

Design of a System for Aircraft Fuselage Inspection

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Abstract—This report describes the current aircraft inspection process that occurs when a commercial aircraft is removed from service and sent for scheduled maintenance at a maintenance, repair and overhaul company. In order to maintain airworthiness, the preventative repairs begin with an inspection method to diagnose the structural integrity of the aircraft. This paper describes the use of new technologies in the inspection and diagnosis portion of the maintenance and repair process.

Index Terms—Aircraft Fuselage Inspection, Laser-Ultrasonics, Synthetic Aperture Imaging

I. INTRODUCTION

Airline carriers today face the challenge of maintaining their existing fleets for longer periods of time than ever before. The average age of a commercial aircraft operating domestic flights in the United States today is more than 11 years. As the age of the aircraft increases, the structural integrity becomes compromised unless properly maintained. Many factors influence structural fatigue such as pressurization and depressurization of the fuselage when taking off, landing, and while in flight. When an airplane is preparing for takeoff it pressurizes the cabin for the planned cruising altitude, this process results in a force typically around eight pounds per square inch. The differential pressure results in repeated cycles of stress on the fuselage structure. Figure 2 depicts differential pressure equal to zero on the left when the aircraft is at ground level before takeoff, where as in flight as shown on the right the force is greater on the interior walls of the fuselage. [1] [2]

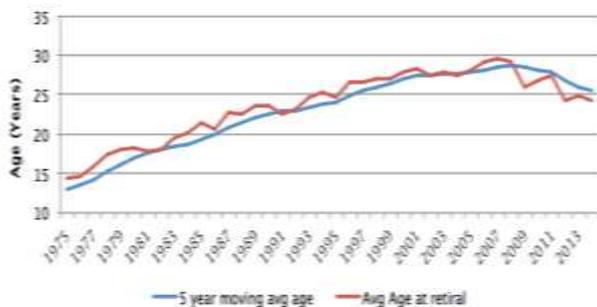


Figure 1 - Average Age of Aircraft at Retirement [1]

In addition to the pressurization forces, the aircraft is also exposed to weather conditions and the take-off and landing cycles. Over time the fuselage of the aircraft

experiences widespread fatigue damage (WFD) where cracking begins to occur where the rivets are located. The increasing number of planes experiencing WFD has created the need for researchers to develop models to calculate the maximum interval between required maintenance checks. [3]

Aircrafts undergo maintenance to ensure optimal performance and airworthiness. In the United States, preventative maintenance is scheduled such that the probability of 1.2 mm sized crack to grow beyond the critical crack size is less than 10^{-7} . Table 1 lists the four main categories of scheduled maintenance and the resources required for each. This project will focus on the “D Check” due to its lengthy duration of two months, and its high costs which can exceed two million dollars.

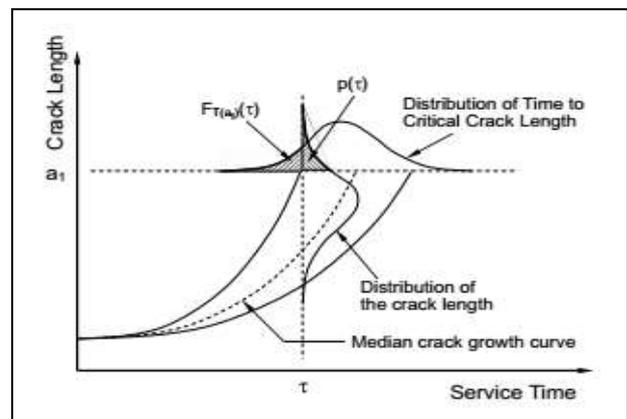


Figure 2- Stochastic Crack Growth Model [Yang JN, Manning SD 1990]

According to the 2013 benchmark analysis by IATA, maintenance, repair and overhaul (MRO) companies servicing the global fleet spent an estimated \$131 billion, including overhead. Commercial flight accounts for approximately 46% of the total with a value of almost \$61 billion with future growth estimated for the following year of almost \$90 billion. The benchmark report also indicates that direct maintenance cost for the 26 domestic airlines included in the study is on a steady rise. From 2010 – 2013 there was a 32% increase in maintenance costs, much of which can be attributed to structural fatigue that impacts the aging fleet of aircraft. [1]

In addition to scheduled preventative maintenance, airlines must also respond to the corrective maintenance

requests originating from Airworthiness Directives (AD) issued by the Federal Aviation Administration (FAA). MRO companies use many types of non-destructive inspection (NDI) methods to diagnose the structural integrity of aircraft. The most cost effective, to-date is the visual inspection process which is usually the first step in the fuselage inspection process. Trained personnel are equipped with various lights and lenses to maximize their potential for identifying deviations in the surface of structural components of the fuselage. Regardless of technique used, visual inspection ultimately relies on the capacity and ability of human eyesight. Many human factor studies have been conducted to develop best practice procedures that the FAA enforces in its oversight of MRO companies. [4]

The visual inspection process identifies areas that require additional inspection methods. One NDI method is named Eddy Current, which utilizes an electrically induced magnetic field that detects disruptions in the current that flows counter to the magnetic current. Eddy current is primarily used in a hand held design where a trained human operator administers the test in a localized area. The test determines the extent of damage throughout the material that may not be evident on the surface. Currently all FAA approved procedures include a human component. [4] [5]

II. STAKEHOLDERS

A. Maintenance, Repair, and Overhaul (MRO) Companies

Objectives: Be able to reduce the cost and time required for inspecting the fuselage while improving the quality of inspection and improving the overall safety of the aircraft.

Tensions: The MRO must allow for the DER to take the necessary time to inspect the aircraft to be able to look for cracks in the fuselage. However, the MRO wants to be able to have the aircraft in and out as quick as possible so that they are able to repair more aircrafts.

B. Airlines

Objectives: Be able to reduce the inspection costs and improving the reliability of the aircraft while reducing the grounding time required for the aircraft.

Tensions: The airplanes being used by the airline must meet the airworthiness directives as well as the time that the airplane is grounded when at the MRO facility will in the long run affect the revenue able to be produced by the airline company since that is one less aircraft in use.

C. Federal Aviation Administration

Objectives: Be able to improve the reliability of the aircraft while simultaneously improving the quality of inspection and ensuring that the aircrafts meet the airworthiness directives.

Tensions: Must ensure that any aircraft leaving the MRO facility meets the airworthiness directives. Due to MRO Company wanting quick turnaround time some planes leaving the facility might not have all the repairs done completely

D. Designated Engineering Representative (DER)

Objectives: Be able to reduce the overall inspection costs while improving the quality of inspection and reducing the time needed to inspect the fuselage.

Tensions: High tension with the MRO Company and the FAA. The DER must be able to inspect the aircraft quickly to keep the time and costs low for the MRO Company while adhering to the strict rules set by the FAA to ensure that the aircraft meets all the airworthiness directives.

III. PROBLEM & NEED

A. Problem

The problem at hand is the current time needed to inspect the aircraft is very high. For a Type D inspection, the process could take upwards of 2 months requiring approximately 50,000 man hours to be able to thoroughly check everything. As a result, the Type D inspection take 12-15% of the airlines annual expenditures in the aircraft maintenance and repair budget. In 2013, approximately \$9.4 billion was spent in aircraft maintenance to ensure they met the airworthiness directives. With the current inspection method, visual inspection, there is a 43.7% probability for a Type II error to occur. In other terms, this is a 43.7% chance that the inspector will miss the crack on the fuselage and it will go unrepaired causing the crack to go overtime. [1]

B. Need

There is a need to optimize the way in which the aircraft fuselage inspection is completed. Specifically, decreasing the total time needed to inspect the fuselage of the aircraft allowing for the aircraft to be repaired and returned to operational status quicker, it will also allow for decreased inspection costs. A new inspection system provides the opportunity to be able to reduce the human error that occurs when inspecting the fuselage visually. What will also occur is the chance to be able to detect early detection of structural fatigue on the fuselage which will allow for improved preventative maintenance while decreasing the need for corrective maintenance.

IV. CONCEPT OF OPERATIONS

The concept of operation has two main categories. First, for noncontact technologies such as synthetic aperture imaging or laser ultrasonic. And the second for imaging technology that requires contact with the surface such as the thermographic imaging process used by Lufthansa-Technik in the robot crawler utilizing a before and after image comparison approach to identify differences when the surface is heated. [12]

In both concepts of operation a documentaion process would take place to accurately document the precise location of the deviation on the airframe. In recently tested handheld scenerios the use of iGPS technology supports the accurate measurement of location on the aircraft.

The first concept for noncontact imaging is to use a track system located above the plane, where an imaging unit could travel the legnth of the aircraft while

recording image data. Much like a camera operates when repositioned it will have a new field of view and therefore the size and shape of the track will be dependent on the limitations and abilities of the technology. For example if the SASHA technology requires a parallel arrangement then the track would need to be curved to match the shape of the plane. A hinged track could allow for customized positioning.

A modified approach to the track system would involve the use of a robotic arm to move the imaging device around the exterior of the plane while capturing images of the surface that when processed will reveal three dimensional data. The robotic arm will need to be able to position the imaging device above the aircraft as well in which case a combination of robotic arms and track may be necessary to adequately image from all angles.

In order to address the contact technologies such as the thermographic mobile robot for fuselage inspection (MORFI) we also have a concept for operation that involves equipping the robotic crawler with other technologies such as ultrasound or eddy current in order to assess what type of non destructive inspection technology performs fastest and most accurately for the cost.

V. DESIGN ALTERNATIVES & SYSTEM VALIDATION

The methods listed A-C below are contact delivery methods. These technologies require contact with the fuselage surface in order to determine where deviations occur. Non-contact delivery method is when the device does not need to be in contact with the fuselage and is able to determine where the crack is from a certain distance from the fuselage. Such an alternative is the synthetic aperture imaging device. It is mounted onto a track and rotates around the aircraft taking images from various angles, then analyzing the images to determine where the cracks are located on the fuselage.

A. Automated Imaging with Human Evaluation

The automated imaging with human evaluation makes use of a handheld device that the inspector is equipped with while inspecting the fuselage of the aircraft. The inspector inspects the aircraft visually as per usual then to confirm if there are or are not cracks on the fuselage the inspector will use the device to confirm. Devices that the inspector could use are ultrasonic or eddy current which is what is currently used.

B. Handheld Imaging with Computer Aided Evaluation

The handheld imaging with computer aided evaluation reduces the dependency of needing the inspector to visually inspect the aircraft. The inspector, with this device, would scan it across the fuselage of the aircraft and then the device will use computer software to be able to determine where the cracks are located on the fuselage, if any are present in that scanned location. This alternative reduces the Type II error, because the computer software is less likely to not detect the crack compared to the inspector.

C. Automated Imaging with Computer Aided Evaluation

The automated imaging with computer aided evaluation eliminates the need for the visual portion of the inspection to be done. The device will go across the fuselage of the aircraft in sections determining where the cracks are and then proceeding to record the fault locations so that the repair crew can more easily locate the cracks. The automated device will allow for faster inspection time and will have a greater detection rate with the elimination of the human inspector.

D. Contact versus Non-Contact Delivery Method

VI. METHOD OF ANALYSIS

We will be simulating the visual inspection process using representative sections of the aircraft. To match our preliminary utility hierarchy, the simulation will give information on how much time is saved by utilizing a given design alternative as well as information on crack detection.

The model boundaries include the visual inspection process of an aircraft, from the initial call for inspection to the completion of the visual inspection.

The requirements of the visual inspection simulation primarily focus on what the simulation needs to do, what edge cases should be covered as well as what statistics need to be collected.

Using Arena Simulation Software, we are building a queuing model that will allow us to evaluate the total time of aircraft inspection. The entities that are created by the initialization in the model include a human inspector, an autonomous thermographic robot, and autonomous synthetic aperture imaging robot. Each entity is limited to specific, predetermined sections of the plane. The number of cracks on each section of the plane is then initialized and the entities move to the actual process.

By changing the distributions of time required to complete the process and supplying the input parameters for number of cracks detectable we can analyze the output data for performance and costs savings in terms of time.

Inputs

- What design alternatives are utilized
- Where design alternative are utilized

Outputs

- Overall time for inspection
- Time per section
- Cracks detected per section
- Type 1 errors per section
- Type 2 errors per section

Our design of experiments will involve variations in technology utilized and the delivery method used for both the interior and exterior of the aircraft per trial. The output of the simulation will give the type one error rate, type two error rate, total inspection time, and the cost of the inspection in labor hours.

The cost of non-human design alternatives will be added to the cost of inspection for final utility vs cost

analysis, and a breakeven point can then be found by mapping the relative type one and type two error rates to a dollar value in addition to their utility.

VII. RESULTS

The simulation was run with a human inspector using the time distributions from the Aging Aircraft Study conducted by the FAA. The difference between the simulated process and actual process varied from 0-5%, but cumulatively came up to within 1 minute of the expected total time over 500 replications, which is an error of approximately 0.1%.

VIII. CONCLUSION & RECOMMENDATIONS

Further simulation modifications are underway to address expansion of our design of experiments. This section of the report will be based on work completed in the coming months.

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