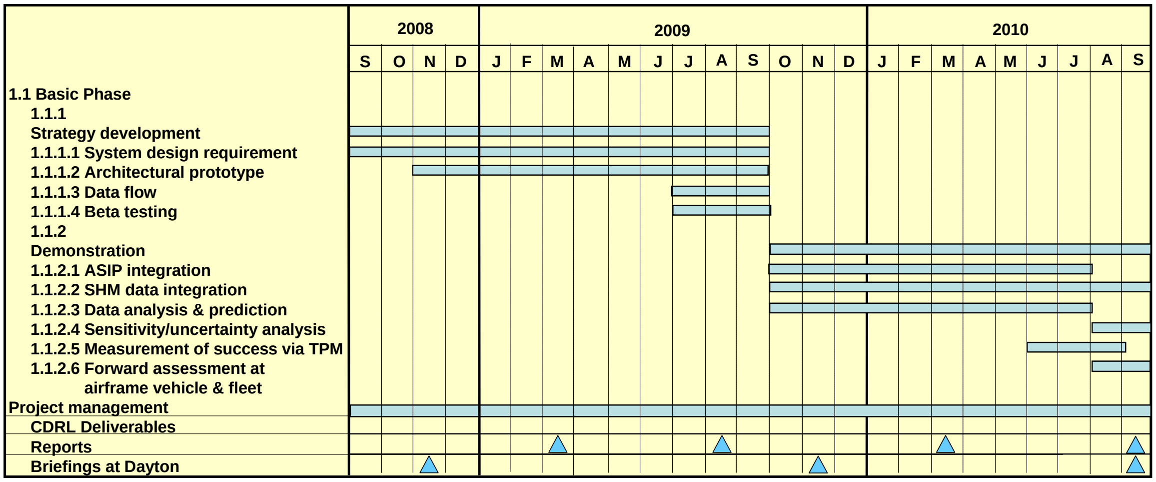
15. DOD GUIDE FOR ACHIEVING RELIABILITY, AVAILABILITY, AND MAINTAINABILITYRAM GUIDE, "Systems Engineering for Mission Success", 08/03/05

Schedule



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APPENDIX A. Data Requirements for TPM Analysis

The main objective of this Appendix is to define the Technical Performance Measurements (TPMs) and the required data sets for evaluations between the baseline and CBM+SI-implemented configurations. In addition, the relationship between TPM and Total Life Cycle Systems Management (TLCSM) is also discussed. Note that the required data sets will then be used by the F-15 program to investigate if all the required data sets are available for the two competitive structural components (see Appendix B).

A.1 Define All the Data Required For CBM+SI

The three TPMs required for assessment are:

- Fleet Availability or Aircraft Availability Rate: This describes the readiness of the fleet by a percentage considered available for missions and not in any maintenance.
- Total Cost of Ownership: This is the total cost to own and maintain the platforms and weapons systems from cradle to grave. For the CBM+SI evaluation, the period will cover from first year of research and development to the last use of the fleet. Other ways to express this TPM include Return on Investment, Net Present Value, and Cash Flow.
- Maintenance Hours per Flight Hour: This is the average maintenance labor hours per flight hour. Another way to view the use of resources during operation is Resource Utilization.

The TPMs for the baseline, or current configuration of the platforms, will be compared with the TPMs for the platforms with CBM+SI configurations.

Required data for the assessment include historic reliability and maintainability (R&M) data on the F-15, especially on the intermediate wing spar and the FS 626 Lower Bulkhead. To understand the impact of these two structures, all 2-digit work unit code (WUC) data for the platform and the 5-digit WUC data for the structures are required. The R&M data should cover inherent failures, induced failures, no defect actions, cannot duplicates (CNDs), retest OKs (RTOKs), removals, labor hours for each action, and number of aborts. To understand the historic use of the F-15, other data needed are the number of missions and sorties, their durations, the fleet size, and accumulated flight hours at fleet and platform levels.

For costs, the required data are labor cost per maintenance hour, cost per repair type (unscheduled and scheduled), additional costs per operating year, cost per removal and replacement, and costs for different maintenance categories (organizational level: O-level, intermediate level: I-level, or depot level: D-level). When the CBM+SI alternatives are evaluated, the costs to evaluate include their development, production, and sustainment.

Possible data sources include historic maintenance databases such as the Maintenance Operating Query System (MOQS), Reliability Maintenance Information System (REMIS), and maintenance cost experts. Data sources will need to be confirmed with Tony Krueger from the F-15 program and contacts from Warner Robins Air Force Base.

A.2 Relationship with TLCSM – TPM

Total Life Cycle Systems Management (TLCSM) is “the implementation, management, and oversight, by the designated Program Manager, of all activities associated with the acquisition, development, production, fielding, sustainment, and disposal of a Department of Defense (DoD) weapon or materiel system across its life cycle" [Defense Acquisition Guidebook, November 2006]. So for a CBM+SI alternative, all activities from the acquisition of the technology to the disposal of it with the platform will need to be covered. The TLCSM has five key measurement that need to be covered [Memo from Under Secretary of Defense, Acquisition, Technology, and Logistics, November 25, 2005]. This section makes sure that the TPMs align with the TLCSM metrics, as shown in the following comparisons. Each defined TLCSM metric can be linked with the required TPMs.

- <u>Operational Availability</u>: This is the percent of time that a weapons system is available to sustain operations. Operational Availability is related to the Fleet Availability TPM for evaluation.
    - Link with TPM: Way to express Fleet Availability in operation
- <u>Mission Reliability</u>: This is the percent of weapons system meeting mission success objectives, such as a sortie, tour, launch, or destination reached. Though not really linked to the above TPMs, Mission Reliability can demonstrate the fleet effectiveness for the scheduled missions.
    - Link with TPM: One way to express Total Cost of Ownership and can be impacted by the use of maintenance resources
- <u>Cost per Unit of Usage</u>: This covers the operating costs per unit of usage, but this can include the life cycle costs from acquisition to disposal. This is another way to express Total Cost of Ownership. In addition, the amount of Maintenance Hours per Flight Hour can affect the overall ownership costs.
    - Link with TPM: Express part of Total Cost of Ownership and can be impacted by the use of maintenance resources
- <u>Logistics Footprint</u>: This deals with the required amount of logistics support for deployment, movement, and sustainment of weapons systems. The logistics can impact all three primary TPMs depending on available materials and personnel at the right place and right time.
    - Link to TPM: Can affect fleet availability if not enough supplies are in stock to minimize fleet down time and can affect Total Cost of Ownership
- <u>Logistics Response Time</u>: This is the average time to acquire Class IX parts from the time of demand to the satisfaction of the demand. The time to acquire parts can impact the downtime of the fleet and cost to sustain, thus impacting the Fleet Availability and Total Cost of Ownership.
    - Link with TPM: Can affect fleet availability from response times for supplies and can affect Total Cost of Ownership

APPENDIX B. Assessment of Inner Wing, Intermediate Spar and Frame Station 626 Bulkhead

The main objective of this Appendix is to summarize the investigation of the required data sets for TPM analysis will be available for the two competitive structural components. Background, crack growth models, NDE methods, SHM application, and the current F-15 program application status of CBM+SI technologies or concepts are also discussed and included. At present, this task is not complete, as the investigation of the data sets is still ongoing and the findings will be completed by the end of April and reported in the next progress report.

B.1 Background and Service Histories

Inner Wing, Intermediate Spar Lower Flange - The F-15 inner wing, intermediate spar has experienced over twenty in-service findings of cracks, which require intermediate spar replacement. In addition, the F-15A/B/C/D Full Scale Fatigue Test (FSFT) was stopped at 18,100 flight hours due to an intermediate spar flange failure. The cracks initiate in the fastener hole and propagate into the web. Final failure occurs when the web losses all load carrying capacity.

FS 626 Lower Bulkhead Flange at the Inboard Longeron - The F-15 has had five lower FS 626 bulkhead flange cracks, one of which has mothballed the aircraft permanently since the current repair costs are around $1M. One of the cracks was detected in the fillet radius at the edge of the longeron interface (this was the aircraft that has been mothballed) and the remaining cracks were found in the first fastener inboard of the longeron interface.

B.2 Crack Growth Models Maturity

Inner Wing, Intermediate Spar Lower Flange - Boeing F-15 Program has developed an extensive analysis package for this location due to the failures, including sophisticated FEMs and hand analysis to correlate with the known problems. The crack growth model for the intermediate spar is very mature. This model was used in the development of correlations with in-service cracking and the full scale fatigue test failure. Currently the F-15 Program relies only on the crack growth life in the web for the tracking system. This is the life once the cracked has already propagated from the hole to the flange the web, due to the complex analysis in determining how large the residual stresses are at the interference fit fastener hole and the complexity of the NDI.

FS 626 Lower Bulkhead Flange at the Inboard Longeron - For this location a special "p-Level" FEM (Mechanica) was created, by the F-15 Program, to accurately determine the stresses and find any and all hot spots in the vicinity. A highly detailed 3-D model has been developed and is being used in the correlation with in-service cracking that has been found. The two locations that have been found cracked, were indicated to be the most critical locations in the region, validating that the model was able to accurately predict the critical locations. A detailed durability and damage tolerance analysis is in the process of correlating with the known in-service cracks and a report will be released by the end of March, 2009 by the program.

B.3 NDI Methods Maturity

The NDI procedures for both critical locations use standard practice techniques and are highly reliable.

Inner Wing, Intermediate Spar Lower Flange – NDI Procedures for this location currently use ultrasonic methods. However, detection of a crack is difficult, due to the wing being sealed and filled with foam. Without removing the upper wing skin and foam, detection of a small crack is difficult or impossible. Once it has reached the web, the most likely way to detect the crack, the spar is not salvageable and requires the installation of a new intermediate spar. The cost of the part is insignificant to the number of labor hours required to drill and ream fastener holes to mate with the skin.

FS 626 Lower Bulkhead Flange at the Inboard Longeron - Both bolt hole eddy current and surface eddy current methods are employed to find cracks. Detection of cracking is tedious and laborious in the current state of standard NDI techniques.

B.4 Work with SHM

Currently the F-15 uses an Individual Aircraft Tracking Program (IATP) to monitor the damage at critical locations. Approximately seventy safety of flight locations are monitored and inspected based on the results of the IATP and the Force Structure Maintenance Plan (FSMP) philosophies. These inspections are based on the concept of an initial flaw, stemming from a material defect or a flaw induced during manufacturing, growing under damage tolerance conditions.

The F-15 has an Individual Aircraft Tracking Program, but no sensors for health monitoring directly on the aircraft.

Inner Wing, Intermediate Spar Lower Flange – Use of SHM will detect a crack that is repairable with an oversized fastener and save a great deal of labor and down time.

FS 626 Lower Bulkhead Flange at the Inboard Longeron - Use of SHM will significantly increase sensitivity of early crack detection and prevent scraping of an airframe.

B.5 Identify Data For TPM Assessment

A short summary on the main Technical Performance Measurements (TPMs), the data needs and sources, and their relationship with the Total Life Cycle System Management (TLCSM), as presented in Appendix A. The F-15 program and Warner-Robins can provide the historic F-15 reliability and maintainability data and costs at O-level and I-level, recorded from now to 5 years ago. The Next action is to ensure that the F-15 Program can provide all the necessary data types for the TPM assessment and to determine the existing maintenance data for the intermediate wing spar and the FS 626 Lower Bulkhead.

The TPM information is readily obtainable for the F-15. We have in-house capability to obtain this information and can obtain some data directly from Warner Robins. One of the near term goals is to have Warner Robins provide us with the cost to repair both the wing intermediate spar and the FS 626 bulkhead. They will provide us with material and labor costs.

B.6 Assess CBM+ 10 Concepts and Technologies Application Status

Current F-15 assessments:

- **Prognostic:** The F-15 uses the FSMP to provide inspection philosophy and criteria, and uses the IATP to determine when each individual aircraft requires inspection. This provides early detection of crack, prior to in-service failures, but does not always catch the cracking prior to growing beyond easy repair options.

- **Diagnostic:** No formal or special diagnostics exists for the F-15. Each issue is developed on an as need basis as it arises. This concept and technology needs to be incorporated into the F-15 daily routine.
- **Portable Maintenance Aids (PMAs):** The F-15 has limited use of PMAs. We have laptop computers used to download information, but this is limited to future transference to other equipment for diagnostics.
- **Interactive Electronic Technical Manuals (IETMs):** Boeing is currently using IETMs for the newer models of aircraft. The original models, F-15 A/B/C/D work under the paper based Tech Orders. This has been a future change desired by the USAF SPO, but funding issues has prevented the update.
- **Interactive Training:** Training, in several media presentations, exists for different aspects of the F-15 inspections, diagnostics, etc., but has not been converted to an interactive format. Training has been limited to providing a straightforward concept of the steps and processes necessary to maintain and provide safety to the airframe.
- **Data Analysis:** This does exist for the F-15, but has only recently been implemented. In large part, this implementation was the direct result of the recent F-15 mishap.
- **Integrated information systems:** No, this does not exist for the F-15.
- **Automatic Identification Technology (AIT):** This has been discussed, in many different formats, but has never been implemented into the F-15. Once again, funding has limited the implementation.
- **Reliability Centered Maintenance (RCM):** Boeing has always maintained an RCM program. Originally this was based on crack initiation concepts, but grew into using damage tolerance concepts as the USAF transferred into the DTA concept. The RCM analysis created the initial inspection requirements. All the original analysis was feed into an RCM process and inspection intervals, inspection methods, inspection sampling plans were derived from this process. Now, many of the main functions of the RCM analysis have been largely superseded by the FSMP. The FSMP has become the main driver for inspection concepts, philosophy, and calling out of required inspections. We still keep the RCM system up to date, but everything has been superseded since we developed a FSMP. Other concerns such as who is responsible for the availability, total flight hours per maintenance hour calculations, needs additional investigation.
- **Joint Total Asset Visibility (JTVA):** This data does not exist for the F-15 Program.

APPENDIX C. SHM

The main objective of this Appendix is to discuss if SHM Technology can be applied to both F-15 structural components: Bulkhead (BH) and Intermediate Spar (IMS). The mature/confidence of SHM technology and what kind of data SHM can provide for risk assessment are also discussed. Finally, a status report on the Hot Spot program (a SHM project using BH for demonstration) is reported.

C.1 Assess the BH Or IMS (Information Gathering)

Several options exist for detecting cracks in the FS 626 Bulkhead Flange and the Inner Wing, Intermediate Spar. Specific technologies include continuity sensors (e.g., crack wires and Comparative Vacuum Monitoring, also called CVM, sensors), in-situ eddy current sensors, and a variety of in-situ piezoelectric-based ultrasonic (e.g., pitch-catch arrays, pulse-echo arrays, phase-arrays, etc.). Developing a Structural Health Monitoring (SHm) system for either location will require first gathering a detailed set of system-level requirements. These requirements will not only define the required level of accuracy and reliability, but also will address such topics as concept of operations, stay-out regions, compatibility and safety (e.g., using a high-voltage technique in a wet wing box), durability, interface controls, etc. These requirements, along with the AFRL/Boeing SHM Design Framework, are used to develop and trade various SHm system designs.

Based on preliminary trade studies, it was determined that an in-situ piezoelectric-based ultrasonic system would meet most, if not all, known requirements and have the best ability to locate and size cracks for the bulkhead hot spot. Note that the solution developed for the bulkhead could be adapted for the spar (assuming all requirements could be met). Thus the focus of the SHm system development and assessment will be on the FS 626 Bulkhead Flange.

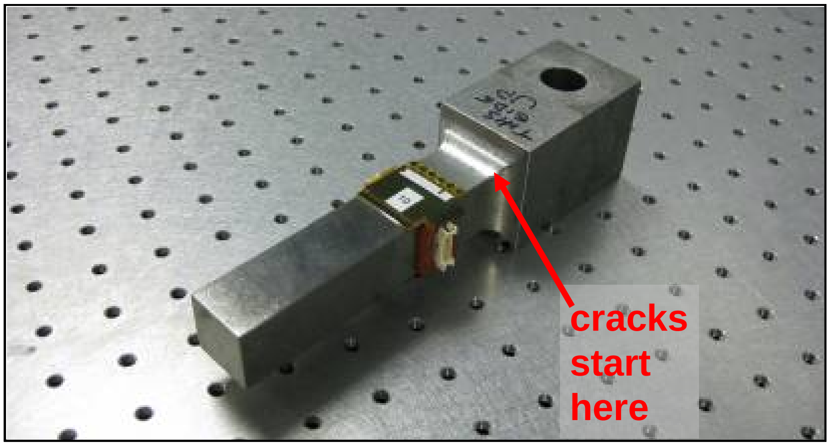
C.1.1 SHM Model Mature (Region Approach Verse Single Direction Approach) and Confidence

Piezoelectric-based ultrasonic systems are a reasonably mature technology. While not considered an off-the-shelf technology, Boeing has an extensive background with this technology. Current state-of-the-art assessments place this technology at a Technology Readiness Level in the range of 4 to 6 (depending upon the application, requirements, etc.).

The application-dependent nature of these systems drives non-standard device topologies. Rapid design and evaluation of these designs requires physics-based modeling tools for ultrasonic wave propagation in three-dimensions. These modeling tools are mature and are being used to develop solutions under the AFRL Hot Spot program.

C.1.2 Define What Type Of Data Will Be Available? Crack Found Or Crack Size Information?

The data produced by the SHm system can vary based on need. Different damage indicators/parameters can be gathered from the same system depending upon what types of actuation signals are used and how the received data is processed. Figure 2 shows a recent example using a piezoelectric receiving array to size a fillet crack in a Titanium cantilever specimen. As shown in the plot in the lower portion of the figure, several different damage indices were developed and calibrated to predict crack length.



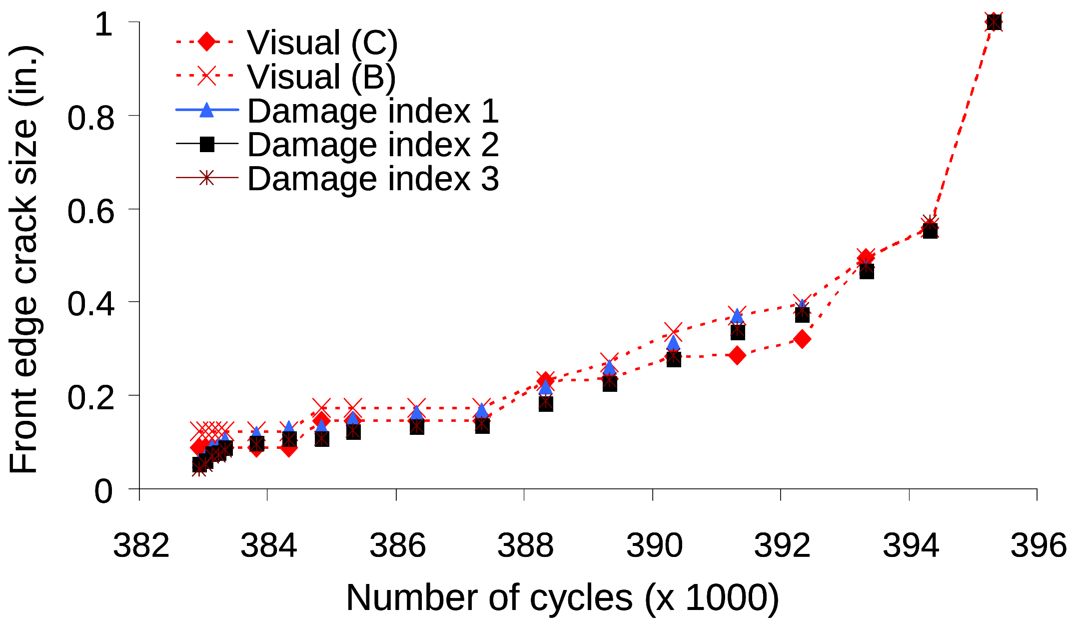


Figure C-1. Plot of Damage Indices versus Load Cycles.
Data from piezoelectric ultrasonic arrays can be processed to form a variety of damage indices. Damage indices can be calibrated using experimental data (visual data in this example) as shown in the lower plot.

A critical element of this type of crack detection is the repeatability of the crack initiation location. For applications where the initiation site can vary, multiple algorithms are used to first help predict initiation, and then determine growth.

C.2 Hot Spot Project Impact Identified And Progress Report To Team

The Hot Spot program is currently developing the AFRL/Boeing SHM Design Framework in the context of metallic and composite crack detection demonstrations. A follow on activity is being negotiated to address the specific needs of F-15 (i.e., the bulkhead). The anticipated start date is sometime during the second quarter of calendar year 2009.

APPENDIX D. Requirements for the Structural Health Monitoring System For the F-15 Fuselage Station 626 Bulkhead - *DRAFT*

D.1 Introduction

This document presents the requirements for a crack detection Structural Health Monitoring (SHm) system for the F-15 airplane fuselage station 626 bulkhead.

On the lower portion of the bulkhead, there is a built-up of materials where it attaches to a longeron and skin. In addition, there is also a splice plate on the inner service (see Figures D-1 and D-2). Cracks have been found in the bulkhead that inspections have indicated are initiated on the section of the bulkhead flange hidden within the stack-up of these parts. By the time the crack is visible on a part of the bulkhead flange that is exposed, it may be too large for any type of repair. If this is the case the aircraft may be retired, as the replacing of the whole bulkhead can be cost prohibitive.

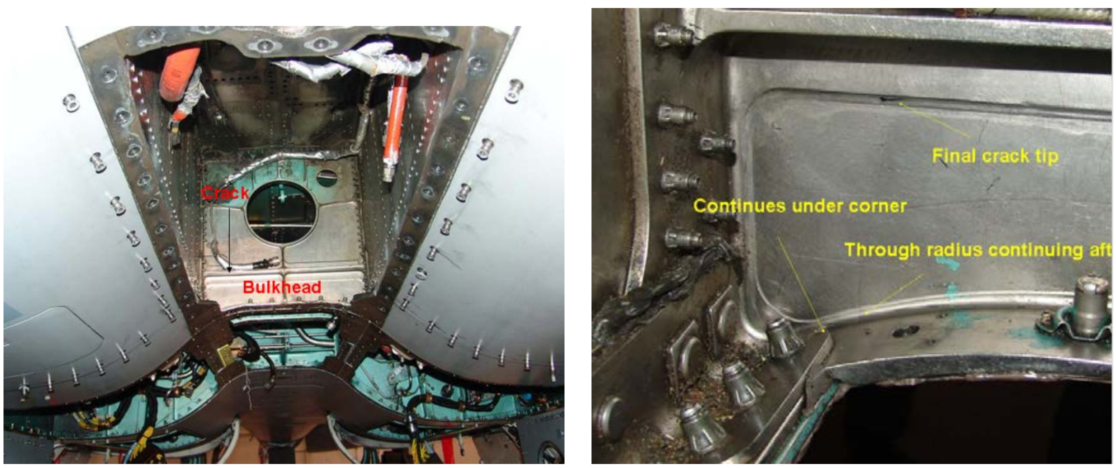


Figure D- 1. Pictures of the FS626 Bulkhead and where cracks have been found

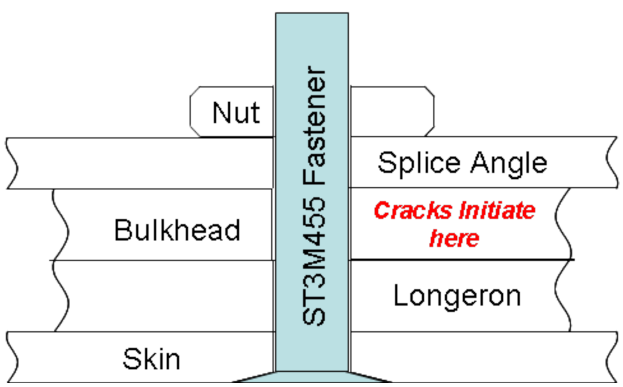


Figure D- 2. Stack-Up illustration

The purpose of a crack detection SHm system would be to autonomously detect the presence of a crack and/or measure the dimensions of a crack in the above mentioned location.

The current Non-Destructive Inspection (NDI) techniques used to inspect the crack consist of standard practices and are highly reliable. However, the current inspection processes are very time intensive resulting in increased support costs and decreased asset availability. Furthermore, if the crack is found too late, it may be unrepairable resulting in the need to replace the bulkhead. This can result in early retirement of the aircraft due to the prohibitively high cost of replacing the bulkhead.

Remote condition-based SHm systems have the potential to increase the value of flight vehicles by reducing costs associated with manual inspection time and increasing the frequency of inspections to avoid not finding cracks until they are too large to repair. As the current maintenance techniques ensure the safety of flight vehicles; SHm systems shall not degrade this capability.

This specification provides the requirements for a structural health monitoring system for crack detection in the F-15 FS 626 Bulkhead. The requirements contained in this document are intended to define the expected functions of structural health monitoring system, and to provide guidelines that ensure that the system can adequately perform those functions.

For requirements with numerical limits, a threshold value and an objective value exist. The threshold value is the minimum acceptable value, and the objective is the desired target. A summary table (Table D.1) containing the numerical thresholds and objectives referenced in the text is provided at the end of the document.

D.2 Scope

This document defines the requirements for a structural health monitoring system for the F-15 FS 626 bulkhead.

D.3 Safety

D.3.1 The design of the system shall be capable of sustaining a failure and retaining its hardware and energy so that no injury to personnel or damage to the flight vehicle is caused.

D.3.2 Safety of flight. The system shall maintain or improve the existing level of safety of flight. Under no circumstances shall the system degrade the safety of flight.

D.3.3 A safety of flight analysis and certification will be performed prior to flight.

D.4 System Function and Performance

The system functional and performance requirements are primarily based on comparisons with conventional non-destructive inspection methods and capabilities determined during discussions with representatives of the Boeing F-15 Program.

Both bolt hole eddy current and surface eddy current methods are currently employed to find cracks. The bolt hole eddy current and surface eddy current methods are expected to find a 0.05" X 0.05" crack with 90/95 probability of detection. Boeing did not conduct this study, the USAF has supplied this to the F-15 program and the Boeing NDI experts concurred that this was obtainable. However, the USAF would have liked to use 0.03" X 0.03", but did not have a POD study to validate that flaw size

The crack has been shown to grow behind an embedded region – a region of the bulkhead between the splice plate and longeron. Visual inspections are not possible when the crack grows in a hidden region. Eddy current inspections are also complicated. In-situ SHm offers the capability of continued inspection as the crack grows in the hidden area.

The performance requirements for the SHm system on the station 626 bulkhead in the F-15 aircraft are:

D.4.1 The system shall monitor crack initiation and/or growth in the region shown in Figure D-1. The system shall detect, locate, and size cracks, and record crack growth rate. The limits on this requirement are provided in Table D-1.

D.4.2 The system shall monitor the condition of the repair itself. During component testing, it was found that a crack can initiate and grow in the radius of the repair. If this crack occurs, the system shall detect, locate, and determine the size of the crack, and record crack growth rate. The limits on this requirement are provided in Table D-1.The system shall quantify the uncertainty associated with any measurement it takes.

D.5 Interfaces

D.5.1 Mechanical

D.5.1.1 The on-airplane system shall be compatible with the host structure that it is designed for, including high and room temperature cure adhesives and two-part epoxy systems.

D.5.1.2 Clearances: The sensor and connectors shall not interfere with the operation of any other system or subsystem; a minimum clearance as shown in Table D.1 shall exist between any portion of the on-board sensor and any adjacent structure.

D.5.2 Thermal

D.5.2.1 Structural or ambient temperatures between -65 degrees Fahrenheit (-54 Celsius) and +160 degrees Fahrenheit (61 Celsius), and temperature change rates of 3.75 degrees Fahrenheit (2.1 Celsius) per second within that range, shall not degrade the performance of the system. This temperature range is still being verified with the F-15 program.

D.5.2.2 Thermal expansion effects shall not degrade the performance of the system; the system shall be able to meet the requirements in this document after thermal expansion or contraction has occurred.

D.5.3 Structural

D.5.3.1 The system shall not adversely affect the load path between the repair and the host structure.

D.5.3.2 Strength and Stiffness

D.5.3.2.1 On-board systems shall be designed to withstand the maximum structural environments for which the host structure was designed, including safety factors. Applicable environments include humidity, fungus, salt fog, sand and dust, acceleration, and vibration.

D.5.3.2.2 Deflection of the host structure at design ultimate load shall not adversely affect system functionality.

D.5.3.2.3 Sufficient structural rigidity shall be provided so that deflections that would jeopardize the proper functioning of any flight equipment shall be avoided. Deflections shall not violate critical clearance requirements or cause physical separation of any preloaded joints.

D.5.4 Flammability

D.5.4.1 Electrical shorting or other energy discharge of the system shall not ignite fuel vapors or other flammable materials.

D.5.4.2 The temperature of the components shall not reach the auto-ignition temperature of JP4 or JP8 fuel (435°F, or 224°C).

D.5.4.3 The flight hardware shall not provide a method of arcing or sparking.

D.5.5 Electro-mechanical

D.5.5.1 Use of electrical connectors shall not degrade the bond attaching the sensor to the structure. Compliance with this requirement can be demonstrated by passing a connector abuse test.

D.6 Design Life

D.6.1 The design life for the system applied to the F-15 station 626 bulkhead shall be 8,000 flight hours. This requirement applies to systems installed on the flight structure and to systems in storage.

D.6.2 The system shall meet all performance requirements over the design life.

D.6.3 The design life shall be used as the basis for qualifying the relevant parts, materials, and assemblies.

D.6.4 There is no requirement for the sensor to survive removal from the structure. Removal is expected to be destructive to the sensor. The structure and finish under the sensor adhesive layer must remain undamaged after removal of the sensor layer.

D.7 Reliability

D.7.1 A failure modes and effects analysis should be performed to guide reliability requirements. To meet the reliability requirement, the testing defined in the reliability test plan shall be successfully completed.

D.8 Mass

D.8.1 Mass of the on-airplane portion of the health monitoring system will be minimized. Flight components are defined as sensors, sensor interconnect wiring, connectors, connector covers, protective overlayers, and epoxy. The maximum mass of the flight components of the system will be as defined in Table 1. This mass is for each side (left and right) of the airplane. For an installation with sensors on both sides of the airplane, the total mass allowed is twice the amount shown.

D.8.2 While there is no specific requirement on mass of the off-board (data acquisition) portion of the system, that portion should be reasonably portable and suitable for convenient use in the field maintenance environment. <requirement can be modified if on-board data acquisition is required>

D.9 Electromagnetic effects

D.9.1 Monitoring systems shall not interfere with existing on-board electronic systems. As the system is designed to be operated when the aircraft is on the ground, this requirement is intended to minimize interference between the sensor/data acquisition system and other maintenance or ground data systems.

D.10 Repairability

D.10.1 The system hardware shall be repairable using normal shop tools.

D.10.2 Sensing elements or transducers may be located in inaccessible regions. The components of the system will be as serviceable as practical. Certain components may necessarily be placed in difficult to access areas.

D.11 Redundancy and fault tolerance

D.11.1 Redundancy shall be applied as required herein to eliminate critical failure modes, avoid single point failures if possible, and to improve reliability.

D.11.2 The system must be robust enough to withstand sensor failures. The requirements in this document shall be met with any one sensor or transducer element failed. <requirement to be reviewed>

D.12 Degradation of structural capability

D.12.1 The system shall not degrade the structural capability of the host structure.

D.12.2 Sensor components may be bonded to the structure. For non-wireless systems, added penetrations in structure are not allowed without engineering authorization.

D.13 Contamination by fluids

D.13.1 The system shall not be degraded by exposure to water, fuels, hydraulic fluids, lubricating oils, solvents and cleaning fluids, de-icing and anti-freeze fluids, runway de-icers, insecticides, disinfectants, coolant dielectric fluid, and fire extinguishants. Testing need only be completed for fluids that the system will be exposed to over extended periods or intermittently (on a regular basis under normal operation or possibly seasonally over the life of the system). Other fluids can be evaluated based on analysis or previous determination of material compatibility.

D.13.2 Cleaning the structure prior to installing the sensor will necessitate removing any corrosion inhibiting compound. The sensor layer must be able to function after reapplication of the corrosion inhibiting compound following sensor installation.

D.14 Allowable Damage Limits

D.14.1 Any increases in allowable damage limits due to the presence of the system shall be validated by testing. There are no planned increases in allowable damage limits for the F-15 station 626 application.

D.15 Inspection Requirements

D.15.1 Additional maintenance requirements due to a condition-based health monitoring system other than gathering data are not acceptable.

D.15.2 After initial installation and checkout of the sensor system, no inspection requirements will exist for the system itself. It is acceptable for the data acquisition system to perform a self-check or sensor health check at each data collection interval.

D.16 Integration with Airplane Systems

D.16.1 The system shall be able to operate independent of other airplane systems.

D.17 Data bus requirements

D.17.1 The system will take data from the structure and process that data to provide feedback to the user. The user may be the operator, mechanic, crew, or another airplane system. No on-aircraft data bus is planned for the F-15 station 626 application.

D.18 Portable Maintenance Aids

D.18.1 On-board health monitoring systems shall interface with portable maintenance aids. This application is not considered on-board, as the data acquisition equipment is ground-based.

D.19 Open System Architecture

D.19.1 Once installed, the system shall allow addition or removal of sensing components without replacing any existing or original data bus.

D.20 Ease of Use

User friendliness is an important feature of the SHM system. Conventional NDI systems usually require specialized knowledge and skill to operate and interpret. One of the goals of the SHM system technology development is to improve upon the user-friendliness of existing NDI methods. User-friendliness is subjective, making this a difficult requirement to levy.

D.20.1 The user interface to the system shall be easy to understand and use for mechanics and support staff.

D.20.2 Wherever possible, language-independent symbolism will be used to convey information.

D.20.3 No special training or skill will be required to use the SHM data acquisition equipment.

D.20.4 The connector for data collection shall be located in an easy to access area.

D.21 Energy Sources

D.21.1 Batteries, energy harvesters, or other energy sources shall meet all applicable requirements within this specification.

D.22 System power requirements

D.22.1The system shall have the capability to operate independent of the power system for the flight vehicle.

D.22.2 The data acquisition system should be self-powered and should not require a power source during data collection at the airplane. It is acceptable for the device to contain a battery that requires charging while the system is not in use.

D.23 Testing

Appropriate testing shall be performed to validate system performance before implementation. An appropriate test plan will be formulated and followed.

D.23.1 Criteria of success. The equipment shall be considered to have successfully completed the required tests in the test plan when the following conditions have been satisfied:

D.23.1.1 Operation throughout all tests shall be within the limits stated in the test plan.

D.23.1.1 No deterioration or degradation of performance has occurred which could, in any manner, prevent the system from meeting its functional requirements during service.

D.24 Ground (Off-Board) Systems

D.24.1 Ground systems, which are the data acquisition system in the application, shall interface with flight systems.

D.25 Workmanship

D.25.1 Workmanship shall be of the highest quality such that the design standards of the host structure and the repair are not degraded or changed. At all points during manufacturing, integration, test, handling, storage, and transportation, these design standards shall be maintained. Written process specifications and standards shall control all operations.

D.26 Interchangeability

D.26.1 All like parts shall have the same part number. Each equipment item shall be directly interchangeable in form, fit, and function with other equipment items of the same part number. The performance characteristics shall permit equipment interchange with a minimum of adjustments and recalibrations in order to avoid retesting. The equipment must be of the same qualification status and reliability to meet interchangeability requirements.

D.27 Labeling and Marking

D.27.1 Each component of the system shall be uniquely and clearly identified. Electrical connectors shall be labeled.

D.28 Information Control Requirements

D.28.1 Upon official authorization, the Information Owner will be identified. The Information Owner will document all sensitivity levels of the data from the SHm system. S/he will consider any U.S. or foreign government classified contract, program, or project information requirements first. For sensitive information, s/he will identify sensitivity. There will be ITAR/EAR and Customer/Supplier Security components.

D.29 Security

D.29.1 The Boeing Computing Security Requirements Manual will be reviewed for the minimum security requirements that computing asset owners are expected to implement to safeguard their asset(s). Details for implementing the manual in specific computing environments (e.g., UNIX, Desk Top, Windows, etc.) are included in the Computing Security Implementation Manuals (CSIMs). Specific care will be taken to ensure compliance to all ITAR/EAR security requirements.

D.30 Document Maintenance

D.30.1 This document is to be maintained by the authors as identified on the signature page of this document. Any revisions must be approved by all authors or the author's designees.

D.31 Requirements summary

Table D.1 contains the values referenced in the text above for the installation of a sensor system in the F-15 airplane.

Requirement	Threshold	Objective
Crack in host structure: detection	0.030 inch <example>	0.001 inch <example>
Crack in host structure: size	0.030 inch <example>	0.001 inch <example>
Crack in host structure: location	0.2 inches <example>	0.030 inch <example>
Flight component mass (each side)	100 grams (0.22 pounds) <example>	10 grams (0.02 pounds) <example>
Temperature limits	-65 to +160 F <example>	-65 to +160 F <example>
Temperature rate-of-change limit	3.75 F per second <example>	3.75 F per second <example>
Clearance between sensor and adjacent structure	0.25 inch minimum <example>	0.25 inch minimum <example>

Table D-1. Summary of Requirements for SHm System