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Vinod K Chakka
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SHOCK REDUCTION METHODS FOR ELECTRONIC COMPONENTS IN A PROJECTILE

by

Vinod K. Chakka

Bachelor of Science in Mechanical Engineering
J.N.T.U.C.E, Hyderabad, Andhra Pradesh
July 2003

A thesis submitted in partial fulfillment of the requirements for the

Master of Science Degree in Mechanical Engineering
Department of Mechanical Engineering
Howard R. Hughes College of Engineering

Graduate College
University of Nevada, Las Vegas
May 2006
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Shock Reduction Methods for Electronic Components in a Projectile

is approved in partial fulfillment of the requirements for the degree of

Masters of Science Mechanical Engineering

BY

Examination Committee Co-Chair

Examination Committee Chair

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Examination Committee Member

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Graduate College Faculty Representative
ABSTRACT

Shock Reduction Methods for Electronic Components in a Projectile

by

Vinod K. Chakka

Dr. Mohamed B. Trabia, Examination Committee Chair
Professor and Chairperson of Mechanical Engineering
University of Nevada, Las Vegas
and

Dr. Brendan J. O'Toole, Examination Committee Chair
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Electronic components within a projectile are subjected to severe loads over extremely short duration. Failure of these components is likely to have negative implications to projectile or mission. While experimental data can be helpful in understanding the failure phenomena, collecting such data is difficult. There are also limitations on the reliability of shock sensors under these circumstances. Finite Element Modeling can offer a means to better understand the behavior of these components. It can also be used to design better techniques to mitigate the shocks these components are subjected to. A model of a projectile and gun barrel is presented. The model is subjected to a realistic launch pressure time-history. The projectile is modified to include a one-pound mass that represents a typical electronic package. The electronic package is supported by a steel plate. Efforts were put in this research to find a suitable material that reduces the shock transmitted to the 1-pound payload. A composite material
with carbon fiber reinforced in an epoxy matrix has been considered to start with. The effect of fiber volume fraction has been studied by varying it from 30%-70%. The model includes effects of friction between the gun barrel and projectile. Effects of the flexibility of the gun barrel and its boundary conditions are also considered. A parametric study of the effects of changing the thickness of the supporting plate on acceleration transmitted to the electronic package within and outside the gun barrel is presented. Sensitivity of payload mounting location is also studied.
TABLE OF CONTENTS

ABSTRACT ............................................................................................................................. iii
TABLE OF CONTENTS ......................................................................................................... v
LIST OF TABLES .................................................................................................................. vii
LIST OF FIGURES ............................................................................................................... viii
ACKNOWLEDGMENTS ........................................................................................................ x

CHAPTER 1  INTRODUCTION ............................................................................................. 1
1.1 Development of Projectiles .............................................................................. 1
1.2 Description of a Typical Projectile ............................................................... 2
1.3 Classification of Projectiles ........................................................................ 4
1.3.1 Classification by Size of Gun ................................................................. 4
1.3.2 Classification by Assembly .................................................................... 5
1.3.3 Classification by Service Use ................................................................. 6
1.3.4 Classification by Purpose and Construction ........................................... 7
1.4 Forces Acting on Projectile ...................................................................... 7
1.5 Summary of Previous Work ..................................................................... 9
1.6 Objectives of the Research .................................................................... 11

CHAPTER 2  DESCRIPTION OF PROJECTILE, GUN BARREL AND FINITE
ELEMENT MODELING ............................................................................. 12
2.1 Introduction .......................................................................................... 12
2.2 Simplified model .................................................................................. 14
2.3 Description of the Parts of the Simplified Projectile ................................ 16
2.3.1 Windshield ...................................................................................... 16
2.3.2 Nacelle ............................................................................................ 16
2.3.3 M795 Ogive .................................................................................... 21
2.3.4 M795 Body ..................................................................................... 22
2.3.5 Band ................................................................................................. 23
2.3.6 Plate and Payload ............................................................................. 24
2.4 Description of Gun Barrel ....................................................................... 27
2.5 Finite Element Modeling ....................................................................... 29
2.5.1 Meshing ............................................................................................ 29
2.5.2 Material Properties .......................................................................... 33
2.5.3 Contact Definitions ............................................................................ 33
2.5.4 Boundary Conditions .......................................................................... 38
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.5 Load Curves</td>
<td>39</td>
</tr>
<tr>
<td>CHAPTER 3 FINITE ELEMENT ANALYSIS</td>
<td>42</td>
</tr>
<tr>
<td>3.1 LS-DYNA Input Cards</td>
<td>42</td>
</tr>
<tr>
<td>3.2 Location of Projectile Inside Gun Barrel</td>
<td>43</td>
</tr>
<tr>
<td>3.3 Final Model</td>
<td>46</td>
</tr>
<tr>
<td>3.4 Phases of the Finite Element Analysis</td>
<td>48</td>
</tr>
<tr>
<td>3.4.1 Static Analysis</td>
<td>48</td>
</tr>
<tr>
<td>3.4.2 Dynamic Analysis</td>
<td>49</td>
</tr>
<tr>
<td>3.5 Results</td>
<td>51</td>
</tr>
<tr>
<td>CHAPTER 4 SHOCK REDUCTION METHODS</td>
<td>58</td>
</tr>
<tr>
<td>4.1 Variation of location of plate</td>
<td>58</td>
</tr>
<tr>
<td>4.1.1 Results</td>
<td>61</td>
</tr>
<tr>
<td>4.2 Variation of Material Properties of the Plate</td>
<td>85</td>
</tr>
<tr>
<td>4.2.1 Calculation of Laminate Properties</td>
<td>88</td>
</tr>
<tr>
<td>4.3 Variation of Thickness of the Composite Plate</td>
<td>92</td>
</tr>
<tr>
<td>4.3.1 Results</td>
<td>94</td>
</tr>
<tr>
<td>4.4 Summary of Results</td>
<td>106</td>
</tr>
<tr>
<td>CHAPTER 5 CONCLUSIONS AND FUTURE WORK</td>
<td>107</td>
</tr>
<tr>
<td>5.1 Conclusions</td>
<td>107</td>
</tr>
<tr>
<td>5.2 Future Work</td>
<td>107</td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>109</td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>111</td>
</tr>
<tr>
<td>APPENDIX C</td>
<td>113</td>
</tr>
<tr>
<td>APPENDIX D</td>
<td>115</td>
</tr>
<tr>
<td>APPENDIX E</td>
<td>116</td>
</tr>
<tr>
<td>APPENDIX F</td>
<td>117</td>
</tr>
<tr>
<td>APPENDIX G</td>
<td>120</td>
</tr>
<tr>
<td>APPENDIX H</td>
<td>121</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>123</td>
</tr>
<tr>
<td>VITA</td>
<td>125</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

Table 2.1: Material Properties of Windshield [11] .............................................................16  
Table 2.2: Mass calculations for Nacelle Along with Electronic Components ..........20  
Table 2.3: Material Properties of Nacelle [11] .................................................................21  
Table 2.4: Material Properties of M795 Ogive [11] .........................................................22  
Table 2.5: Material Properties of M795 Body [11] ............................................................23  
Table 2.6: Material Properties of Band .............................................................................24  
Table 2.7: Material Properties of Plate [11] ......................................................................26  
Table 2.8: Material Properties of Payload [11] .................................................................26  
Table 2.9: Material Properties of Gun Barrel [11] ............................................................27  
Table 2.10: Summary of Number of Nodes and Elements ..............................................30  
Table 2.11: List of Contacts ..............................................................................................37  
Table 3.1: Boundary Conditions on Planes of Symmetry ...............................................43  
Table 3.2: List of Elements and Nodes for Each Part ......................................................46  
Table 3.3: Modal Results of the Projectile ........................................................................54  
Table 4.1: Variation of Total Mass and Center of Mass for the Projectile .......................60  
Table 4.2: Summary of Results for Node on Payload .....................................................77  
Table 4.3: Summary of Filtered Results for Node on Payload ........................................78  
Table 4.4: Summary of Results for Node on Projectile ..................................................80  
Table 4.5: Summary of Filtered Results for Node on Projectile .......................................81  
Table 4.6: Summary of Results for Node on Plate ............................................................83  
Table 4.7: Summary of Results for Node on Plate ............................................................84  
Table 4.8: Variation of Laminate Properties with Change in Fiber Volume Fraction ......92  
Table 4.9: Maximum Y Acceleration (filtered) Inside Gun Barrel for Node on payload ....100  
Table 4.10: Maximum Y Acceleration (filtered) Outside Gun Barrel for Node on Payload ......100  
Table 4.11: RMS Y Acceleration (filtered) Inside Gun Barrel for Node on Payload ..........102  
Table 4.12: RMS Y Acceleration (filtered) Outside Gun Barrel for Node on Payload ....102  
Table 4.13: Maximum Von Mises Stress Induced in the Electronic Package .................104
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>External Features of a Typical Projectile [3]</td>
<td>3</td>
</tr>
<tr>
<td>1.2</td>
<td>Separated Ammunition and Fixed Ammunition [3]</td>
<td>6</td>
</tr>
<tr>
<td>2.1</td>
<td>Sectional View of Projectile with Electronic Components</td>
<td>13</td>
</tr>
<tr>
<td>2.2</td>
<td>Sectional View of the Simplified Projectile</td>
<td>15</td>
</tr>
<tr>
<td>2.3</td>
<td>Electronic Components Inside Nacelle</td>
<td>17</td>
</tr>
<tr>
<td>2.4</td>
<td>Details of Electronic Components</td>
<td>19</td>
</tr>
<tr>
<td>2.5</td>
<td>Gun Barrel</td>
<td>28</td>
</tr>
<tr>
<td>2.6</td>
<td>Fully Meshed 3D Projectile</td>
<td>31</td>
</tr>
<tr>
<td>2.7</td>
<td>Sectional View of the Fully Meshed Projectile</td>
<td>32</td>
</tr>
<tr>
<td>2.8</td>
<td>Defining Set Segment</td>
<td>34</td>
</tr>
<tr>
<td>2.9</td>
<td>Contact Surfaces for Windshield and Nacelle</td>
<td>35</td>
</tr>
<tr>
<td>2.10</td>
<td>Contact Surfaces for Nacelle and Ogive</td>
<td>35</td>
</tr>
<tr>
<td>2.11</td>
<td>Contact Surfaces for Ogive and M795</td>
<td>36</td>
</tr>
<tr>
<td>2.12</td>
<td>Contact Surfaces for Ogive and Plate</td>
<td>36</td>
</tr>
<tr>
<td>2.13</td>
<td>Contact Surfaces for Band and Gun barrel</td>
<td>37</td>
</tr>
<tr>
<td>2.14</td>
<td>Meshed Gun Barrel with Boundary Conditions</td>
<td>38</td>
</tr>
<tr>
<td>2.15</td>
<td>Wire Frame View of M 795 and Band</td>
<td>40</td>
</tr>
<tr>
<td>2.16</td>
<td>Pressure on Flat and Slanted Faces</td>
<td>40</td>
</tr>
<tr>
<td>2.17</td>
<td>Pressure Curve</td>
<td>41</td>
</tr>
<tr>
<td>3.1</td>
<td>Applied Boundary Condition on the Planes of Symmetry [9]</td>
<td>44</td>
</tr>
<tr>
<td>3.2</td>
<td>Axial Displacement Versus Time [9]</td>
<td>45</td>
</tr>
<tr>
<td>3.3</td>
<td>Gun Barrel and Exploded View of the Projectile Inside Gun Barrel</td>
<td>47</td>
</tr>
<tr>
<td>3.4</td>
<td>Static Deflection of the Gun Barrel</td>
<td>49</td>
</tr>
<tr>
<td>3.5</td>
<td>Locations of Data Collection</td>
<td>50</td>
</tr>
<tr>
<td>3.6</td>
<td>Axial Displacement Versus Time for Node on Top Center of the Mass</td>
<td>51</td>
</tr>
<tr>
<td>3.7</td>
<td>Axial Velocity Versus Time for Node on Top Center of the Mass</td>
<td>52</td>
</tr>
<tr>
<td>3.8</td>
<td>Axial Acceleration Versus Time for Node on Top Center of the Mass</td>
<td>53</td>
</tr>
<tr>
<td>3.9</td>
<td>Mode Shape of the First Bending Frequency of the Projectile</td>
<td>56</td>
</tr>
<tr>
<td>3.10</td>
<td>Axial Acceleration Versus Time for Node on Top Center of the Mass after Filtering at 6000HZ</td>
<td>57</td>
</tr>
<tr>
<td>3.11</td>
<td>Axial Acceleration Versus Time for Node on Projectile after Filtering at 6000HZ</td>
<td>57</td>
</tr>
<tr>
<td>4.1</td>
<td>Location of Plate in the Projectile</td>
<td>60</td>
</tr>
<tr>
<td>4.2</td>
<td>Variation of Location of the Plate in the Projectile</td>
<td>62</td>
</tr>
<tr>
<td>4.3</td>
<td>Y Displacement for the Node on Payload</td>
<td>63</td>
</tr>
<tr>
<td>4.4</td>
<td>Y Displacement for the Node on Projectile</td>
<td>64</td>
</tr>
<tr>
<td>4.5</td>
<td>Y Displacement for the Node on Plate</td>
<td>65</td>
</tr>
<tr>
<td>4.6</td>
<td>Velocity for the Node on Payload</td>
<td>66</td>
</tr>
<tr>
<td>4.7</td>
<td>Y Velocity for the Node on Projectile</td>
<td>67</td>
</tr>
</tbody>
</table>
Figure 4.8: Y Velocity for the Node on Plate ................................................................. 68
Figure 4.9: Y Acceleration for the Node on Payload ...................................................... 69
Figure 4.10: Y Acceleration for the Node on Payload (filtered at 6000Hz) ............... 71
Figure 4.11: Y Acceleration for the Node on Payload (filtered at 6000Hz) ............... 72
Figure 4.12: Y Acceleration for the Node on Projectile ............................................... 73
Figure 4.13: Y Acceleration for the Node on Projectile (filtered at 6000Hz) .............. 74
Figure 4.14: Y Acceleration for the Node on Projectile (filtered at 6000Hz) .............. 75
Figure 4.15: Y Acceleration for the Node on Plate ......................................................... 76
Figure 4.16: Y Acceleration for the Node on Plate (filtered at 6000Hz) ................. 79
Figure 4.17: Y Acceleration for the Node on Plate (filtered at 6000Hz) ................. 79
Figure 4.18: Y Acceleration for the Node on Payload (filtered at 6000Hz) .............. 82
Figure 4.19: RMS Y Acceleration for the Node on Payload (filtered at 6000Hz) ........ 82
Figure 4.20: Y Acceleration for the Node on Projectile (filtered at 6000Hz) .......... 85
Figure 4.21: RMS Y Acceleration for the Node on Projectile (filtered at 6000Hz) .... 85
Figure 4.22: Y Acceleration for the Node on Plate (filtered at 6000Hz) .............. 87
Figure 4.23: Y Acceleration for the Node on Plate (filtered at 6000Hz) .............. 89
Figure 4.24: The 3 Laminas Used for the Composite Laminate .................................. 93
Figure 4.25: Stacking Sequence of Laminas in the Laminate ...................................... 94
Figure 4.26: Variation of Thickness of the Composite Plate .......................................... 95
Figure 4.27: Acceleration Comparison for Node on Mass for Steel Plate and Composite plate with Fiber volume Fraction 30% ............................................................ 96
Figure 4.28: Filtered Acceleration Comparison for Node on Mass for Steel Plate and Composite plate with Fiber volume Fraction 30% .................................................. 97
Figure 4.29: Filtered Acceleration Comparison Outside Gun Barrel for Node on Mass for Steel Plate and Composite plate with Fiber volume Fraction 30% ................. 98
Figure 4.30: Acceleration Comparison for Node on Projectile for Steel Plate and Composite plate with Fiber volume Fraction 30% .................................................. 94
Figure 4.31: Filtered Acceleration Comparison for Node on Projectile for Steel Plate and Composite plate with Fiber volume Fraction 30% .................................................. 99
Figure 4.32: Filtered Y Acceleration Comparison Outside Gun Barrel for Node on Projectile for Steel Plate and Composite plate with Fiber volume Fraction 30% .......... 96
Figure 4.33: 3D Chart Representing the Variation of Y acceleration Outside the Gun Barrel (filtered 6000Hz) with Variation in Thickness and Fiber Volume Fraction of the Plate ................................................................. 101
Figure 4.34: 3D Chart Representing the Variation of RMS Y acceleration Outside the Gun Barrel (filtered 6000Hz) with Variation in Thickness and Fiber Volume Fraction of the Plate ................................................................. 103
Figure 4.35: 3D Chart Representing the Variation of Maximum Von Mises Stress with Variation in Thickness and Fiber Volume Fraction of the Plate ................................................................. 105
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CHAPTER 1

INTRODUCTION

1.1 Development of Projectiles

A projectile is any object sent through space by the application of a force. In a general sense, even a football or baseball may be considered a projectile, but in practice most projectiles are designed as weapons. Arrows, darts, spears, and similar weapons are fired using pure mechanical force applied by another solid object; conversely, other weapons use the compression or expansion of gases as their motive force. Some projectiles provide propulsion during the flight by means of rocket engine. In military terminology a rocket is considered as unguided projectile while guided projectile is called a missile [1].

Gunpowder, known in China by the ninth century and transported to Europe during the thirteenth century, radically changed the development of ballistic weaponry. The pivotal event was the development by European smiths in the early 1300s of tubular barrels that could fire spherical projectiles. The development of high explosives and nitrocellulose-based (smokeless) propellants in the final decades of the nineteenth century produced a revolution in ballistic weaponry. The maximum muzzle velocities and ranges of gun systems increased enormously and high-explosive shells gave artillery an order-
of-magnitude leap in destructive capacity. Advances in aerodynamic knowledge were applied to the projectile design enhancing accuracy, range, and terminal effect. Tube artillery approached a plateau of tactical effectiveness with the development in the early twentieth century of fire-control systems attached to the gun, which produced the proper elevation and lead angle for moving targets when the estimated range was entered. The first of these were mechanical analog systems (that is, working on the same principles as a slide rule) for long-range naval gunnery. By World War II, electro-mechanical analog fire-control systems were the norm for naval and antiaircraft artillery, and fighter aircraft were fitted with gyroscopic lead-computing gun sights. Currently, artillery of all kinds is directed by digital electronic fire-control systems using inputs from electronic-sensor and target-acquisition systems. Radar-activated fuses, developed by American and British scientists during World War II, increased the lethality of antiaircraft and field artillery, in the latter case with precisely controlled low-altitude air bursts. A wide array of ballistic antitank weapons and munitions appeared in World War II [2]. The most recent major ballistic weapons are the aerial bomb and intermediate- and intercontinental-range ballistic missiles, IRBMs and ICBMs.

1.2 Description of a Typical Projectile

Generally gun ammunition consists of a projectile and propelling charge. The projectile is a component of ammunition that when fired from a gun carries out the tactical purpose of the weapon. While some types of projectiles are one piece and some are assemblies of several components but all the projectiles have common external features, which are shown in Figure 1.1.
OGIVE: The ogive is the curved forward portion of a projectile. The curve is determined by a complex formula designed to give maximum range and accuracy. The shape of the ogive is generally expressed by stating its radius in terms of calibers. It may be a combination of several arcs of different radii.

BOURRELET: The bourrelet is a smooth, machined area that acts as a bearing to stabilize the projectile during its travel through the gun bore. Some projectiles have only one bourrelet forward one or two aft, the after one being located adjacent to and either forward and/or aft of the rotating band. Bourrelets are painted to prevent rusting.

BODY: The body is the main part of the projectile and contains the greatest mass of metal. It is made slightly smaller in diameter than the bourrelet and is given only a machine finish.

ROTATING BAND: The rotating band is circular and made of commercially pure copper, copper alloy, or plastic seated in a scored cut in the after portion of the projectile body. In all minor and medium caliber projectiles, rotating bands are made of
commercially pure copper or gilding metal that is 90 percent copper and 10 percent zinc. Major caliber projectile bands are of cupro-nickel alloy containing 2.5 percent nickel or nylon with a Micarta insert. As a projectile with a metallic band passes through the bore of the gun, a certain amount of copper will be wiped back on the rotating band and will form a skirt of copper on the after end of the band as the projectile leaves the muzzle of the gun. This process is known as fringing and is prevented by cutting grooves, called cannelures, in the band or by undercutting the lip on the after end of the band. These cuts provide space for the copper to accumulate. The primary functions of a rotating band are:

1. To seal the forward end of the gun chamber against the escape of the propellant gas around the projectile,

2. To engage the rifling in the gun bore and impart rotation to the projectile.

3. To act as a rear bourrelet on those projectiles which, do not have a rear bourrelet.

1.3 Classification of Projectiles

Development of technology has invented many types of projectiles, which are classified in several different ways depending on specific needs such as the size of gun, assembly configuration, service use or purpose and construction.

1.3.1 Classification by Size of Gun

Gun ammunition is most commonly classified by the size of the gun in which it is used. In addition to designations of bore diameter, such as 25-mm, 76-mm, or 5-inch, the length of the gun bore in calibers (inches) is also used as a means of classification. Thus a 5-inch, 54-caliber projectile is one used in a gun having a bore diameter of 5 inches and a bore length of 54 times 5 inches, or 270 inches.
1.3.2 Classification by Assembly

The three types of ammunition classified by assembly are shown in Figure 1.2.

FIXED AMMUNITION: The fixed class applies to ammunition that has the cartridge case crimped around the base of the projectile. The primer is assembled in the cartridge case. The projectile and the cartridge case, containing the primer and propellant charge, all form one unit as a fixed round of ammunition. Guns through 76-mm use fixed ammunition.

SEPARATED AMMUNITION: This class applies to ammunition that consists of two units—the projectile assembly and the cartridge case assembly. The projectile assembly consists of the projectile body containing the load, nose fuze, base fuze, and auxiliary detonating fuze, as applicable. The cartridge case assembly consists of the cartridge case, primer, propellant charge, wad, distance piece, and a plug to close the open end of the cartridge case. The projectile and cartridge are rammed into the gun chamber together as one piece though they are not physically joined. Separate ammunition has been produced in gun sizes of 5-inch, 38-caliber through 8-inch, 55-caliber guns.

SEPARATE-LOADING (BAGGED GUN) AMMUNITION: This class applies to gun sizes 8 inches and larger. Separate-loading ammunition does not contain a cartridge case. The propellant charge is loaded in silk bags that are consumed during the combustion of the propellant when fired from the gun. The projectile, propellant charge and primer are loaded separately. There are currently no naval guns in use that use separate-loading ammunition.
1.3.3 Classification by Service Use

For economy and safety, gun ammunition is assembled and classified by service use, as follows

SERVICE: Ammunition for use in combat. These projectiles carry explosive, illuminating, or chemical payloads.
TARGET and TRAINING: Ammunition for training exercises. The projectiles are comparable in weight and shape to those of service ammunition but are of less expensive construction and normally contain no explosive. Variable time, nonfragmenting (VT NONFRAG) projectiles are an exception in that they are for training purposes.

DUMMY or DRILL: Any type of ammunition assembled without explosives, or with inert material substituted for the explosives, to imitate service ammunition. The ammunition may be made of metal or wood. Dummy or drill ammunition is used in training exercises or in testing equipment. It is normally identified as dummy cartridges, dummy charges, or drill projectiles. Drill projectiles will not be fired from any gun.

1.3.4 Classification by Purpose and Construction

Service projectiles are classified by their tactical purpose as one of the following types: penetrating, fragmenting, and special purpose. Since targets differ in design and purpose, projectiles must also differ in their construction to make them more effective. If you were to cut open, for purposes of inspection, the different types of projectiles listed previously (other than small arms), you would find their construction and characteristics are common. For example, penetrating projectiles have thick walls and a relatively small cavity for explosives, while fragmenting projectiles are thin-walled and have a relatively large cavity for explosives. Because of this difference, projectiles may also be classified by their construction [3].

1.4 Forces Acting on Projectile

During the last twenty years the U.S. Army has been developing "smart artillery" munitions. These munitions contain sophisticated embedded electronic systems.
Unfortunately the artillery environment is extremely harsh. The munitions must operate in temperatures from -60°F to 160°F. The projectiles are subjected to a quasi-static axial load in excess of 15,000 g's augmented by a transient load of up to 5000 g's [4]. The projectiles can spin at up to 300 revolutions per second and as the projectile travels down the gun barrel, it also is subjected to off-axis loads from impacts with the gun tube walls caused by balloting [4]. After leaving the gun barrel in the outside atmosphere, ballistic projectiles are affected by gravity and follow a parabolic arc. Trajectories within the atmosphere are affected by aerodynamic drag, the resistance of the air to movement. At subsonic velocities, drag is a product of the velocity squared; atmospheric density; and the size, shape, and surface texture (relative smoothness) of the projectile. At supersonic velocities, drag is further influenced by Mach number, that is, the velocity of the projectile as a multiple of the speed of sound. Drag increases sharply as the velocity approaches and exceeds the speed of sound, and supersonic drag is particularly sensitive to projectile shape.

Impact and shock imparted to the electronic components due to the high 'g' forces during the launch phase of the projectiles can cause significant functional and physical damage in the form of internal component failure or damage on the external housing. To avoid the cost and inconvenience associated with repair or replacement, such components must be able to accommodate occasional severe impacts and yet sustain minimal damage. Therefore we are not only concerned with the physical ruggedness of the electronic components but also with the reliability to impact and shock [8]. These challenges present significant problems for the designers who typically resort to the use of numerical simulations to provide guidance on these issues. However, the complex nature of these
structures present a particular difficulty to designers using finite element analysis to obtain quick and reliable answers to these questions.

A complete transient simulation of the launch event, including the projectile and its components can consist of millions of degrees of freedom and take several weeks to execute, even with the use of parallel processing techniques. Post-processing the results may require a long time also [4].

1.5 Summary of Previous Work

The Army Research Laboratory (ARL) is developing techniques and methodologies for significantly reducing the run and processing time requirements for these simulations. The techniques that ARL are developing revolve around various forms of submodelling and/or global/local approaches. In these approaches, a global model is built that lacks substructure details. The substructures in the global model are represented by a structure with approximate mass and stiffness parameters. In a separate simulation, the loads measured between the global model and the simplified substructures are then applied to a detailed model of the substructure. This approach yields a good approximation to a comprehensive finite element model for quasistatic conditions, assuming reasonably accurate mass and stiffness approximations. However, if the structure is responding in a non-linear, transient fashion, the interaction between local and global are much more complex. In a transient simulation, there could be dynamic interactions between the detailed components and the global structure, which would not be predicted in a quasistatic analysis. An outgrowth of the above limitations is the need to construct an experiment for the projectile model and simulation of a very simple structure.
subjected to a series of loads from quasi-static to transient in duration. The development of the experiment and numerical model will lead to a much better understanding of the structural response of circuit cards to very short duration loads. A more representative projectile model could then be built which is more computationally efficient and physically accurate [5]. A detailed finite element analysis of the projectile and its internal components was developed by Nallani [9]. A parametric study regarding the effect of electronic component mounting location on peak acceleration and RMS acceleration was also performed [9].

One of the difficulties facing the U.S. Army and its contractors is the specification of gun launch loads to component manufacturers prior to the final design of the projectile. In the past, pressure-time curves and peak acceleration values were provided to contractors, the peak values were used to perform static analysis and quasi-static centrifuge tests. The dynamics of the projectile structure [6], particularly during the muzzle exit transient, were neglected. As a result, programs like the U.S. Army’s Excalibur and SADARM experienced numerous failures of sensitive equipment during the early stages of development [5]. In the Excalibur program, several failures of sensitive equipment were traced to the muzzle exit event using break-wire tests. A simple method [5] was described for early predictions of acceleration along the projectile, it predicted the muzzle exit event, the locations of maximum and minimum acceleration along the projectile, and the joint loads. These Predictions can be used to place sensitive equipment or to design components that better resist the high, transient g-forces resulting from gun-firings.
1.6 Objectives of the Research

The current project was commenced as a cooperative venture between the University of Nevada, Las Vegas (UNLV) and the Army Research Laboratories (ARL). The goal is to develop a methodology to reduce transmitted shock loading to electronic components within an artillery shell during the launch phase (including setback and muzzle exit conditions).

At the initiation of this research, detailed solid model of the projectile was obtained from the U.S. ARMY ARDEC [7]. A 1-pound payload supported by a plate is incorporated within the projectile. The objective is to explore the ways to reduce the acceleration transmitted to the mass by conducting a transient Finite Element Analysis (FEA) of the launch conditions. In the previous work by Nallani [9] the 1-pound payload was supported by a steel plate. Efforts were put in this research to find a suitable material that reduces the shock transmitted to the 1-pound payload. A composite material with carbon fiber reinforced in an epoxy matrix has been considered to start with. Composite materials have a number of valuable properties including high specific strength and rigidity, high fatigue resistance and satisfactory resistance to damage etc [10]. The effect of fiber volume fraction has been studied by varying it from 30%-70%. A parametric study was performed to find the suitable thickness of the plate.
CHAPTER 2

DESCRIPTION OF PROJECTILE, GUN BARREL AND FINITE ELEMENT MODELING

2.1 Introduction

The present chapter deals with the description of the original projectile, the modifications done to the original model to make it more adaptable for the finite element modeling and, the description of the finite element methodology. Figure 2.1 depicts the Sectional view of the original projectile supplied by the ARDEC. Initially this projectile is placed inside the gun barrel. Pressure loads are applied to the base of the projectile to move it. The projectile mainly consists of five parts namely, Windshield, Nacelle, M795 Ogive, M795 Body, Bottom Nacelle and Band. The windshield is threaded to the nacelle, the nacelle is attached to M795 Ogive with help of screws and bolts, the M795 Ogive is threaded to M795 Body, the plate is threaded to M795 Ogive, the mass may be glued or welded to the plate and Band is shrink fitted to M795 Body. The basic purpose of this test projectile is to measure the radial, axial accelerations and the strains that the projectile experiences during the launch phase. The sensors to measure the accelerations and to measure strains induced are mounted inside bottom nacelle, which is placed inside the M795 body. The antennas, data storage devices and batteries etc.. are placed inside the
nacelle. The total length of the projectile is 20.4 inches. The maximum diameter of the projectile is 6.1 inches.

Figure 2.1: Sectional View of Projectile with Electronic Components
2.2 Simplified model

As Figure 2.1 shows the projectile consists of several components. Incorporating all of them in a finite element analysis will result in an extremely complex model. To avoid such difficulty, several modifications of the model are considered. The major modification is to eliminate electronic components and modify the mass of the nacelle accordingly. A payload of mass 1 pound which represents typical electronic package is mounted over a plate. The ogive geometry is modified to allow attaching plate to it. This simplified projectile, Figure 2.2, consists of the following parts. The simplified model has the following parts:

1. Windshield
2. Nacelle
3. M795 Ogive
4. M795 Body
5. Band
6. Plate
7. Payload
Figure 2.2: Sectional View of the Simplified Projectile
2.3 Description of the Parts of the Simplified Projectile

2.3.1. Windshield

Windshield is placed at the front end of the projectile to improve the aerodynamic performance of the projectile. To reduce the weight it is made of Ultem 2300 plastic. It is threaded on the top of the nacelle. The physical and metallurgical properties are taken from supplier’s website [5]. The material properties and a picture of the quarter-section of the windshield are shown in Table 2.1.

Table 2.1: Material Properties of Windshield [5]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultem 2300 (30% glass)</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>1.42E-04 lb/in³</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>8E+05 psi</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.4</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>24.5E+03 psi</td>
</tr>
<tr>
<td>Volume</td>
<td>2.62 in³</td>
</tr>
<tr>
<td>Mass</td>
<td>0.1441 lb</td>
</tr>
</tbody>
</table>

2.3.2 Nacelle

Nacelle is a streamlined enclosure for sheltering the electronic components of the projectile. It is made up of Aluminum 7075-T6511. The electronic components of the projectile are stacked inside cups as shown in Figure 2.3. Figure 2.4 shows a detailed view of these components. To avoid over complicating the finite element analysis, these
electronic components are removed from the model, while maintaining the total mass of the nacelle. A description of the electronic components is given below and the mass and volume of each component are listed in Table 2.2.

Figure 2.3: Electronic Components Inside Nacelle
2.3.2.1 Mass Calculations of Electronic Components

The details of these electronic components are shown in Figure 2.2. The following is a list of these components.

1. Antenna/Antenna Ring - Antenna and Antenna Ring are used to transmit and receive signals.
2. Cylinders - The cylinder holds the cups and lids.
3. Accelerometer Cup - This cup contains the accelerometer, which is used to measure acceleration.
4. Lid 1 - A removable or hinged cover for the Mux Cup.
5. Mux Cup - This cup contains the electrical parts.
6. Lid 2 - A removable or hinged cover for the cylinder.
7. Lid 3 - A removable or hinged cover for the Battery Cup.
8. Battery Cup - This cup contains the battery.
9. Lid 4 - A removable or hinged cover for the cylinder.
10. Potting - All voids are filled with potting.

Mass calculations are discussed in Table 2.2.
Figure 2.4: Details of Electronic Components
Table 2.2: Mass calculations for Nacelle Along with Electronic Components

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna/Antenna Ring</td>
<td>0.101</td>
<td>4.95E+00</td>
<td>5.00E-01</td>
</tr>
<tr>
<td>Cylinders</td>
<td>0.101</td>
<td>6.52E+00</td>
<td>6.59E-01</td>
</tr>
<tr>
<td>Accelerometer Cup</td>
<td>0.101</td>
<td>4.66E+00</td>
<td>4.71E-01</td>
</tr>
<tr>
<td>Lid 1</td>
<td>0.101</td>
<td>1.10E+01</td>
<td>9.19E-01</td>
</tr>
<tr>
<td>Mux Cup</td>
<td>0.101</td>
<td>6.90E-01</td>
<td>6.97E-01</td>
</tr>
<tr>
<td>Lid 2</td>
<td>0.101</td>
<td>1.22E+00</td>
<td>1.23E-01</td>
</tr>
<tr>
<td>Lid 3</td>
<td>0.101</td>
<td>1.25E+00</td>
<td>1.26E-01</td>
</tr>
<tr>
<td>Battery Cup</td>
<td>0.101</td>
<td>1.94E+00</td>
<td>1.96E-01</td>
</tr>
<tr>
<td>Lid 4</td>
<td>0.101</td>
<td>6.20E-01</td>
<td>6.26E-02</td>
</tr>
<tr>
<td>Potting</td>
<td>0.072</td>
<td>2.82E+00</td>
<td>2.03E-01</td>
</tr>
<tr>
<td>Nacelle</td>
<td>0.101</td>
<td>83.78E+00</td>
<td>8.46E+00</td>
</tr>
</tbody>
</table>

Total Mass = 10.96E+00

As we are adjusting the density without changing the volume, therefore volume of electronic components is not considered.

Volume of nacelle = 83.78 in^3

We know that,

\[
Density = \frac{Mass}{Volume}
\]

\[
Density = \frac{10.96}{83.78}
\]

Density = 1.31E-01 lb/in^3

The quarter-section of the model and material properties are listed in Table 2.3.
### Table 2.3: Material Properties of Nacelle [5]

<table>
<thead>
<tr>
<th>Property</th>
<th>Aluminum 7075-T6511</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified/Original Density</td>
<td>3.39E-04/2.61E-04 lb/in³</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>1.04E+07 psi</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>68E+03 psi</td>
</tr>
<tr>
<td>Tangent Modulus</td>
<td>185,185 psi</td>
</tr>
<tr>
<td>Volume</td>
<td>83.78 in³</td>
</tr>
<tr>
<td>Mass</td>
<td>10.96 lb</td>
</tr>
</tbody>
</table>

#### 2.3.3 M795 Ogive

This part protects the payload from heat during its passage through the atmosphere. It is made up of 4340 steel. This ogive is modified to incorporate the plate and payload. The plate rests inside the ogive. To incorporate the plate and payload at the bottom of the ogive, the inner diameter of the ogive is reduced slightly. Material characteristics of the M795 Ogive are listed in Table 2.4.
2.3.4 M795 Body

This is the bottom part of the projectile, which is subjected to the pressure load and is made up of 4340 steel. Data of the M795 Body material are listed in Table 2.5.
Table 2.5: Material Properties of M795 Body [5]

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
<th>Young’s Modulus</th>
<th>Poisson’s Ratio</th>
<th>Yield Stress</th>
<th>Tangent Modulus</th>
<th>Volume</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>4340 Steel</td>
<td>7.32E-04 lb/in³</td>
<td>2.9E+07 psi</td>
<td>0.32</td>
<td>120E+03 psi</td>
<td>5.21E+04 psi</td>
<td>157.85 in³</td>
<td>44.483 lb</td>
</tr>
</tbody>
</table>

2.3.5 Band

This is the part of the projectile which comes in contact with the gun barrel. It surrounds the bottom part of the M795 body. The purpose of the band is to reduce the area of contact of the projectile with the gun barrel and hence loss of energy due to friction. This takes a minor portion of the pressure load. This is made up with Brass alloy C 18900 according to military standards MIL E 45829. Table 2.6 shows the properties of the band along with the quarter-section of the part.
Table 2.6: Material Properties of Band

<table>
<thead>
<tr>
<th>Alloy C 18900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density = 8.22E-04 lb/in³</td>
</tr>
<tr>
<td>Young’s Modulus = 56E+03 psi</td>
</tr>
<tr>
<td>Poisson’s Ratio = 0.3</td>
</tr>
<tr>
<td>Yield Stress = 52E+03 psi</td>
</tr>
<tr>
<td>Volume = 4.6 in³</td>
</tr>
<tr>
<td>Mass = 1.301 lb</td>
</tr>
</tbody>
</table>

2.3.6 Plate and Payload

The plate is a 0.2 inches thick steel piece. The payload is modeled as a solid cylinder. The plate and payload are made up of 4340 steel. Later in this research the 0.2 inch steel plate is replaced with a composite plate. Thickness of the plate also varies as discussed in chapter 4. Payload is rigidly attached to the plate. The height of the mass is calculated using the radius, mass and density.

2.3.6.1 Calculation of the height of Steel Cylindrical Mass

As we are incorporating a one-pound mass of 2 in diameter and as the material is steel. Therefore the volume can be calculated from this data.

\[ \text{Radius} = 1 \text{ in} \]
\[ \text{Specific Weight} = 0.283 \text{ lb/in}³ \]
\[ \text{Weight} = 1 \text{ lb} \]
Since,

\[
\text{Specific Weight} = \frac{\text{Weight}}{\text{Volume}}
\]

Substituting in the above equations,

\[
0.283 = \frac{1}{\pi r^3 h}
\]

\[
h = \frac{1}{(0.283)(1)^2 \pi}
\]

\[h = 1.125 \text{ in}\]

Table 2.7 and 2.8 represents the properties of plate and mass along with \(\frac{1}{4}\) model of the parts.
### Table 2.7: Material Properties of Plate [5]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4340 Steel</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>7.32E-04 lb/in³</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>2.9E+07 psi</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.32</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>120E+03 psi</td>
</tr>
<tr>
<td>Tangent Modulus</td>
<td>5.21E+04 psi</td>
</tr>
<tr>
<td>Volume</td>
<td>1.92 in³</td>
</tr>
<tr>
<td>Mass</td>
<td>0.54 lb</td>
</tr>
</tbody>
</table>

### Table 2.8: Material Properties of Payload [5]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4340 Steel</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>7.32E-04 lb/in³</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>2.9E+07 psi</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.32</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>120E+03 psi</td>
</tr>
<tr>
<td>Tangent Modulus</td>
<td>5.21E+04 psi</td>
</tr>
<tr>
<td>Volume</td>
<td>3.53 in³</td>
</tr>
<tr>
<td>Mass</td>
<td>1 lb</td>
</tr>
</tbody>
</table>
Fastening methods such as threading or bolting are initially considered and investigated for mounting plate inside ogive. After analytical calculations, Nallani [9] found that using set screws is impractical as it requires large number of bolts and nuts. Threading turns out to be more suitable one with comfortable factor of safety both in yield and shear.

2.4 Description of Gun Barrel

The gun barrel is modeled as a cylindrical tube. The inside and outside diameters of the gun barrel are 6.22 inch and 11.62 inches respectively. The inside diameter of the gun barrel is assumed to be equal to the outside diameter of the band. The length of the gun barrel is equal to 264 inches. Figure 2.5 shows the gun barrel and table 2.9 describes its properties.

<table>
<thead>
<tr>
<th>Table 2.9: Material Properties of Gun Barrel [5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4340 Steel</td>
</tr>
<tr>
<td>Density = 7.32E-04 lb/in³</td>
</tr>
<tr>
<td>Young's Modulus = 2.9E+07 psi</td>
</tr>
<tr>
<td>Poisson's Ratio = 0.32</td>
</tr>
<tr>
<td>Yield Stress = 120E+03 psi</td>
</tr>
<tr>
<td>Volume = 19974.80 in³</td>
</tr>
<tr>
<td>Mass = 5649.76 lb</td>
</tr>
</tbody>
</table>

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Figure 2.5: Gun Barrel
2.5 Finite Element Modeling

The Finite element modeling starts importing the assembly from SOLIDWORKS to HYPERMESH. The imported model undergoes the following operations which results in the "K" file that can be run in LSDYNA

1. Meshing
2. Material Properties
3. Contact Definitions
4. Boundary Conditions
5. Loads

LSDYNA post-processor is used to view the results.

2.5.1 Meshing

The entire model is meshed with 8 node solid elements. Each component is first meshed as a 2D surface and later the 2D surface is revolved around axis of the projectile to get the 3D component. The nodes at the starting and ending of the revolution are merged to avoid duplicate nodes. After creating the 3D component the 2D surface is deleted. While Windshield, Nacelle, Ogive, M795 Body, Band are created by the above method, Gun barrel, Mass and plate are created by dragging the 2D surface along the axis. Figure 2.7 shows the fully meshed projectile while Figure 2.8 shows the sectional view of the same. It can be observed from Figure 2.7 that element height of the M 795 Body and the band is same so that the nodes at the interface can be merged. In all the components the number of divisions circumferentially is maintained 40, which yields good results. This number is found by trial and error method, where 20 divisions resulted in poor results while 60 divisions resulted in increased runtime and abnormal termination.
of the program. Table 2.10 shows the summary of number of nodes and elements in the model. This mesh density is chosen from the previous work by Nallani [9]. Moreover this density resulted in an average aspect ratio of 2.5 which is good.

Table 2.10: Summary of Number of Nodes and Elements

<table>
<thead>
<tr>
<th>Component</th>
<th>Number of elements</th>
<th>Number of nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windshield</td>
<td>1560</td>
<td>2280</td>
</tr>
<tr>
<td>Nacelle</td>
<td>2260</td>
<td>3224</td>
</tr>
<tr>
<td>M795 Ogive</td>
<td>2530</td>
<td>3512</td>
</tr>
<tr>
<td>M795 Body</td>
<td>1800</td>
<td>2680</td>
</tr>
<tr>
<td>Plate</td>
<td>600</td>
<td>804</td>
</tr>
<tr>
<td>Mass</td>
<td>720</td>
<td>847</td>
</tr>
<tr>
<td>Band</td>
<td>200</td>
<td>480</td>
</tr>
<tr>
<td>Gun Barrel</td>
<td>20640</td>
<td>26000</td>
</tr>
<tr>
<td>Total</td>
<td>30310</td>
<td>39827</td>
</tr>
</tbody>
</table>
Figure 2.6: Fully Meshed 3D Projectile
Figure 2.7: Sectional View of the Fully Meshed Projectile
2.5.2 Material Properties

Each component of the model is assigned with respective materials once meshing is done. The material properties such as Density, Young’s Modulus, Poisson’s Ratio, and Yield Stress are assigned using input card. At this point we input one more information about element type that is solid in our case.

2.5.3 Contact Definitions

In the actual scenario, the parts that come in contact are attached to each other as described below:

- The windshield is threaded to the nacelle
- The nacelle is attached to Ogive with help of screws and bolts
- The Ogive is threaded to M795 body
- The plate is threaded to Ogive
- Payload may be glued or welded to the plate.

Contact surfaces are defined to simulate the effect of these fastenings. Defining contact in HYPERMESH involves defining the surfaces that come in contact. This is done by defining the surface as a Set Segment. The Set Segment contains elements whose face forms the surface and nodes which define these element faces. Figure 2.8 shows defining Set Segment for surface of Ogive which comes in contact with Nacelle. The Figure 2.8(a) shows the elements which form the surface, Figure 2.8(b) shows the nodes that define the element faces and finally Figure 2.8(c) shows the Set Segment. Each Set Segment is given an ID which is used to define the role of the surface in the contact. Each surface can be either master or slave. Master is the guiding surface and slave is the following surface. The types of contacts used in this model are

33
- CONTACT_SURFACE_TO_SURFACE
- CONTACT_TIED_SURFACE_TO_SURFACE.

Figure 2.9 through 2.13 depicts the contact surfaces used in this model.

![Figure 2.8(a). Elements Forming the Contact Surface](image1)

![Figure 2.8(b). Nodes Forming the Contact Surface](image2)

![Figure 2.8(c). Set Segment](image3)

Figure 2.8: Defining Set Segment
Figure 2.9: Contact Surfaces for Windshield and Nacelle

Figure 2.10: Contact Surfaces for Nacelle and Ogive

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Figure 2.11: Contact Surfaces for Ogive and M795

Figure 2.12: Contact Surfaces for Ogive and Plate
Table 2.11: List of Contacts

<table>
<thead>
<tr>
<th>Master</th>
<th>Slave</th>
<th>Contact Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nacelle</td>
<td>Windshield</td>
<td>Tied surface to surface</td>
</tr>
<tr>
<td>Ogive</td>
<td>Nacelle</td>
<td>Tied surface to surface</td>
</tr>
<tr>
<td>Plate</td>
<td>Mass</td>
<td>Tied surface to surface</td>
</tr>
<tr>
<td>Ogive</td>
<td>Plate</td>
<td>Tied surface to surface</td>
</tr>
<tr>
<td>M795 body</td>
<td>Ogive</td>
<td>Tied surface to surface</td>
</tr>
<tr>
<td>Gun barrel</td>
<td>Band</td>
<td>Surface to surface</td>
</tr>
</tbody>
</table>

Figure 2.13: Contact Surfaces for Band and Gun barrel
2.5.4 Boundary Conditions

The boundary conditions in this model are the displacement and rotational constraints applied to the nodes of the gun barrel. The nodes at 10 inch and 40 inch from the bottom of the gun barrel are constrained in all degrees of freedom. This represents the bearings that hold the gun barrel in the actual case. Only the outer surface nodes at these locations are constrained. Figure 2.14 depicts the constraints on the gun barrel.

Figure 2.14: Meshed Gun Barrel with Boundary Conditions
2.5.5 Load Curves

The pressure is the driving force that propels the projectile inside the gun barrel. The pressure curve is obtained from ARL [11] it is shown in Figure 2.10. All the surfaces below the Band including the Band bottom surface are subjected to the pressure. These surfaces include both flat and slanted as shown in Figure 2.15. Figure 2.15 shows the wire frame view of the lower part of M 795 and Band. For the flat surfaces pressure is applied directly and for the slanted surfaces the sine component of pressure is applied. Since M795 is symmetric the cosine component gets cancelled. $\theta$ is the angle between the vertical and slanted face. It is found to be $7.5^\circ$ from Solidworks. Figure 2.16 shows the pressure on flat and slanted faces. Figure 2.17 depicts the pressure curve applied on the flat faces. It can be observed that the pressure is reduced to zero after 0.0125 seconds and this is the time the projectile comes out of the gun barrel.
Figure 2.15: Wire Frame View of M 795 and Band

Figure 2.16: Pressure on Flat and Slanted Faces
Figure 2.17: Pressure Curve
CHAPTER 3

FINITE ELEMENT ANALYSIS

3.1 LS-DYNA Input Cards

An input file is created after modeling the projectile in the pre-processor. This input file is run in LS-DYNA solver to get the results. The information about the model is written in the form of cards in the input file. Cards are the commands, which contain the information about various aspects of the model such as node definitions, element definitions, materials used, loads applied etc. The following are the cards that are used in the present model.

1. Control cards
2. Database cards
3. Material cards
4. Cards defining the parts and sections
5. Cards defining the nodes, elements
6. Contact cards
7. Cards defining the boundary conditions
8. Cards defining the loads

The detailed description of these cards is given in appendix A through H respectively.
3.2 Location of Projectile Inside Gun Barrel

Location of projectile inside gun barrel is determined based on Nallani [9]. He simulated the projectile alone in his work. The quarter symmetry projectile is considered keeping into account the simulation time of 20 milliseconds. In the quarter model, there are two planes of symmetry, the X-Y plane and Y-Z plane. The boundary conditions are applied on these two planes. The boundary conditions are summarized in Table 3.1. Figure 3.1 shows the applied boundary conditions [9].

Table 3.1: Boundary Conditions on Planes of Symmetry

<table>
<thead>
<tr>
<th></th>
<th>UX</th>
<th>UY</th>
<th>UZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Y plane</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Y-Z plane</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

0 – Represents no constraints in that direction

1 – Represents displacement constraint in that direction
Figure 3.1: Applied Boundary Condition on the Planes of Symmetry [9]
The location of the projectile is determined by identifying the distance traveled by the projectile for 12.5 milliseconds, which is the time when the pressure becomes zero according to Figure 2.17. As Figure 3.2 shows, this distance is 191 inches. This means that the projectile is placed at a distance 73 inches from the bottom of the gun barrel.

![Figure 3.2: Axial Displacement Versus Time](image)

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3.3 Final Model

The final model consists of 30,310 elements and 39,827 nodes in total. The number of elements and nodes for each part are represented in Table 3.2. The Figure 3.3 represents the projectile inside the gun barrel.

Table 3.2: List of Elements and Nodes for Each Part

<table>
<thead>
<tr>
<th>Component</th>
<th>Number of elements</th>
<th>Number of nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windshield</td>
<td>1560</td>
<td>2280</td>
</tr>
<tr>
<td>Nacelle</td>
<td>2260</td>
<td>3224</td>
</tr>
<tr>
<td>M795 Body</td>
<td>2530</td>
<td>3512</td>
</tr>
<tr>
<td>M795 Ogive</td>
<td>1800</td>
<td>2680</td>
</tr>
<tr>
<td>Plate</td>
<td>600</td>
<td>804</td>
</tr>
<tr>
<td>Mass</td>
<td>720</td>
<td>847</td>
</tr>
<tr>
<td>Band</td>
<td>200</td>
<td>480</td>
</tr>
<tr>
<td>Gun Barrel</td>
<td>15040</td>
<td>26000</td>
</tr>
<tr>
<td>Total</td>
<td>30310</td>
<td>39827</td>
</tr>
</tbody>
</table>
Figure 3.3: Gun Barrel and Exploded View of the Projectile Inside Gun Barrel
3.4 Phases of the Finite Element Analysis

Simulation of the projectile launch is done in two phases.

- Static analysis
- Dynamic analysis

3.4.1 Static Analysis

In the first phase of the analysis the gun barrel is allowed to deflect due to gravity only. This analysis is conducted for 0.5 seconds. Figure 3.4 shows the normal and deflected gun barrels. The deflection at the end of the gun barrel is equal to 0.287 inches. The boundary conditions discussed in section 2.5.4 indicate that the gun barrel may be treated as a cantilever beam. The deflection of a point along the neutral axis of its end section is,

\[ \delta = \frac{wL^4}{8EI} \]

where,

- \( w \) Linear specific weight of the gun barrel cross-section = 0.283 lb/in³
- \( L \) Length of the gun barrel = 223.4 inches
- \( E \) Young's modulus of elasticity of the gun barrel = 2.9E+07
- \( I \) area moment of inertia of the gun barrel's cross-section = 782.08 in⁴

On substituting these values in the above equation, the deflection of the gun barrel is found out to be 0.2847. In the finite element analysis LOAD_BODY_GENERALIZED card is used to apply the gravity on the nodes of the gun barrel.
3.4.2 Dynamic Analysis

In the second phase of the analysis, the pressure curve is applied to the bottom half of the projectile in presence of the initial conditions obtained from the first phase of the analysis. A card STRESS_INITIALIZATION is used to carry the final conditions of the first phase to the second phase. Gravity load continues to be active in this phase also. The duration of the simulation for the second phase is 0.02 seconds. As Figure 2.17 shows, the pressure is applied to the projectile for 0.0125 seconds. The projectile is out of the gun barrel by the time pressure is reduced to zero. Projectile is moved using the pressure curve through the deformed gun barrel. A coefficient of friction of 0.1 is assigned for the contact between gun and the projectile.

Data for the acceleration, velocity and displacements at three different locations is recorded. The three locations are nodes on the payload, the plate, and the Nacelle.
respectively, Figure 3.5. In the Figure 3.5 the nodes are marked with a circle around to locate them easily.

Figure 3.5: Locations of Data Collection

Node on the Projectile Nacelle

Node on the Bottom of the Plate

Node on the Bed
3.5 Results

After the simulation is done the results are viewed using LS-DYNA post processor. The nodeout file is generated by LS-DYNA in which the output data such as displacement, velocity and acceleration are stored and can be plotted against time. The time step for the output data is $1E^{-3}$ seconds. Figures 3.6, 3.7 and 3.8 show the plots for the displacement, velocity and acceleration respectively in axial direction for the node on the payload.

![Figure 3.6: Axial Displacement Versus Time for Node on Top Center of the Mass](image)

Figure 3.6: Axial Displacement Versus Time for Node on Top Center of the Mass
Figure 3.7: Axial Velocity Versus Time for Node on Top Center of the Mass
The acceleration result shows that projectile model experiences significant higher-order acceleration that are caused by the flexibility of the gun barrel, the fiction between the projectile and the gun barrel through friction, and the interaction between elements of the gun and the ring. These accelerations are significantly above what is observed in experimental results. Results are therefore filtered at a frequency of 6,000 Hz. This value was chosen after conducting a modal analysis on the projectile. Results, Table 3.3, show that this range includes all major frequencies of the projectile. Figure 3.9 shows the mode shape of the first bending frequency. Figure 3.10 and 3.11 show respectively the acceleration plots for node on payload and on projectile after filtering at 6000Hz.
Table 3.3: Modal Results of the Projectile

<table>
<thead>
<tr>
<th>MODE Number</th>
<th>FREQUENCY (Hz)</th>
<th>TYPE OF MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3204</td>
<td>1st Bending Mode of the Projectile</td>
</tr>
<tr>
<td>2</td>
<td>3204</td>
<td>1st Bending Mode of the Projectile</td>
</tr>
<tr>
<td>3</td>
<td>3836</td>
<td>1st Torsional Mode of the Projectile</td>
</tr>
<tr>
<td>4</td>
<td>5312</td>
<td>2nd Axial Mode of the Projectile / 1st Axial Mode of the Mounting Plate (in phase)</td>
</tr>
<tr>
<td>5</td>
<td>5634</td>
<td>2nd Bending Mode of the Projectile</td>
</tr>
<tr>
<td>6</td>
<td>5634</td>
<td>2nd Bending Mode of the Projectile</td>
</tr>
<tr>
<td>7</td>
<td>5989</td>
<td>1st Radial Mode (Lower Half of the Projectile)</td>
</tr>
<tr>
<td>8</td>
<td>5990</td>
<td>1st Radial Mode (Lower Half of the Projectile)</td>
</tr>
<tr>
<td>9</td>
<td>6632</td>
<td>2nd Axial Mode of the Mounting Plate</td>
</tr>
<tr>
<td>10</td>
<td>6855</td>
<td>2nd Bending Mode of the Projectile / 1st Bending Mode of the Mounting Plate (in phase)</td>
</tr>
<tr>
<td>11</td>
<td>6923</td>
<td>2nd Bending Mode of the Projectile / 1st Bending Mode of the Mounting Plate (in Phase)</td>
</tr>
<tr>
<td>12</td>
<td>7579</td>
<td>3rd Bending Mode of the Projectile / 2nd Bending Mode of the Mounting Plate (out of Phase)</td>
</tr>
<tr>
<td>13</td>
<td>7612</td>
<td>3rd Bending Mode of the Projectile / 2nd Bending Mode of the Mounting Plate (out of Phase)</td>
</tr>
<tr>
<td>14</td>
<td>7693</td>
<td>2nd Radial Mode (Upper Half of the Projectile)</td>
</tr>
<tr>
<td>15</td>
<td>7695</td>
<td>2nd Radial Mode (Upper Half of the Projectile)</td>
</tr>
<tr>
<td>16</td>
<td>8056</td>
<td>2nd Torsional Mode of the Projectile</td>
</tr>
</tbody>
</table>
Figure 3.9: Mode Shape of the First Bending Frequency of the Projectile
Figure 3.10: Axial Acceleration Versus Time for Node on Top Center of the Mass After Filtering at 6000HZ

Figure 3.11: Axial Acceleration Versus Time for Node on Projectile After Filtering at 6000HZ
CHAPTER 4

SHOCK REDUCTION METHODS

It is evident from the Figure 3.10 that even after filtering the acceleration data the payload/electronic package is experiencing vibrations. As explained in section 1.6 the main objective of the research is to find methods to reduce these vibrations. This chapter describes the methods explored. The following are the methods investigated.

1. Variation of location plate
2. Variation of material properties of the plate
3. Variation of the thickness of the plate.

4.1 Variation of location of plate:

Figure 4.1 shows that the plate is located at 8.3 inches from the bottom of the projectile. The effect of varying the plate mounting location on peak accelerations value and the vibrations on the payload is studied. It is clear from the Figure 4.1 that the plate location can be varied within a span of 0.54 inches, which is the available gap between nacelle and the payload. The plate location is being changed in five different steps as shown in Figure 4.2. As the plate location is varied, material is to be added to the ogive in order to support the plate. Due to this the mass of the projectile is increased. The center
of mass varies with the change of mass. Table 4.1 shows the variation of the mass and center of gravity of the projectile for all the five locations.

Figure 4.1: Location of Plate in the Projectile
Figure 4.2: Variation of Location of the Plate in the Projectile

Table 4.1: Variation of Total Mass and Center of Mass for the Projectile

<table>
<thead>
<tr>
<th>Plate Location along Y-direction</th>
<th>Distance w.r.t. Center of mass (inches)</th>
<th>New Mass (pounds)</th>
<th>New Center of mass location (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>0.07</td>
<td>87.36</td>
<td>(0,8.23,0)</td>
</tr>
<tr>
<td>Location 2</td>
<td>0.16</td>
<td>87.40</td>
<td>(0,8.23,0)</td>
</tr>
<tr>
<td>Location 3</td>
<td>0.28</td>
<td>87.46</td>
<td>(0,8.24,0)</td>
</tr>
<tr>
<td>Location 4</td>
<td>0.41</td>
<td>87.51</td>
<td>(0,8.24,0)</td>
</tr>
<tr>
<td>Location 5</td>
<td>0.52</td>
<td>87.56</td>
<td>(0,8.24,0)</td>
</tr>
</tbody>
</table>
4.1.1 Results

Data for the acceleration, velocity and displacements at three different locations as explained earlier in the section 3.4.2 is recorded for all the five cases. The three locations are nodes on the payload, the plate, and the Nacelle respectively as shown in Figure 3.5. The maximum acceleration and root mean square acceleration are calculated for these five cases.

Figures 4.3, 4.4, 4.5 respectively show the displacement for the node on payload, projectile, plate for all the five locations. From the figures it is evident that displacement is same in all the cases with a maximum value of 462 inches.

Figures 4.6 through 4.8 respectively show the velocity for the node on payload, projectile, plate for all the five locations. From the figures it is clear that displacement is same in all the cases. The velocity remains constant after the projectile leaves the gun barrel at 12.5 milliseconds.
Figure 4.3: Y Displacement for the Node on Payload
Figure 4.5: Y Displacement for the Node on Plate
Figure 4.6: Velocity for the Node on Payload
Figure 4.7: Y Velocity for the Node on Projectile
Figure 4.9 shows the acceleration plot for node on payload for all five locations. Figure 4.10 shows the acceleration plots filtered at a frequency 6000Hz. Figure 4.11 shows the filtered acceleration plot after the projectile leaves the gun barrel. From the plots it can be observed that though for all the locations the peak accelerations and frequency of vibrations remain almost the same when the projectile is inside the gun barrel it varies afterwards. Outside the gun barrel the locations 1 and 2 behaves similarly while for the rest of locations the peak accelerations are decreased.
Figure 4.9: Y Acceleration for the Node on Payload
Figure 4.10: Y Acceleration for the Node on Payload (filtered at 6000Hz)
Figure 4.11: Y Acceleration for the Node on Payload (filtered at 6000Hz)

after Projectile Leaves the Gun Barrel

Figure 4.12 shows the acceleration plot for node on projectile for all five locations. Figure 4.13 shows the acceleration plots filtered at a frequency 6000Hz. Figure 4.14 shows the filtered acceleration plot after the projectile leaves the gun barrel.
Figure 4.12: Y Acceleration for the Node on Projectile
Figure 4.13: Y Acceleration for the Node on Projectile (filtered at 6000Hz)
Figure 4.14: Y Acceleration for the Node on Projectile (filtered at 6000Hz) after Projectile Leaves the Gun Barrel

Figure 4.15 shows the acceleration plot for node on plate for all five locations. Figure 4.16 shows the acceleration plots filtered at a frequency 6000Hz. Figure 4.17 shows the filtered acceleration plot after the projectile leaves the gun barrel.
Figure 4.15: Y Acceleration for the Node on Plate
Figure 4.16: Y Acceleration for the Node on Plate (filtered at 6000Hz)
Figure 4.17: Y Acceleration for the Node on Plate (filtered at 6000Hz) after Projectile Leaves the Gun Barrel

Table 4.2 shows the displacement, velocity, acceleration and RMS values for the node on payload. Table 4.3 shows the filtered acceleration and RMS values for the same.
Table 4.2: Summary of Results for Node on Payload

<table>
<thead>
<tr>
<th>Node on Payload</th>
<th>Location1</th>
<th>Location2</th>
<th>Location3</th>
<th>Location4</th>
<th>Location5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Y Displacement (inch)</td>
<td>4.62E+02</td>
<td>4.62E+02</td>
<td>4.62E+02</td>
<td>4.61E+02</td>
<td>4.62E+02</td>
</tr>
<tr>
<td>Max. Y Velocity (Inch/sec)</td>
<td>3.51E+04</td>
<td>3.51E+04</td>
<td>3.51E+04</td>
<td>3.50E+04</td>
<td>3.50E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (total travel of projectile)</td>
<td>1.54E+04</td>
<td>2.06E+04</td>
<td>1.82E+04</td>
<td>1.88E+04</td>
<td>1.59E+04</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (inside barrel)</td>
<td>1.24E+05</td>
<td>1.39E+05</td>
<td>1.24E+05</td>
<td>1.51E+05</td>
<td>1.31E+05</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (inside barrel)</td>
<td>1.85E+04</td>
<td>2.50E+04</td>
<td>2.20E+04</td>
<td>2.29E+04</td>
<td>1.93E+04</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (outside barrel)</td>
<td>2.30E+04</td>
<td>2.76E+04</td>
<td>2.24E+04</td>
<td>2.62E+04</td>
<td>1.87E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (outside barrel)</td>
<td>6.18E+03</td>
<td>7.34E+03</td>
<td>6.56E+03</td>
<td>6.04E+03</td>
<td>5.28E+03</td>
</tr>
</tbody>
</table>
Table 4.3: Summary of Filtered Results for Node on Payload

<table>
<thead>
<tr>
<th>Node on Payload (Filtered)</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Y acceleration filtered (g's) (total travel of projectile)</td>
<td>7.31E+03</td>
<td>7.23E+03</td>
<td>7.08E+03</td>
<td>7.07E+04</td>
<td>7.07E+04</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (inside barrel)</td>
<td>1.75E+04</td>
<td>1.81E+04</td>
<td>1.85E+04</td>
<td>1.84E+04</td>
<td>1.85E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (inside barrel)</td>
<td>8.73E+03</td>
<td>8.75E+03</td>
<td>8.71E+03</td>
<td>8.70E+03</td>
<td>8.70E+03</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (outside barrel)</td>
<td>6.26E+03</td>
<td>5.16E+03</td>
<td>3.21E+03</td>
<td>3.23E+03</td>
<td>3.00E+03</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (outside barrel)</td>
<td>3.36E+03</td>
<td>2.73E+03</td>
<td>1.54E+03</td>
<td>1.51E+03</td>
<td>1.52E+03</td>
</tr>
</tbody>
</table>

Figures 4.18 and 4.19 represent respectively the Y acceleration and RMS Y acceleration filtered at 6000 Hz for node on payload.
Figure 4.18: Y Acceleration for the Node on Payload (filtered at 6000Hz)

Figure 4.19: RMS Y Acceleration for the Node on Payload (filtered at 6000Hz)
Table 4.4 shows the displacement, velocity, acceleration and RMS values for the node on Projectile. Table 4.5 shows the filtered acceleration and RMS values for the same.

Table 4.4: Summary of Results for Node on Projectile

<table>
<thead>
<tr>
<th>Node on Projectile</th>
<th>Location1</th>
<th>Location2</th>
<th>Location3</th>
<th>Location4</th>
<th>Location5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Y Displacement (inch)</td>
<td>4.62E+02</td>
<td>4.62E+02</td>
<td>4.61E+02</td>
<td>4.62E+02</td>
<td></td>
</tr>
<tr>
<td>Max. Y Velocity (Inch/sec)</td>
<td>3.52E+04</td>
<td>3.52E+04</td>
<td>3.50E+04</td>
<td>3.51E+04</td>
<td></td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (total travel of projectile)</td>
<td>2.96E+04</td>
<td>3.32E+04</td>
<td>3.22E+04</td>
<td>3.12E+04</td>
<td>3.30E+04</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (inside barrel)</td>
<td>1.78E+05</td>
<td>2.19E+05</td>
<td>1.64E+05</td>
<td>2.13E+05</td>
<td>2.17E+05</td>
</tr>
<tr>
<td>RMS Y acceleration (g’s) (inside barrel)</td>
<td>3.53E+04</td>
<td>3.98E+04</td>
<td>3.84E+04</td>
<td>3.74E+04</td>
<td>3.97E+04</td>
</tr>
<tr>
<td>Max. Y acceleration (g’s) (outside barrel)</td>
<td>5.38E+04</td>
<td>5.18E+04</td>
<td>5.05E+04</td>
<td>4.78E+04</td>
<td>4.79E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g’s) (outside barrel)</td>
<td>1.37E+04</td>
<td>1.49E+04</td>
<td>1.50E+04</td>
<td>1.32E+04</td>
<td>1.38E+04</td>
</tr>
</tbody>
</table>
### Table 4.5: Summary of Filtered Results for Node on Projectile

<table>
<thead>
<tr>
<th>Node on Projectile (Filtered)</th>
<th>Location1</th>
<th>Location2</th>
<th>Location3</th>
<th>Location4</th>
<th>Location5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Y acceleration filtered (g’s) (total travel of projectile)</td>
<td>6.95E+03</td>
<td>6.97E+03</td>
<td>6.96E+03</td>
<td>6.94E+03</td>
<td>6.95E+03</td>
</tr>
<tr>
<td>Max. Y acceleration (g’s) (inside barrel)</td>
<td>1.77E+04</td>
<td>1.81E+04</td>
<td>1.73E+04</td>
<td>1.79E+04</td>
<td>1.74E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g’s) (inside barrel)</td>
<td>8.63E+03</td>
<td>8.62E+03</td>
<td>8.61E+03</td>
<td>8.59E+03</td>
<td>8.60E+03</td>
</tr>
<tr>
<td>Max. Y acceleration (g’s) (outside barrel)</td>
<td>1.94E+03</td>
<td>3.06E+03</td>
<td>3.74E+03</td>
<td>2.65E+03</td>
<td>2.94E+03</td>
</tr>
<tr>
<td>RMS Y acceleration (g’s) (outside barrel)</td>
<td>6.67E+02</td>
<td>8.66E+02</td>
<td>9.69E+02</td>
<td>8.65E+02</td>
<td>8.56E+02</td>
</tr>
</tbody>
</table>

Figures 4.20 and 4.21 represent respectively the Y acceleration and RMS Y acceleration filtered at 6000 Hz for node on projectile.
Figure 4.20: Y Acceleration for the Node on Projectile (filtered at 6000Hz)

Figure 4.21: RMS Y Acceleration for the Node on Projectile (filtered at 6000Hz)
Table 4.6 shows the displacement, velocity, acceleration and RMS values for the node on Plate. Table 4.7 shows the filtered acceleration and RMS values for the same.

### Table 4.6: Summary of Results for Node on Plate

<table>
<thead>
<tr>
<th>Node on Plate</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Y Displacement (inch)</td>
<td>4.62E+02</td>
<td>4.62E+02</td>
<td>4.62E+02</td>
<td>4.61E+02</td>
<td>4.62E+02</td>
</tr>
<tr>
<td>Max. Y Velocity (Inch/sec)</td>
<td>3.51E+04</td>
<td>3.51E+04</td>
<td>3.51E+04</td>
<td>3.50E+04</td>
<td>3.50E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g's)</td>
<td>1.79E+04</td>
<td>2.23E+04</td>
<td>1.94E+04</td>
<td>1.82E+04</td>
<td>1.60E+04</td>
</tr>
<tr>
<td>(total travel of projectile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Y acceleration (g's)</td>
<td>1.42E+05</td>
<td>2.27E+05</td>
<td>1.74E+05</td>
<td>1.67E+05</td>
<td>1.45E+05</td>
</tr>
<tr>
<td>(inside barrel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMS Y acceleration (g's)</td>
<td>2.19E+04</td>
<td>2.75E+04</td>
<td>2.38E+04</td>
<td>2.24E+04</td>
<td>1.97E+04</td>
</tr>
<tr>
<td>(inside barrel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Y acceleration (g's)</td>
<td>1.94E+04</td>
<td>1.86E+04</td>
<td>1.81E+04</td>
<td>1.92E+04</td>
<td>1.35E+04</td>
</tr>
<tr>
<td>(outside barrel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMS Y acceleration (g's)</td>
<td>4.89E+03</td>
<td>4.87E+03</td>
<td>4.94E+03</td>
<td>4.79E+03</td>
<td>3.61E+03</td>
</tr>
<tr>
<td>(outside barrel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Table 4.7: Summary of Results for Node on Plate

<table>
<thead>
<tr>
<th>Node on Plate (Filtered)</th>
<th>Location1</th>
<th>Location2</th>
<th>Location3</th>
<th>Location4</th>
<th>Location5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Y acceleration filtered (g's) (total travel of projectile)</td>
<td>7.32E+03</td>
<td>7.24E+03</td>
<td>7.09E+03</td>
<td>7.07E+03</td>
<td>7.08E+03</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (inside barrel)</td>
<td>1.76E+04</td>
<td>1.82E+04</td>
<td>1.86E+04</td>
<td>1.84E+04</td>
<td>1.85E+04</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (inside barrel)</td>
<td>8.73E+03</td>
<td>8.75E+03</td>
<td>8.72E+03</td>
<td>8.70E+03</td>
<td>8.71E+03</td>
</tr>
<tr>
<td>Max. Y acceleration (g's) (outside barrel)</td>
<td>6.23E+03</td>
<td>5.19E+03</td>
<td>3.22E+03</td>
<td>3.30E+03</td>
<td>3.11E+03</td>
</tr>
<tr>
<td>RMS Y acceleration (g's) (outside barrel)</td>
<td>3.40E+03</td>
<td>2.76E+03</td>
<td>1.56E+03</td>
<td>1.53E+03</td>
<td>1.53E+03</td>
</tr>
</tbody>
</table>

Figures 4.19 and 4.20 represent respectively the Y acceleration and RMS Y acceleration filtered at 6000 Hz for node on plate.
Figure 4.22: Y Acceleration for the Node on Plate (filtered at 6000Hz)

Figure 4.23: Y Acceleration for the Node on Plate (filtered at 6000Hz)
All these acceleration plots, Tables and bar graphs revealed that the response of the plate and the payload is similar. The acceleration and frequency of vibrations for the node on projectile is different when compared to nodes on payload and plate. This may be due the fact that the nacelle material is aluminum while plate and payload are made of steel. One more reason could be due to the fact that the nacelle is located on the top of projectile which is far from the region where the pressure load is applied when compared to the location of plate. It can be concluded from the above results that locations 3, 4 and 5 are the better places for mounting electronic package.
4.2 Variation of Material Properties of the Plate

In search for a suitable material for the plate to reduce the accelerations transmitted to the payload, a composite material made of T-300 carbon fibers in an epoxy matrix is considered arbitrarily. The plate is designed as a quasi-isotropic composite laminate for which material properties are isotropic in plane. Since the plate is subjected to symmetric loading it is desirable to have isotropic properties in plane. Initially the number of layers in the laminate is assumed as 3 which gives the fiber angle orientation $60^\circ$, $0^\circ$ and $-60^\circ$ because in a quasi-isotropic laminate the angle between adjacent layers of the laminate is $\Pi/N$ [15]. $N$ is the number of layers in the laminate. The exploded and stacked view of the 3 laminas are shown in Figure 4.24.

![Image of 3 laminas](attachment:image.png)

Figure 4. 24: The 3 Laminas Used for the Composite Laminate
The properties of the composite laminate are calculated using the individual fiber and epoxy properties. The following section shows the individual properties of fiber and epoxy, also details the procedure followed in finding the laminate properties.

4.2.1 Calculation of Laminate Properties [14]

Young’s Modulus of Fiber \( E_f = 3.19 \times 10^7 \) psi;

Young’s Modulus of Matrix \( E_m = 5.22 \times 10^5 \) psi;

Poisson’s Ratio of Fiber \( v_f = 0.2 \)

Poisson’s Ratio of Matrix \( v_m = 0.35 \)

Shear Modulus of Fiber \( G_f = 1.32 \times 10^7 \) psi;

Shear Modulus of Matrix \( G_m = 1.92 \times 10^5 \) psi

Density of the Fiber \( \rho_f = 1.65 \times 10^{-4} \) lb/in\(^3\);

Density of the Matrix \( \rho_m = 1.064 \times 10^{-4} \) lb/in\(^3\);

Volume Fraction of fiber \( V_f \)

Volume Fraction of Matrix \( V_m = 1 - V_f \)

Young’s Modulus of the composite lamina along the fiber is calculated by the formula

\[
E_{11} = E_f V_f + E_m V_m
\]

Transverse modulus of the composite lamina is calculated by the formula

\[
E_{22} = \frac{E_f E_m}{E_f V_m + E_m V_f}
\]

Shear modulus of the composite lamina is calculated by the following formula

\[
G_{12} = \frac{G_f G_m}{G_f V_f + G_m V_m}
\]

Major Poison’s ratio of composite lamina is calculated by the following formula
\[ v_{12} = v_f v_f + v_m v_m \]

Minor poison's ratio of composite lamina is calculated by the following formula

\[ v_{21} = \frac{E_{22}}{E_{11}} v_{12} \]

Figure 4.25 shows the stacking sequence of the laminas in the laminate. The material properties of the laminate are found by calculating extensional stiffness matrix \([A]\) of the laminate. \([A]\) is calculated using the following formula [14]

\[
[A] = (\tilde{Q})_{+60^0}(h_0 - h_1) + (\tilde{Q})_{0^0}(h_1 - h_2) + (\tilde{Q})_{-60^0}(h_2 - h_3)
\]

where \([\tilde{Q}]_\theta\) is the stiffness matrix for the individual lamina, elements of which are calculated using the following formulae [14]

\[
\tilde{Q}_{11} = Q_{11} \cos^4 \theta + 2(Q_{12} + 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{22} \sin^4 \theta
\]

\[
\tilde{Q}_{12} = Q_{12} (\sin^4 \theta + \cos^4 \theta) + (Q_{11} + Q_{22} - 4Q_{66}) \sin^2 \theta \cos^2 \theta
\]
\[ \ddot{Q}_{22} = Q_{11} \sin^4 \theta + 2(Q_{12} + 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{22} \cos^4 \theta \]

\[ \ddot{Q}_{16} = (Q_{11} - Q_{12} - 2Q_{66}) \sin \theta \cos^3 \theta + (Q_{12} - Q_{22} + 2Q_{66}) \sin^3 \theta \cos \theta \]

\[ \ddot{Q}_{26} = (Q_{11} - Q_{12} - 2Q_{66}) \sin^3 \theta \cos \theta + (Q_{12} - Q_{22} + 2Q_{66}) \sin \theta \cos^3 \theta \]

\[ \ddot{Q}_{66} = (Q_{11} + Q_{12} - 2Q_{12} - 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{66} (\sin^4 \theta + \cos^4 \theta) \]

Where,

\[ \theta \] = the fiber orientation angle of the lamina

\[ Q_{11} = \frac{E_{11}}{1 - V_{12}V_{21}} \]

\[ Q_{22} = \frac{E_{22}}{1 - V_{12}V_{21}} \]

\[ Q_{12} = Q_{21} = \frac{V_{12}E_{22}}{1 - V_{12}V_{21}} \]

\[ Q_{66} = G_{12} \]

Hence

\[ [\ddot{Q}]_\theta = \begin{bmatrix} \ddot{Q}_{11} & \ddot{Q}_{12} & \ddot{Q}_{16} \\ \ddot{Q}_{12} & \ddot{Q}_{12} & \ddot{Q}_{26} \\ \ddot{Q}_{16} & \ddot{Q}_{26} & \ddot{Q}_{66} \end{bmatrix} \]

and

90
Finally the Properties of the laminate are

In plane Young’s Modulus \( E_{xx} = E_{zz} = \frac{A_{11}^2 - A_{22}^2}{h} \)

In plane Poison’s ration \( v_{xz} = \frac{A_{12}}{A_{11}} \)

In plane Shear stress \( G_{xz} = \frac{A_{11} - A_{12}}{2h} \)

Transverse Modulus \( E_{yy} = 10 E_{xx} \)

Poisson’s ratio in transverse direction \( v_{xy} = \frac{V_{xy}}{10} \)

Shear modulus in Transverse direction \( G_{xy} = 10 G_{xz} \)

Density of the Composite Laminate \( \rho_c = \rho_f V_f + \rho_m V_m \)

First of all it is made sure that by replacing the steel plate with composite plate (thickness 0.2 and volume fraction 30%) the acceleration transmitted to the payload are reduced. Figures 4.27 through 4.29 depict this fact. Hence in the later stages 5 different material properties are assigned to the composite laminate by changing the fiber volume fraction from 30%-70% in steps of 10. The variation of material properties of the laminate with change in fiber volume fraction is tabulated in Table 4.8
4.3 Variation of Thickness of the Composite Plate

The effect of variation of the thickness of the plate along with the variation of material properties on the peak accelerations transmitted to the electronic package is also studied. The thickness of the plate is varied from 0.2 inches to 0.6 inches in steps of 0.1 inch. Figure 4.26 shows the different thickness of the plate. However, the thickness variation didn't affect the material properties.

Table 4.8: Variation of Laminate Properties with Change in Fiber Volume Fraction

<table>
<thead>
<tr>
<th>Fiber Volume Fraction</th>
<th>$E_{xx}=E_{zz}$ (psi)</th>
<th>$E_{yy}$ (psi)</th>
<th>$\rho_c$ (lbf/in$^3$)</th>
<th>$G_{xz}$ (psi)</th>
<th>$G_{xy}$ (psi)</th>
<th>$v_{xz}$</th>
<th>$v_{xy}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>3.8E+06</td>
<td>3.8E+07</td>
<td>0.046</td>
<td>1.4E+06</td>
<td>1.4E+07</td>
<td>0.33</td>
<td>0.033</td>
</tr>
<tr>
<td>40%</td>
<td>4.9E+06</td>
<td>4.9E+07</td>
<td>0.050</td>
<td>1.8E+06</td>
<td>1.8E+07</td>
<td>0.33</td>
<td>0.033</td>
</tr>
<tr>
<td>50%</td>
<td>6.0E+06</td>
<td>6.0E+07</td>
<td>0.050</td>
<td>2.3E+06</td>
<td>2.3E+07</td>
<td>0.32</td>
<td>0.032</td>
</tr>
<tr>
<td>60%</td>
<td>7.2E+06</td>
<td>7.2E+07</td>
<td>0.054</td>
<td>2.7E+06</td>
<td>2.7E+07</td>
<td>0.32</td>
<td>0.032</td>
</tr>
<tr>
<td>70%</td>
<td>8.5E+06</td>
<td>8.5E+07</td>
<td>0.058</td>
<td>3.2E+06</td>
<td>3.2E+07</td>
<td>0.32</td>
<td>0.032</td>
</tr>
</tbody>
</table>

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Figure 4.26: Variation of Thickness of the Composite Plate
4.3.1 Results

Comparison of results between the steel plate and composite plate with thickness 0.2 and volume fraction 30% is presented in Figures 4.27 through 4.32. Figures 4.27 through 4.29 represent the acceleration comparison for node on mass. Figures 4.30 through 4.32 represent the acceleration comparison for node on projectile.

Figure 4.27: Acceleration Comparison for Node on Mass for Steel Plate and Composite Plate with Fiber volume Fraction 30%
Figure 4.28: Filtered Acceleration Comparison for Node on Mass for Steel Plate and Composite plate with Fiber volume Fraction 30%
Figure 4.29: Filtered Acceleration Comparison Outside Gun Barrel for Node on Mass for Steel Plate and Composite plate with Fiber volume Fraction 30%
Figure 4.30: Acceleration Comparison for Node on Projectile for Steel Plate and Composite plate with Fiber volume Fraction 30%
Figure 4.31: Filtered Acceleration Comparison for Node on Projectile for Steel Plate and Composite plate with Fiber volume Fraction 30%
It is evident from the above plots that using composite plate has considerably reduced the peak accelerations transmitted to the electronic package. Amplitude of the vibrations is also decreased along with the frequency of vibrations. The acceleration response for node on projectile has remained same as expected. Hence as said earlier the fiber volume fraction and thickness of the plate are changed which resulted in 25 different models. The outcomes of these 25 different runs are tabulated below. Table 4.9 and 4.10 represent the filtered accelerations for these models inside and outside of gun barrel respectively.
Table 4.9: Maximum Y Acceleration (filtered) Inside Gun Barrel for Node on Payload

<table>
<thead>
<tr>
<th>Fiber Volume Fraction → Thickness (in)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.37E+04</td>
<td>1.39E+04</td>
<td>1.41E+04</td>
<td>1.42E+04</td>
<td>1.49E+04</td>
</tr>
<tr>
<td>0.3</td>
<td>1.50E+04</td>
<td>1.59E+04</td>
<td>1.70E+04</td>
<td>1.81E+04</td>
<td>1.91E+04</td>
</tr>
<tr>
<td>0.4</td>
<td>1.65E+04</td>
<td>1.78E+04</td>
<td>1.70E+04</td>
<td>1.67E+04</td>
<td>1.65E+04</td>
</tr>
<tr>
<td>0.5</td>
<td>1.66E+04</td>
<td>1.64E+04</td>
<td>1.60E+04</td>
<td>1.60E+04</td>
<td>1.62E+04</td>
</tr>
<tr>
<td>0.6</td>
<td>1.64E+04</td>
<td>1.66E+04</td>
<td>1.68E+04</td>
<td>1.75E+04</td>
<td>1.84E+04</td>
</tr>
</tbody>
</table>

Table 4.10: Maximum Y Acceleration (filtered) Outside Gun Barrel for Node on Payload

<table>
<thead>
<tr>
<th>Fiber Volume Fraction → Thickness (in)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.68E+03</td>
<td>1.70E+03</td>
<td>2.11E+03</td>
<td>1.60E+03</td>
<td>1.40E+03</td>
</tr>
<tr>
<td>0.3</td>
<td>3.21E+03</td>
<td>3.88E+03</td>
<td>5.64E+03</td>
<td>5.71E+03</td>
<td>4.44E+03</td>
</tr>
<tr>
<td>0.4</td>
<td>4.36E+03</td>
<td>5.06E+03</td>
<td>3.06E+03</td>
<td>2.03E+03</td>
<td>1.51E+03</td>
</tr>
<tr>
<td>0.5</td>
<td>2.27E+03</td>
<td>1.22E+03</td>
<td>1.30E+03</td>
<td>1.76E+03</td>
<td>1.53E+03</td>
</tr>
<tr>
<td>0.6</td>
<td>2.78E+03</td>
<td>2.06E+03</td>
<td>2.24E+03</td>
<td>3.53E+03</td>
<td>4.77E+03</td>
</tr>
</tbody>
</table>
Table 4.11 and 4.12 represent the RMS accelerations of the 25 models for node on payload inside and outside of the gun barrel respectively.

![3D Chart](image)

**Figure 4.33:** 3D Chart Representing the Variation of Y acceleration Outside the Gun Barrel (filtered 6000Hz) with Variation in Thickness and Fiber Volume Fraction of the Plate

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Table 4.11: RMS Y Acceleration (filtered) Inside Gun Barrel for Node on Payload

<table>
<thead>
<tr>
<th>Fiber Volume Fraction → Thickness (in)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>7.84E+03</td>
<td>7.84E+03</td>
<td>7.84E+03</td>
<td>7.84E+03</td>
<td>7.86E+03</td>
</tr>
<tr>
<td>0.3</td>
<td>7.89E+03</td>
<td>7.93E+03</td>
<td>8.16E+03</td>
<td>8.52E+03</td>
<td>8.38E+03</td>
</tr>
<tr>
<td>0.4</td>
<td>8.26E+03</td>
<td>8.10E+03</td>
<td>7.97E+03</td>
<td>7.93E+03</td>
<td>7.90E+03</td>
</tr>
<tr>
<td>0.5</td>
<td>7.91E+03</td>
<td>7.88E+03</td>
<td>7.88E+03</td>
<td>7.91E+03</td>
<td>7.89E+03</td>
</tr>
<tr>
<td>0.6</td>
<td>7.91E+03</td>
<td>7.92E+03</td>
<td>7.92E+03</td>
<td>7.98E+03</td>
<td>8.01E+03</td>
</tr>
</tbody>
</table>

Table 4.12: RMS Y Acceleration (filtered) Outside Gun Barrel for Node on Payload

<table>
<thead>
<tr>
<th>Fiber Volume Fraction → Thickness (in)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.08E+03</td>
<td>1.06E+03</td>
<td>1.30E+03</td>
<td>8.41E+02</td>
<td>6.84E+02</td>
</tr>
<tr>
<td>0.3</td>
<td>1.64E+03</td>
<td>1.87E+03</td>
<td>2.86E+03</td>
<td>3.23E+03</td>
<td>2.45E+03</td>
</tr>
<tr>
<td>0.4</td>
<td>2.14E+03</td>
<td>3.02E+03</td>
<td>1.79E+03</td>
<td>1.07E+03</td>
<td>6.68E+02</td>
</tr>
<tr>
<td>0.5</td>
<td>1.17E+03</td>
<td>5.96E+02</td>
<td>5.64E+02</td>
<td>7.23E+02</td>
<td>5.85E+02</td>
</tr>
<tr>
<td>0.6</td>
<td>1.34E+03</td>
<td>8.02E+02</td>
<td>8.02E+02</td>
<td>1.20E+03</td>
<td>1.10E+03</td>
</tr>
</tbody>
</table>
Figure 4.34: 3D Chart Representing the Variation of RMS Y acceleration Outside the Gun Barrel (filtered 6000Hz) with Variation in Thickness and Fiber Volume Fraction of the Plate

Table 4.13 is the maximum Von Mises stress induced in the electronic package for these models. Figure 4.35 is the 3D bar graph representing the same.
Table 4.13: Maximum Von Mises Stress Induced in the Electronic Package

<table>
<thead>
<tr>
<th>Fiber Volume Fraction Thickness (in)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>6.46E+04</td>
<td>6.65E+04</td>
<td>9.11E+04</td>
<td>8.681E+04</td>
<td>6.077E+04</td>
</tr>
<tr>
<td>0.3</td>
<td>4.20E+04</td>
<td>4.20E+04</td>
<td>4.90E+04</td>
<td>4.84E+04</td>
<td>4.01E+04</td>
</tr>
<tr>
<td>0.4</td>
<td>4.146E+04</td>
<td>4.41E+04</td>
<td>4.09E+04</td>
<td>4.62E+04</td>
<td>3.87E+04</td>
</tr>
<tr>
<td>0.5</td>
<td>4.54E+04</td>
<td>4.13E+04</td>
<td>3.292E+04</td>
<td>7.521E+04</td>
<td>6.39E+04</td>
</tr>
<tr>
<td>0.6</td>
<td>3.64E+04</td>
<td>5.36E+04</td>
<td>5.06E+04</td>
<td>3.54E+04</td>
<td>3.05E+04</td>
</tr>
</tbody>
</table>
Considering the axial accelerations transmitted to the payload outside the gun barrel plates with 0.5 inch thickness, 40% and 50% fiber volume fractions produced 77% less vibrations compared to the plate with 0.3 inch thickness and 60% fiber volume fraction. Similarly in the case of axial RMS acceleration outside gun barrel plates with 0.5 inch thickness, 40% and 50% fiber volume fractions produced 80% less RMS values compared to Plate with 0.4 inch thickness and 40% fiber volume fraction. Taking von mises stress also into consideration 0.5 thick and 50% fiber volume fraction material yielded good results.
4.4 Summary of Results

On the basis of the plots and tables in this chapter it can be said that:

- The results were not effected much with the plate location when the projectile is inside the gun barrel.
- The acceleration curves look similar until the shell exits the gun barrel.
- After the shell leaves the gun barrel, it is observed that there is change in acceleration curves for different plate mountings.
- The curves plotted for node on mass and plate yielded similar data whereas there is significant change in comparison with that of node plotted on projectile.
- The amplitudes of the plots remained same for the nodes on mass and plate after the projectile leaves the gun barrel.
- Maximum axial acceleration transmitted to the payload is decreased by 51.2% from location 1 to location 5.
- Axial RMS acceleration for the payload is decreased by 54.5% from location 1 to location 5.
- There is 21.7% and 73.1% reduction in the axial accelerations transmitted to the payload while the projectile is inside and outside the gun barrel respectively by changing the plate material to a composite with 30% fiber volume fraction and maintaining the same thickness as that of the steel plate.
- Considering maximum axial acceleration, RMS acceleration outside the gun barrel and von mises stress induced in the payload plate with 0.5 inch thickness and 50% fiber volume fraction yielded good results.
CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

- Flexibility of gun barrel and the friction between gun barrel and projectile have significant effect on the vibrations transmitted to the payload.
- Modal analysis is necessary to find the appropriate filtering frequency.
- Mounting location of the plate has significant effect on the accelerations transmitted to the payload.
- Composite material considerably reduced the accelerations transmitted to the payload.
- Considering maximum axial acceleration, RMS acceleration outside the gun barrel and von mises stress induced in the payload plate with 0.5 inch thickness and 50% fiber volume fraction yielded good results.

5.2 Future Work

- The fiber angle orientation can be optimized
- The material of the plate can be further changed to more realistic one such as flame retardant composites.
- The optimization can be done using optimization algorithm
• Reason for lack of particular trend in the results as a function of fiber volume fraction or thickness needs to be studied by assigning more appropriate elastic modulus in the thickness direction of the plate.
APPENDIX A

CONTROL CARDS

Control cards are optional cards in an LS-DYNA input file and can be used to change the defaults, activate solution options such as mass scaling, adaptive remeshing, and an implicit solution. A control card defines the properties such as termination time, time step controls, warpage angle for shell, hourglass effect, rigid wall effect etc. A sample control card is shown below:

```
*CONTROL_TERMINATION
$---------1---------2---------3---------4---------5---------6
$$ ENDTIM ENDCYC DTMIN ENDENG ENDMAS
   0.52  0.0  0.0  0.0  0.0
```

This card defines the termination of the simulation. This card provides different options to define the termination time. The parameters of the card are described below:

- **ENDTIM.** Specifies the Termination for the simulation. This is mandatory.

- **ENDCYC** defines the termination cycle. The termination cycle is optional and will be used if the specified cycle is reached before the termination time. Default value 0.0 is used.

- **DTMIN** is the reduction factor for initial time step size to determine minimum time step. Default value 0.0 is used.
- **ENDENG** is the percent change in energy ratio for termination of calculation. If undefined, this option is inactive. Default value 0.0 is used.

- **ENDMAS** is the percent change in the total mass for termination of calculation. This option is relevant if and only if mass scaling is used to limit the minimum time step [13]. Default value 0.0 is used.

Card to specify the type of analysis:

```
*CONTROL_implicit_general
$1$2$3$4$5$6
$$IMFLAG DT0 IMFLAG NSBS IGS CNSTN
1
```

- **IMFLAG** defines the type of analysis. It takes the values 0, 1, 2, 4, 5, 6 and \(-n\) where \(n\) is +ve any number other than the above numbers. IMFLAG 0 means explicit analysis and 1 means implicit analysis. \(n\) is the curve ID, which specifies the value of IMFLAG as a function of time. More details can be found from [13].
APPENDIX B

DATABASE CARDS

Database card defines the type of output format for results. The database card is shown below:

```
*DATABASE_BINARY_D3PLOT
$-------1-------2-------3-------4-------5-------6-------7-------8
$$ DT/CYCL LCDT BEAM NFLTC PSETID ISTATS TSTART IAVG
1.0000E-03
```

The parameters of the card are described below:

- **DT/CYCL** defines the time interval between the outputs. DT/CYCL is 1.00E-03, implies 20 D3Plots are generated for total dynamic simulation time of 0.02 seconds.
- **LCDT** is the optional load curve ID specifying the time intervals between the dumps [13].

The Nodout card is used to define the number of data points intended when plotting a graph. It is shown below:

```
*DATABASE_NODOUT
$-------1-------2-------3-------4-------5-------6-------7-------8
DT       BINARY
1.0000E-06   1
```

```
*DATABASE_HISTORY_NODE_SET
$-------1-------2-------3-------4-------5-------6-------7-------8
ID1   ID2   ID3   ID4   ID5   ID6
28838  32128  32777
```

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• DT Time interval between outputs. Default value 0.0 is used.

• BINARY is 1 indicates the ASCII file is written. Default is 1 or 2.

The DATABASE_HISTORY_NODE_SET card is used to define specific nodes for which the data are to be collected. The Nodout card can be used to produce less number of D3plots with large number of data points.
APPENDIX C

MATERIAL CARDS

Material cards are used to assign the respective material properties to the respective parts in the model.

*MAT_ORTHOTROPIC_ELASTIC
$HMNAME MATS 1plate_mat
$--------1--------2--------3--------4--------5--------6--------7--------8
MID  RO  EA  EB  EC  PRBA  PRCA  PRCB
1 0.0001 3.8e+006 3.8e+006 3.8e+007 0.33 0.033 0.033

GAB  GBC  GCA  AOPT
1.4e+006 1.4e+007 1.4e+007 0.0

*MAT_PLASTIC_KINEMATIC
$--------1--------2--------3--------4--------5--------6--------7
MID  RO  E  PR  SIGY  ETAN  BETA
23.3900E-04 1040000.0 0.33 68000.0 185185.0

• MID defines the material identification number. This number is used to assign this material to the parts in the model. Mandatory.

• RO defines the mass density. Mandatory.

• E defines the Young's modulus. Mandatory.
In the MAT_ORTHOTROPIC_ELASTIC card

- EA, EB and EC define the young’s modulus in 3 orthogonal directions A, B and C respectively, which represent the material axes. Mandatory.
- PR defines the Poisson’s ratio. Mandatory.
- PRBA, PRCA and PRCB represent the Poisson’s ratios in the planes BA, CA and CB respectively. Mandatory.
- SIGY defines the Yield stress. Mandatory.
- GAB, GBC and GCA specify the shear modulus of the material in the planes AB, BC and CA. Mandatory.
- ETAN defines the Tangent modulus [13]. Default is 0.0.
APPENDIX D

SECTION and PART CARDS

SECTION_SOLID card is used to indicate that solid elements are used in meshing a part. In this card we give SECID. This ID used in defining the part indicates that the specific part is made up of solid elements. PART card is used to define the characteristics of the part such as the material properties and element type of the part. A sample card is shown below:

```
*PART
1 2 4
1 2 4
```

- PID is the part identification number. This is a unique number and is used while defining the elements. Mandatory.
- SECID is the section ID which assigns element type used in meshing the part. Mandatory.
- MID is the material ID which assigns the material properties to the part. Mandatory.

All the other options are optional and a default value 0.0 is used. More details can be found from [13].
APPENDIX E

NODE and ELEMENT CARDS

The purpose of NODE card is to define the node and its coordinates in the global system. Also the boundary conditions in the global system can be specified. Generally nodes are assigned to elements. ELEMENT_SOLID is used to define the solid elements. The eight nodes, which form the element, the part to which the element belongs and the element ID are defined in this card. The 2 cards are shown below:

*NODE
$-------1-------2-------3-------4-------5-------6-------7-------8-------9$
  NID    X      Y      Z    TC    RC
  1      2.0    8.5    1.75

*ELEMENT_SOLID
$-------1-------2-------3-------4-------5-------6-------7-------8-------9-------10$
  EID    PID    N1    N2    N3    N4    N5    N6    N7    N8
  1      3     1001  1003  1006  1008  1011  1012  1015  1018

- NID and EID are the node and element identification numbers respectively.
- X, Y and Z are the coordinates of the node in the global system. Default is 0.0.
• TC and RC are translational constraints and rotational constraints. But the constraints are generally specified using boundary specific set option. Default is 0.0.

• In the ELEMENT_SOLID card PID represents the part to which that particular element belongs. Mandatory.

• N1 through N8 are the node IDs which form that particular element. Mandatory.
APPENDIX F

CONTACT CARDS

The contact cards are used to simulate the fastenings between various parts in an assembly. The Contact card is shown below:

*CONTACT_SURFACE_TO_SURFACE
S-------1-------2-------3-------4-------5-------6-------7-------8
SSID  MSID  SSTYP  MSTYP  SBOXID  MBOXID  SPR  MPR
1     2

FS    FD    DC    VC    VDC    PENCHK  BT    DT
0.1   0.1

- SSID indicates the slave segment ID representing the slave surface of the part in the contact.
- MSID indicates the master segment ID representing the master surface of the part in the contact.

There are different methods in which the slave and master surfaces can be defined. SET_SEGMENT is one such option in which the nodes and elements which form the contact surfaces are defined as set segments and the set segment is given a unique identification number. That number is used as SSID or MSID. The other methods by which slave and master surfaces can be defined are by defining the part which forms the contact surface or by defining a BOXID. Box is a 3 dimensional region defined by X, Y and Z coordinates. The defined box is given an ID and it is used in the contact card.
• FS and FD are coefficient of static and dynamic friction respectively [13]. Default is 0.0.
APPENDIX G

BOUNDARY CONDITION CARDS

BOUNDARY_SPC_NODE card is used to define the degrees of freedom for the nodes.

The card is shown below:

*BOUNDARY_SPC_NODE

\[
\begin{array}{cccccccc}
\text{NID/NSID} & \text{CID} & \text{DOFX} & \text{DOFY} & \text{DOFZ} & \text{DOFRX} & \text{DOFRY} & \text{DOFRZ} \\
22200 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\
\end{array}
\]

- NID/NSID NID is node ID and NSID is node set ID. Hence a specific node or a set of nodes can be constrained using this card.

- DOFX is the degree of freedom in direction X. 1 means it is constrained in that direction and 0 means it is not constrained.

- DOFRX is the Rotational degree of freedom in about X axis [13].

Except for NID all the other options have a default value 0.0.
APPENDIX H

LOAD CARD

LOAD_SEGMENT applies the distributed pressure load over one triangular or quadrilateral segment defined by the four nodes [13]. A sample LOAD_SEGMENT has been shown below:

*LOAD_SEGMENT
LCID SF AT N1 N2 N3 N4
1 1

Where,

- LCID in the card represents the load curve id. Mandatory.
- SF represents the scale factor for Load curve. Default is 1.0.
- AT represents the time for pressure or birth time of pressure. Default is 0.0.
- N1, N2, N3, N4 represents the node numbers.

One more card is used to define the body force loads prescribed base acceleration or prescribed angular velocity over a subset of complete problem. The card is shown below
• N1 and N2 define the beginning and ending node ID's for body force load. Mandatory.

• LCID represents the curve ID, which is a force curve, applied to the above subset of nodes N1 through N2. Mandatory.

• AX, AY, AZ is the scale factor for the acceleration for their respective directions. Default is 0.0.
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