



Origami Inspired Airbag for Landing and Crash Protection

ME420 Mechanical Engineering Individual Research Project

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by

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Peradeniya, 2023

Declaration

I declare that this report does not incorporate, without acknowledgment, any material previously submitted for any other Degree or Diploma to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due references are made. It has not been accepted for any other course and is not being concurrently submitted to any other person.

Signature of candidate

Date 2023/12/26

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Date 2023/12/26

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Preface

This research reports presents a comprehensive review of Origami Inspired airbag design with the problem to the solution step by step, highlighting the potential benefits of incorporating origami principles into airbag technology. Due to time constraints, no new simulations were conducted, but the report provides insights into design options and guiding principles for origami-inspired airbags.

The report begins with a discussion of the principles and methods of origami, followed by an overview of the potential applications of origami in airbag design. The focus is on how origami principles can be used to improve the safety and effectiveness of airbag systems in mitigating the impact of landings and crashes. A systematic literature review is then presented, covering a wide range of academic papers, articles, and patents on origami-inspired airbags and airbag technology.

The review identifies potential research gaps and unexplored avenues in this emerging field, paving the way for future research and development. Overall, this report provides a valuable resource for researchers and engineers interested in advancing the state-of-the-art in origami inspired airbag design. It sets the stage for more profound exploration of this promising field and the development of safer and more effective airbag systems.

Abstract

This research report offers a comprehensive review of the application of origami principles in airbag design, emphasizing the potential advantages of integrating origami concepts into airbag technology. The report outlines a step-by-step approach from problem identification to potential solutions, providing valuable insights into design options and guiding principles for origami-inspired airbags. While the report did not conduct new simulations of Origami Airbag Design due to time constraints, it delves into the principles and methods of origami, and select suitable folding patterns for Airbag design, and explores potential applications in airbag design, and assesses how origami principles can enhance the safety and efficacy of airbag systems in mitigating impacts from landings and crashes. A systematic literature review is presented, encompassing diverse academic papers, articles, and patents related to origami-inspired airbags and airbag technology. The review identifies research gaps and unexplored opportunities in this emerging domain, laying the foundation for future research and development. Ultimately, this report serves as a valuable resource for researchers and engineers seeking to advance origami-inspired airbag design, fostering deeper exploration in this promising field and the creation of safer and more efficient airbag systems.

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1 Introduction

1.1 Airbag as occupant Safety

Airbags have become an essential safety feature in modern vehicles. Protecting occupants during collisions and reducing risk of severe injuries. Over the years, airbag technology has evolved significantly, driven by a continuous pursuit of improved performance and enhanced occupant safety. This introduction aims to be an introduction to the research project with examine the evolution of airbag technology, providing a historical overview that highlights key milestones and technological advancements which will help to increase the quality of the research.

The journey of airbag development in 1950s, with early experiments involving inflatable devices to cushion vehicle occupants. However, it was not until the 1970s that the first commercially available airbag systems emerged. These early airbags were rudimentary compared to their modern counterparts, employing simple sensors and inflation mechanisms.

As automotive safety standards advanced, so did airbag technology. In the 1980s, significant improvements were made in sensor technology, allowing airbags to deploy more accurately and reliably.



Figure 1.1 Allen Breed obtained a patent for airbags in 1968

The 1990s witnessed the widespread adoption of dual-stage airbags, which could adjust their deployment force based on the severity of the collision. This innovation helped reduce the risk of airbag-induced injuries.

Despite these advancements, traditional airbag designs have limitations and face challenges. Conventional airbags are typically large and bulky, occupying significant space in the vehicle's interior. This can pose challenges in terms of packaging and design flexibility. Additionally, the force exerted by airbag deployment can sometimes cause injuries, particularly for smaller occupants or in certain collision scenarios.

1.2 Origami Engineering for airbags

To overcome these limitations, researchers and engineers have turned to origami-inspired design principles. Origami, the ancient art of paper folding, offers a unique approach to design, characterized by intricate folding patterns and efficient use of space. By applying origami techniques to airbag design, engineers can create compact and adaptable structures that optimize occupant protection.

Various origami folding patterns and optimization methods have been explored in the context of airbags. These techniques allow for the creation of airbag modules that can expand and deploy effectively while occupying minimal space when not in use. Optimization strategies further enhance airbag performance by fine-tuning factors such as folding angles, material properties, and deployment dynamics.

Origami-inspired airbag design offers several potential advantages. The compact storage and efficient deployment characteristics of origami-inspired airbags can allow for more versatile and space-saving installations in various vehicles, aircraft, and other applications. Additionally, the ability of origami-inspired structures to distribute forces and absorb energy can lead to improved crash protection and reduced injuries to occupants.

Exploring the applications of origami principles in airbag design holds promise for advancements in safety technology. By harnessing the inherent properties of origami, engineers are pushing the boundaries of traditional airbag design to create innovative solutions for landing and crash protection.



Figure 1.2 Solar Panel Design

2 Fundamentals of Airbag Design

2.1 Key Components of an Airbag System

An integral component of airbag systems is the sensor system, which plays a pivotal role in impact detection. This system comprises an array of sensors, such as accelerometers and gyroscopes, strategically positioned within the vehicle or equipment. Continuously monitoring the vehicle's acceleration, deceleration, and angular velocity, these sensors are designed to detect abrupt changes indicative of a collision or impact event.

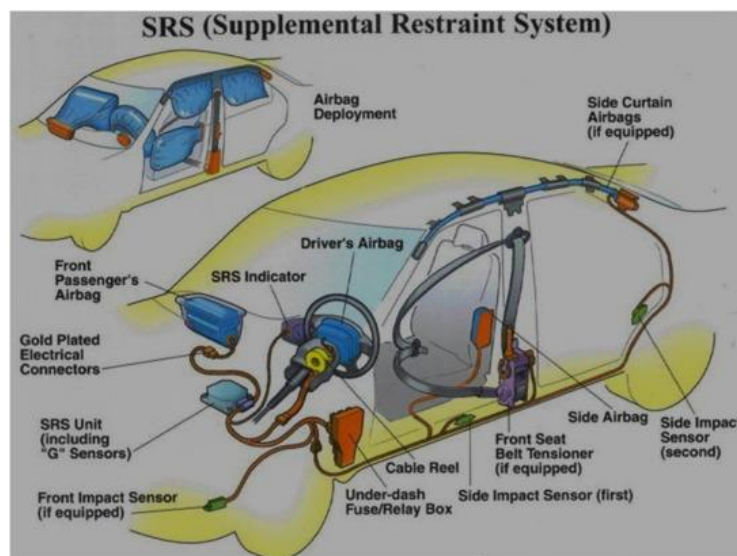


Figure 2.1 SRS Supply Restraint System

Another essential element is the inflation system, which is tasked with ensuring the rapid and controlled deployment of the airbag upon impact detection. Typically housing an inflator module containing a propellant or gas generator, the inflation system swiftly produces the gas necessary to inflate the airbag. The deployment dynamics are meticulously engineered to ensure that the airbag reaches its full inflation before the occupant comes into contact with it.

Furthermore, the cushioning material forms a critical interface between the airbag system and the occupants. This material is meticulously designed to efficiently absorb and distribute the forces generated during a collision, thereby reducing the risk of injury to the occupants. Common materials utilized for this purpose include nylon, polyester, or silicone-coated fabric, each offering distinct energy absorption and cushioning properties.

By comprehensively understanding and optimizing these key components, airbag systems can effectively contribute to mitigating the impact forces experienced during vehicular or equipment-related accidents. These components collectively form a sophisticated safety system that exemplifies the culmination of advanced engineering principles and materials science.

Inflation System for Rapid Deployment

The inflation system is a crucial component responsible for the swift and controlled deployment of the airbag upon detecting an impact. Within the inflation system, an inflator module plays a pivotal role, housing a propellant or gas generator. These elements rapidly produce the gas necessary to inflate the airbag. The gas generation process typically involves a precisely engineered chemical reaction or the controlled combustion of a solid propellant, resulting in the rapid expansion of the gas. This swift generation of gas ensures that the airbag reaches its full inflation before the occupant comes into contact with it, thereby enhancing its effectiveness in mitigating the impact forces during a collision.

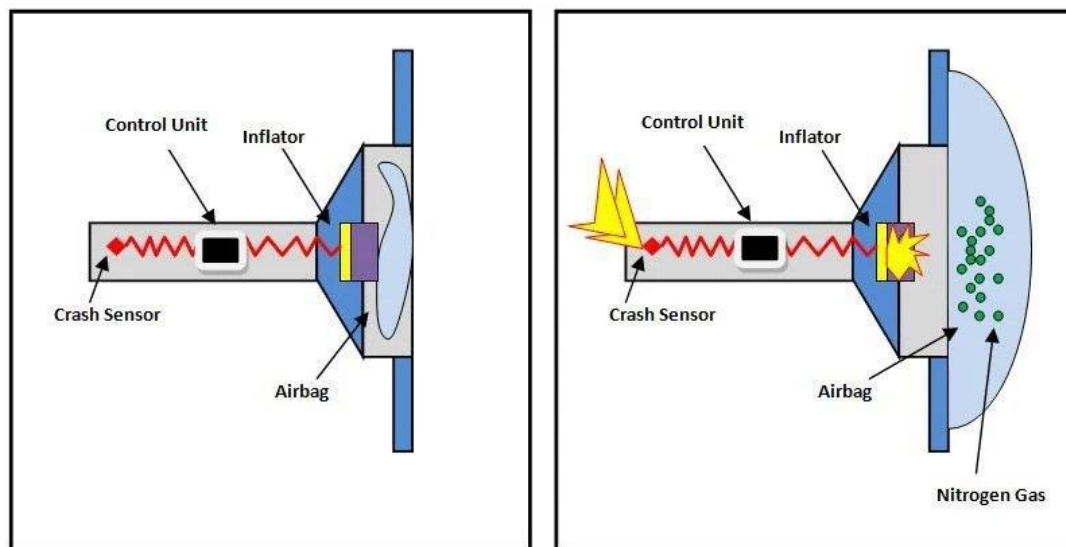


Figure 2.2 Inflation System

Cushioning Material to Mitigate the Force of Impact

The cushioning material within the airbag system serves as a critical interface between the occupants and the airbag during deployment. Its primary function is to efficiently absorb and distribute the forces generated in a collision, thereby minimizing the risk of injury to the vehicle's occupants. Various materials are employed to achieve the desired energy absorption and cushioning properties, each chosen for its specific characteristics that contribute to effective energy dissipation and impact mitigation.



Figure 2.3 Airbag

Nylon

Nylon is a synthetic polymer recognized for its remarkable material characteristics, including high strength, durability, and elasticity. These properties make it a popular choice in various applications where resilience and flexibility are essential. Moreover, nylon's ability to stretch and deform under pressure enables it to absorb a significant amount of energy during a collision, making it valuable for impact-resistant purposes. Its high tensile strength further contributes to its effectiveness in withstanding the forces generated during impact, thereby preventing the material from tearing or failing. Overall, these attributes position nylon as a versatile and reliable material for a wide range of uses, particularly in scenarios where energy absorption and tensile strength are crucial.



Figure 2.4 Nylon

Polyester

A synthetic polymer known for its resistance to abrasion, chemicals, and UV light, offers valuable characteristics for airbag applications. Its ability to deform and elongate allows it to effectively absorb impact energy, making it well-suited for use in cushioning applications within airbags. Additionally, the material's resistance to chemicals ensures stability over time, maintaining performance in various environmental conditions, which is crucial for the long-term reliability of airbag systems. Consequently, the combination of these material characteristics positions polyester as a viable option for enhancing the safety and effectiveness of airbag technology.



Figure 2.5 Polyester Fiber

Silicone-coated Fabrics

Blending the flexibility of fabric with the protective properties of silicone, present a compelling option for airbag applications. Their heat resistance is particularly valuable, as it prevents the material from degrading under high temperatures, which is crucial in collision scenarios involving heat or fire. Additionally, the silicone coating provides water repellency, ensuring that the cushioning material remains effective even in wet conditions, thereby enhancing the reliability of airbag systems in various environmental circumstances. Consequently, the combination of these characteristics' positions silicone-coated fabrics as a resilient and adaptable choice for airbag technology, offering both heat resistance and water repellency for enhanced safety and performance.

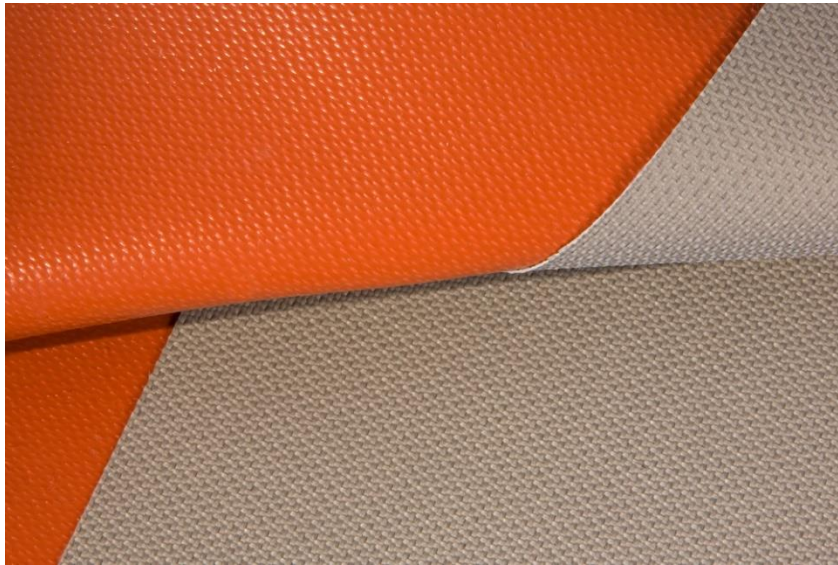


Figure 2.6 Silicon coated Fabrics

Foam Materials

Various foam materials, including polyurethane foam, play a crucial role in airbag systems due to their energy absorption capabilities and density variability. These foam structures are engineered to compress and deform upon impact, effectively absorbing and dissipating energy, thereby contributing to enhanced safety in collision scenarios. Moreover, the ability to utilize different foam densities allows for tailoring the material's response to specific impact scenarios, further enhancing its effectiveness in mitigating forces during collisions. This adaptability makes foam materials, such as polyurethane foam, valuable components within airbag technology, providing a versatile solution for energy absorption and impact mitigation in automotive safety systems.

Stitching and Seam Design

Stitching and seam design are essential factors that significantly influence the structural integrity and performance of airbags upon deployment. The reinforcement provided by the stitching technique and seam design is crucial in ensuring that the airbag maintains its integrity and effectively functions as intended during a collision. Additionally, proper stitching and seam

design contribute to the overall tear resistance of the cushioning material, reducing the risk of unintended failures during deployment. By carefully considering the stitching methods and seam design, manufacturers can enhance the reliability and durability of airbag systems, thereby bolstering their ability to provide crucial protection to vehicle occupants in the event of an impact.

Testing and Standards

Cushioning materials, including those used in airbag systems, undergo comprehensive testing to meet stringent industry standards and regulatory requirements, ensuring their effectiveness in real-world collision scenarios. One critical aspect of this testing is dynamic performance evaluation, which involves impact testing to assess how well the material absorbs and disperses energy under dynamic conditions. This rigorous testing process helps to validate the material's ability to protect occupants by effectively mitigating forces during collisions, thereby contributing to the overall safety and reliability of airbag systems. By subjecting cushioning materials to dynamic performance testing, manufacturers can ensure that their products meet the necessary criteria for regulatory compliance and provide optimal protection in the event of vehicle accidents.

3. State of art in Origami Engineering Air bag design

Origami Engineering involves the application of origami principles to engineering design, with diverse applications across fields such as aerospace, robotics, and airbag design. In the context of airbag engineering, origami-inspired techniques aim to create airbags that are not only more compact during storage but also deploy in a more controlled and predictable manner, offering potential benefits in scenarios where space is limited, such as in autonomous vehicles, drones, or small spacecraft.

3.1 Compact Storage

Origami-inspired folding patterns have garnered significant attention in airbag engineering due to their potential to revolutionize the design and functionality of airbag systems. By leveraging these intricate folding techniques, engineers can achieve a breakthrough in compact storage solutions for airbags. The utilization of origami principles enables the creation of folding patterns that allow airbags to be tightly and efficiently packed, minimizing the space they occupy when not in use. This innovation is particularly crucial in the context of compact vehicles, where interior space is at a premium, and in constrained environments, such as autonomous vehicles and drones. Moreover, the implementation of origami-inspired folding patterns can lead to more versatile and adaptable airbag systems, providing the automotive industry with the flexibility to integrate safety features into a diverse range of vehicle designs.

3.2 Controlled Deployment

The controlled deployment of airbags is another critical aspect where origami engineering principles come into play. By carefully designing the folding patterns, engineers can influence the deployment dynamics of airbags, ensuring a more controlled and predictable expansion during activation. This controlled deployment has the potential to enhance the overall safety and effectiveness of airbag systems, particularly in scenarios where precise deployment is crucial.

3.3 Material Selection

Material selection is also a key area of focus in origami-inspired airbag design. Researchers are exploring advanced materials that are lightweight, durable, and capable of withstanding the forces involved in rapid deployment. These materials need to exhibit exceptional foldability and resilience to ensure that the airbags maintain their structural integrity and protective capabilities throughout their lifecycle.

3.4 Integration with Vehicle Design

In the integration of origami airbags with vehicle design, engineers are adopting a holistic approach to seamlessly incorporate these advanced airbags into the overall vehicle framework. This integration encompasses several crucial factors,

Placement Engineers meticulously determine the optimal placement of origami airbags within the vehicle to ensure maximum effectiveness during deployment. Strategic positioning contributes to enhanced safety and protection for vehicle occupants.

Attachment The attachment of origami airbags is carefully considered to guarantee secure and reliable fixation within the vehicle structure. This aspect involves the utilization of advanced attachment mechanisms tailored to the specific design and functionality of the airbags.

Aesthetic Appeal Beyond functionality, engineers are also mindful of the aesthetic impact of origami airbags within the vehicle interior. Balancing safety requirements with visual harmony, they strive to integrate airbags seamlessly into the overall design, complementing the vehicle's aesthetics.

This comprehensive approach to integration underscores the commitment to not only enhancing safety and performance but also ensuring that origami airbags harmoniously blend with the vehicle's design, thereby offering a heightened level of occupant protection without compromising the vehicle's visual appeal and functionality.

To sum up, the application of Origami Engineering concepts to airbag design is a major advancement in the search for improved system performance and occupant safety. Through the resolution of crucial issues including material selection, regulated deployment, compact storage, and smooth integration with vehicle design, engineers are both redefining the spatial limitations of airbags and improving their performance in a variety of scenarios. When space is at a premium and innovative engineering solutions are required, folding patterns inspired by origami can be employed in autonomous vehicles, drones, and other applications. Furthermore, the regulated deployment made possible by the careful design of the folding pattern helps to make airbag activation safer and more reliable.

Simultaneously, research into new materials emphasizes the need for robustness and longevity, which are critical for maintaining airbag performance throughout their useful lives. The integrated design approach, which takes into account the advanced airbags' placement, attachment, and aesthetic appeal, is a testament to the commitment to integrating them seamlessly into the overall vehicle framework.

This chapter explains how airbag design influenced by origami breaks traditional boundaries and combines safety, functionality, and design in a harmonious whole. Further exploration of the process, outcomes, and consequences of applying these novel engineering concepts will be provided in the following chapters, which will ultimately aid in the advancement of airbag technology in the search for more flexible and safe transportation options.

4. Problem identification and specification

Origami-inspired airbag design presents a promising avenue for advancing occupant safety and system efficiency. However, as with any innovative approach, it is crucial to clearly define the problems that this research seeks to address and the specifications guiding the exploration. This chapter aims to articulate the specific challenges in conventional airbag design, laying the groundwork for the subsequent innovative solutions. By comprehensively identifying and delineating the deficiencies inherent in traditional airbag systems, this project seeks to illuminate the critical areas where current airbag designs fall short. From the potential for injury due to rapid and forceful deployment to the constraints imposed by one-size-fits-all solutions, the limitations of traditional airbags are multifaceted. Furthermore, the single-use nature of conventional airbags poses economic and environmental challenges, while the spatial constraints in aircraft cabins necessitate a reevaluation of deployment mechanisms. By delineating these challenges with precision, this chapter aims to set the stage for the introduction of pioneering origami-inspired airbag designs tailored to address these critical deficiencies. Through a detailed exploration of the shortcomings of traditional airbags, this chapter seeks to underscore the pressing need for innovative and adaptive airbag systems that can revolutionize occupant safety in a diverse range of vehicular and aerospace applications.

4.1 Challengers in Conventional Airbag Design

Spatial Constraints

Traditional airbag systems may pose spatial challenges in compact vehicles or constrained environments, limiting their adaptability. The confined interiors of modern vehicles, particularly in urban settings where compact cars are prevalent, present a notable challenge for the effective deployment of traditional airbags. The spatial constraints within these vehicles demand a reevaluation of airbag design to ensure optimal occupant protection without compromising on interior space utilization.

Injury Risk

Traditional airbags deploy forcefully, and rapid inflation can sometimes cause injuries, especially if the occupant is too close to the airbag or not seated properly. This inherent risk of injury during airbag deployment underscores the need for a more controlled and adaptive deployment mechanism to mitigate potential harm to occupants.

Single-Use

Traditional airbags are single-use devices. Once deployed, they need to be replaced, which can be costly and wasteful. The single-use nature of traditional airbags raises economic and environmental concerns, necessitating the exploration of reusable and efficient airbag solutions to alleviate the drawbacks associated with single-use systems.

Unpredictable Deployment

The inherent limitations in controlling the deployment dynamics of traditional airbags can lead to suboptimal performance in critical safety scenarios. Factors such as varying occupant positions, collision angles, and impact forces contribute to the unpredictable nature of airbag deployment. As a result, traditional airbag systems may not consistently provide the desired level of protection, highlighting the need for more adaptive and controllable deployment mechanisms to ensure enhanced safety across a spectrum of real-world crash scenarios.

Material Limitations

The materials traditionally used in airbags may not fully meet the evolving requirements of lightweight, durable, and rapidly deployable systems. With the increasing emphasis on vehicle weight reduction, fuel efficiency, and occupant safety, the demand for advanced materials capable of withstanding dynamic deployment forces while offering enhanced durability has become imperative. The limitations of traditional airbag materials in meeting these evolving requirements necessitate a strategic reexamination of material selection and integration to align with the demands of modern automotive and aerospace safety standards.

4.2 Problem Specification

The challenges associated with conventional airbag systems have prompted a critical reassessment of their design and deployment mechanisms. These challenges include spatial constraints, injury risk, single-use limitations, and unpredictable deployment dynamics. Addressing these issues is vital for enhancing occupant safety and system efficiency in automotive and aerospace applications. The evolution of airbag technology, particularly the integration of origami-inspired designs, presents an opportunity to overcome these challenges and elevate safety standards in vehicular and aerospace environments.

Resolving Spatial Constraints

Origami-inspired airbag designs offer a compelling solution to the spatial constraints encountered in compact vehicles and constrained environments. By leveraging the principles of origami, these innovative designs enable compact storage and efficient deployment, thereby circumventing the spatial limitations that hinder traditional airbag systems. The adaptability and flexibility inherent in origami-inspired structures facilitate optimized airbag deployment within confined spaces, ensuring enhanced occupant protection without compromising interior design or functionality.

Mitigating Injury Risk

The application of origami-inspired airbag designs addresses the inherent risk of injury associated with traditional airbags. By incorporating controlled folding patterns and deployment sequences, origami-inspired airbags can mitigate the forceful and rapid inflation that may lead to occupant injuries. The strategic utilization of origami principles allows for tailored deployment dynamics, ensuring a gentler and more adaptable response to crash scenarios, thereby reducing the potential for occupant harm.

Overcoming Single-Use Limitations

Origami-inspired airbag designs offer the potential for reusable deployment, addressing the single-use limitations of traditional airbag systems. The structural integrity and foldable nature of origami-based configurations enable efficient deployment and subsequent refolding, allowing for multiple applications without the need for replacement after deployment. This reusability aspect presents a significant advancement in mitigating the economic and environmental concerns associated with single-use airbag systems.

Enhancing Deployment Control

The integration of origami-inspired designs empowers a more controlled and predictable deployment mechanism, mitigating the unpredictable nature of traditional airbag systems. By harnessing the geometric precision and modularity of origami patterns, these innovative airbag designs offer enhanced deployment control, effectively adapting to varying crash scenarios and occupant positions. The tailored folding and unfolding characteristics enable a more adaptive response, ensuring optimal performance in critical safety scenarios.

In summary, the incorporation of origami-inspired airbag designs addresses the shortcomings of traditional airbag systems by offering solutions that cater to spatial constraints, mitigate injury risk, enable reusability, and enhance deployment control. This innovative approach represents a significant leap forward in advancing occupant safety and system efficiency, setting new standards for the next generation of airbag technology in automotive and aerospace domains.

5. Advanced Airbag Design and Deployment

In recent years, the pursuit of enhanced occupant safety and system efficiency has spurred remarkable advancements in airbag technology, propelling a paradigm shift towards innovative design approaches. Central to this evolution are the optimization factors, origami folding patterns, and crash safety principles that have redefined the landscape of airbag engineering. As vehicles and aerospace systems continue to evolve, the need for airbag solutions that transcend the limitations of traditional designs has become increasingly apparent. This preliminary background sets the stage for a comprehensive exploration of the transformative potential inherent in origami-inspired airbag configurations, as well as the fundamental principles that underpin their efficacy. By delving into the intricacies of optimization, origami-based folding patterns, and crash safety considerations, this introductory framework lays the groundwork for a nuanced understanding of the cutting-edge developments shaping the future of airbag design and deployment.

5.1 Origami Concepts

Origami, the art of paper folding, encompasses several fundamental concepts and principles that serve as the foundation for creating intricate paper sculptures and designs. Here are some key origami folding concepts and other principles commonly used in the world of origami,

Basic Folds

Valley Fold Folding the paper inward along a line to create a "V" shape.

Mountain Fold Folding the paper outward along a line to create a peak.

Creases

Pre-crease Making preliminary folds to prepare the paper for more complex folding.

Crease Pattern A diagram indicating where to make folds and creases in a specific origami model.

Bases

Square Base A foundational origami structure often used as the starting point for many models.

Bird Base A base that resembles the shape of a bird and serves as the foundation for various bird-related origami models.

Sinks and Pleats

Sink Fold A technique where a portion of paper is folded inward to create a three-dimensional shape. **Pleat Fold** Creating a series of alternating valley and mountain folds in a straight line.

Modules and Units

Modular Origami Creating complex structures by assembling multiple identical or similar folded units. **Unit Origami** Making individual units that can be combined to create larger designs.

Folding Sequences

Following a specific order of folds and steps to transform a flat sheet of paper into a finished origami model.

Symmetry

Emphasizing- symmetry in origami designs to create balanced and aesthetically pleasing models. Types of symmetry include bilateral, radial, and rotational.

Design Principles

Proportion Ensuring that the relative sizes and dimensions of folds and elements are harmonious. **Balance** Distributing the weight of folds and layers evenly to maintain stability in the final model. **Color Management** Using the color and texture of paper strategically to enhance the design.

Advanced Folds

Reverse Folds Folding a portion of the paper back on itself to create a new flap or layer, often used to shape complex origami models. **Wet Folding** A technique involving lightly dampening the paper before folding to allow for more sculptural and rounded shapes in the finished model. **Rabbit Ear Fold** Creating a triangular or rabbit ear-shaped fold by folding a square corner to the center of the paper. **Crimp Fold** A fold that involves pinching the paper to create narrow, crimped sections, commonly used in tessellations and corrugations.

Design Patterns

Utilizing various design patterns, such as tessellations, corrugations, and pleats, to create intricate and repeating geometric designs in origami.

Crease Patterns and Tessellations

Advanced origami often starts with a crease pattern, a diagram illustrating the intended creases and folds required to create a specific model. Tessellations involve repeating geometric patterns across the entire sheet of paper to create complex, interconnected designs.

Thermorph Origami

A technique that utilizes heat to shape and deform paper, enabling the creation of organic and dynamic origami forms.

These concepts and techniques form the foundation of origami, allowing for the creation of intricate and diverse paper sculptures and designs.

5.2 Crash Safety Principles

The pursuit of safety in vehicular transportation is underpinned by a comprehensive set of crash safety principles that guide the design and manufacturing of automobiles, aircraft, and various modes of transportation. These principles, developed through years of research and analysis, are fundamental to mitigating the severity of injuries and fatalities resulting from vehicular accidents.

Structural Integrity

The first key principle revolves around ensuring the structural integrity of vehicles. Employing high-strength materials and well-engineered frames, manufacturers aim to create vehicle structures capable of withstanding and effectively distributing crash forces, thereby maintaining the integrity of the passenger compartment during collisions.

Crumple Zones

Crumple zones represent a critical innovation in crash safety. Engineered sections at the front and rear of vehicles deform upon impact, absorbing energy and slowing down the deceleration of the vehicle. By doing so, crumple zones play a crucial role in reducing the force transferred to passengers during a collision.

Restraint Systems

Restraint systems, including seatbelts and airbags, are indispensable components for occupant safety. These systems aim to keep occupants securely in their seats, minimizing movement during a collision and preventing severe injuries.

Occupant Protection

Vehicle interiors are designed with occupant protection in mind, incorporating energy-absorbing materials, well-padded surfaces, and effective headrests to shield occupants from impact and potential whiplash injuries.

Side Impact Protection

Recognizing the prevalence and severity of side impact collisions, vehicles are equipped with side airbags and reinforced door structures to provide enhanced protection for occupants in these scenarios.

Electronic Stability Control (ESC)

ESC systems contribute to accident prevention by preventing skidding and loss of control, especially in slippery or emergency situations. By reducing the likelihood of rollovers and serious accidents, ESC enhances overall vehicle safety.

Anti-Lock Braking System (ABS)

ABS prevents wheel lockup during hard braking, enabling the driver to maintain steering control. This technology is vital for avoiding accidents during sudden stops.

Collision Avoidance Systems

Advanced driver assistance systems (ADAS) play a pivotal role in avoiding crashes altogether. Features like adaptive cruise control, lane-keeping assistance, blind spot monitoring, and automatic emergency braking provide additional layers of protection.

Crash Testing and Evaluation

Vehicles undergo rigorous crash testing and evaluation to assess their safety performance. These tests serve as critical tools for identifying potential weaknesses and areas for improvement in vehicle safety design.

Pedestrian Safety

Considering the vulnerability of pedestrians, vehicle designs incorporate features such as energy-absorbing bumpers and hoods, as well as sensors for detecting pedestrians and cyclists.

Child Safety

Special attention is given to child safety through the appropriate design and installation of child seats and restraint systems to protect young passengers.

Emergency Response

Vehicles are designed to facilitate quick and safe extraction of occupants by emergency responders. This includes easy access to doors, windows, and roof panels.

Post Crash Safety

Measures like fuel system shutoff, battery disconnection, and automatic emergency notification systems are implemented to reduce the risk of post-crash fires and improve emergency response times.

Material Selection

The choice of materials in vehicle construction directly impacts crash safety. High-strength steel, aluminum, and composite materials are strategically used to improve safety without adding excessive weight.

Safety Regulations

Compliance with safety standards and regulations set by government agencies is critical. These regulations ensure that vehicles meet minimum safety requirements and are safe for public use.

These crash safety principles collectively contribute to ongoing improvements in vehicle safety, reducing the severity of injuries and saving lives in the event of accidents.

5.3 Airbags as a Complementary Safety System Enhancing Crash Safety Principles

While the crash safety principles are foundational to vehicular safety, airbags serve as a complementary safety system, addressing specific challenges and enhancing protection in critical scenarios. The following sections explore how airbags can mitigate certain risks associated with traditional safety principles.

Mitigating Injury Risk

Traditional airbags, known for forceful deployment, can pose a risk of injury. Origami-inspired airbag designs offer the potential for more controlled and gentler deployment, thereby mitigating the risk of injuries associated with rapid inflation.

Adaptable Restraint Systems

Airbags act as an additional layer of restraint, working in conjunction with seatbelts to enhance occupant protection. The controlled deployment of airbags can contribute to minimizing movement during a collision and preventing severe injuries.

Optimizing Occupant Protection

Origami-inspired airbag designs can contribute to optimizing occupant protection by providing adaptable and customizable airbag sizes and shapes. This addresses the limitation of one-size-fits-all solutions, ensuring enhanced safety for various occupant types and crash scenarios.

Controlled Energy Absorption

Incorporating origami principles into airbag design enables controlled energy absorption, complementing the function of crumple zones. This controlled absorption helps in slowing down deceleration, reducing the force transferred to occupants.

Integration with Advanced Driver Assistance Systems (ADAS)

Airbags can be integrated with ADAS to enhance collision avoidance systems. In scenarios where ADAS detects an imminent collision, airbags can be pre-deployed in a controlled manner to prepare for impact, further reducing the severity of injuries.

Sustainable Practices

Origami-inspired airbag designs with the potential for reuse align with the sustainability aspect of post-crash safety. Reusable airbags contribute to reducing the environmental impact associated with single-use traditional airbags.

By integrating airbags as a complementary safety system, the research explores how origami-inspired designs can enhance and optimize existing crash safety principles, contributing to a more comprehensive and adaptive approach to vehicular safety. The subsequent chapters will delve into the methodologies employed, results obtained, and implications for the future of airbag technology in the context of crash safety. So that's the purpose of this research project.

5.4. Optimization Factors for Origami-Inspired Airbag Design Enhancing Safety and Efficiency in Aerospace and Automotive Applications

Selecting the optimal origami pattern for airbag design is a nuanced process that involves a careful evaluation of various critical factors. These factors are instrumental in determining the overall performance, safety, and efficiency of the airbag system. Below are the key optimization factors that need to be considered.

5.4.1 Crash and Impact Characteristics

Evaluate how well the origami pattern absorbs and dissipates impact forces during a crash or landing. Consider the pattern's ability to provide a controlled and cushioned landing or collision experience for passengers or crew, minimizing the risk of injuries.

5.4.2 Deployment Efficiency

Assess how quickly and reliably the selected pattern allows the airbag to deploy upon impact. Consider the pattern's ability to cover and protect the intended area effectively, ensuring optimal performance in real-world crash scenarios.

5.4.3 Structural Integrity

Examine the strength and durability of the origami pattern under various stress conditions. Ensure that the pattern maintains its integrity during the entire deployment process, contributing to the airbag's effectiveness in protecting occupants.

5.4.4 Space Utilization and Storage

Analyze how well the origami pattern allows for efficient storage in the limited space available in vehicles or aircraft. Consider how compactly the airbag can be folded or stored when not in use, optimizing space usage in the transportation system.

5.4.5 Material Compatibility

Ensure that the chosen origami pattern is compatible with the materials used for airbag construction. Assess how well the materials integrate with the folding pattern to achieve the desired performance, durability, and safety.

5.4.6 Cost Effectiveness

Evaluate the cost implications of using the origami pattern in terms of materials, manufacturing, and assembly. Compare the cost of production and maintenance with the expected benefits, ensuring that the solution is economically viable.

5.4.7 Regulatory Compliance

Confirm that the selected origami pattern meets safety standards and regulations for automotive and aerospace applications. Ensure that the design aligns with industry-specific requirements, adhering to established safety protocols.

5.4.8 Environmental Impact

Evaluate the environmental sustainability of the chosen pattern, focusing on its reusability and reduced material usage. Consider how the pattern may contribute to reducing the environmental footprint of airbag production and disposal through its ability to be reused.

5.4.9 Manufacturability

Examine how easily the origami-inspired airbag can be manufactured at scale. Consider the feasibility of incorporating the pattern into existing production processes, ensuring practicality and efficiency in large-scale production.

5.4.10 Adaptability to Vehicle or Aircraft Design

Ensure that the selected pattern integrates seamlessly with the overall design of the vehicle or aircraft. Evaluate how well it fits within the constraints of the vehicle's or aircraft's structure, ensuring compatibility with existing designs.

5.4.11 User Experience and Safety

Consider how the chosen origami pattern impacts the comfort and safety of passengers or crew members. Assess potential risks associated with airbag deployment and ensure user safety, promoting a positive user experience.

5.4.12 Testing and Validation

Rely on empirical testing and validation to confirm that the selected pattern performs as expected under real-world conditions. Use data from testing to make informed decisions about pattern suitability, providing evidence of its effectiveness.

5.4.13 Industry Acceptance

Gauge the willingness of automotive and aerospace manufacturers to adopt the selected origami pattern in their safety systems. Consider industry feedback and collaboration opportunities, fostering acceptance and integration within the broader industry.

Balancing these optimization factors is essential to select the optimum origami pattern for an airbag design that offers enhanced safety, efficiency, and practicality in both automotive and aerospace applications. The subsequent chapters of the project report will delve into the methodology employed to evaluate these factors and present the findings that contribute to the advancement of origami-inspired airbag technology.

6. Results

In this study, the development of an origami-inspired airbag for landing and crash protection was undertaken in three stages. The first stage involved the selection of folding patterns using feasible optimization factors. Subsequently, the existing airbag simulation was conducted, yielding insightful results. However, due to time limitations, the conclusive design and simulation of the new airbag using origami patterns could not be finalized. Despite this, the obtained results from the initial stages provide valuable insights into the potential of origami-inspired solutions for airbag design, laying the groundwork for future exploration and development in this innovative area of impact protection technology.

6.1 Folding Pattern Selection and Feasible Optimization Factors.

When selecting folding patterns for an origami-inspired airbag design, the process involves a comprehensive evaluation of various factors to determine the optimum pattern. The initial stage encompasses an overview of available folding patterns such as Miura Ori Tessellation, Hexa-Tri Tessellation, Lang Honeycomb Tessellation, and Huffman Waterbomb Tessellation. This phase includes a detailed discussion of the unique characteristics, advantages, and disadvantages of each pattern. Feasible optimization factors are carefully considered to ensure the selection aligns with the specific requirements of the airbag design. This thorough assessment lays the foundation for identifying the most suitable folding pattern to be utilized in the development of the origami-inspired airbag.

6.2 Discussion of feasible optimization factors considered.

The feasible optimization factors for selecting folding patterns in the context of an origami-inspired airbag design encompass various crucial elements, including:

Crash and Impact Characteristics

Evaluation of how the folding pattern influences the airbag's performance during crash and impact scenarios, ensuring effective protection and energy absorption.

Deployment Efficiency

Examination of how well the chosen pattern facilitates the swift and reliable deployment of the airbag in response to potential collisions or landing impact.

Structural Integrity

Consideration of the folding pattern's ability to maintain structural stability and integrity under stressful conditions, contributing to the overall robustness of the airbag system.

Space Utilization and Storage

Assessment of how efficiently the selected pattern utilizes space when folded and stored, optimizing the airbag's compactness and deployment readiness.

Material Compatibility

Analysis of how the chosen pattern aligns with the materials used in the airbag's construction, ensuring compatibility and enhancing overall performance.

Environmental Impact

Evaluation of the environmental implications associated with the chosen folding pattern, aiming to minimize negative environmental effects throughout the airbag's lifecycle.

Manufacturability

Consideration of the pattern's practicality in terms of manufacturing processes, ensuring that it can be feasibly and cost-effectively produced at scale.

Industry Acceptance

Assessment of how well the selected folding pattern aligns with industry standards, regulations, and acceptance, ensuring seamless integration into existing airbag manufacturing practices and technologies.

6.3 Making Mathematical model for Generating Scalable Vector Graphics

When it comes to creating a mathematical model for generating Scalable Vector Graphics (SVG) and producing SVG files for folding pattern simulation in an Origami simulator, Python comes to the rescue with its powerful libraries. By utilizing Python libraries such as numpy, matplotlib, and itertools, one can construct intricate mathematical models and visualize them using the rich plotting capabilities provided by these libraries. With features like Ellipse, Wedge, Polygon, and Path from the matplotlib library, one can craft complex shapes and patterns, which can then be converted into SVG files for further simulation.

However, despite the potential of these tools, there are limitations that need to be addressed. The process of creating a new tessellation for an airbag involves not only the generation of SVG files but also the development of novel folding patterns. This task demands a significant investment of time and a deep understanding of mathematical concepts. Given the constraints of time and expertise, creating a completely new design with unique folding patterns becomes a challenging endeavor.

To overcome these challenges, an alternative approach can be adopted. Instead of starting from scratch, existing folding patterns can be leveraged to expedite the design process. By utilizing established folding patterns, which will be discussed in the following section, it becomes feasible to create innovative designs for airbags within a limited timeframe. This approach allows for the adaptation of airbag designs to various vehicles while circumventing the need for extensive mathematical background and additional time investment.

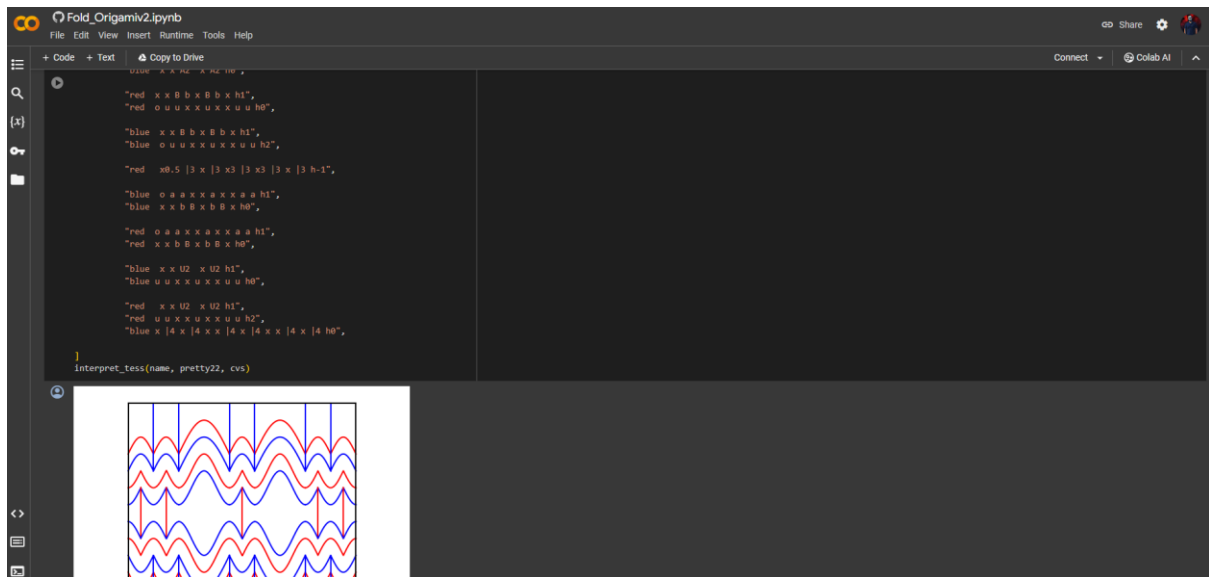


Figure 6.1 Python model for SVG

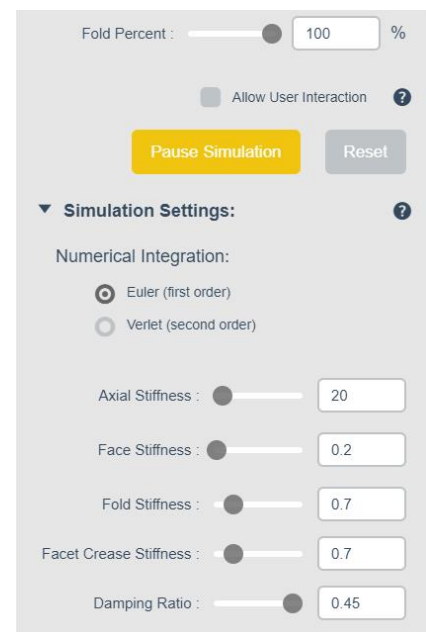
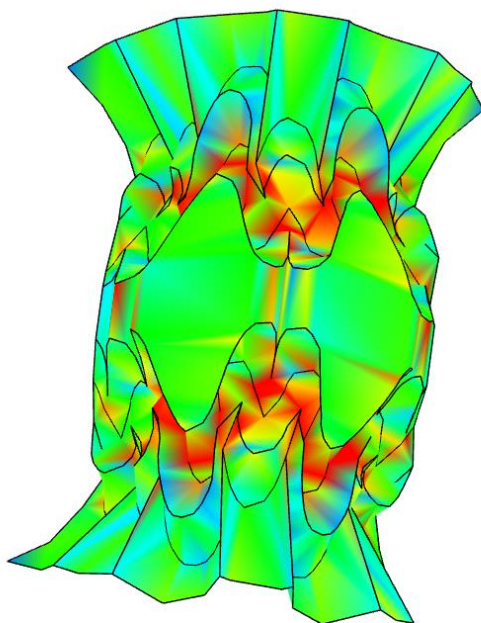


Figure 6.2 Imported SVG file in Origami Simulator

6.4 Selecting Optimum Folding Pattern

To determine the optimum origami pattern for an airbag design among Miura Ori Tessellation, Hexa-Tri Tessellation, Lang Honeycomb Tessellation, and Huffman Waterbomb Tessellation, a thorough evaluation based on the factors mentioned earlier is required. Each pattern has its unique characteristics, advantages, and disadvantages. Here's a comparative assessment of these patterns,

Index for

Figure (6.6, 6.10, 6.14, 6.18)

Mountain folds have red stroke - rgb(255, 0, 0), hex #ff0000

Valley folds have blue stroke - rgb(0, 0, 255), hex #0000ff

Boundary edges have black stroke - rgb(0, 0, 0), hex #000000

1. Miura Ori Tessellation -

Crash and Impact Characteristics - Offers good impact absorption due to its accordionlike structure.

Deployment Efficiency - Deploys relatively quickly and efficiently.

Structural Integrity - Maintains structural integrity during deployment.

Space Utilization and Storage - Folds compactly, making it suitable for efficient storage.

Material Compatibility - Compatible with a wide range of materials.

Cost effectiveness - Generally, cost effective to manufacture.

Regulatory Compliance - Can be designed to meet safety standards.

Environmental Impact - Potential for reduced material usage.

Manufacturability - Relatively easy to manufacture.

Adaptability to Vehicle or Aircraft Design - Fits well within the constraints of most designs.

User Experience and Safety - Provides cushioned landing experience.

Testing and Validation - Well documented and tested pattern.

Industry Acceptance - Widely recognized and used in various applications.

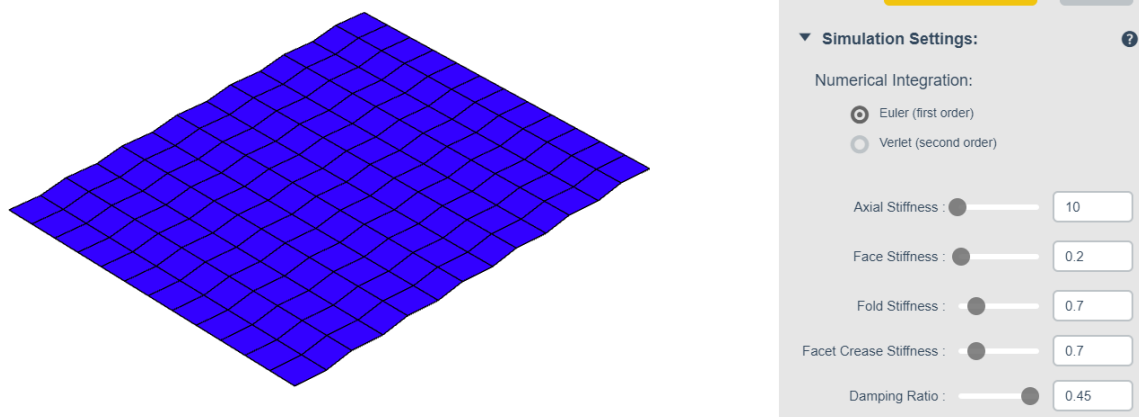
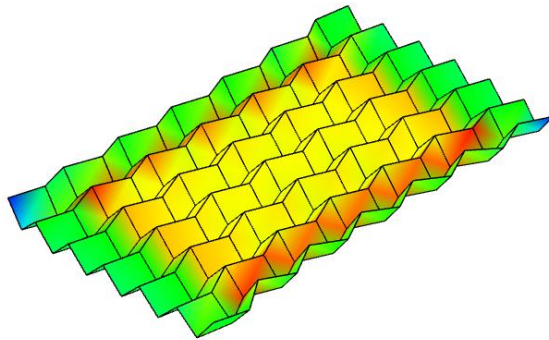


Figure 6.3 - 0% fold Miura Ori Tessellation



Fold Percent : 45 %

☐ Allow User Interaction ?

Pause Simulation **Reset**

▼ **Simulation Settings:** ?

Numerical Integration:

☒ Euler (first order)

☐ Verlet (second order)

Axial Stiffness : 10

Face Stiffness : 0.2

Fold Stiffness : 0.7

Facet Crease Stiffness : 0.7

Damping Ratio : 0.45

Figure 6.4 - 45%-fold Miura Ori Tessellation



Fold Percent : 100 %

☐ Allow User Interaction ?

Pause Simulation **Reset**

▼ **Simulation Settings:** ?

Numerical Integration:

☒ Euler (first order)

☐ Verlet (second order)

Axial Stiffness : 10

Face Stiffness : 0.2

Fold Stiffness : 0.7

Facet Crease Stiffness : 0.7

Damping Ratio : 0.45

Figure 6.5 - 100%-fold Miura Ori Tessellation

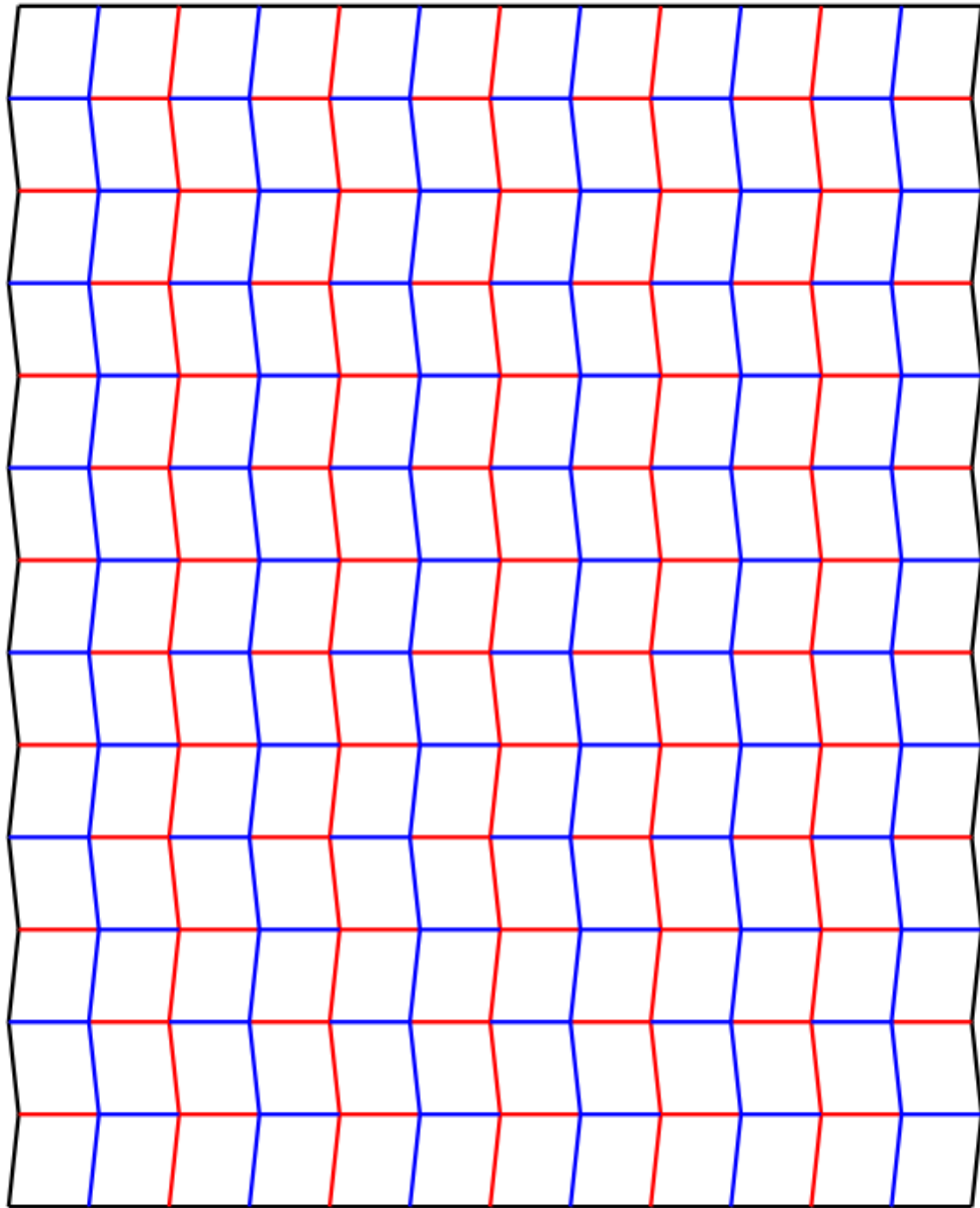


Figure 6.6 - Miura Ori Tessellation

2. Hexa-Tri Tessellation -

Crash and Impact Characteristics - Offers good impact absorption due to its triangular segments.

Deployment Efficiency - Can deploy effectively but may be slower than some other patterns.

Structural Integrity - Generally, maintains structural integrity.

Space Utilization and Storage - Folds into a compact shape for storage.

Material Compatibility - Compatible with various materials.

Cost effectiveness - Can be cost effective, depending on the design.

Regulatory Compliance - Can meet safety standards with proper design.

Environmental Impact - Potential for reduced material usage.

Manufacturability - Requires precise manufacturing.

Adaptability to Vehicle or Aircraft Design - May require adjustments to fit specific designs.

User Experience and Safety - Provides reasonable cushioning during impact.

Testing and Validation - Tested in some applications but may require further validation.

Industry Acceptance - Acceptance may vary depending on the application.

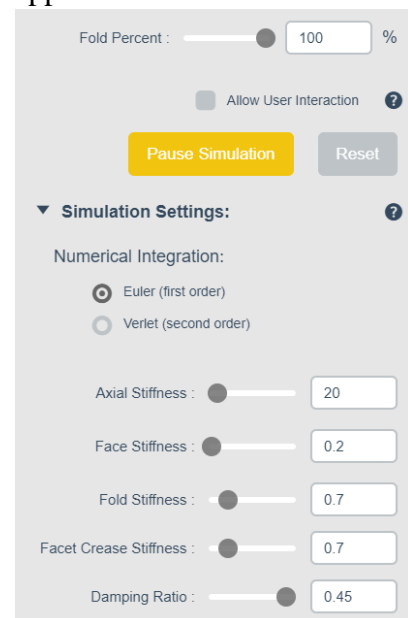
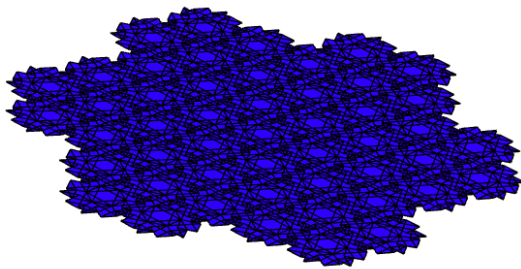
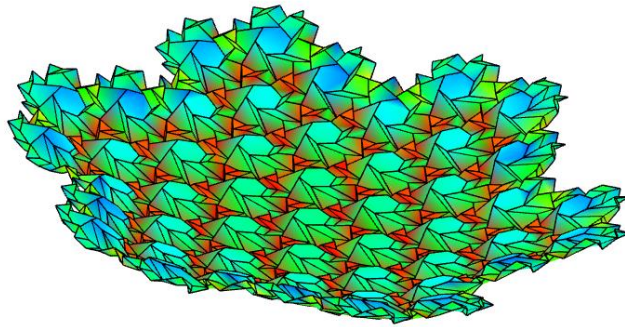


Figure 6.7 - 100% fold Hexa-Tri Tessellation



Fold Percent : 50 %

☐ Allow User Interaction ?

Pause Simulation Reset

▼ **Simulation Settings:** ?

Numerical Integration:

☒ Euler (first order)

☐ Verlet (second order)

Axial Stiffness : 20

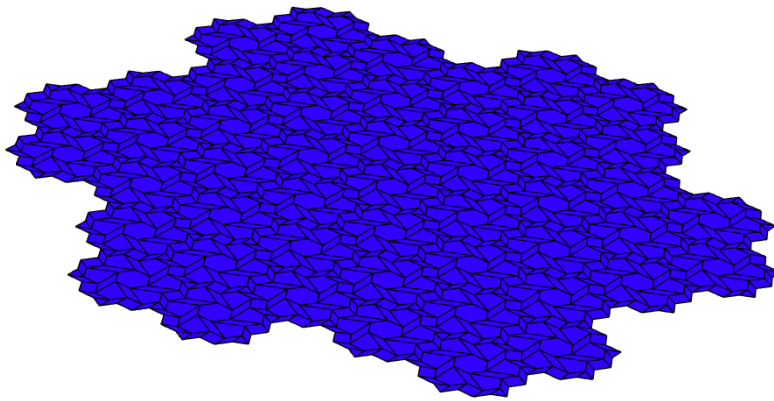
Face Stiffness : 0.2

Fold Stiffness : 0.7

Facet Crease Stiffness : 0.7

Damping Ratio : 0.45

Figure 6.8 - 50% fold Hexa-Tri Tessellation



Fold Percent : 0 %

☐ Allow User Interaction ?

Pause Simulation Reset

▼ **Simulation Settings:** ?

Numerical Integration:

☒ Euler (first order)

☐ Verlet (second order)

Axial Stiffness : 20

Face Stiffness : 0.2

Fold Stiffness : 0.7

Facet Crease Stiffness : 0.7

Damping Ratio : 0.45

Figure 6.9 - 0% fold Hexa-Tri Tessellation

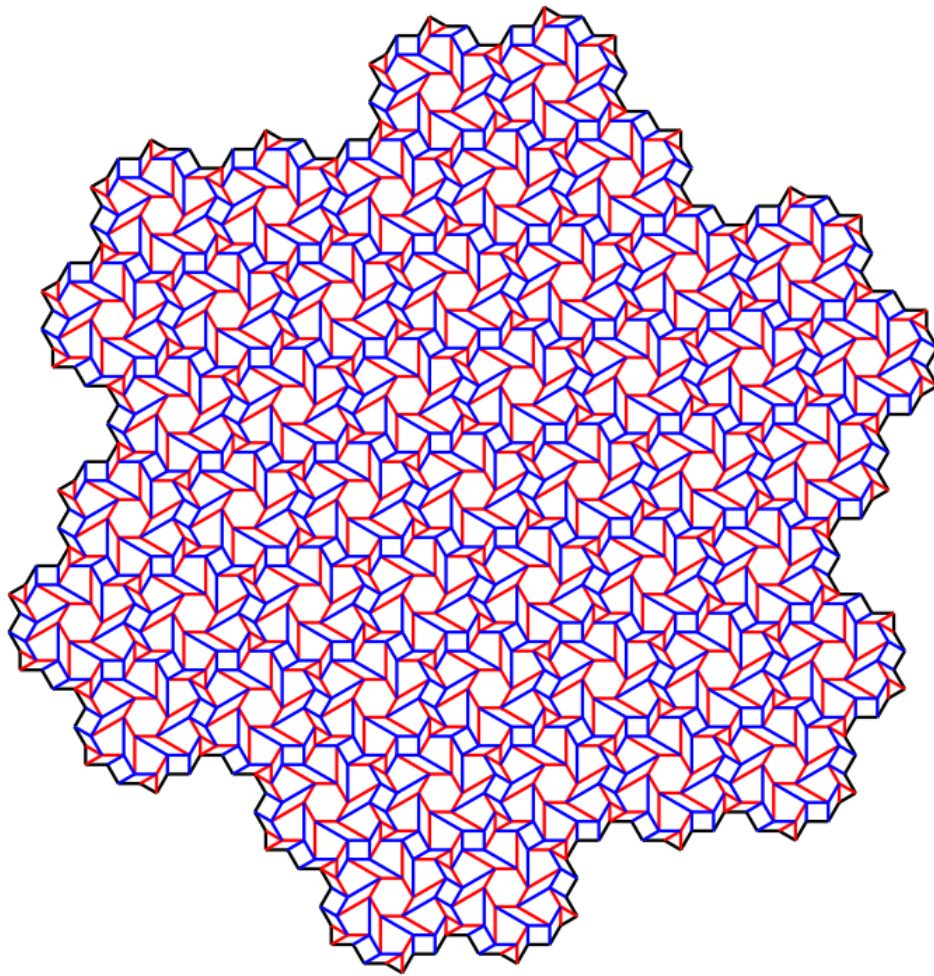


Figure 6.10 - Hexa-Tri Tessellation

3. Lang Honeycomb Tessellation -

Crash and Impact Characteristics - Offers good impact absorption due to its hexagonal structure.

Deployment Efficiency - Can deploy efficiently.

Structural Integrity - Generally, maintains structural integrity.

Space Utilization and Storage - Can fold into a relatively compact shape.

Material Compatibility - Compatible with various materials.

Cost effectiveness - Can be cost effective, depending on the design.

Regulatory Compliance - Can meet safety standards with proper design.

Environmental Impact - Potential for reduced material usage.

Manufacturability - Requires precision in manufacturing.

Adaptability to Vehicle or Aircraft Design - May require adjustments to fit specific designs.

User Experience and Safety - Provides reasonable cushioning during impact.

Testing and Validation - Tested in some applications but may require further validation.
Industry Acceptance - Acceptance may vary depending on the application.

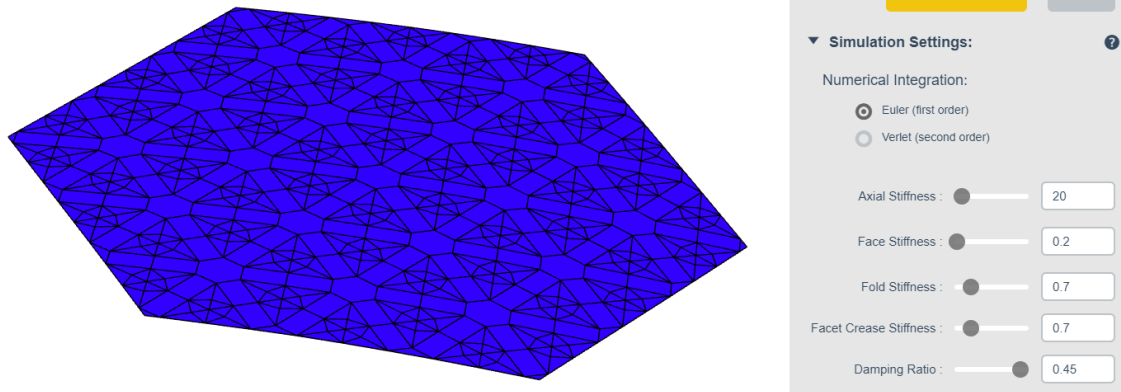


Figure 6.11 - 0% fold Lang Honeycomb Tessellation

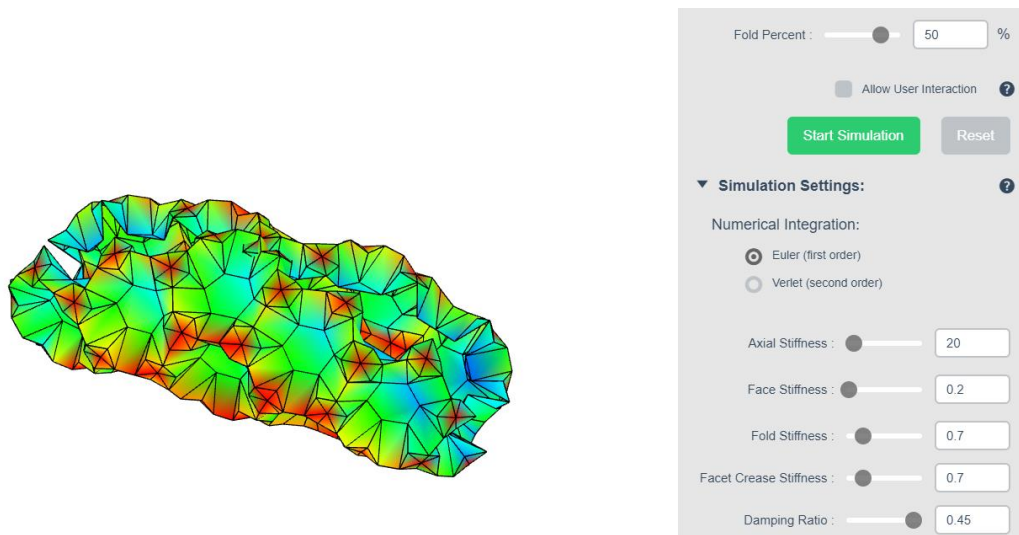


Figure 6.12 - 50% fold Lang Honeycomb Tessellation

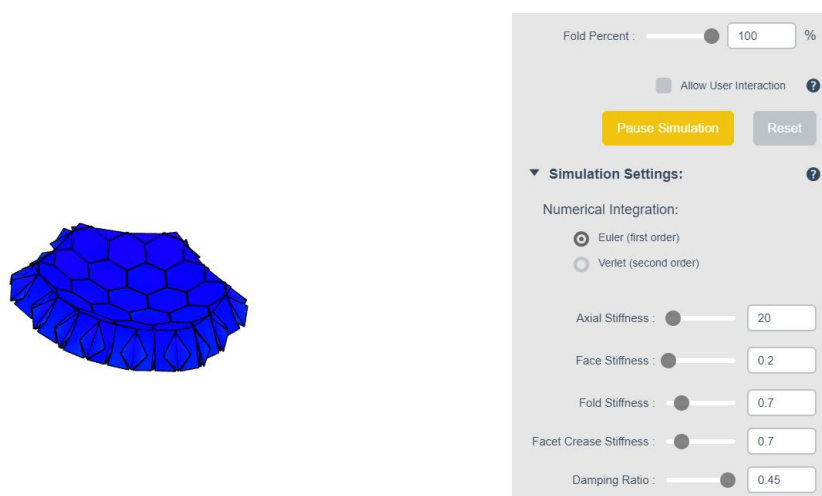


Figure 6.13 - 100% fold Lang Honeycomb Tessellation

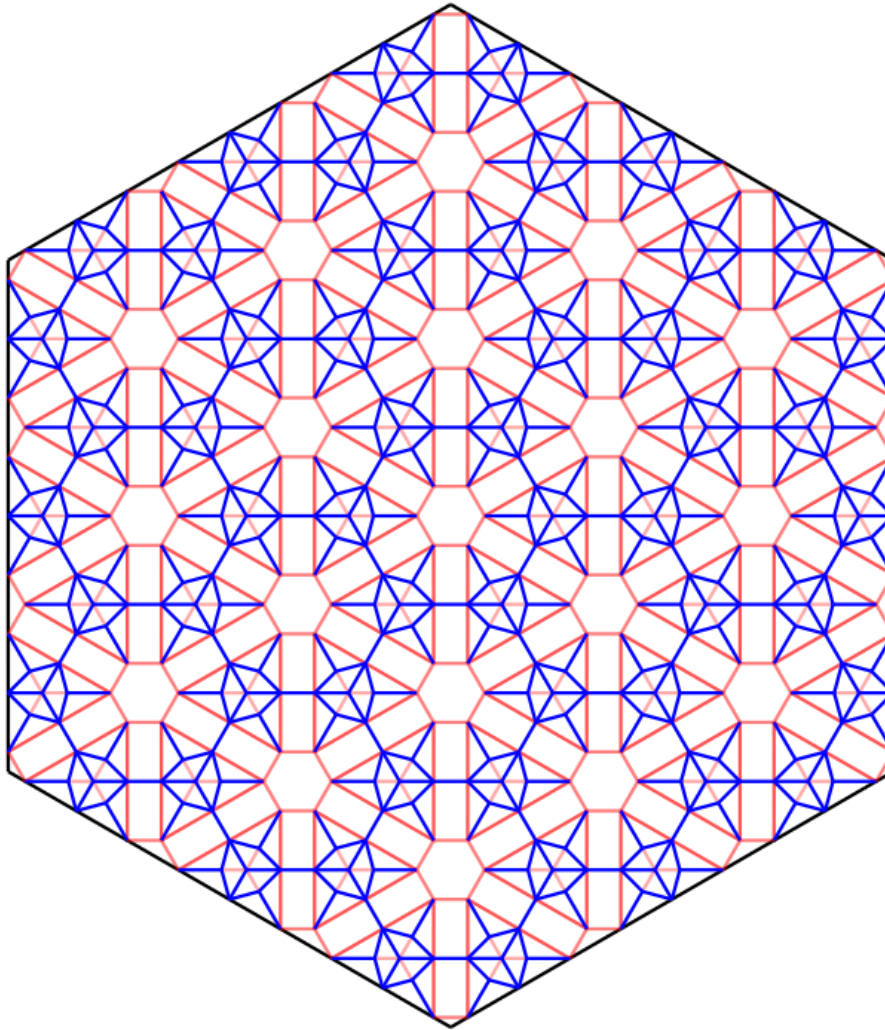


Figure 6.14 - Lang Honeycomb Tessellation

4. Huffman Waterbomb Tessellation -

Crash and Impact Characteristics - Offers reasonable impact absorption.

Deployment Efficiency - Deploys relatively quickly.

Structural Integrity - May have some challenges in maintaining structural integrity.

Space Utilization and Storage - Can fold into a compact shape.

Material Compatibility - Compatible with various materials.

Cost effectiveness - Can be cost effective, depending on the design.

Regulatory Compliance - May require careful design to meet safety standards.

Environmental Impact - Potential for reduced material usage.

Manufacturability - Requires precision in manufacturing.

Adaptability to Vehicle or Aircraft Design - May require adjustments to fit specific designs.

User Experience and Safety - Provides reasonable cushioning during impact.

Testing and Validation - May require additional testing and validation.

Industry Acceptance - Acceptance may vary depending on the application.

Considering the factors mentioned, the choice of the optimum origami pattern for an airbag design would depend on the specific priorities and requirements of the application. Miura Ori Tessellation and Lang Honeycomb Tessellation appear to offer a good balance of characteristics for many applications, including impact absorption, deployment efficiency, and storage efficiency.

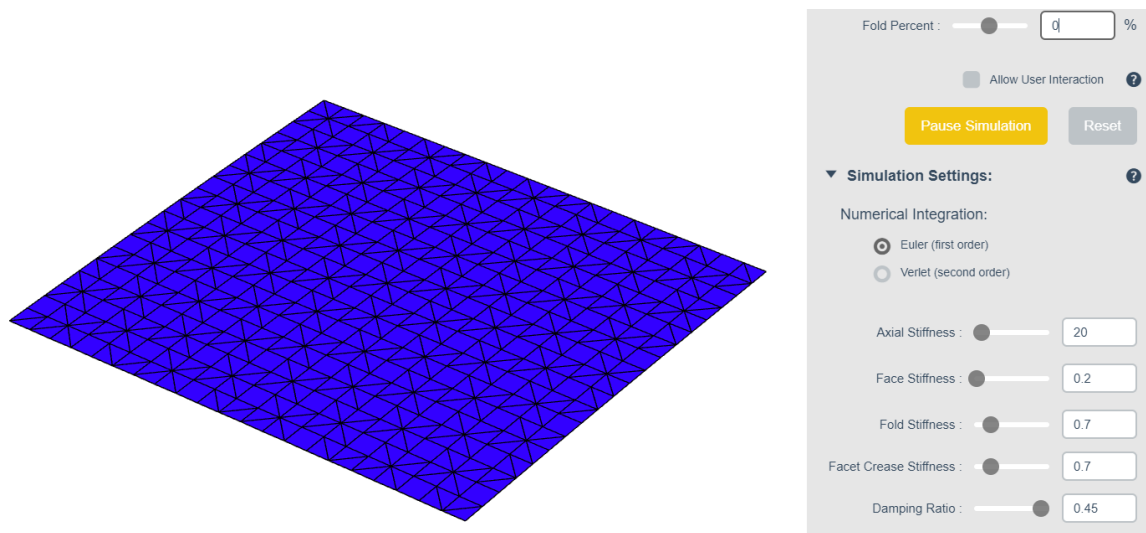


Figure 6.15 - 0% fold Huffman Waterbomb Tessellation

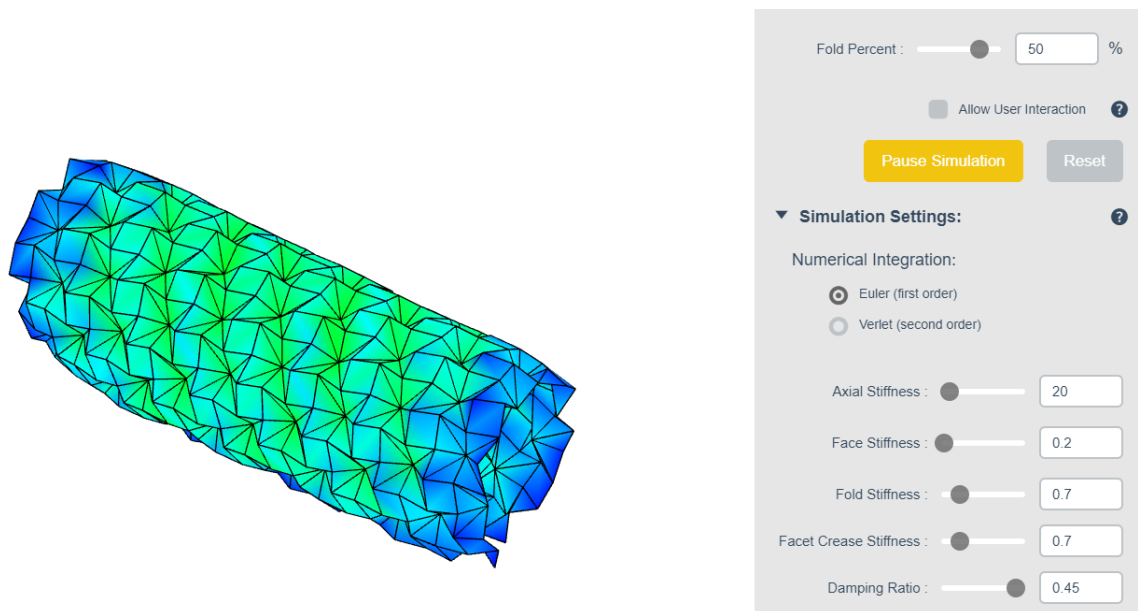


Figure 6.16 - 50% fold Huffman Waterbomb Tessellation

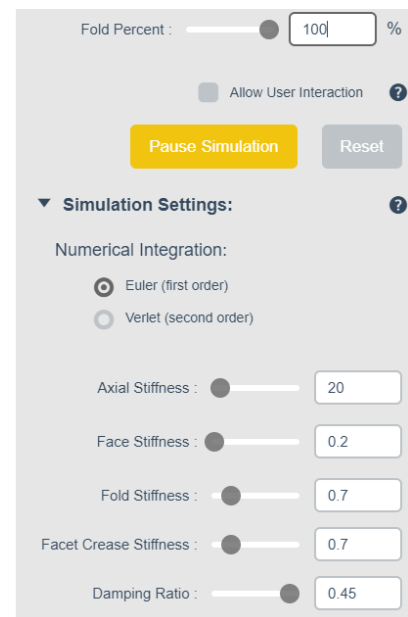
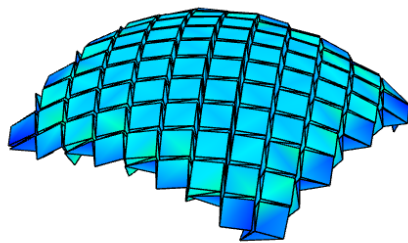


Figure 6.17 - 100% fold Huffman Waterbomb Tessellation

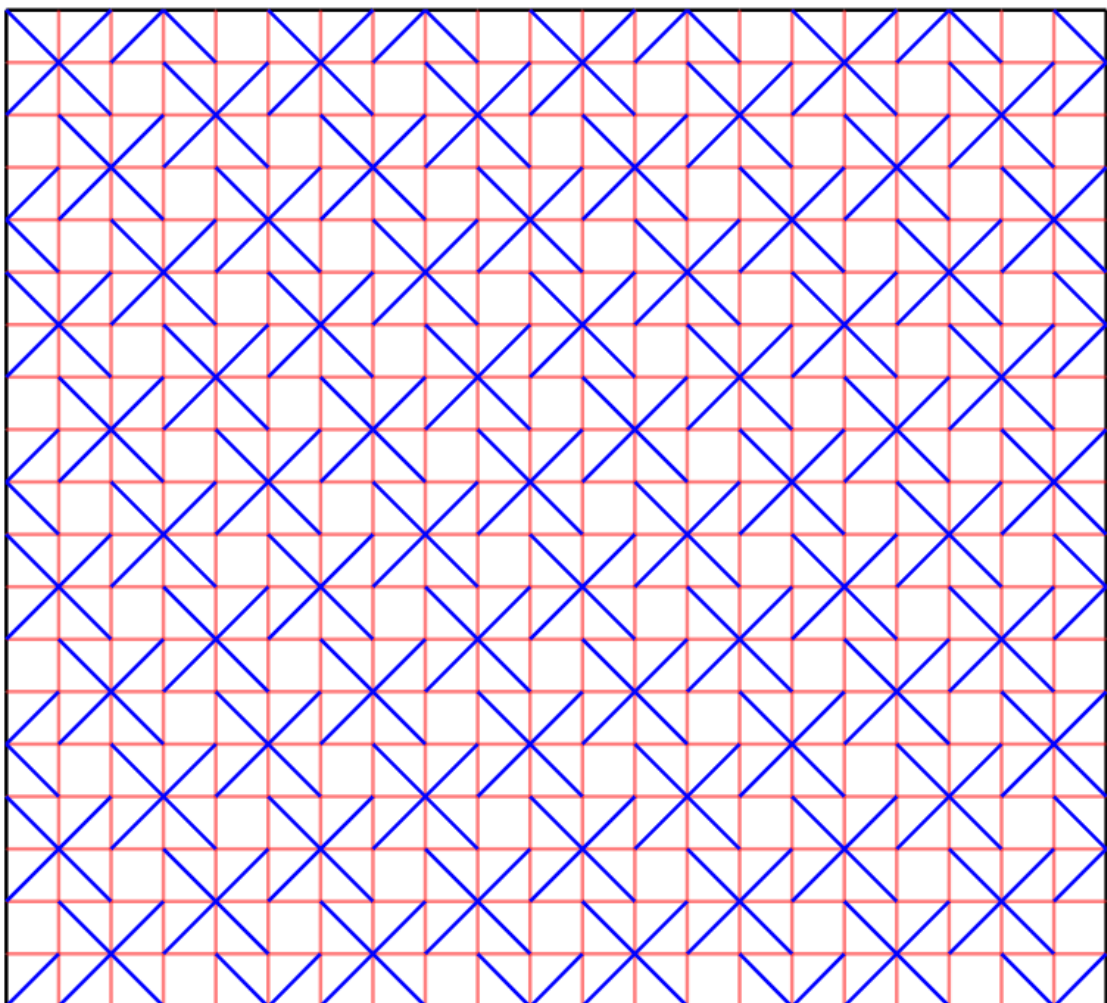


Figure 6.18 - Huffman Waterbomb Tessellation

When considering the optimization factors for origami-inspired airbag design and selecting an optimal folding pattern, each characteristic plays a crucial role. Assigning importance levels on a scale of 1-10 helps prioritize these factors based on their significance in achieving an effective and efficient airbag design. The importance level may vary depending on specific use cases and requirements, but here's a general assessment,

1. **Crash and Impact Characteristics (9/10)**
This is paramount for airbag performance. The folding pattern should be optimized to absorb and distribute impact energy effectively during a crash.
2. **Deployment Efficiency (8/10)**
A swift and reliable deployment is critical. The folding pattern must allow for rapid and consistent inflation to ensure the airbag's timely response.
3. **Structural Integrity (7/10)**
The folding pattern should contribute to the overall structural strength of the airbag, ensuring it withstands the forces experienced during deployment.
4. **Space Utilization and Storage (6/10)**
Optimizing the folding pattern for compact storage is important for space efficiency within the vehicle or aircraft.
5. **Material Compatibility (7/10)**
The folding pattern should be compatible with the materials used in the airbag to ensure durability and reliability.
6. **Cost Effectiveness (6/10)**
The folding pattern should balance cost considerations while maintaining performance standards.
7. **Regulatory Compliance (9/10)**
Ensuring adherence to safety and regulatory standards is critical. The folding pattern should align with industry guidelines and legal requirements.
8. **Environmental Impact (5/10)**
Minimizing environmental impact is important, but it may have a lower priority compared to safety and regulatory concerns.
9. **Manufacturability (8/10)**
The folding pattern should be designed for efficient and cost-effective manufacturing processes.
10. **Adaptability to Vehicle or Aircraft Design (7/10)**
The folding pattern should be adaptable to various vehicle or aircraft designs, allowing for integration without significant modifications.

11. User Experience and Safety (9/10)

Prioritizing user safety and a positive experience during airbag deployment is crucial for overall effectiveness.

12. Testing and Validation (8/10)

The folding pattern should facilitate thorough testing and validation processes to ensure reliability and performance.

13. Industry Acceptance (6/10)

The design should be accepted within the industry, considering standards and practices.

Considering Optimization factors assigning value from 1-10 scale,

	Huffman Water bomb	Miura Ori	Hexa Tri	Lang Honeycomb
Crash and Impact Characteristics	8	9	7	8
Deployment Efficiency	7	8	4	7
Structural Integrity	8	9	7	8
Space Utilization and Storage	8	9	8	8
Material Compatibility	7	8	7	7
Cost Effectiveness	7	7	4	7
Regulatory Compliance	7	8	4	7
Environmental Impact	6	7	7	4
Manufacturability	8	7	7	8
Adaptability to Vehicle or Aircraft Design	7	8	8	7
User Experience and Safety	8	9	7	8
Testing and Validation	8	8	7	8
Industry Acceptance	7	8	6	7
Total	96	105	83	94

Table 6.1 Assigned Values for Optimization Factors

Assigning the value using Importance level,

	Huffman Water bomb	Miura Ori	Hexa Tri	Lang Honeycomb
Crash and Impact Characteristics	7.2	8.1	6.3	7.2
Deployment Efficiency	6.3	7.2	3.6	6.3
Structural Integrity	7.2	8.1	6.3	7.2
Space Utilization and Storage	7.2	8.1	7.2	7.2
Material Compatibility	6.3	7.2	6.3	6.3
Cost Effectiveness	6.3	6.3	3.6	6.3
Regulatory Compliance	6.3	7.2	3.6	6.3
Environmental Impact	5.4	6.3	6.3	3.6
Manufacturability	7.2	6.3	6.3	7.2

Adaptability to Vehicle or Aircraft Design	6.3	7.2	7.2	6.3
User Experience and Safety	7.2	8.1	6.3	7.2
Testing and Validation	7.2	7.2	6.3	7.2
Industry Acceptance	6.3	7.2	5.4	6.3
Total	86.4	94.5	74.7	84.6

Table 6.2 Assigned Values with Importance level for Optimization Factors

In the evaluation of folding patterns for optimum airbag design, the Miura Ori folding pattern emerges as the preferred choice, garnering high importance level values across critical criteria. With an exceptional score of 9/10 for Crash and Impact Characteristics, Miura Ori stands out for its ability to effectively distribute impact energy during a collision, ensuring optimal protection. Achieving a commendable 9/10 for Space Utilization and Storage, the pattern excels in compactness, making it well-suited for efficient storage within the constraints of a vehicle or aircraft. Furthermore, its user-friendly deployment characteristics contribute to a positive User Experience and Safety score of 9/10. The pattern's versatility and adaptability to various vehicle or aircraft designs are reflected in its solid scores of 8/10 in Adaptability to Vehicle or Aircraft Design and Testing and Validation. Miura Ori's overall robust performance and alignment with key optimization factors make it the optimal folding pattern for airbag design, balancing crash effectiveness, space efficiency, and user safety.

Summary

The ongoing project has managed opportunities as well as challenges in the development of an airbag system inspired by origami with the goal of enhancing landing and crash protection. Though time constraints have left some aspects of the work incomplete, a thorough review of the literature has made significant progress possible. The project has investigated a wide range of topics, such as crash impact scenarios, origami techniques, airbag regulations, and a careful evaluation of different optimization factors. A deep understanding of these components has been attained as a consequence of this thorough investigation, providing the foundation for wise decision-making.

One of the main goals of the project has been to carefully optimize the airbag's folding pattern. This focused on improving crucial elements like crash and impact characteristics, deployment efficiency, and the overall structural integrity of the airbag by utilizing the knowledge obtained from the literature review. One significant accomplishment in this endeavor has been the creation of a Python-based mathematical model. This model is an essential tool for making use of an origami simulator, allowing for in-depth analyses and simulations of various folding patterns.

The project looks forward to working on the actual construction and testing of the airbag prototypes inspired by origami. In order to improve their performance characteristics, the optimized folding patterns will be translated into actual airbag designs and put through rigorous simulations. Further testing, in controlled settings as well as in crash simulations, will offer priceless insights into the origami airbag's practical effectiveness. Through the integration of theoretical understanding, computational modeling, and hands-on testing, the project is well-positioned to make additional progress in the field of origami-inspired airbag design, ultimately leading to improved safety in landing and crash situations.

References

- 24 (28) *films and clips up-dates about Kresling-origami 08i2021*. Available at: https://www.researchgate.net/publication/344780932_24_28_Films_and_Clips_up-dates_about_Kresling-origami_08i2021 (Accessed: 26 December 2023).
- A study of airbag design and optimization methodology ... - transportation*. Available at: <https://www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000365.pdf> (Accessed: 26 December 2023).
- Ghassaei, A. (no date) *Origami Simulator*. Available at: <https://origamisimulator.org/> (Accessed: 26 December 2023).
- Ionut Radu, A. *et al.* (2018) ‘Study regarding the influence of airbag deployment time on the occupant injury level during a frontal vehicle collision’, *MATEC Web of Conferences*, 184, p. 01007. doi:10.1051/mateconf/201818401007.
- Meloni, M. *et al.* (2021) ‘Engineering origami: A comprehensive review of recent applications, design methods, and Tools’, *Advanced Science*, 8(13). doi:10.1002/advs.202000636.
- Origami 4* (no date) *Google Books*. Available at: https://books.google.com/books?hl=en&lr=&id=kOPqBgAAQBAJ&oi=fnd&pg=PA129&dq=Airbag%2BFolding%2BBased%2Bon%2BOrigami%2BMathematics&ots=_Oa2_FL3tD&sig=_KRJASNc4xzvDCvqzIwTh2mQ9k (Accessed: 26 December 2023).
- Origami theory and its applications: A literature review - semantic scholar* (no date) *Origami Theory and its Applications: A Literature Review*. Available at: <https://www.semanticscholar.org/paper/Origami-Theory-and-Its-Applications%3A-A-Literature-Fei-Sujan/27574f640bca2b58ebcca3cfafccb89541110f17> (Accessed: 26 December 2023).
- Tason (no date) *Robert J. Lang origami*. Available at: <https://langorigami.com/> (Accessed: 26 December 2023).
- Turner, N., Goodwine, B. and Sen, M. (2015) ‘A review of Origami applications in Mechanical Engineering’, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 230(14), pp. 2345–2362. doi:10.1177/0954406215597713.
- Yue, S. (2023) ‘A review of origami-based deployable structures in aerospace engineering’, *Journal of Physics: Conference Series*, 2459(1), p. 012137. doi:10.1088/1742-6596/2459/1/012137.
- Zhang, X., Xue, Z. and Tu, W. (2023) ‘Design and performance research of a wearable airbag for the human body’, *Applied Sciences*, 13(6), p. 3628. doi:10.3390/app13063628.

Appendix A



Figure A - QR code for the code of the SVG pattern maker