Prediction Modeling of Foreign Object Impact Debris on Aircraft Through Digital Engineering

Luis Eduardo Rodriguez

University of Texas at El Paso

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PREDICTION MODELING OF FOREIGN OBJECT IMPACT DEBRIS ON AIRCRAFT THROUGH DIGITAL ENGINEERING

LUIS EDUARDO RODRIGUEZ

Master’s Program in Mechanical Engineering

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PREDICTION MODELING OF FOREIGN OBJECT IMPACT DEBRIS ON AIRCRAFT THROUGH DIGITAL ENGINEERING

by

LUIS EDUARDO RODRIGUEZ, B.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Aerospace and Mechanical Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2024
Dedication

I want to dedicate this work to my mother and father; they have supported me all through my academic years and inspired me to pursue a master’s in mechanical engineering. They have set the example of how I should respect, listen, and collaborate with my peers with passion. To my brothers and sister, for creating the steps for me to follow in any way as the younger brother and the care that each of them have provided to get through the hard and good times. To my friends, Alan, Alexis, Sabina, Diana, Asahel, and Alejandro who have supported me and mentored me in research, academics, and life. I am grateful for all the adventures that we shared in this school. Lastly, to Ivana who has supported me 24/7 and guided me in many different ways to accomplish my personal and professional goals. Without the help of my friends and loved ones, I would not be able to write this thesis and have such an accomplishment.
I want to thank Dr. Tseng and Dr. Lin for the mentorship provided since I started at the Aerospace Center and IMSE back in 2022. The advice given through the years and the feedback has made me grow personally and professionally. Being exposed to Dr. Lin’s and Dr. Tseng research environment, I was able to meet wonderful peers and experience many adventures throughout my bachelor's and master’s. In addition, I was able to learn from such talented scientists as my advisors.

I want to acknowledge my peers as they have become close friends to me. Thank you, Alexis, Aaron, Sabina, Alan, Asahel, Antonio, Diana, and Jean, for all the mentorships given and for always listening to me when there was a concern or a question. The experiences that I had with each of you have marked me and would help me grow more personally and professionally. It is a pleasure to call each of you, my friend.

Furthermore, I would like to acknowledge my family and girlfriend. Without the support of all of you, I would not be able to complete my thesis. I want to express my gratitude for all the help given, for listening to me through my ups and downs and for all the advice given.
Abstract

The contribution of the research made is derived into two sections. The first topic discusses the prediction modeling of Foreign Object debris (FOd) impact on aircraft structures through the use of digital engineering. The program used in this project is Ansys Explicit Dynamics to evaluate the stress and strain caused by the initial conditions of flight trajectory and impact created from FOd found inside of aircraft structures. The prediction modeling consists of creating a repetition of simulations with different FOds to evaluate the damage created to subsystems of the wing bay such as the fuel system and internal structures. The FOds used for this analysis are washers, fasteners, & plastic caps. By defining the solutions from the explicit dynamic environment, it can be concluded that such foreign objects (FO) can or cannot cause failure to the aircraft. The development of these simulations would be exported to Unity to create a model for in-depth analysis of impact and location of FOd after flight trajectory. With this research, it would assist engineers in how to prevent a major accident from happening while an aircraft is operating. The second topic focuses on the optimization of scanning parameters of Non-Destructive Equipment (NDE) and the development of different intentional defects on manufactured curved carbon fiber composites. Composites are made of carbon fiber and epoxy resin with placement of washers and teflon pieces layer by layer through compression pressing and molded vacuum bagging. The technique used for NDE is ultrasonic testing and the transducer used was a phased array probe and the NDE equipment was an Omniscanner SX. The use of this technique allows us to scan the composite row by row to detect handmade defects on composites at different locations. The Omniscanner SX would allow us to obtain high resolution scans for present research. By having different scans, an AI model is created and trained to automatically detect such defects at different depths and location on composites.
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Chapter 1: Prediction Modeling of Foreign Object Impact Debris on Aircraft Through Digital Engineering

INTRODUCTION

There have been multiple cases where Foreign Object Debris (FOD) has affected commercial and private aircraft because of leaving materials and debris inside structures while on manufacturing plants. These issues have brought deep attention to ways of preventing FOD on manufacturing lines. According to current research, aerospace companies still depend on human interface to locate any left behind material, tools, and debris on aerospace components which allows to be a percentage of error. Making it hard to completely have a plane FOD free when sending to customer. The main concern in this scenario is to evaluate what type of foreign objects (FOs) are being found and the location. It is noted that foreign objects have been found in the cockpit area, where the pilot seats, as well as in the fuel system and in addition to many other places within the plane.

This discussion raises an alarming scenario where an accident can happen on the airplane and compromise the safety of the pilot and surroundings. This paper focuses on creating a prediction model through digital engineering to understand the impact of different FOs inside the wing bay of an aircraft. In addition, it will evaluate if the FO would cause a major failure to the internal components of the wing bay and a user interface would be created in Unity 3D for in-depth analysis. The software used in this study is called Ansys Explicit Dynamics. Explicit Dynamics is a Finite Element Analysis (FEA) [1] tool to perform dynamic simulations when speed is important. It accounts for quickly changing conditions or discontinuous events such as free falls, high-speed impacts, and applied loads. This software allows the user to create a 6 degrees of freedom environment where a flight trajectory can be evaluated while having FOs inside the
system. Through this tool, the strain and stress can be analyzed to determine if the impact velocity of FOs can damage the structures and systems of the wing bay.

![Figure 1.1 Demonstration of Explicit Dynamics](image)

The information from an aerospace company was provided to locate the most common foreign objects found on manufacturing plants as shown in Figure 1.1. This is the list of the promising FOs that would be used to evaluate flight trajectories.

![Figure 1.2: Most Common FOs found in Quality Inspections](image)
Furthermore, this is the diagram used to accomplish our study.

![Diagram](image)

**Figure 1.3: FOD Flow Diagram**

**METHODODOLOGY**

**Ansys Explicit Dynamics**

**Space Claim geometry**

Space Claim is Computer Aided Design (CAD) software within Ansys that allows to design and import any .step file that will be used for FEA simulation. It is the beginning step to complete our explicit dynamics simulation. In our case, the team exports a mockup design of a F-35 Right Wing Bay with inner pipes that was created using Autodesk Fusion 360 CAD software. In addition, multiple foreign object debris (FOD) are placed inside of the wing bay at different locations to start...
our analysis cycle. Once completing the analysis cycle, the results enable us to predict the aftermath after operating the wing bay plus FOd. In Figure 1.4 & Figure 1.5, it demonstrates how the wing bay plus piping looks after exporting and also the location of our FOds (Washer, Plastic Cap, Fastener, Etc.)

Figure 1.4: Mock F-35 Wing Bay & Pipe System

Figure 1.5: FOd Placement Inside Wing Bay
Explicit Dynamics Modeling:

Once obtaining the desired geometry and FOds on Space Claim, then the modeling can start. The additive tool that we use in Ansys is called Explicit Dynamics. This additive tool allows us to evaluate simulation trials of Multiphysics movement to understand the impact created from the movement of FOds inside the wing bay and pipe system. The additive tool produces different information such as strain, stress, and deformation per simulation trial that consists of second order differential equations [3].

To retrieve the strain, stress, and deformation results from the simulation, multiple parameters were changed and labeled as stated below.

The materials/properties used for simulation:

<table>
<thead>
<tr>
<th>System/Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Bay</td>
<td>Titanium/Carbon Fiber</td>
</tr>
<tr>
<td>Pipe System</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Plastic Cap</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Washer</td>
<td>Stainless Steel</td>
</tr>
<tr>
<td>Fastener</td>
<td>Stainless Steel</td>
</tr>
</tbody>
</table>

To have an accurate response when modifying parameters, it is needed to have a high density of meshes. A mesh is a set of nodes and faces that create an overall three-dimensional shape. There are different mesh methods that allow the user to create a three-dimensional figure such as tetrahedral, hexagonal, triangular, etc. [4] The higher the elements and nodes, the higher the quality of results is obtained after running the simulation. In the parameters box, the element size placed for the wing bay is 0.035mm and for the FOds are 0.015mm. Also, adaptive mesh is
added to the element size to create curved mesh for the complex geometries of the FOs and Wing Bay. From the element size, about 35,000 nodes & 110,000 elements are developed. The reason behind the difference of element size from the wing bay to the FOds is that it is required for the Target Body as shown on Figure 1.6 must have a bigger element size to create more impact nodes once creating friction with the contact body. In our case, the target bodies are the FOds and the contact body is the wing bay and fuel system. In Figure 1.7, it demonstrates the resulting structure of the wing bay after setting our previously mentioned nodes and elements.

Figure 1.6: Contact and Target Bodies of Plastic Cap and Pipe System

Figure 1.7: Wing Bay Mesh
Figure 1.8: (a) Element Quality Color Mapping of Wing Bay Mesh. (b) Element Quality Range

To validate the change of parameters on the mesh section, Element Quality is created to demonstrate that the mesh would work efficiently after running a stress and strain simulation. As noted on the figure above, the average element quality is 0.75. After optimizing the mesh of the wing bay system, fixed supports were added to the edges of the pipe system to allow for a 6 degrees of freedom response when performing our modeling and for the pipe to not deform once on flight trajectory. Also, the projectile velocity is determined and its direction. As our current baseline, the FOd’s velocity is 150m/s to 200m/s on the (negative) -Z-axis to follow a flight trajectory as shown in table 1.2.
Table 1.2: Flight Trajectory

<table>
<thead>
<tr>
<th>Aircraft Take Off</th>
<th>Velocity applied on Z direction of Wing Bay.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft “Constant” Maneuver</td>
<td>Velocity applied on X direction of Wing Bay.</td>
</tr>
<tr>
<td>Aircraft Tilting</td>
<td>Velocity applied on XZ &amp; YZ (45 degrees) direction of Wing Bay (Perform twice but opposite direction)</td>
</tr>
<tr>
<td>Aircraft Landing</td>
<td>Velocity applied on -Z direction.</td>
</tr>
</tbody>
</table>

After labeling the initial conditions of the simulation, the analysis settings are placed to enable the total cycle time of flight after each step of the flight trajectory. The time cycle used for the simulation trials is 0.007 seconds with 100 data points. Then, result trackers are placed in the solution section to analyze in real time the trend of the stress and strain per time step.

**RESULTS**

The outputs from the Modeling section of Ansys are strain, stress, and deformation. The stress output allows the user to understand how much force per area (stress) is needed to create damage on the wing bay and pipe system. The strain output elaborates the deflection of the system before breaking point and the deformation illustrates the change of shape and design caused by the stress and strain.
These are current results that we have gained from our experimentation:

**Flight trajectory – Take off**

<table>
<thead>
<tr>
<th>Table 1.3: Take Off Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washers</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Stress (Pa)</td>
</tr>
<tr>
<td>Strain (m/m)</td>
</tr>
</tbody>
</table>

After evaluating the results from the take-off, the highest stress seen was at the moment of impact from the stainless-steel washer to the inside of the wing bay’s structure at $1.03 \times 10^6$ Pa and to comprehend the amount of damage, the strain was evaluated to check for deformation or displacement of the structure and was noted that the highest displacement shown was $2.71 \times 10^{-5}$ m/m. This concludes that there was no severe damage to the system caused by a washer FO.
Flight trajectory – Constant Maneuver

Table 1.4: Constant Maneuver Results

<table>
<thead>
<tr>
<th>Plastic Cap</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain</td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td></td>
</tr>
</tbody>
</table>

While the aircraft being on constant maneuver, most of the FOs did not cause any damage to the wing bay and did not deform. The only FO to get deformed was a plastic cap that impacted the pipe system. As shown on the table, the plastic cap had a strain of 1.57 m/m and a stress of $1.729 \times 10^9$ Pa. In the visuals, the plastic cap can be interpreted as damaged. To conclude, the pipe system was out of danger. This helps to understand the impact that a plastic could cause to the subsystems of the wing bay, which in this case seems to not affect any component.
Flight trajectory - Tilting

Table 1.5: Tilting Results

<table>
<thead>
<tr>
<th>Strain (m/m)</th>
<th>Washer</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stress (Pa)</th>
<th>Washer</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 1.9: Tilting Effect on Wing Bay

The results for the tilting section of the flight trajectory were not accurate. An issue was found on the structure of the wing bay which the material is titanium. At an angular velocity of 150 m/s on the X axis, it demonstrates that at the end of the flight cycle, the structure seems to deform. This creates an unrealistic scenario due to the material properties of the system. Further
tests would be run to illustrate the correct scenario. Aside from this issue, in this study, it can be evaluated that by having FOs near the close section of the wing bay that it can impact the engine or can go to the sublevels of the cockpit.

**Flight trajectory - Landing**

<table>
<thead>
<tr>
<th>Table 1.6: Landing Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washer</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain (m/m)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00069122 Max</td>
<td></td>
</tr>
<tr>
<td>0.00061442</td>
<td></td>
</tr>
<tr>
<td>0.00053762</td>
<td></td>
</tr>
<tr>
<td>0.00046031</td>
<td></td>
</tr>
<tr>
<td>0.00038401</td>
<td></td>
</tr>
<tr>
<td>0.00030721</td>
<td></td>
</tr>
<tr>
<td>0.00023041</td>
<td></td>
</tr>
<tr>
<td>0.0001536</td>
<td></td>
</tr>
<tr>
<td>7.6802e-5</td>
<td></td>
</tr>
<tr>
<td>0 Min</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stress (Pa)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1515e9 Max</td>
<td></td>
</tr>
<tr>
<td>1.9124e9</td>
<td></td>
</tr>
<tr>
<td>1.6734e9</td>
<td></td>
</tr>
<tr>
<td>1.4343e9</td>
<td></td>
</tr>
<tr>
<td>1.1953e9</td>
<td></td>
</tr>
<tr>
<td>9.5621e8</td>
<td></td>
</tr>
<tr>
<td>7.1716e8</td>
<td></td>
</tr>
<tr>
<td>4.7811e8</td>
<td></td>
</tr>
<tr>
<td>2.3905e8</td>
<td></td>
</tr>
<tr>
<td>0 Min</td>
<td></td>
</tr>
</tbody>
</table>
As shown in Figure 1.10, the impact from the washer and cap was not able to deform the pipe system at a velocity of 150m/s. The two washers were placed at the inner surface of the wing bay shell. It is noted that after impact, the two FOs had further impacted different sections of the wing bay system, causing the washer and the cap to deform further. However, no damage to the aircraft structure was found.

Export of Files

After the simulation is complete, name selections are created to label the elements and nodes as shown in Figure 1.11. Once the data is labeled, then is exported as a txt file which allows you to have a mapping of nodes that can be imported to Unity3D for illustration. Also, stress and strain text files are exported with node information. This contributes with the export of the mapping nodes because the result data can be simplified and can be in depth analyzed by looking at the strain and stress per node on the wing bay as illustrated on Figure 1.12.
CONCLUSION

Multiple finite element analysis simulations were developed through Explicit Dynamics to evaluate the flight trajectory of an aircraft. After analyzing the results of the take-off, constant maneuver, tilting, and landing, it was noted that none of the foreign objects placed affected the structure of the pipe system and wing bay at the velocities tested. This study showed that such FOs used such as plastic cap, fastener, and washers did not cause any failure. Although, to completely create an efficient predicting model, a stronger computer is required to test high speed velocities and to add multiple FOs to the subsystems aside then being restricted to 3 FOs per simulation.

To conclude, this study was able to assist with the creation of a predicting modeling where the outcome of the impact of FOs can be evaluated on a flight cycle. In addition, the export of the result data of the simulation was able to be sent as a txt file to Unity3D to allow a in depth analysis of the stress and strain resulted.
**Future Work**

Based on current results and the progress made on the project, it is known that there will be additional action items to further our results. From the modeling perspective, more simulations would be performed with different FOs, such as a combination of washer, tape, metal shavings, and fasteners with the purpose to create a pool of data that can assist with the in-depth analysis once exported to Unity3D. In addition, more FOs would be placed inside any subsystem of an aircraft aside from only testing from 1 to 3 FOs. The limiting factor while evaluating our study was the GPU potential from the computer. With the addition of a more powerful system, more FOs can be added to the simulations and higher speeds can be tested. Furthermore, the wing bay design would also be changed to have fuel tanks and pumps within the pipe system to create a close scenario to an actual aircraft instead of a dummy representation. Also, different subsystems from the aircraft would be evaluated such as the cockpit, engine, etc. Lastly, upcoming simulations would be run in time step variables to allow for a simplification of data and to export each time step to Unity3D for better result interpretation.

Finally, the end goal of having a ‘game’ or program that is available to visualize the simulation data within Unity in a Virtual Reality (VR) environment, where the user can select the area of interest inside the aircraft and select the desired Foreign Object to evaluate and the data should display consistently as in the FEA simulations.
Chapter 2: Optimization of Scanning Parameters of Non-Destructive Equipment (NDE) on Manufactured Composites with Internal Defects

INTRODUCTION

Non-Destructive Techniques (NDT) [5] have assisted different industries to validate the properties of their material on the surface or internally and to locate concerns on finished product without the need of destroying the material. Some of the concerns that can be found while inspecting with Non-Destructive equipment are cracking, delamination, location of foreign object inside components, etc. The benefits of these methods are that the system that has been inspected by NDT can still be operated. There are different methods of nondestructive evaluation such as x-ray, ultrasonic, acoustic, radiography, etc.

When evaluating composites, it is well known that the method used for Non-Destructive Evaluation (NDE) [6] is ultrasonic testing [7]. The ultrasonic technique is used for the detection of internal defects in sound conducting materials. A short pulse of ultrasound is generated by an electric charge applied to a piezoelectric crystal, which vibrates for a very short period at a frequency related to the thickness of the crystal. [8] Usually, there are different ultrasonic transducers that can be used and the most applied is a pulse echo response transducer. In a scanning probe, a sound wave would generate and travel through the material. The sound wave would bounce back to the probe and generate a data scan. With such probes, defects can be defined with high accuracy. In figure 2.1, a schematic is shown to demonstrate how a pulse echo transducer works while scanning an object. If a flaw is found, the transducer would capture through the bouncing response and map with high resolution the defect inside the component.
The objective in this chapter is to generate high resolution of images to train an Artificial Intelligence (AI) model where depth, location, and defect type can be found on manufactured composites. Scan parameters would be optimized from labeled experiments and allow for the trained AI to identify such defects with higher accuracy. This study would assist any user that inspects composite material and reduce the amount of scanning operation and analysis. The visualization of defects would be examined through the exports of C-Scan and B-Scan reading within the equipment used.
MATERIALS

The materials used to manufacture composites with handmade defects are shown on Table 2.1.

Table 2.1: Materials to Manufacture Composite

<table>
<thead>
<tr>
<th>Materials</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepreg Uni 4.3 Oz In, 12 Wide</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>Breather Cloth, 60 Wide - Yard</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>Yellow Sealant Tape</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>Low Temp Release Film, Non-Perf, 60-Yard</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>Nylon Bagging Film, Below 330F, 59 - Yard</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>System 2000 Epoxy - 5 Gallon Pail (Part A)</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>2 Hour Epoxy Cure – Gallon (Part B)</td>
<td>FiberGlast</td>
</tr>
<tr>
<td>Carbon Fiber Fabric UNI Directional 12k 50in/127cm 8.85oz/300gsm</td>
<td>Composite Envisions</td>
</tr>
</tbody>
</table>

NDT EQUIPMENT

The equipment used to scan curved composites is as illustrated on Table 2.2. The NW1 probe (Olympus, Tokyo, Japan) [10] scans the curvature of the composite with high accuracy and comfort. This transducer allows detecting internal defects easier. The mini encoder (Olympus, Tokyo, Japan) [11] is attached to the probe to anticipate the hand movement of the user while scanning curved composite. In addition, an Aqualene Wedge (Olympus, Tokyo, Japan) [12] is placed below of the transducer to create an output area for water to lubricate the transducer to
obtain higher resolution on scan. Lastly, an Omniscan SX was used to operate the phased array probe and obtain data from scanned composite as a value of A-Scan, B-Scan, & C-Scan.

The following in table 2 lists the names of the NW1 probe components, quantities required, and their cost.

<table>
<thead>
<tr>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omniscan SX – Olympus</td>
</tr>
<tr>
<td>Phased Array Probe - Olympus</td>
</tr>
<tr>
<td>Mini Encoder - Olympus</td>
</tr>
<tr>
<td>Aqualene Wedge - Olympus</td>
</tr>
</tbody>
</table>

**METHODOLOGY**

The composite that was used to test scan parameters consisted of a unidirectional carbon fiber strip that were layered up to 16 strips. While stacking strip by strip, metal washer and Teflon pieces were placed to represent inclusions and delamination. The process consisted of first placing low temperature bagging film in top of the curved mold, and nylon film. In addition, a strip of carbon fiber on a would be placed in top of the films. Then, a resin Part A to B ratio of epoxy was developed and coated each strip plus the washer and Teflon pieces layer by layer. Lastly, once stacking up the fiber, a breather film and nylon film would be placed on top of the composite to place the vacuum nozzle. This would allow to apply pressure by vacuum and have an efficient surface finish on the composite to ease the operation of scanning.

In the pursuit of optimizing scan parameters, an Omniscanner SX was used to operate and troubleshoot test scans. Within the Omniscanner, the data that can be retrieved are the A-Scan, B-
Scan, S-Scan & C-Scan. In addition, the depth and size can be exported from the user interface. The A-Scan represents the pulse travel response from the ultrasonic sensor. In this scan, the user can inspect the accuracy of the sensor and change the depth, gain and position of the signal sent. This allows the user to understand if there is a defect found or if there is attenuation [13] while scanning. The B-Scan represents the cross-sectional view of the test specimen. The C-Scan is the side view of the test specimen. Lastly, the S-Scan is the real time scan of a small area displayed in a B-Scan format. In Figure 2.2, the types of scans used on the Omniscanner SX are shown.

![Figure 2.2: NDE Scan Data [14]](image)

In total there are three curved composites that were used to test the abilities of the network to detect defects. Figures 2.3, 2.4, 2.5 provide a visual representation of the layout where the defects were placed. There are a total of 543 images produced by the NDE. Table 2.3 demonstrates the dimensions and images that are produced per composite scan. The composite scan is divided
into different sections where the raster scan would travel from left to right in three separate rows. Figure 2.6 illustrates the orientation of scan from left to right on composite.
Table 2.3: Dimension and Images Scans of Composites

<table>
<thead>
<tr>
<th>Name</th>
<th>Dimensions LxWxH</th>
<th>Layers</th>
<th>Defect Types</th>
<th>Number of Images</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite 6</td>
<td>30”x12”x1.84mm</td>
<td>26</td>
<td>Inclusions: 11 Delaminations: 12</td>
<td>222</td>
<td>3.70 mm</td>
</tr>
<tr>
<td>Composite 7</td>
<td>30”x12”x1.84mm</td>
<td>15</td>
<td>Inclusions: 6 Delaminations: 21</td>
<td>156</td>
<td>4.10 mm</td>
</tr>
<tr>
<td>Composite 8</td>
<td>30”x12”x1.84mm</td>
<td>16</td>
<td>Inclusions: 8 Delaminations: 11</td>
<td>165</td>
<td>4.58 mm</td>
</tr>
</tbody>
</table>

The A & I Gates are adjusted to align with front and back echo response from the pulse echo transducer. This allows for the recording of time of flight and evaluates the loss of sign in real time during operation of scan. In addition, the Time-Corrected Gain (TCG) [15] is edited to compensate for attenuation by increasing the range of reflection. TCG points are created and placed at different lengths. Point 1 is placed at the surface of the composite. Point 2 would represent ¼ of the total thickness of the composite. Point 3 would be a ½ of the total thickness. Point 4 represents the total thickness of the manufactured composite.

Figure 2.7 (a) A & I Gate Adjustment (b) Time-Corrected Gain
**RESULTS**

Multiple parameters were changed through different trials of scan parameters. As shown in Figure 2.8, different scan attempts were performed to evaluate the change of NDE parameters from the Omniscanner SX. The top two red rectangles represent two of the tested trials where the position and gain of the transducer were changed. In the first rectangle, the position was set at the midpoint of the thickness of the composite and a gain of 6db was used. As noted on the image, the two washers can be seen with accuracy, although there are yellow spots that are hard to label and identify. This could cause a failure once labeling the images in the AI model. As a result of the issues found on the first trial, the second trial was performed. In the second iteration, the position of the TCG was changed. Three points were added to the TCG that consisted at point 1, 0.86mm of position of depth and with an add on of gain to be 1.3 db. Point 2 had a depth position of 2.58mm and gain of 2.3 dB and lastly 3.05mm with a gain of 3.3 db. By decreasing the value of gain depth, it was noted that the resolution of the scan decreased. The washers were still available to map, but the rest of the scan was completed differently and difficult to comprehend. Comparing trial one and two, it was noted that the decrease of gain size would affect the resolution. In the third trial as shown on Figure 2.9, the gain was increased with the same position. At point 1, the gain stayed at 0 because it was close to the surface, so adding more gain to the constant provided by the Omniscanner SX was not going to be beneficial. At point 2, the value increased to 2dB and point 3, the gain increased to 4 db. Figure 2.9 retrieved a higher resolution where now the delamination could be well seen and the washers as well. The red line on the left section of the image represents human error and issues with beginning of scan. After evaluating the variety of trials, the TCG was adjusted to the position on point 1. The gain increased to 0.5db. With the change of parameters as seen in Figure 2.10, the image obtained was able to demonstrate with clarity the inclusion and delamination as shown on the green and pink rectangles.
Figure 2.8: Scan Trials

Figure 2.9: TCG Optimized Scan

Figure 2.10: NDE Optimized Scan
CONCLUSION

Optimization of scan parameters were achieved through experimentation where the threshold of depth was analyzed as well as the position and gain from the time corrected gain. With the incrementation of gain per position, it was noted that the resolution changed drastically and allowed for better labeling when exported to the machine learning model. The washers and teflon pieces across layouts of composite were validated by the outcome of the images. The images generated train the AI model to represent in a 3D rendering software named Unity 3D. This allows the user to develop an in-depth analysis of where the debris or delamination and defects could be found once scanning the composite. In addition, by the creation of this model, it assisted in operational cost because of removing the need of hiring a third-party inspector that would evaluate the composite.

FUTURE WORK

The results given by the optimization of NDE parameters allowed the team to expand our knowledge to different tasks and this study could help more. Through the labeling of images, the AI model that was trained only consisted of delamination and inclusions. In future work, the composites would be evaluated with more types of defects, such as voids, cracks, porosity, and bumps caused by debris. Different add on of materials would be tested in addition to the metal washers and teflon pieces. In the upcoming stages of this study, the scanning method should also change. With current results, it is noted that there is still human error on scans. This can be prevented by creating an automation process where the scanner can move across the cross-sectional area of the composite. In addition, it would be beneficial to scan complex curved designs to align with realistic scenarios of aerospace components.
References


Vita

Luis Rodriguez is pursuing his final semester of Master of Science in Mechanical Engineering at The University of Texas at El Paso (UTEP). Mr. Rodriguez completed his Bachelor of Science in Mechanical Engineering from UTEP in December 2022. Currently, he is working with The Aerospace Center and Industrial, Manufacturing, and System Engineering (IMSE) center.

Mr. Rodriguez had the opportunity to participate in a sponsored project with Lochheed Martin Aeronautics in 2023 & 2024. In 2023, he focused on optimizing non destructive testing parameters to generate high resolution images to train an artificial intelligence model. In 2024, Luis had the opportunity to work on a research project that consisted of developing a predicting model for foreign object impact debris through digital engineering.

Mr. Rodriguez has interned with multiple industries throughout his bachelor and graduate years. Luis interned in DuPont Vespel in 2021 as a Mechanical Engineer Intern. Also, Mr. Rodriguez interned with Ford Motor Company in 2022 as a Manufacturing Engineer Intern as a senior student in his bachelor. After graduating from his bachelor’s degree, he was able to intern with Apple Inc in 2023 as an Engineering Program Manager Intern.

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