DESIGN AND ANALYSIS OF AIR TRANSPORTATION CRATE FOR RADIO-FREQUENCY AMPLIFIER

By

Abhay Prajapati

(21MMCC10)

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

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DESIGN AND ANALYSIS OF AIR TRANSPORTATION CRATE FOR RADIO-FREQUENCY AMPLIFIER

Major Project Report

Submitted in Complete fulfilment of the requirements

For the degree of

MASTER OF TECHNOLOGY IN
MECHANICAL ENGINEERING (CAD/CAM)

By
Abhay Prajapati
(21MMCC10)

Guided by

Dr. Shashikant J Joshi

NIRMA UNIVERSITY
NAAC ACCREDITED 'A+' GRADE

DEPARTMENT OF MECHANICAL ENGINEERING

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MAY 2023

Declaration

This is to certify that

- The Report comprises my original work towards the degree of Master of Technology in CAD/CAM Engineering at Nirma University and has not been submitted elsewhere for degree or diploma.
- Due acknowledgement has been made in the text to all other material used.

Abhay Prajapati

21MMCC10

Undertaking for Originality of the Work

I Abhay Prajapati (21MMCC10) give undertaking that the Major Project entitled ("Design and Analysis of Air Transportation Crate for RF-Amplifier") submitted by me, towards the complete fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Nirma University, Ahmedabad, is the original work carried out by me. I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Place: Nirma University, Ahmedabad

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This is to certify that the Major Project Report entitled "**Design and Analysis of Air Transportation Crate for RF-Amplifier**" submitted by **Mr. Abhay Prajapati (21MMCC10)**, towards the complete fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (CAD/CAM)** of School of Engineering, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

Date:

Institute Guide
Dr. Shashikant J Joshi
Department of Mechanical Engineering,
Institute of Technology and Engineering,
Nirma University, Ahmedabad

Industrial Guide:
Mr. Prashanth Gururaj
Project Lead,
Philips India Limited, Pune

Head of Department
Prof. K M Patel
Department of Mechanical Engineering,
Institute of Technology and Engineering,
Nirma University, Ahmedabad

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With Regards

Abhay Prajapati

21MMCC10

Abstract

Packaging is the section which is very crucial to safe shipping of released components from business author to the customer without any damage. Specifically, in critical components which are dominant for whole systems and affects other deliverable product for continuous operation. RF Amplifier is one of the electronic devices having weight of around 110Kg, used in MRI system to amplify low power to high power output for generating Radio-frequency waves and scanning images of patient. Here in this study, optimization of existing packaging system (wooden crate) used for RF-Amplifier is carried out to minimize defects which are causing damage to amplifier and affecting its form, fit and functionality. Main objective of this study is to improve dynamic strength of packaging crate design by selecting an impact resistance material in place of wooden crate, propose a new design for packaging crate considering shipping and handling parameters and evaluate the performance of the crate by simulating drop test in Finite Element Analysis software at different orientations of crate. The term impact load will be defined as potential occurrence of drop events during the packaging, stacking, and transportation of the proposed crate design. The prototype of new design of crate has been developed. Physical testing of new design of the crate has been carried to determine the response of system under impact loading. It has been noted that the design of crate meets safety requirements. There is good agreement in the FE simulation results and experimental results of the new crate design.

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CHAPTER 1 Introduction

1.1 Introduction to MRI

MRI, which stands for Magnetic Resonance Imaging, is a radiology method employed in medical imaging to generate detailed images of the body's anatomy and physiological functions. MRI scans generate images of the organs and tissues in the body by using strong magnetic fields and radio waves. The presence of water molecules with hydrogen atoms inside of our bodies aids the MRI scan. Every hydrogen proton in a state of spin behaves as a miniature magnet, revolving independently on its own axis, much like the Earth rotates on its axis, possessing north and south magnetic poles. The billions of hydrogen protons that make up our bodies are constantly spinning on their axes and in random positions. Like how a compass needle aligns to the magnetic field of the Earth, the unpredictability of hydrogen proton changes when a human body is placed in an MRI scanner’s strong magnetic field. These hydrogen protons, which spin at random, realign their axes with the increased magnetic field of the MRI scanner. The magnetic field of a scanner is known as the B0 field.

Figure 1. 1 MRI Examination room

The body coils help the radio waves from the RF coils transmit signals to these protons and receive signals from the body. The computer attached to the scanner transforms these signal returns into images. A unit called a Tesla is used to express the magnet's strength (T). Hospitals and research facilities typically use 1.5 or 3T MRI scanners. The earth's magnetic field is around 0.00006T, which means that a 3T MRI scanner is approximately 60,000 times stronger than the earth's magnetic field.

1.2 About Company

Philips India Limited is a leading health technology company in Personal healthcare having different business units like Magnetic Resonance Imaging, Computer Tomography, Image Guided Therapy, Mobile Devices, X-rays/DXR and Ultrasound. Company provides healthcare products as per user requirements with goal of improving 2.5 billion people by 2030. Philips is a company dedicated to health technology, with a focus on enhancing people's lives through significant innovation throughout the entire health journey. This encompasses various aspects, including promoting healthy living, preventive measures, accurate diagnosis, effective treatment, and supportive home care. Philips has a long history of breakthrough innovation. The company began in lighting and founded its first research lab in 1914. Applying its technical knowledge to healthcare, Philips introduced a medical X-ray tube in 1918. This marked the point when the company began to diversify its product range and to systematically protect its innovations with patents in areas stretching from X-ray radiation to radio reception.

Along the way, we've been responsible for some truly ground-breaking discoveries and standards, such as the X-ray tube, the high-pressure mercury lamp, the triple-headed dry electric razor, the Compact Cassette, the 40-slice CT scanner, CD, DVD, Ambilight TV, and more recent innovations such as, portable ultrasound, and the all-digital PET/CT scanner.

1.2.1 About Department

Philips Magnetic Resonance business unit having different departments working on MRI hardware system for new product developments, coil design, Reliability and Lifecycle Engineering. Lifecycle Engineering department involves different activities like part recovery, service reliability, defect management and End of life extension.

Part Recovery

For new Concept to reality got converted to actual production after verification and validation, product is supplied to customers. After specific life of product in regular use, some of the components having end of life. Main aim of Part recovery is to provide service for different products and components, refurbishment as per custom/specific requirements. Part recovery deals with identifying and harvesting these components by bringing back to the manufacturing unit, specifying guidelines, and applying testing for verification and implementations. Parts which cannot be recovered are proceed for recycled.

1.3 Packaging Crate

It is hard to think of the world not including carrying cases. They are utilizing every day in an enormous variety of ways. They get our matter from point A to point B without destruction. When they break, we are at a deficit, whether economic, material, or for sort words. With the capability to purchase or customize a quality case for nearly any purpose, getting things where they need to be, intact, is no longer a gamble.

Carrying cases come in many shapes, sizes, and compositions. They are often rectangular, sometimes with recesses or pockets to secure items. They may be tubes with sealed end caps and/ or hinged sides. They may be internally or externally shaped to the contours of the things inside. Carrying cases may be flame retardant, static free, resistant to electromagnetic interference, or waterproof. They may be hard or soft sided, single chambered or compartmentalized, and may have wheels for ease of movement.

Shipping cases are typically meant to be reused to increase efficiency. Shipping cases can be constructed from various materials such as wood, aluminium, steel, or different types of plastics. Common plastic options include high-density polyethylene (HDPE), fiberglass-reinforced polyester (FRP), carbon fibre, rotationally molded polyethylene, and linear low-density polyethylene (LLDPE). While traditional shipping cases have a straightforward design, there is also a wide range of custom and specialty cases available to cater to specific needs and requirements. Many are boxlike and have packing material inside, such as packing peanuts, heavy foam, special racks, shelving, or a lining made of paper, foam, rubber, wood shavings, plastic, or other materials.

Shipping cases can range from large basic crates to ones that are customized for a specific product. For sensitive, delicate, or expensive items, the packing material inside is often custom cut foam specially made to fit around the components.

1.3.1 Types of Crates

1. **Corrugated cartoon boxes:** They are widely employed as shipping containers. The product needs to be contained in boxes from manufacture through distribution to sale and occasionally end-use. Boxes offer some degree of product protection on their own, but frequently inside components are needed to safeguard contents. These are also referred to as shipment cartons, plain boxes, colored boxes, simple cartons, and more. Corrugated boxes play a crucial role in various industries, including food, beverage, cosmetic, pharmaceutical, medical, electronic, and wine sectors. These industries heavily rely on the use of corrugated boxes for packaging, transportation, and storage purposes. Depending on the needs of the customer, they are made from different types of paper and come in different thicknesses. They are useful in moving things from one place to another in addition to being used to pack food, small consumer products, glass, and pottery. These

Figure 1. 2 Wooden Crate

crates are stronger than cardboard boxes. During the process of packing, storage, and transportation, items often experience significant mechanical stress. In such cases, wooden packing crates prove to be an excellent option, especially for long-distance transport. These crates provide robust protection and durability, ensuring the safety of the items contained within them, even under high mechanical stress conditions.This crate can be stacked in multiple layers and one on top of the other without risk of breaking. Wooden box crates can withstand moisture better than boxes made of other materials. They are therefore a better choice to package non-durable items.

2. **Aluminium crates:** May be purchased as standard models, or they may be custom manufactured to design specs. They may be virtually any size, deep or shallow, wide or long, and still remain lightweight and heavy duty. These shipping cases may be small enough to be used as an attaché case or large enough to carry wood or metal working machines with molded pockets for accessories. Aluminium cases may be collapsible for easy storage. They are often used as transit cases for delicate gear being shipped by air.

Figure 1. 3 Aluminum Crate

3. **Hard Plastic Protective Cases:** Inexpensive, lightweight, and durable. They may be blow molded, injection molded, or roto-molded into any shape and almost any size for custom cases and components.

4. **Flight crates:** ATA cases are also referred to as road cases or flight cases. ATA road cases are specifically designed to safeguard sensitive equipment, such as motion picture equipment, production gear, musical instruments, and other valuable equipment that requires transportation between different locations. These cases are available in a wide range of sizes, starting from small custom-designed cases for individuals to large cases capable of accommodating the needs of entire production companies. Their purpose is to ensure the protection and secure transportation of valuable equipment. ATA cases provide protection for a wide variety of items during shipping, storage, and transportation.

1.4 RF Amplifier

RF Amplifier is an electronics device used in Magnetic Resonance Imaging to amplify low power into high power output. RF- Amplifier is a part of DACC (Data Acquisition and Control Cabinet) unit. RF Amplifier comes with advanced cooling system containing biocides for thermal management and reduce acoustic level of amplifier. It provides necessary gain to produce high power RF transmit pulse for MR Imaging. RF amplifier is having weight around 110Kg. Rf Amplifier capacity directly affects the imaging resolution of MRI scanning. As amplifier can develop high power frequency, it will be better for scanning images of patient in high magnetic field. It affects scanning time, RF wave intensity and quality of image to detect local tissue of patient's body.

1.5 Problem Identification

Currently, for RF-Amplifier transport from various country, wooden crates are used. Wooden crates creating severe damage to medical equipment (RF-Amplifier). And Rate of Defect on Arrival is high, which leads cost of non-quality.

Main reason behind this defect is RF-Amplifier having greater than 100kg weight under sudden/impact loading during transit.

(a) (b) (c)

Figure 1. 4 Defects on Arrival

1.6 Objectives of project

- To select alternate material for RF Amplifier Packaging Crate.
- To study dynamic behavior of Flight Crates.
- To perform drop test for Flight crate to ensure robust design.
- To minimize defects on arrival for Flight crates.

CHAPTER 2 Literature Review

This chapter gives a summary of certain research that has taken place by authors related to the current project. It gives study related to design parameters, air transportation standards used to carry Flight crates and drop test evaluation to ensure robust design of flight crate.

F. C. Teng, F. T. Wu, Chih-Chun Cheng, and Cheng-Kuo Sung [1] studied optimization technique, ways to minimize natural frequency and mean compliance and drop test after optimization for packaging box of flat LED display. Topology optimization technique was performed in ANSYS software to understand volume constraints. Behavior of expanded polypropylene (EPP) box was observed by force vs displacement results. Sequential linear programming was performed to improve design of flat Led panel with packaging box. Acceleration comparison between experimental and FEM simulations were observed for different parameters like drop at each side, edges, and corners of packaging box. After topology optimization it was observed that optimized design occupies smaller volume 14.85% as compared to traditional design. Again, acceleration results are also better 8.9% as compared to current design. It gives understanding of systemic method for optimized design to increase shock protection under defined constraints.

Meng-Kao Yeh and Tzu-Heng Huang [2] focused on the drop test of FR-4 test board to determine reliability of component and to understand mechanical behavior and variations in stress and strains on test board. Finite element software ANSYS was used to perform drop test simulation under 0.5ms pulse time and peak accelerate conditions. Experimental drop test for test board was performed on JEDEC test standard facility and acceleration conditions are applied. Maximum strain results for the experimental drop test were noted and they are compared with explicit analysis of drop test that was performed in FEA software. Both results were quietly same for experiment and simulation.

Sarah Dill, Kyle Brees, Andrew Stahly, Elizabeth Cheng, John Carpenter and Liron Caplan [3] evaluated performance of packaging system for medications to describe mechanical shocks that occurs during shipment. In this Foam material was used Expandable polystyrene (EPS) and accelerometer used to measure g force in dropping varying heights. They evaluated 2 different types of shipping containers. The first was a cardboard box having an expanded polystyrene foam cooler. The second was a cardboard box having a lint-like material cooler. Drop height of 0.75 meter is recommended by the International Safety in Transit Association and by specific vendors for testing packages that will be shipped via different service providers.

Total 1000 tests were performed to evaluate mechanical shocks. At 0.75 meters, there were numerically higher g's measured with the EPS foam as compared to soft foam.

Yuchen Hao, Jinhua Wang, Bin Wu, Tao Ma, Haitao Wang, Bing Liu and Yue Li [4] studied most severe condition for structural to validate nuclear fuel transport package under impact loading conditions. In current study, an integrated method with grey relational analysis method and the quaternary triangular mesh spherical sampling model is identified to determine the maximum shock and damage of packaging of nuclear crate under drop loading. The finite element model of the nuclear fuel transportation package is firstly established to perform the drop analysis. Design of experiment was performed to understand the design variables and drop orientation was evaluated out using the QTM. Then selected orientations are resolved through GRA and the major cause analysis. It is observed by the comprehensive analysis regarding the safety operation. The findings showed that these angles determine important and exceptional potential as the most dangerous condition. This study provides recommendation to improve model of nuclear package.

Kap-Sun Kima, Sung-Hwan Chung b, Jong-Soo Kima, Kyu-Sup Choi and Hyun-Do Yun [5] demonstrated structural performance of IP-2 packaging with help of analytical simulation and drop test was performed. In this study, an advanced critical simulation and an assessment process using the finite element method have been developed for the design measurement of the newly developed IP-2s. Then, analytical simulations for the various drop preferences were implemented to calculate the structural implementation of the packages. To validate the accuracy of the analytical tools, development procedures, and implementation of the IP-2s, comprehensive drop tests were performed. These tests aimed to confirm the reliability of the calculations and procedures used in the analysis. Furthermore, parametric studies were conducted to assess the impact of various analytical variables, including material models and modeling methodologies, on the outcomes. Both the analytical results and experimental results shows that there is no considerable damage that could lower the structural performance of the packaging crate.

E. Tempelman [6] carried out experimental and analytical study of free fall drop impact testing of portable components. This paper presents a comprehensive investigation involving both experimental and analytical approaches to study the dynamic behavior of everyday products equipped with internal shock fittings under impact conditions. By using drop tower having guiding frame, products were dropped at various angles and acceleration outcomes were recorded on outer case and inner mounted plate. Here, 3mm and 5mm cubes were considered for experiment. This study concludes that systematic impact testing can be performed with sensors which can be placed in different location within the component. It gives better understand of using sensors for drop-impact analysis, which improves accuracy of testing.

Alemayehu Ambaw and Matia Mukama [7] published design verification of packaging by virtual prototyping technique. This study gives brief about a holistic packaging design procedure in the fruit harvest handling system including virtual prototyping approach. The method gives the cardboard box compressive property and fruit cooling rate performances of new designs before the manufacturing. It involves computational fluid dynamics and computational heat transfer methods to understand performance. This virtual methodology took very less time to give data like cooling rate, airflow resistance, compressive strength and temperature behavior. Six different designs were studied in this paper. The new packaging design is more compact having higher fruit capacity. It also improved the precooling process 17% faster and energy usage 30%.

Jing-en Luan and Tong Yan Tee [8] conducted drop test simulation by implicit transient analysis. A lumped prototype with one degree of freedom mass-spring-damping system is suggested to illustrate the dynamic behaviors of PCB under drop effect. Based on this, the Input-G technique for implicit transient dynamic analysis is developed and recognized both theoretically and numerically. A finite component model for board drop impact has been proved based on implicit Input-G method, and good relationships on dynamic behaviors of PCB and solder joint reliability were attained between modeling and experiment results.

A. F. Zakki1, A. Windyandari and Q. T. [9] Medina evaluated drop test analysis of Glass fiber reinforced plastic pontoon using numerical method. The drop test recreations have been carried out to understand the structural reaction of the GFRP modular pontoon unit due to the impact load on the different heights of 2m and 4m condition. It was noted that the maximum effective (Von Mises) stress occurred on the corner side of the drop position. The maximum effective stress of 293 MPa and 348 MPa are greater than the yield stress limit of the GFRP material. Therefore, it is concluded that the plastic deformation can be found on the structure of modular pontoon unit during the corner drop position. It shows that corner side is having more damage by impact on package.

Mohammad kh.Abunawas [10] developed mathematical modelling for plastic PET (polyethylene terephthalate) with purpose of FEA drop test analysis. To assess the accuracy of the PET material model, the impact force of a 510 ml PET container was measured by dropping it from heights of 0.5, 1.0, and 1.5 meters above the floor the water was packed to full level of the bottle and a force plate measuring system measured the impact force on the ground. The MSC. Dytran 2006 was utilized for the drop – test FEA replication using the substantial model of equation. The obtained PET material model indicated good understanding in term of the park impact force with standard error of 1.303 %.

M. Muni Prabaharan [11] performed static analysis for container drop test. Design methodology was evaluated by iteration analysis for container. This methodology decreases cost to buy such high-priced software's to reproduce. In the sensible test, the new design was improved than previous design. Static finite element analysis with a good enough mesh size and time step function can reliably calculate the dynamic response of the system. The forecast of a new product was determined based on the circumstance that break will occur if the maximum yield stress of the design surpasses the specified material property. The simulated results in this work showed that the total plastic work can be effectively utilized as a fracture standard to predict a product fracture during impact test.

Chevrychkina A, Volkov GA and Estifev AD [12] studied experimental investigation of ABS Plastic material under dynamic load conditions. The strength properties of ABS material were determined through tensile testing conducted on a Shimadzu AG-50kNX and Instron CEAST 9350 testing machines equipped with an accelerator. The accomplished experimental studies on the size of the tensile intensity of an additive material made of ABS plastic on a 3D printer in quasi-static and dynamic modes demonstrated that the static concentration and the young's modulus of the printed examples correspond to the values of the raw quantifiable. The experiments data demonstrated the possibility of testing miniature samples to achieve superior strain rates. The following rate dependence of muscle was described using the standard of incubation time.

Sharon Olivera, Handanahally Basavarajaiah Muralidhara and Krishna Venkatesh [13] reviewed plating on Acrylonitrile Butadiene styrene (ABS) Plastic. This review represents the history and development of ABS plastics, evolution of ABS-like materials by Additive manufacturing, and their general estates and, effects of plating on ABS and fused deposition modeled ABS material. The procedures and mechanisms concerned in plating are successfully described. Plating on the ABS raw material is shown to enhance the mechanical linkage, impart aesthetical appearance and provide deterioration resistance to the sample. The breakthrough in the plating process was seen in the substitution of traditional surface habituation methods by nature-friendly processes.

Mariusz warscheza, Andrez and Tadeusz [14] studied prediction of plastic component part durability with drop test simulation. Material model was developed for plastic component. Performed simulations have demonstrated, that a real drop test of synthetic parts can be easily substituted with a numerical simulation. An organized computation method can be implemented without complications in industrial environments and can be used in a comparatively short time. Regular tensile tests with unique strain rates and shear tests are appropriate to create a rate determined elastic-plastic fabric model, which can be used in the developing process of subjective shape impact analysis. The produced material model can be accompanied by failure criteria, which should additionally increase the precision at calculations.

Ajaykumar Narke and Manisha Yadav [15] studied alternative material for packaging material polyurethane. Following the test standard ASTM D 4169-16, DC 2, a total of four test items were subjected to the testing technique. Throughout and after the drop tests, no visible damage was observed. Among the tested items, FIBI-buffer E1 exhibited the lowest acceleration values, indicating the highest level of impact reduction. Normal acceleration decline values are 62.5 % and 43.85 % during the one-meter impact in the upright direction. The achieved parameter values can be used in future computations with the confirmed material. The utilization of polyurethane has resulted in an environmental concern due to its limited biodegradability. As a consequence, water bodies such as rivers and oceans, as well as landscapes and even mountain peaks, have become contaminated with non-recyclable polyurethane waste that persists in the environment. So FIBI buffer should be preferred and promoted as a packaging material.

CHAPTER 3 Methodology

3.1 Introduction:

As shown in fig3.1 the drive of this research started by Problem Identification, Objective, and literature review. All the related theories and relevant survey were studied and summarized. Selection of the materials and design parameters carried out based on research study. Further, as per standard design and handling parameters, design of Flight Crate was created in Solidworks software. To evaluate dynamic behavior of Crate under different conditions, Finite Element Analysis will be simulated in software and obtained results will be compared with experimental data.

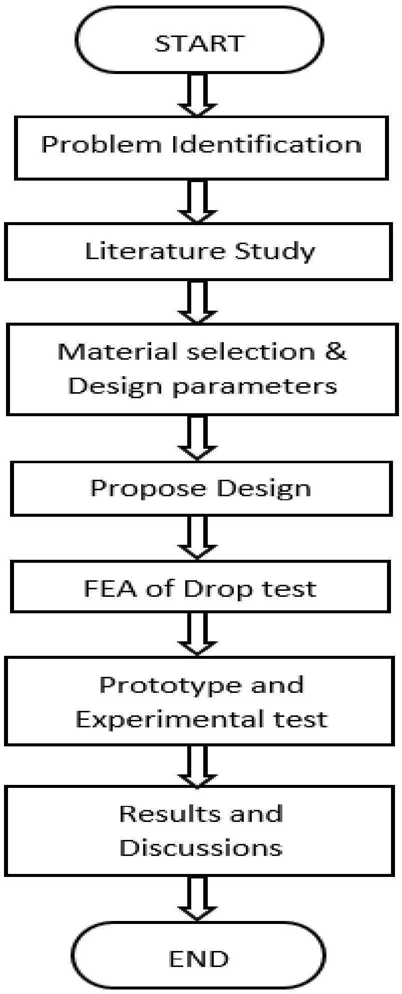


Figure 3. 1 Process flow

3.2 Selection of Material and Design Parameters:

ATA cases share a standardized structure that is mandated by regulations they must adhere to. These regulations cover various aspects, ranging from the specific materials used to the type of rivets employed in their construction. Authentic ATA cases strictly follow these rules to ensure compliance and maintain the required level of quality and durability. They must be constructed of a certain plastic laminate, fiberglass, or aluminum. They may be constructed from wood, aluminum, steel, or plastics, such as high density polyethylene (HDPE), fiberglass reinforced polyester (FRP), carbon fiber, rotationally molded polyethylene, or linear low density polyethylene (LLDPE).

In present research study, ABS (Acrylo butadiene styrene) Plastic laminated with plywood is used for Flight crate material. ABS plastic is laminated over plywood to improve impact resistance under dynamic condition during transit. ABS (Acrylonitrile Butadiene Styrene) combine the strength and rigidity and toughness of Acrylonitrile, butadiene & styrene. It is having higher impact strength & less cost as compared to other fiberglass materials, which gives benefit in event of accidental damage.

The inclusion of ABS plastic in the composite material plays a crucial role in preventing damage to the parts. When compared to a conventional wooden crate, the composite material with ABS plastic offers numerous advantages, making it an ideal choice for users seeking parts with high modulus, excellent surface quality, dimensional stability, and ease of handling. The specific properties of the material are summarized in the accompanying table.

Material	**Concrete**	**ABS**	**Nickel plated 316SS**	**Unit**
Type	Rigid	Linear Plastic	Linear Plastic	-
Density	2.40E-06	1.05E-06	8.90E-06	Kg/mm3
YM(E)	26	1.47	200	Gpa
PR	0.2	0.3	0.29	-
SIGY(Yiels strength)	-	0.0438	0.345	Gpa

Table 1 Material Properties

3.2.1 SWOT ANALYSIS

SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is one of the most general and widely spread analysis tools for strategic planning. SWOT analysis is straight forward and easy to use. SWOT analysis helps to understand various aspects of application which we are undergoing research. It is briefing us about strength and weakness of the area of study. Also, it give summary of what are the precautions that need to consider that can be derived from SWOT analysis

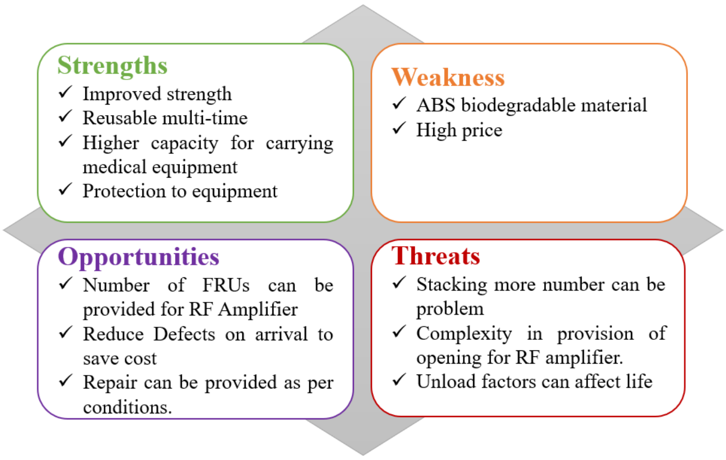


Figure 3. 2 SWOT Analysis

3.2.2 Selection of Design and Handling Parameters:

Design parameters which are considered for evaluation of dynamic strength are stickability, unloading at specific height, reusability, and compartment provisions. Design of the flight crate is done by considering all these parameters to avoid defect on arrival and to make a flexible sliding of RF-Amplifier in DACC cabinet. While other drop parameters need to be considered as per Air Transportation Authority Standard-300 to make a legal approved and durable design of crate. All these drop parameters are evaluated for experimental and simulation of Flight crates.

Weight	Orientation	Drop Height
<= 272Kg	Face	0.5 & 1 meter
	Edge	0.5 & 1 meter
	Corner	0.5 & 1 meter

Table 2 Drop Orientations

CHAPTER 4 Design and Analysis

4.1 Design of Flight Crate

CAD Modelling of Flight crate is prepared in Solidworks software considering all design parameters and Field replacement units.

- This Flight crate mainly used for medical electronics devices
- Total length of Flight crate is 570mm, width 870mm and height is 402mm.
- Aluminum corner plates are used to avoid edge damage
- Nickel plated steel ball corner used to provide corner protection

Figure 4. 1 Isometric view ATA Crate

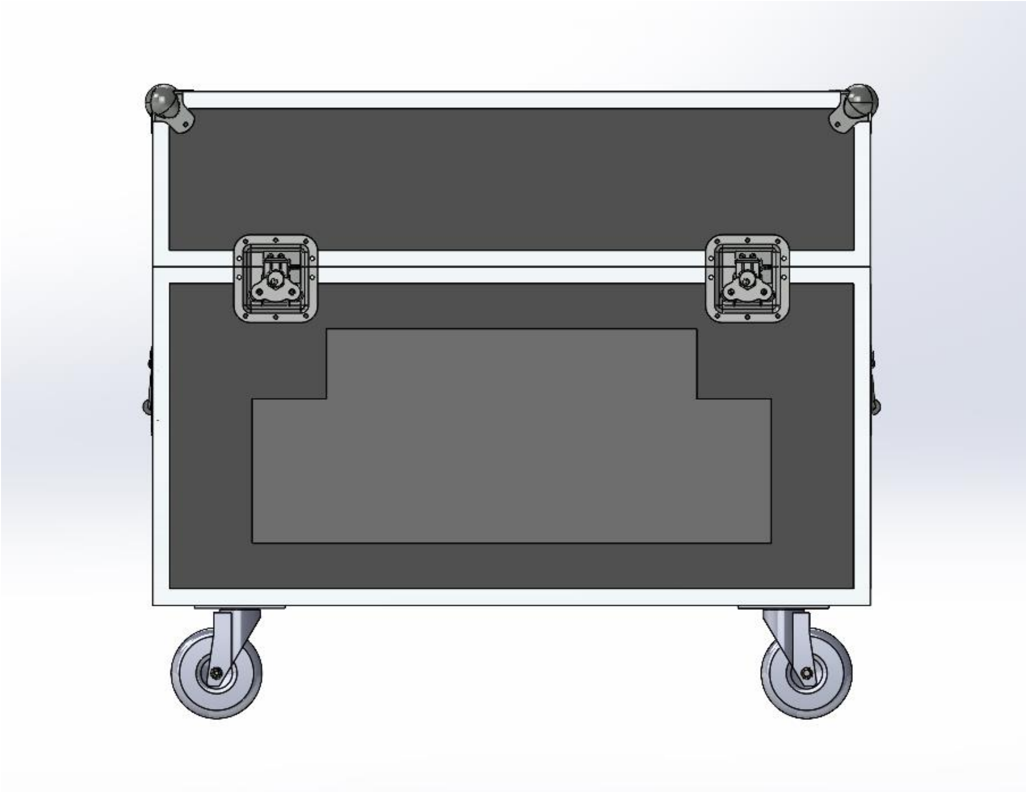


Figure 4. 3 Front view

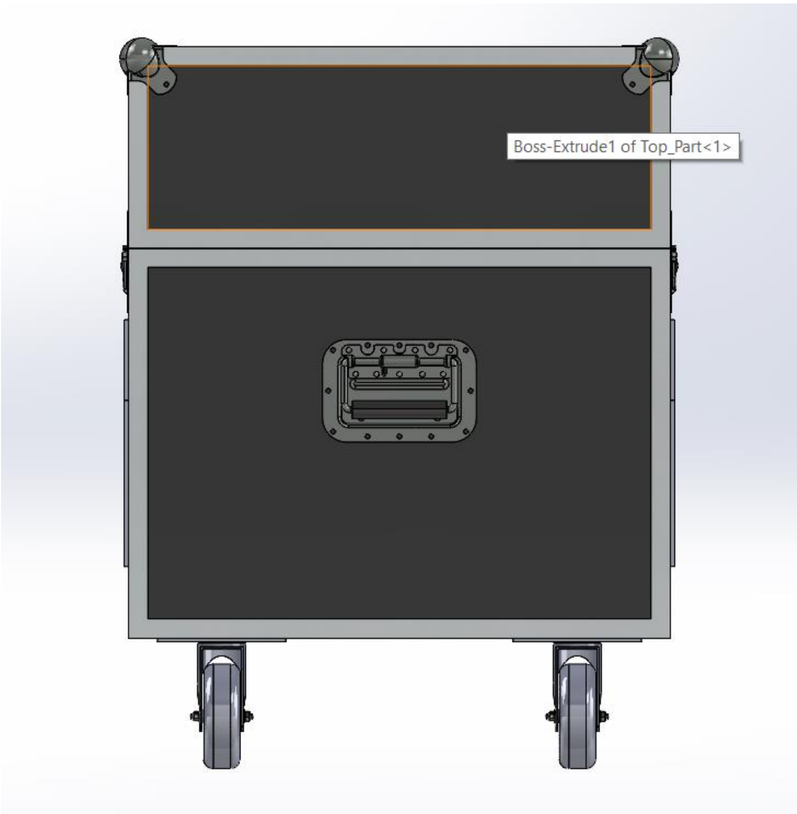
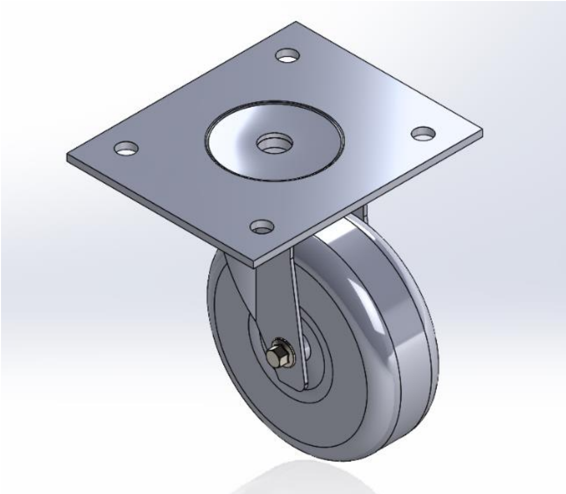
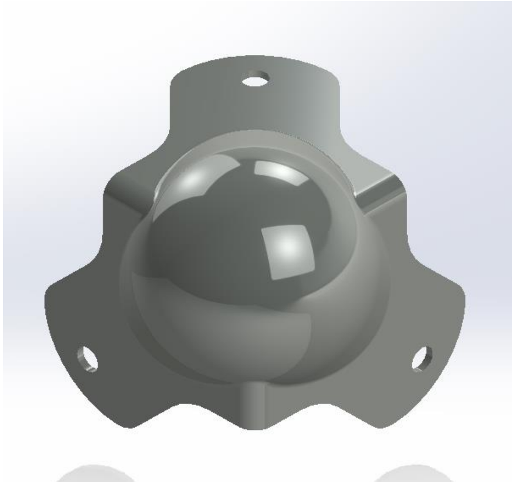


Figure 4. 2 Side view



(a)



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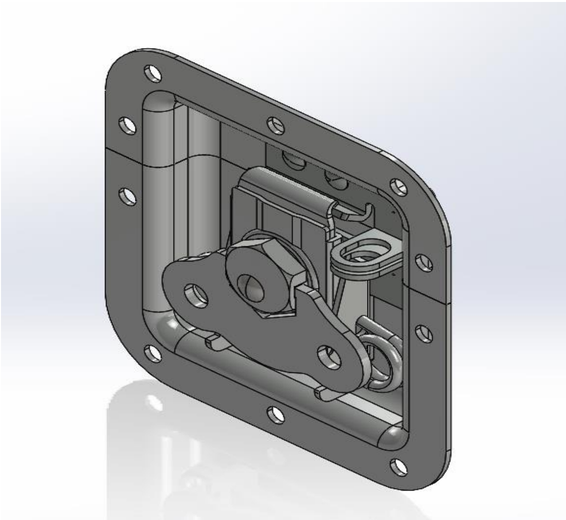

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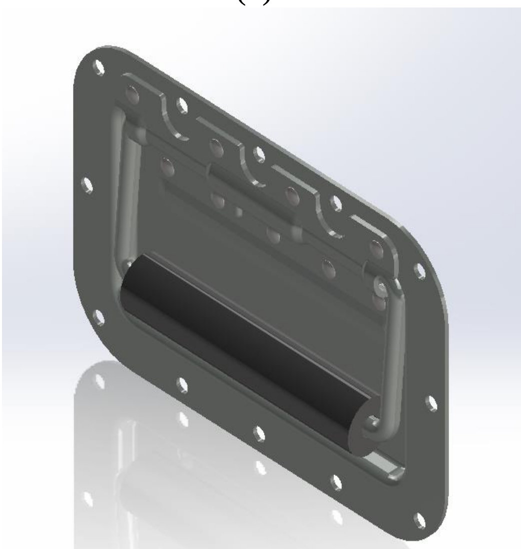


(d)

Figure 4. 4 Crate Accessories

4.2 FINITE ELEMENT MODEL

A Finite Element Model (FEM) is a numerical representation of a physical system or structure used to simulate and analyze its behavior under various conditions. It is a mathematical approximation that divides the system into smaller subdomains called finite elements, allowing complex geometries and material properties to be represented in a discretized manner. The purpose of creating a Finite Element Model is to gain insights into the structural response, performance, and behavior of the system under different loading and boundary conditions. In general, a finite-element result may be broken into the following three stages.

1. Geometry and Meshing:
    a. The first step is to define the geometry of the system or structure to be analyzed. This involves creating or importing the CAD model.
    b. The geometry is then divided into a mesh of finite elements, which are interconnected at specific nodes. The choice of element type and mesh density depends on the complexity of the system and the desired accuracy of the analysis.
2. Material Properties:
    a. Assigning appropriate material properties to the elements is crucial for accurate simulations. Material properties include stiffness, density, thermal conductivity, and more.
    b. Different materials can be assigned to different regions or elements within the model to represent heterogeneous systems.
3. Boundary Conditions:
    a. Boundary conditions define how the model interacts with the external environment. They include applied loads, constraints, displacements, temperatures, and other constraints.
    b. Boundary conditions simulate the physical constraints and forces acting on the system.
4. Analysis:
    a. With the geometry, mesh, material properties, and boundary conditions defined, the Finite Element Model is ready for analysis.
    b. The model is subjected to various types of analysis, such as static analysis, dynamic analysis, thermal analysis, or fluid-structure interaction, depending on the nature of the problem.

5. Results and Interpretation:
    a. The analysis generates numerical results, such as displacements, stresses, strains, temperatures, and other relevant quantities.
    b. These results are used to evaluate the performance, safety, and efficiency of the system under different operating conditions.
    c. Results can be visualized through contour plots, animations, or graphs to aid in understanding the system's behavior and making informed design decisions.

The purpose of a Finite Element Model is to provide engineers and designers with a virtual representation of a physical system that enables them to predict and analyze its response to various conditions. It allows for optimization, sensitivity analysis, and the exploration of different design scenarios without the need for costly physical prototypes.

4.2.1 LS DYNA

LS-DYNA is a versatile software package for finite element analysis that is extensively utilized in the simulation of intricate engineering problems encountered in various real-world applications. It is known for its versatility in simulating various physics, including structural mechanics, fluid dynamics, and metaphysics interactions. Industries such as automotive, aerospace, defense, and manufacturing frequently rely on LS-DYNA for a wide range of applications. This powerful software package finds common usage in these industries due to its ability to effectively address the complex analysis needs and challenges encountered in these fields. Here is a general overview of LS-DYNA and the typical steps involved in using the software:

1. Preprocessing:
    - Define the geometry: Create or import the geometry of the system or structure you want to analyze.
    - Mesh generation: Divide the geometry into discrete elements to create a mesh that represents the structure.
    - Define material properties: Specify the mechanical properties of the materials used in the simulation.
    - Apply boundary conditions: Define constraints and loads that simulate the operating conditions of the system.
    - Define contact interactions: Set up contact interfaces between different parts or components to model their interactions during simulation.

2. Solver Setup:

- Configure analysis parameters: Set up the simulation parameters such as time step, integration method, and solution controls.
- Choose analysis type: Select the appropriate analysis type based on the problem being solved, such as static, dynamic, explicit, implicit, etc.

3. Simulation:

- Run the simulation: Execute the LS-DYNA solver to perform the analysis based on the defined setup.
- Monitor the simulation: Monitor the progress of the simulation, check for convergence, and ensure stability.
- Post-processing: Once the simulation is complete, analyze and interpret the results to gain insights into the system's behavior.

4. Post-processing:

- Visualize results: Use LS-DYNA's post-processing tools or export the results to other software for visualization.
- Extract relevant data: Extract and analyze the desired quantities or variables from the simulation results.
- Validate and interpret results: Evaluate the simulation results against experimental data or design criteria to validate the model and draw conclusions.

5. Iteration and refinement:

- If necessary, refine the model or analysis setup based on the initial results or further investigations.
- Adjust parameters, boundary conditions, or geometry to improve accuracy and convergence.
- Repeat the analysis to refine the understanding of the system behavior or optimize the design.

It's important to note that LS-DYNA is a powerful and complex software, and the specific steps and setup details may vary depending on the problem at hand, the desired analysis objectives, and the available resources. Familiarity with finite element analysis principles, knowledge of the specific physics involved, and experience with the software are essential for effectively using LS-DYNA.

4.2.2 Pre-Processing

Geometry Import: 3D model of ATA Crate prepared in Solidworks is imported in LS Dyna as .IGES file. Base is created by Shape masher with specific solid elements which will work as Concrete floor for the drop test of crate. Distance between Base and Packaging crate is defined with transform command as per orientation like Face, Edge and Corner to reduce the computation time to the software.

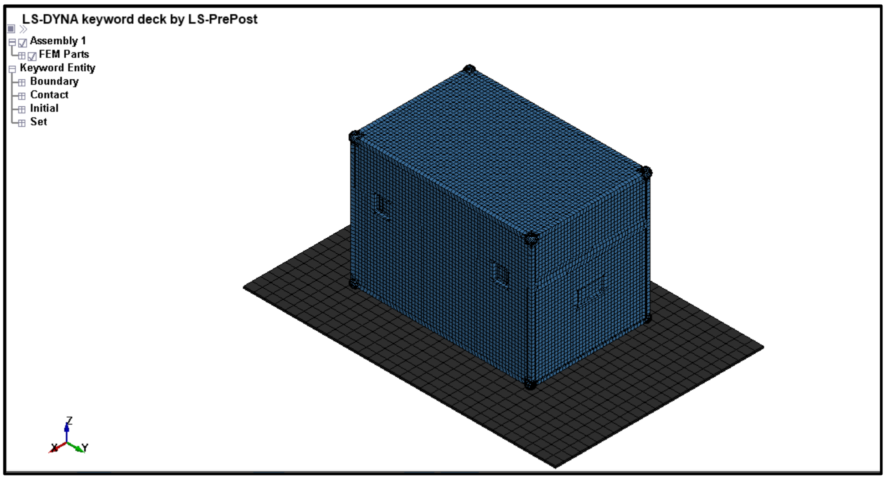
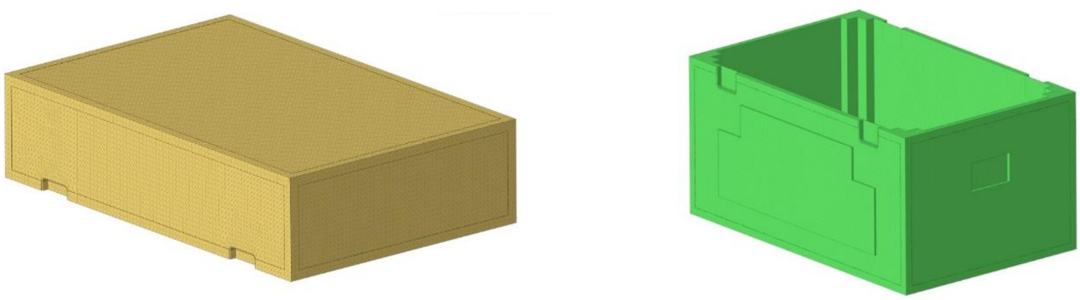
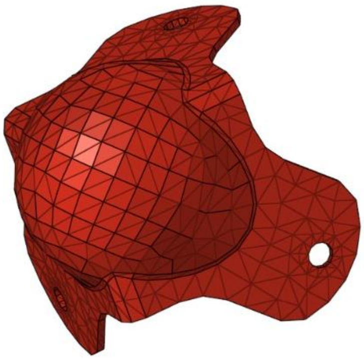


Figure 4. 5 Geometry Import LS-Dyna

Mesh Generation: Mesh generation divides the geometry into finite. This process involves discretizing the geometry into smaller elements to capture accurate behavior during the drop test. Concrete base is auto meshed in shape masher command defining solid elements. ATA crate is meshed with range of minimum size 5mm element to maximum 15mm element to refine corner and fillets or round area of model. Total 1500 number of solid elements are generated for concrete base floor. While ATA crate consisting of 27089 shell elements. By considering less calculation time, most of elements having 15 to 10mm size where the region is not critical. While critical parts such as corners are defined with 5mm of element size.



(a) (b)



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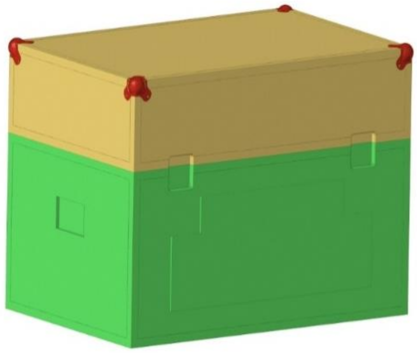


(d)

Figure 4. 6 Meshing

Material Definition: ATA Crate and Concrete floor is defined with material as per specifications according to simulation criteria. Two different material types which are Type 20 (***MAT_RIGID**) as rigid material and Type 24 (***MAT_PIECEWISE_LINEER_PLASTICITY**) as linear plastic material. ATA crate and its accessories are defined in Type 24 material card as per mentioned in below table. Type 20 material card is used for concrete floor for which material properties are described in table.

Material	Type	Density (Kg/mm3)	Young's Modulus (GPa)	Poisson's Ratio	Yield Strength(GPa)
Concrete	Type 20	2.40E-06	26	0.2	0.0357
ABS	Type 24	1.05E-06	1.47	0.3	0.0438
316 Stainless Steel	Type 24	8.90E-06	200	0.29	0.345

Table 3 Material types

Contact setup: model during the drop test, including contact between rigid bodies, deformable bodies, or between deformable bodies and rigid surfaces. Proper contact modeling is essential for accurately simulating the impact and collision behavior in the drop test. ***AUTOMATIC_SINGLE_SURFACE** contact card is defined between the parts of the ATA crate mechanical structure for the self-contact of each part. Contact between the rigid floor and the ATA Crate is defined with ***AUTOMATIC_SURFACE_TO_SURFACE** contact card. Master and slave segment is assigned to the base and Crate respectively.

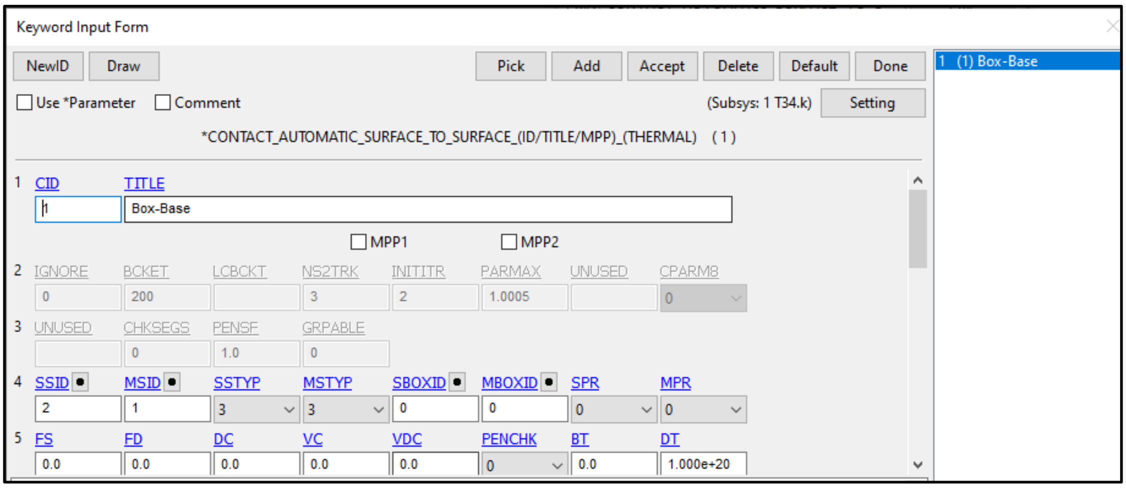


Figure 4. 7 Contact card

Boundary conditions: Rigid concrete floor is defined as fixed contact in Spc boundary card. All degree of Floor is constrained. ATA crate is given velocity by using ***INITIAL_VELOCITY_GENERATION** card and 3.5m/s, 4.5m/s velocities are defined as per different cases.

Section type: Two type of part section card is used in this simulation. Solid section is assigned to the concrete base and Shell section card is applied to the ATA crate with wall thickness of 12.5mm.

4.2.3 Solver setup

Time step: Control termination card is used to define time step for drop simulation. Defined the termination time of the simulation which is necessary to run the simulation. Termination time is given as 5 second in **CONTROL TERMINATION** Keyword as shown below. Step size is defined as 0.05s.

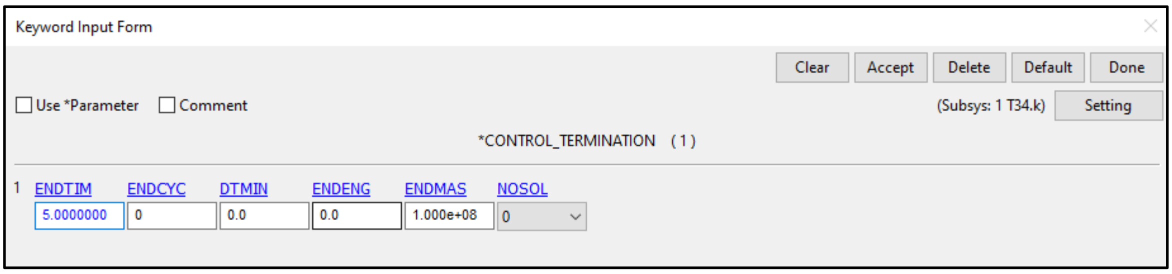


Figure 4. 8 Control Termination

Solution control: DATABASE is required after defining all the conditions required for simulation, we can generate output requests or results which we are interested in the model. Here **BINARY_D3PLOT** under **DATABASE** is defined as keyword and Time interval is defined as 5 second.

4.2.4 Simulation

ASCII Card is defined to get plotted results for drop simulation between time intervals. **GLSTAT** and **MATSUM** cards are inserted in ASCII section with time step of 0.05 to get energy output data of drop simulation. Keyword is used to check model constraints and parameters for drop test.

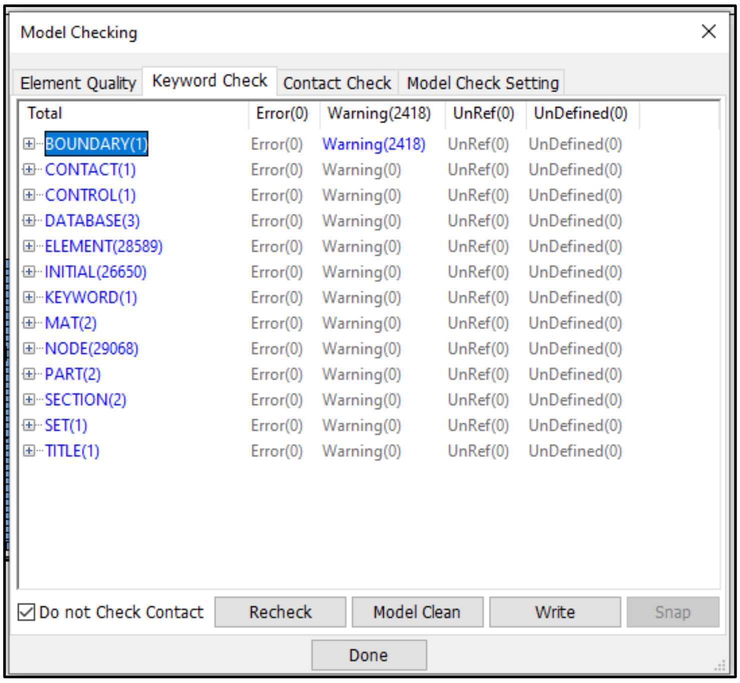


Figure 4. 9 Model check

4.2.5 Post-Processing:

LS-Post & Data Extraction: LS-Post is used to post process the results of drop test visualization. Required outputs Von-Mises stress and Acceleration results are plotted as per different orientations and time step size.

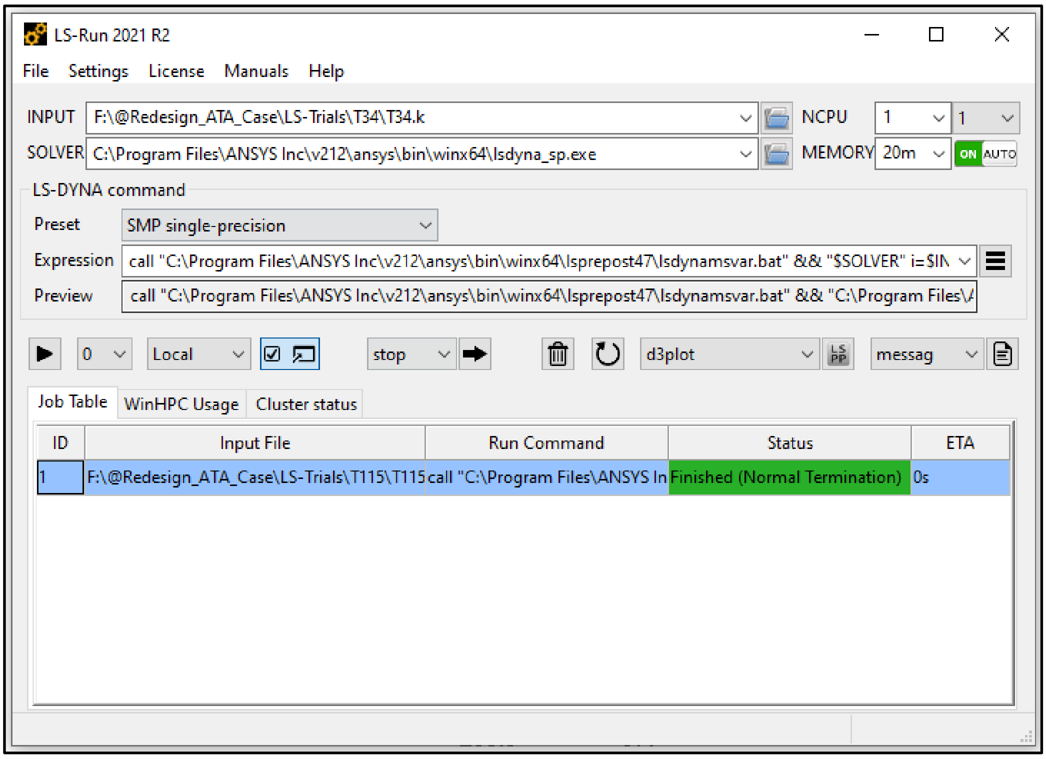


Figure 4. 10 Post-Processing

CHAPTER 5 Experimental Drop Test

The main goals of the current drop test utilizing the prototype models are twofold: first, to validate the performance of the package, and second, to verify the accuracy of the numerical tools and modeling methodology employed in the analysis. These objectives are accomplished by comparing the results obtained from the analytical simulations with the physical test outcomes, which include data on deformation behavior, strain and acceleration over time, sizes of the opening gaps, bolt axial force, and more. To conduct these evaluations, a total of five drop tests were performed using two full-scale prototype test models. The drop orientations for the test models were selected based on the analysis results conducted prior to the actual tests. These chosen orientations represent the most severe scenarios in terms of package damage in the 1m and 0.5m free drop scenario.

The drop test program took place at the drop testing facilities located at the NEFAB laboratory, Pune. These facilities comprise a drop tower structure, support to prototype, a release mechanism, and a rigid target. The target used at the NEFAB facility adheres to the regulations set by the International Safe Transit Association (ISTA). To conduct the tests, the test specimen was supported to a 10-ton hoist using suitable rigging, and the package was lifted to the desired height of 1 and 0.5 meters. An electronically activated tang-type release device was employed to initiate the free fall of the package. During the drop tests, the packages were outfitted with strain gauges and acceleration sensors positioned at specific predetermined locations. These instruments were utilized to calculate the impact forces and measure the deformations in terms of accelerations and Von-misses stresses experienced by the package throughout the drop tests. Furthermore, to capture the test events, both a high-speed camera and a video camera were employed. The high-speed camera served the purpose of verifying orientation angles immediately before impact and examining the instantaneous behavior at the moment of impact. Before and after each drop test, visual conditions of crate was noted.

Figure 5. 1 Prototype of ATA Crate

Test equipment: Lansmont Drop tester, model PDT-56ED

Data analyzer: Lansmont TP3 Lite

Accelerometer: PCB, model 354C10

Test level: drop height from 0.5 m and 1 m

Number of drops: 06

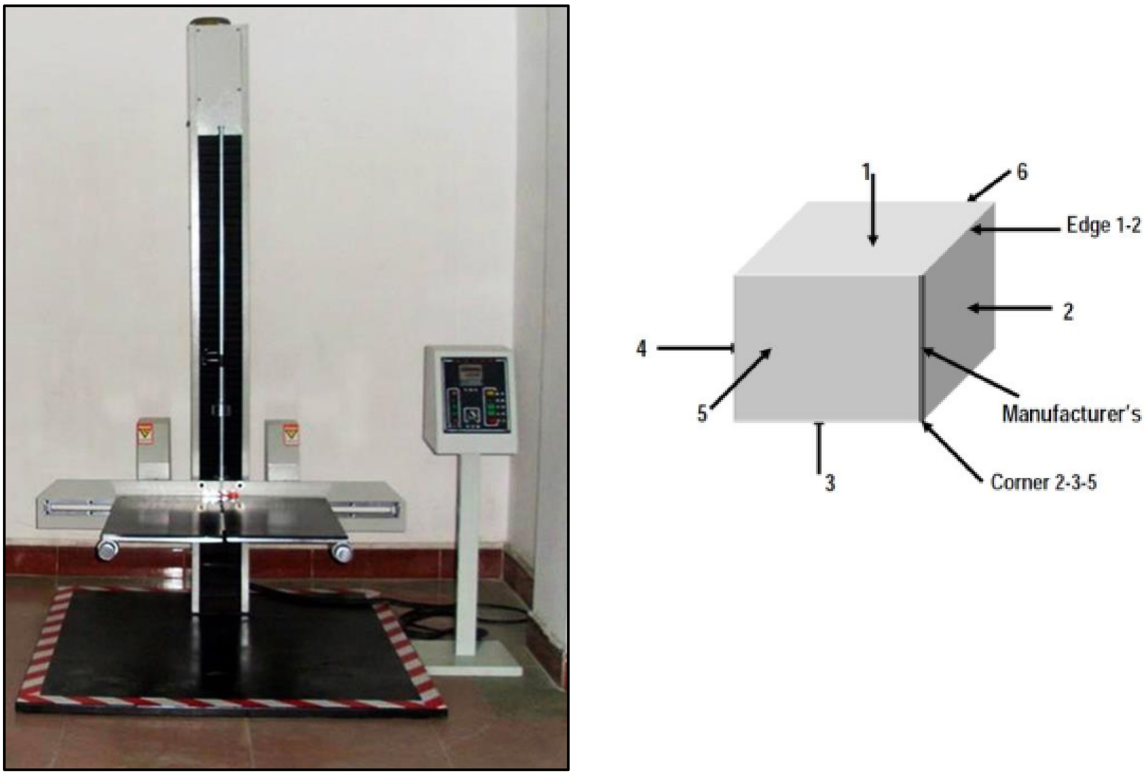


Figure 5. 2 Experimental set-up

CHAPTER 6 Results & Discussions

Simulation of drop test focusses on von Mises stress and acceleration results is primarily to assess the structural integrity and evaluate the potential for damage or failure of the test specimen. In a drop test, the impact forces generated during the drop can result in high stress concentrations and localized deformation. Monitoring the von Mises stress helps identify critical areas that may experience plastic deformation, yielding, or fracture. While Acceleration data during a drop test provides information about the dynamic loading experienced by the test specimen. It helps evaluate the severity of impact and the potential for structural deformation or displacement. By analyzing the acceleration data, we can identify regions of high loading and understand the response of the test specimen to the impact. By focusing on von Mises stress and acceleration results, we can gain insights into the structural behavior and potential failure modes of the test specimen during a drop test.

6.1 Simulation Results ATA Crate

After pre-processing of the Finite element model, Maximum von misses stress and acceleration results were evaluated for each orientation and different velocity. For different time steps during time interval of 5 second, different states are observed for results of Von-misses stress and Accelerations.

6.1.1 Maximum effective (Von Mises) stress

The simulation results are post-processed to extract the von Mises stress distribution for further evaluation and interpretation. In a simulated drop test, the von Mises stress results represent the distribution of equivalent stress throughout the test specimen. These results are derived from the simulation and indicate the regions of the test specimen that are experiencing the highest stress levels. The simulation results and observations of Von Mises stress distribution of ATA crate structure is shown in figure.

In the flat position drop, the maximum stress experienced is lower compared to the other drop positions. The maximum effective stress is measured at 43 MPa for a drop height of 1m with impact velocity of 3.1 meter/second and 49 MPa for a drop height of 0.5m with impact velocity of 4.5 meter/second. These values indicate that the structural damage did not occur during the flat position drop. Figure 6.1 shows flat drop simulation results.

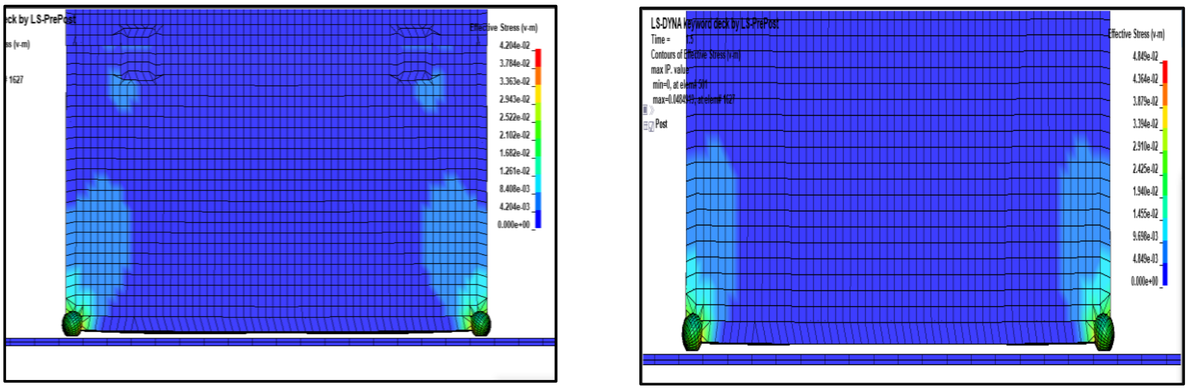
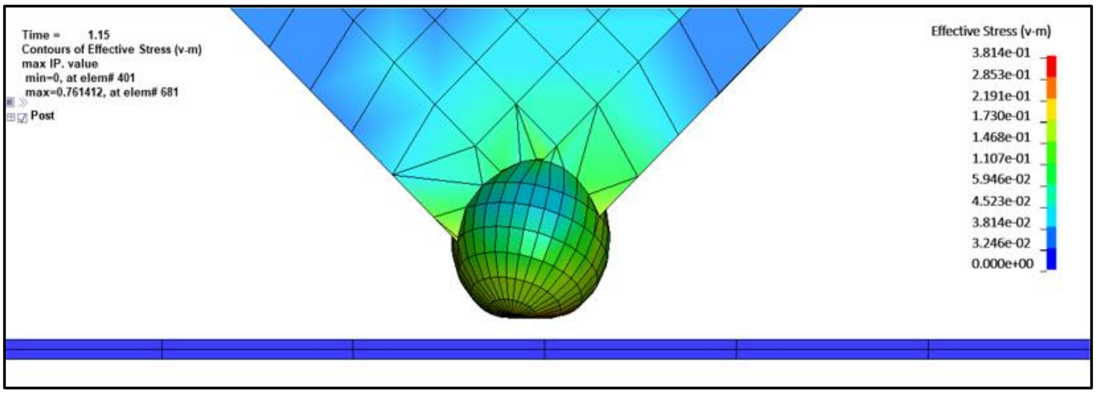
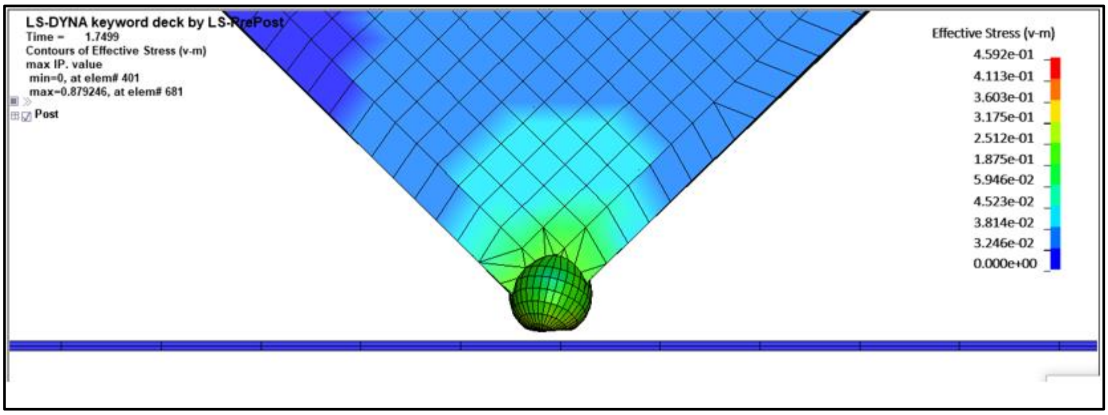


*Figure 6. 1 Effective von-mises **Face drop***

Edge drop simulation results represents that defined impact velocity affects structural rigidity. Edge drop results indicates some deformation on the corner side, but this deformation is near range to the yield strength of corner and edge material. Maximum Von-Mises stress at this position is 459.2MPa while having impact velocity of 4.5m/s and 381.4Mpa stress while having impact velocity of 3.1m/s. Since yield limit of corner and edge material is 345Mpa, results have crossed yield limit of material and that results in deformation in this orientation. Figure 6.2 shows edge drop simulation results.



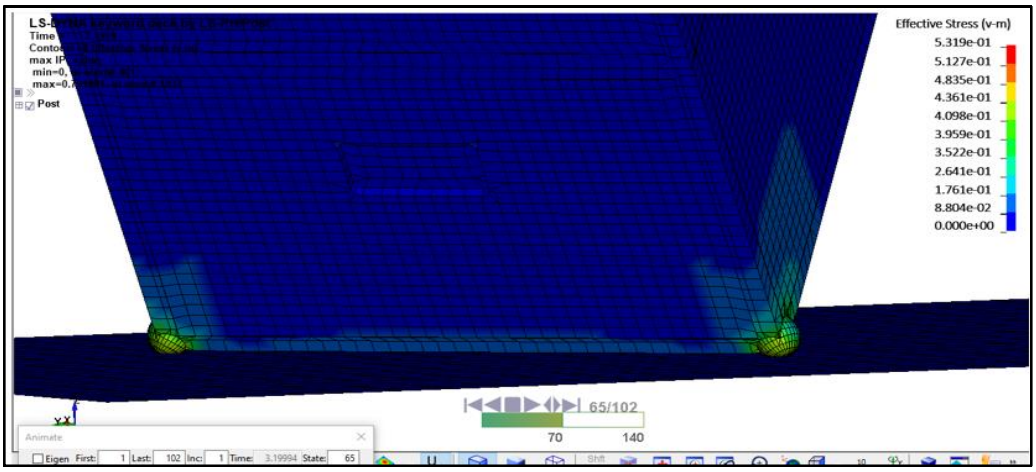
(a)



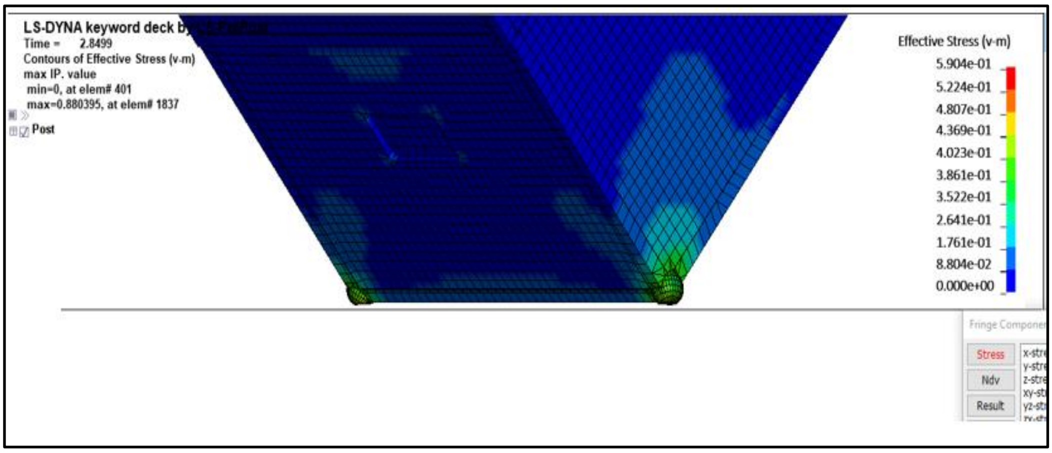
(b)

*Figure 6. 2 Effective von-mises stress **Edge drop***

Corner drop simulation results represents that defined impact velocity affects more severity in structural rigidity. It shows large deformations as compared to the Face and edge drop, and these deformation crossed 1.5 times range to the yield strength of corner material. Maximum Von-Mises stress at this position is 532 MPa while having impact velocity of 3.1m/s and 590.4Mpa stress while having impact velocity of 4.5m/s. Since yield limit of corner and edge material is 345Mpa, results have crossed yield limit of material and that results in large deformation in corner side orientation. Figure 6.3 shows corner drop simulation results.



(a)



(b)

*Figure 6. 3 Effective von-mises stress **Corner drop***

6.1.2 Acceleration Results

The simulated results of the drop test show the distribution of acceleration throughout the test specimen. These results provide insight into the dynamic loading experienced by the specimen during the drop. By analyzing the acceleration distribution, we can identify regions of high acceleration and assess the severity of impact. Higher acceleration values indicate larger inertial forces acting on the specimen, which can lead to significant structural deformation or displacement.

In the flat position drop, the maximum acceleration observed is lower compared to the other drop positions. The maximum acceleration is measured at 4.48g for a drop height of 1m with impact velocity of 3.1 meter/second and 5.45g for a drop height of 0.5m with impact velocity of 4.5 meter/second. These values indicate that the dynamic behavior under flat drop does not much affect ATA Crate. Figure 6.4 shows flat drop simulation results.

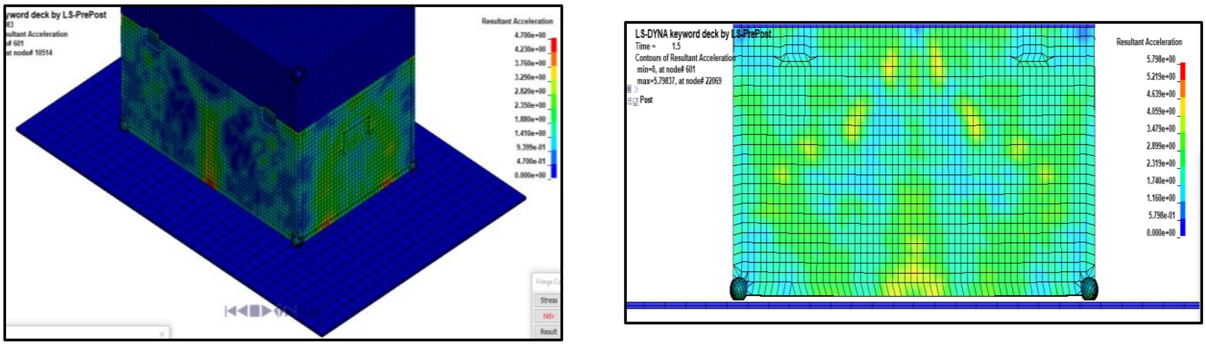


Figure 6. 4 Accelerations ***Face drop***

In the edge position drop, the maximum acceleration observed is comparatively higher that the flat positions. The maximum acceleration is measured at 4.7g for a drop height of 1m with impact velocity of 3.1 meter/second and 5.8g for a drop height of 0.5m with impact velocity of 4.5 meter/second. Acceleration results represents that is the considerable amount of damage as certain zones near to the edge. Figure 6.5 shows flat drop simulation results.

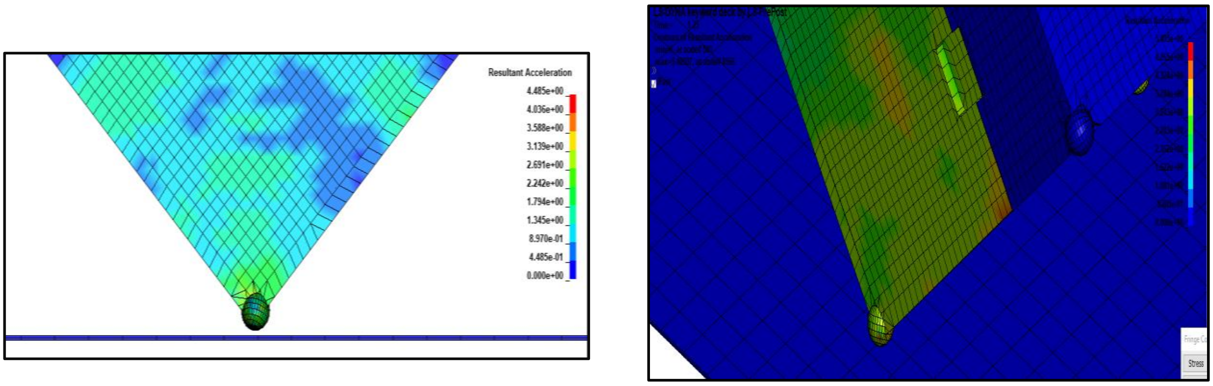
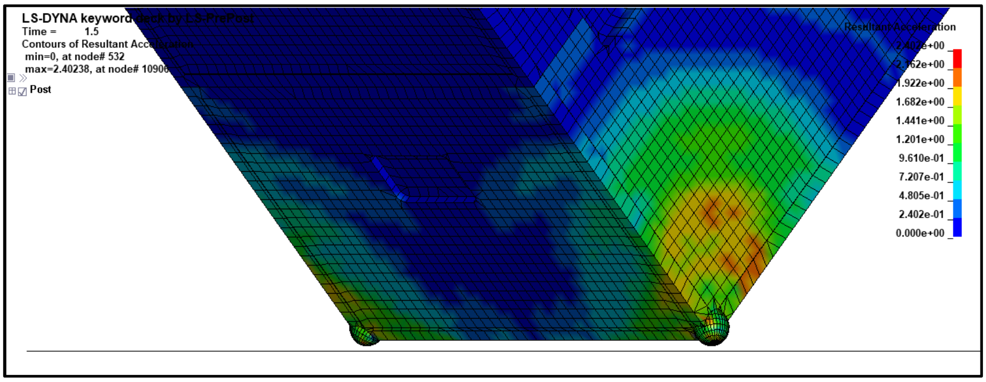


Figure 6. 5 Accelerations **Edge drop**

Acceleration results on corner drop orientations shows that, there are zones near to the corner and edge are most affected under impact load conditions. Maximum acceleration observed is 5.94g with impact velocity of the 4.5m/s. While acceleration value measured with impact velocity of 3.1m/s is 4.85g. Apart from this, acceleration values in both velocities are more as compare to the face and edge drop.



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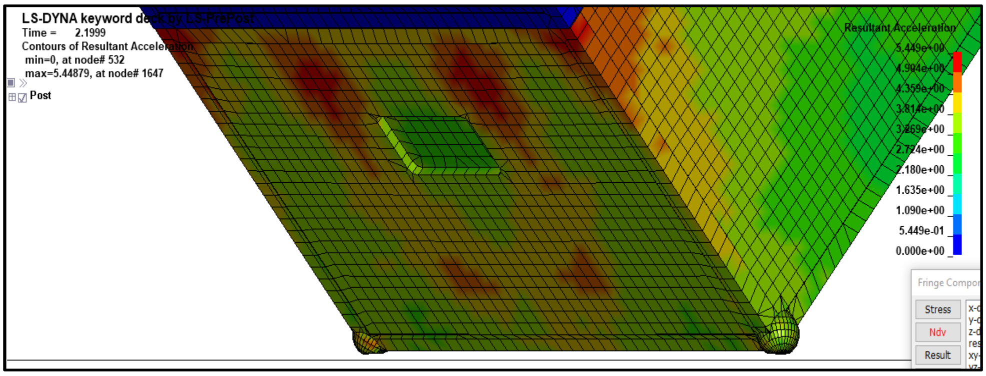
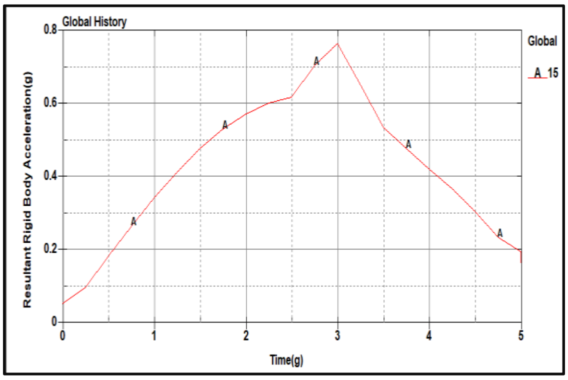


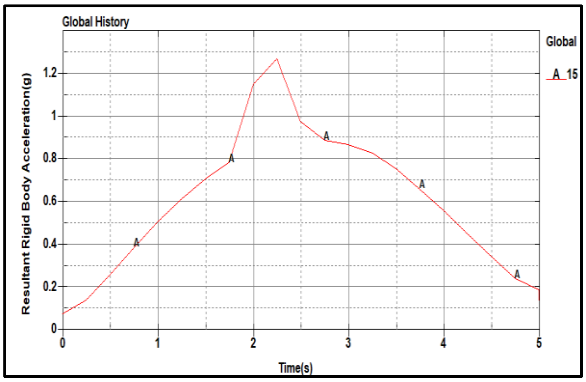
(b)

*Figure 6. 6 Accelerations **Corner drop***

Acceleration plots



(a)



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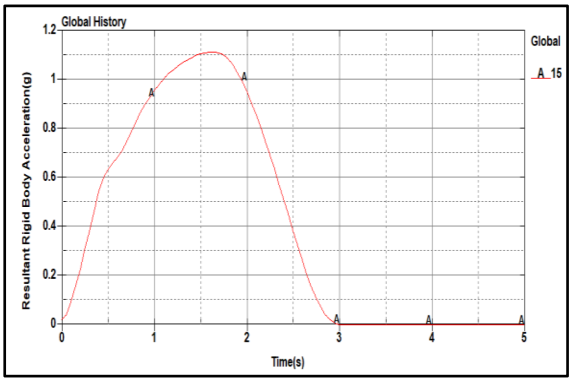
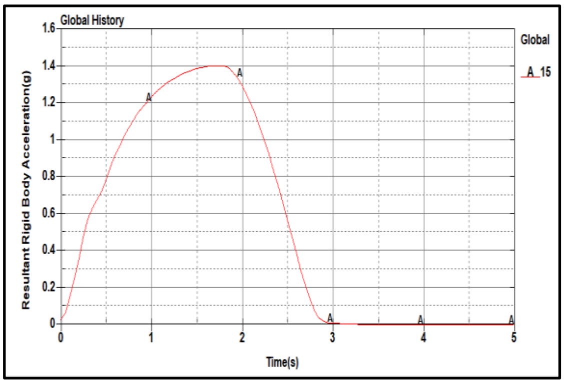
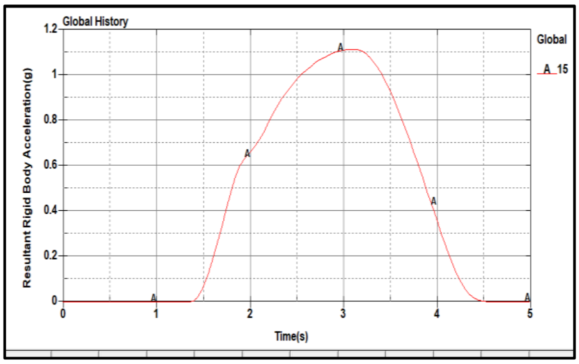


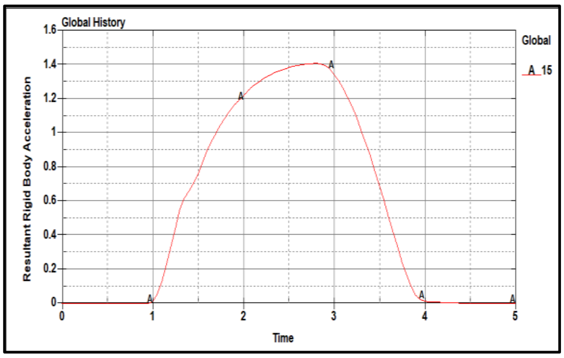
(c)



(d)



(e)



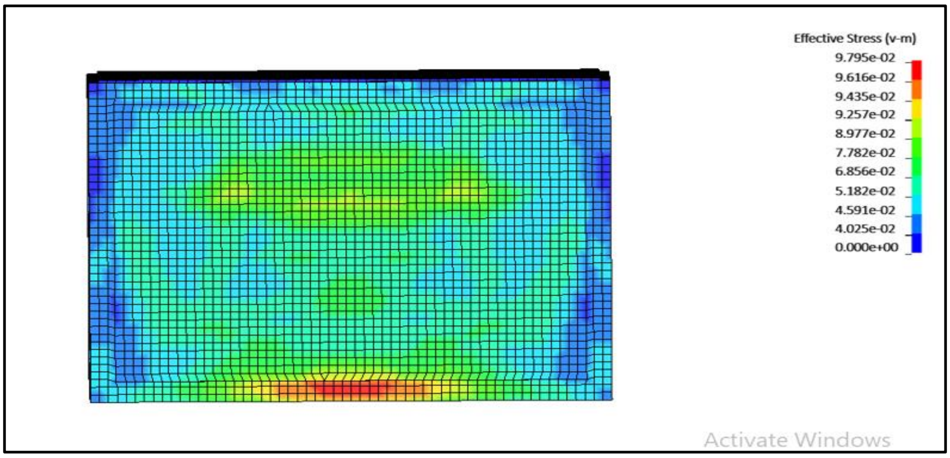
(f)

Figure 6. 7 Acceleration plots for Face, Edge & Corner drops

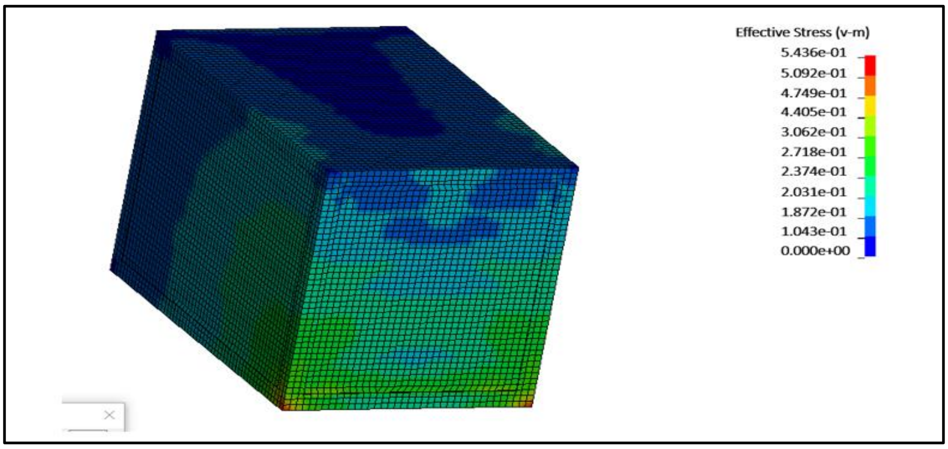
6.2 Simulation Results Wooden Crate

Drop test simulation on wooden crate is performed to validate comparison of proposed material ABS Crate under impact loading. Here, Normal wooden crate is designed which is not having any corner or edge protection. Also, this wooden crate is taken as reference to normal day to day usage of packaging box for all component which is conventionally preferred as low cost packaging. Purpose of simulation on wooden crate is only to compare results with proposed packaging material ABS (ATA Crate) consisting of handle, corner and edge accessories. Simulates results are settled in terms of von-mises stress.

Simulation results of wooden crates are presented only in form of von-mises stress and considering maximum impact velocity of 4.5m/s to compare with ATA Crete. Results shows that maximum stress occurred in corner drop position in wooden packaging crate. Also, it shows maximum stress of 695MPa in corner drop, 544Mpa in edge drop and 98Mpa in face drop. It clearly shows that in all 3 orientations, this wooden crate crosses its yield limit in too high margin. Now when comparing these results with ATA Crate, we can infer that wooden crate is having more stress at critical region like edge and corners as compare to the proposed ATA Crate packaging. That means ATA Crate shows more structural rigidity as compare to wooden crate and it can sustain more number of times mishandling and transport movement under dynamic conditions.



(a)



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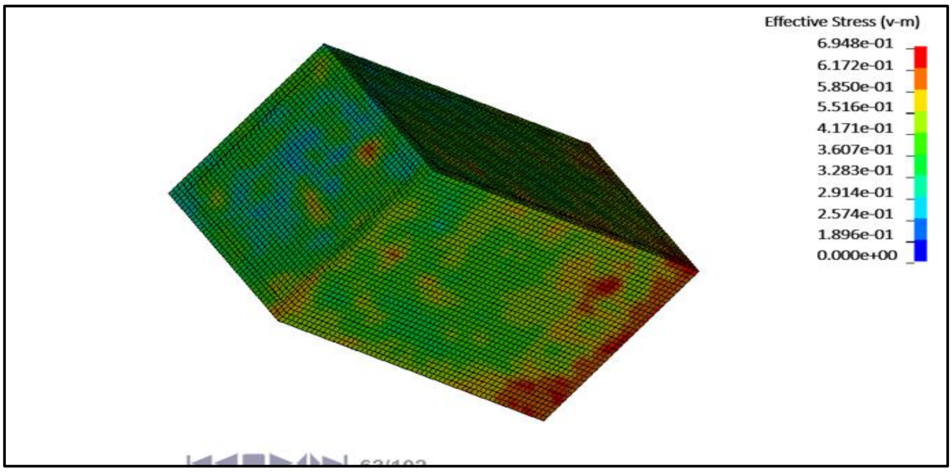

(c)

Figure 6. 8 Wooden crate V-M stresses

6.3 Experimental Results

To validate simulated results of drop test, physical test was performed, and results are observed in terms of accelerations and von mises stress to understand behavior of ATA Crate under impact loading. It also gives confidence to understand most severe regions where the part can be fail. Experiment is carried out as per test described in section 5. Calibrated Accelerometer and strain gauges are used to measure output of physical drop test. Packaged product test according ISTA 3A has been performed on Drop tester. Due to the size and design of the packaging, the packaged product is classified as standard and is tested accordingly. Results are shown in below table.

Drop No	Drop Height(m)	Orientation	Stress(MPa)
1	0.5	Face	49
2	0.5	Edge	440
3	0.5	Corner	470
4	1	Face	52
5	1	Edge	541
6	1	Corner	710

Table 4 Experimental stress results

Drop No.	Drop Height(m)	Orientation	G-value[g's]
1	0.5	Face	5
2	0.5	Edge	5.2
3	0.5	Corner	5.5
4	1	Face	5.6
5	1	Edge	6
6	1	Corner	6.5

Table 5 Experimental acceleration results

6.4 Comparison of Simulation and Experimental data

Analytical and Experimental results are compared to understand which parameter affect most on which quantity and to observe change in percentage between both results.

Drop No	Drop Height(m)	Orientation	Experimental results(MPa)	Analytical results(MPa)	Difference (%)
1	0.5	Face	49	43	12
2	0.5	Edge	440	381.4	15.5
3	0.5	Corner	470	532	-11.6
4	1	Face	52	49	5
5	1	Edge	541	459.2	18
6	1	Corner	710	590	20.5

Table 6 Difference between Experiment and simulation stress results

Drop No	Drop Height(m)	Orientation	Experimental results(g)	Analytical results(g)	Difference (%)
1	0.5	Face	5	4.484	5
2	0.5	Edge	5.2	4.7	11
3	0.5	Corner	5.5	4.85	8.1
4	1	Face	5.6	5.45	3
5	1	Edge	6	5.8	7.56
6	1	Corner	6.5	5.94	9.98

Table 7 Difference between Experiment and simulation acceleration results

From both tables, we can infer that difference between Analytical and Experimental results for Von-mises stress is in between 20%. While acceleration results have difference below 10% while comparing analytical results with experiment.

Further graph is plotted in Minitab software to understand which orientation is affecting ti the results while considering other two parameters velocity and stress outputs.

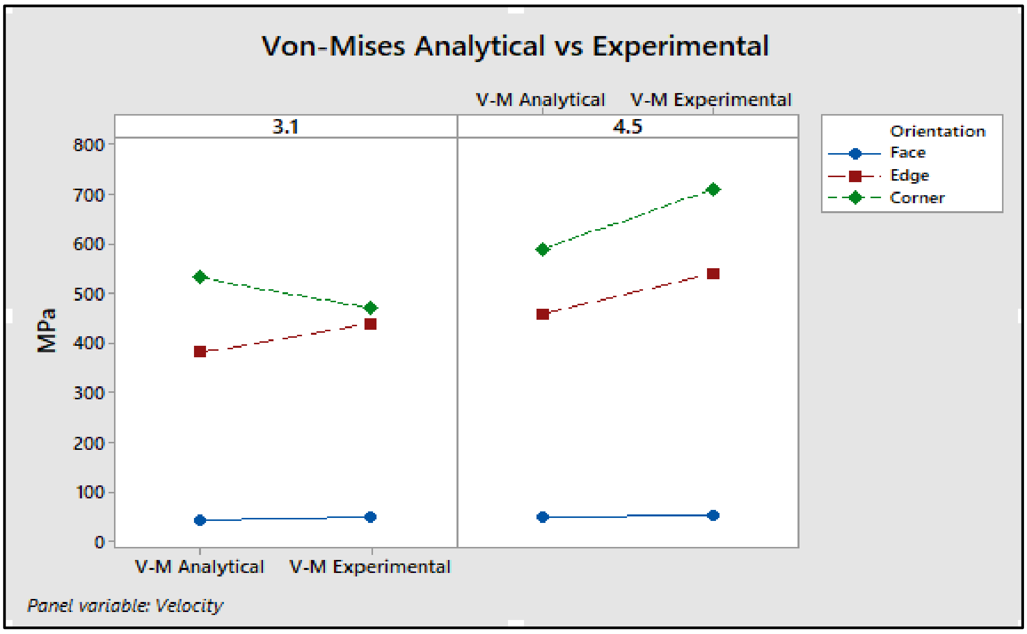

Figure 6. 9 Analytical vs Experimental Stress

CHAPTER 7 Conclusions

In present study, an advanced analytical simulation and evaluation process using the FE method have been developed for the design assessment of the newly proposed ATA crate for packaging of RF-Amplifier. Analytical simulations for the various drop orientations were performed to study dynamic behavior of the ATA packages and to ensure robust design of the proposed crate. Also, experimental drop test on prototype was carried out to verify the analysis results and confirm the performance of the ATA Crate. From this study, the following conclusions are drawn.

The drop test simulations have been conducted to understand dynamic behavior of ATA Crate due to the impact load on the 0.5m and 1m drop height condition. It was observed that the maximum effective (Von Mises) stress is happened on the corner side drop position. The maximum effective stress of 590 MPa and 532 MPa are larger than the yield stress limit of the ABS and 316-SS material. Therefore, it is indicated that the plastic deformation can be found on the corner side only. This will not affect regular day to day operation as corners and other accessories are used as Field replaceable Unit. So as whenever such severe damage occurs to the corners, they can be replaced with new one by Field service engineer.

Comparison between simulated data between Wooden crate packaging and ATA Crate packaging shows that, ABS material with combination of nickel-plated stainless-steel corner has more tendency to resist impact loads considering mishandling during transport of RF Amplifier. Further ATA Crates can be used number of times for packaging as compared to wooden crates as it gives better von-mises and acceleration results as compared to wooden crates.

The physical test results were compared with the preliminary analytical results to verify the numerical tools and the methodology used in the analyses. In general, the analysis results correspond well with the test results for most of the cases evaluated as there is deviation of less than 20 percentage between analytical and experimental results.

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