Project III

Exploration & Application of Compliant Mechanisms in Furniture

Under the Guidance of : Prof. Kums

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Acknowledgement

I take the opportunity to thank everyone who helped me in any way to the successful completion of the project. I express my gratitude to my guide Prof. Kums, who pointed out my flaws and advised the corrections and guided me constantly throughout the project. My acknowledgement also goes to the entire family of IDC, my mother, father and my brother as they were a constant support behind me and without whose prayers and blessings this work would have been impossible.

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Introduction to **Compliant Mechanisms**

1. What is Compliant Mechanism?

If something bends to complete the desired motion then it is a compliant. And if the achieved bending can be converted into a useful task, then it is a compliant mechanism.

Compliant mechanisms as those which utilize the deformation of flexible members to successfully transfer motion, force, and energy. Compliant mechanisms are encountered on a daily basis, most moving things in nature are very flexible instead of stiff, and the motion comes from bending the flexible parts. A human heart can be taken as an amazing example of compliant mechanism, which started working before we are born and will keep working till we will die. Blooming flower, wings of insects, a mosquito, our spine, every things is a natural compliant mechanism.

Fig 1.1: Some examples of compliant mechanisms found in nature, a dragonfly, mosquito, a flower and an eel fish

Early man made compliant mechanism designs include the ancient bow and many compliant mechanism designs by **Leonardo da Vinci.** Even one of the great achievements of engineering began with a compliant mechanism when the **Wright brothers** used wing warping to achieve control of their early aircraft.

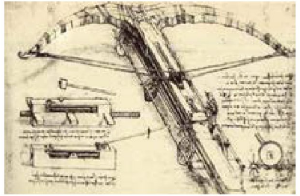


Fig 1.2: The sketch of cross bow by Leonardo da Vinci and first flight by the Wright Brothers

There are a lot of examples of compliant mechanisms in our day to day life. We come across these mechanisms every where. A few of very common examples are hair clips, paper clips, flip caps, bendable straws, etc.

Fig 1.3: Some common examples of compliant mechanisms, clips, flip caps and bendable straw

2. Advantages of Compliant Mechanisms

Following are the advantages of compliant mechanisms over traditional mechanisms:

• **Part Count -** It reduces the total number of parts required to accomplish a specified task. Flexible parts are used instead of springs, pins, and traditional rigid hinges.

• **Productions processes -** Can be made with various manufacturing processes like machining, stamping, a laser cutter, 3D printing, etc. Many compliant mechanisms can be fabricated flat from planar sheets of material.

• **Price -** The reduction in part count may simplify manufacturing and reduce both the manufacturing and assembly time and cost.

• **Precise motion -** Compliant mechanisms can allow precise motion by reducing or eliminating backlash and wear.

• **Performance -** Smaller number of movable joints reduced friction and need for lubrication, which helps in applications where the mechanism is not easily accessible.

• **Proportions -** The size of a compliant mechanism can be varied. They can be effectively used in the fabrication of micro mechanisms like Micro Electromechanical Systems (MEMS).

• **Portability -** Using a compliant mechanism instead of rigid body counterparts reduces weight. It have also benefited companies by reducing the weight and shipping costs of consumer products.

• **Predictability -** In compliant mechanisms, energy is stored in the form of strain energy in the flexible members. This can be used to easily store and/or transform energy to be released at a later time or in a different manner.

3. Challenges with Compliant Mechanisms

Along with all the advantages, there are also some challenges and disadvantages with compliant mechanism.

• **Combination of complex systems -** Difficult to analysing and designing compliant mechanisms. Knowledge of mechanism analysis methods and the deflection of flexible members is required.

• **Non-linear equations -** Many compliant mechanisms are based on deflection of the material, so normal physics equations are not applicable. Thus most of the time, the compliant structures are made by trial and error approaches.

• **Energy storage -** Stored energy is an advantage but in some applications having energy stored in flexible members is a disadvantage. For example, if a mechanism's function is to transfer energy from the input to an output, not all of the energy is transferred since some is stored in the mechanism.

• **Fatigue -** Since compliant members are often loaded cyclically when a compliant mechanism is used, it is important to design those members such that they will have sufficient fatigue life to perform their prescribed functions.

• **Limited motion -** The motion from the deflection of compliant links are also limited by the strength of the deflecting members. A compliant link cannot produce a continuous rotational motion such as that possible with a pin joint.

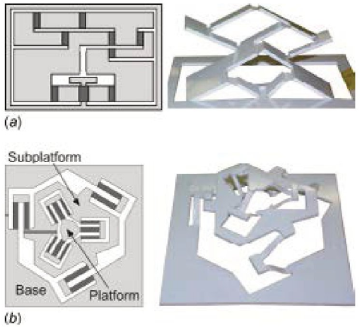


Fig 4.1: Basic example of Lamina Emergent Mechanism

4. Types of Compliant Mechanisms

Compliant Mechanisms can be of different types depending on the function they perform and the form of the structure.

4.1 Lamina Emergent Mechanisms

Lamina emergent mechanisms (LEMs) are mechanical devices fabricated from planar materials (laminae) with motion that emerges out of the fabrication plane. They are monolithic within each planar layer. They can be manufactured using simplified processes common to sheet materials.

4.2.1 Advantages of LEM

- Fabricated in plane with Flat initial state
- Compact packaging and shipping applications (e.g., high-volume packaging that reduces cost of handling, storing, and shipping products)
- Applications with limited manufacturing processes available (e.g., micro electromechanical systems and cost-sensitive applications)

4.1.2 LEM Applications

- Fabricated in plane with Flat initial state
- Compact packaging and shipping applications (e.g., high-volume packaging that reduces cost of handling, storing, and shipping products)
- Applications with limited manufacturing processes available (e.g., micro electromechanical systems and cost-sensitive applications)

Fig 4.2: Packaging boxes, a good example of LEM

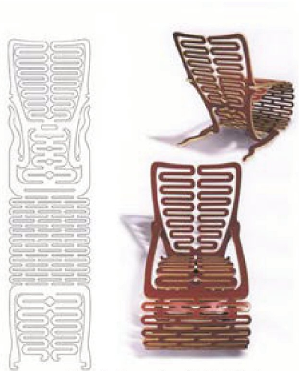


Fig 4.3: Example of LEM Chair

4.2 Compliant Mechanism in Origami

Traditionally, the term origami has been primarily associated with the ancient art of folding paper.

The underlying principles of origami are very general, it takes two-dimensional components that are easy to manufacture (sheets, plates, etc.) into three-dimensional structures.

In origami, a goal shape is obtained from an initially planar sheet exclusively through folding. In any origami structure, we can identify two region types: the folds and the faces.

Fig 4.4: Examples of Origami Structures

5.2.1 Active Origami Structure

Origami that uses active materials that convert various forms of energy into mechanical work to produce the desired folding behaviour.

Energies such as electrical, magnetic or electromagnetic are used to trigger the mechanism.

Active origami structures are extensively used in medical field where there is use of small machines and in aerospace where large structures are to be deployed are carried in confined spaces in space ships.

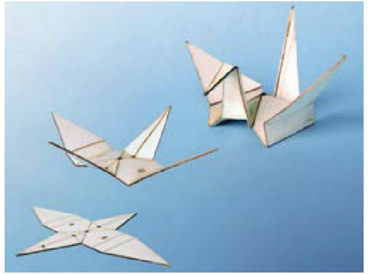


Fig 4.5: Active Origami Structures

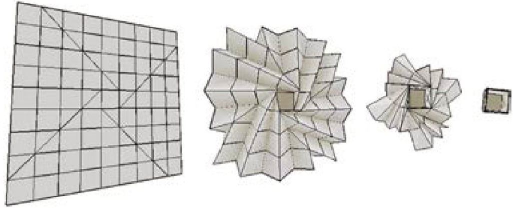


Fig 4.6: Active Origami Structures for satellites

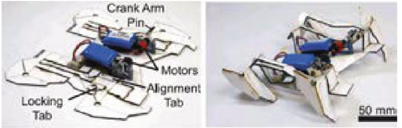


Fig 4.7: Active Origami Structures for fold-able robot

5. Uses of Compliant Mechanisms

5.1 Compliant Mechanism in MEMS

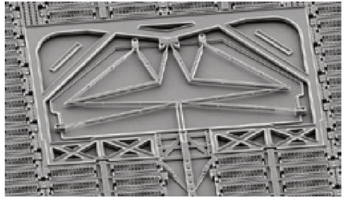


Fig 5.1: A micro electromechanical system

Compliant mechanisms are extensively being used in micro electromechanical systems (MEMS).

These micro mechanisms are made using micro 3D printing and laser cutting. MEMS are also used in medical applications.

5.2 Use in Aerospace Industries

Fig 5.2: Satellite thruster model by NASA

NASA along with BYU is developing different compliant mechanisms that can be more reliable. In this figure, is a compliant mechanism used or the satellite thrusters. By using only two motors, we can achieve very precise movements without requirement of lubricants.

5.4 Preventing Accidental Nuclear Attacks

A nuclear attack is something which should never happen, specially by an accident.

To prevent such hazards from happening, a compliant mechanism is developed, ass shown in the figure. As it works with stress, there is no chance of accidental launch due to earthquake, etc.

Fig 5.3: Dragon model by Disney

5.5 In the field of Animation

In collaboration with BYU, Disney is developing compliant mechanisms to mimic body movements of animals.

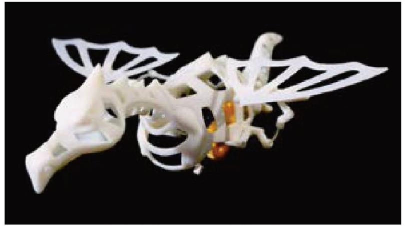


Fig 5.4: Dragon model by Disney

6. Production Processes for Compliant Mechanisms

Compliant mechanisms can be simple to manufacture because they lend themselves well to various manufacturing processes.

They can be manufactured methods including -

- Machining
- Stamping
- Injection Moulding
- Extrusion
- Laser cutting
- Water jet cutting
- 3D printing
- Electrical discharge machining (EDM)

7. Materials Suitable for Compliant Mechanisms

The two most common properties to measure quality in material are tensile strength and strain.

A compliant structure works due to the ability of a material to accommodate deformation (compression, tension, shear, bending and torsion) before failure.

Materials like Polythene and Polypropylene are the best suitable for these kind of bending mechanisms as they can handle much more stresses during the motion. They also handle fatigue much better compared to other plastics like acrylic and styrene.

3D printed metal is also used for heavy duty compliant mechanisms. They add some extra strength for heavy duty uses such as in aerospace industry.

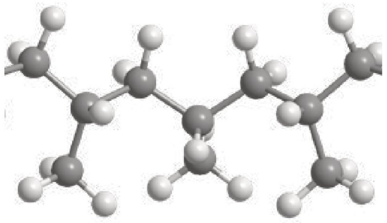


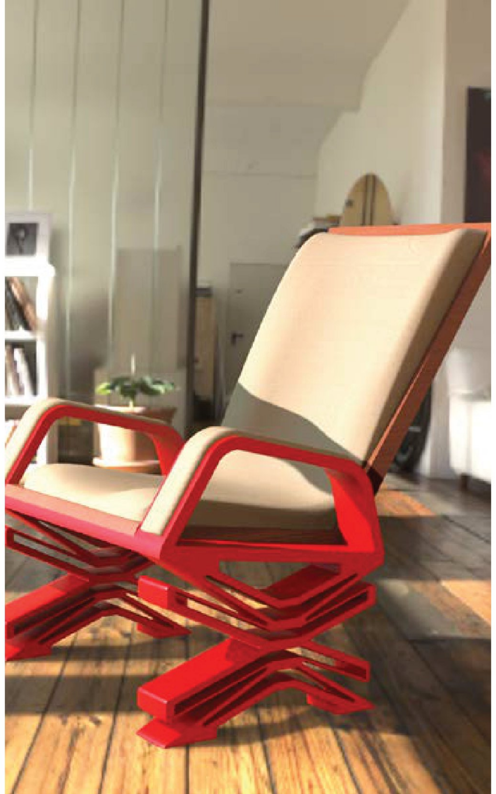
Fig 7.1: Molecular structure of Polypropylene

8. Learnings from Present Applications

- Compliant mechanisms have more advantages than limitations which makes it a very suitable to use over mechanisms

- Most of the current applications range from micro level (MEMS) to macro level (satellite thrusters of NASA). Thus, we can play with the scale and can achieve favourable outcomes.

- There's very less or almost negligible application of compliant mechanisms in furniture, which makes is a very vast field to explore.



The
Design Process

9. Possibilities with Furniture

The things we can possibly achieve with application of compliant mechanisms in furniture are –

- Replacement of commonly used **traditional joints** and hinges with compliant mechanisms
- Assembly of different parts and components using the compliant structures
- **Stackable** & **fold-able** furniture, optimization of stack-ability and fold-ability of furniture with application of compliant structures reducing space consumption
- We can achieve **manufacturing optimization** by design such components which can be easily mass manufactured using simple processes like injection moulding or extrusion.

10. Design Statement & Design Brief

9.1 Design Statement

"To **study and understand compliant mechanisms** and exploring their **possible applications in furniture** and other products for better and efficient spaces".

9.2 Design Brief

To study and understand the principles of compliant mechanism an implement it in the daily life products such as furniture and other products.

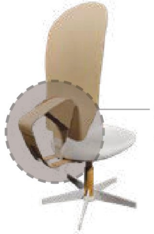
- To achieve motion in the product using compliant structures
- To reduce the complexity and make the mechanism simple
- To reduce the part count and wear and tear of the components
- To achieve easy manufacturability of the product

11. Initial Ideation

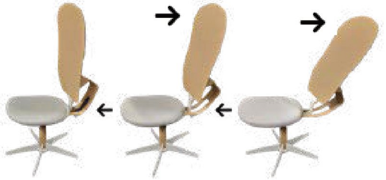
11.1 Office Chair

Office chairs are among the most complex piece of furnitures which can include a number of moving parts and different mechanisms assisting them. Ranging from adjustable seat height, adjustable lean back backrest, arm rest, etc.

In this ideation, the lean back mechanism is replaced by a compliant structure which uses the tension and compression property of the material to achieve the motion. The mechanism not only helps in the inclination of the back support but also moves the seat forward, maintaining the centre of gravity, which prevents the person from falling.



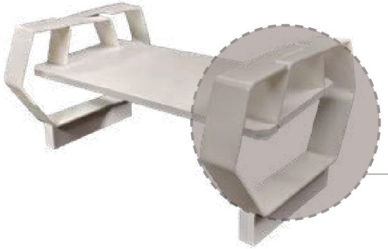
This portion of the chair is a compliant structure which achieves the desired motion



11.2 Park Bench

This is a basic example of public seating made using members in stresses. These benches can be for two persons or three. The seating platform is suspended in air through the compliant structural support at both the ends. The sitting plane is supported by tension in the frame, thus when a person sits on it, the weight of the person applies force which gives the bench a dynamic motion.

Since the motion is achieved by the weight of the users and the stress which the members can withstand is limited, overloading of the bench can cause failure of the structure.



This structure acts as a spring mechanism which absorbs the force when people sit on it and also suspends the platform, giving it a dynamic property

11.3 Foldable Chair

This is a folding chair made flexible plastic material such as polypropylene with live hinges. As pp is very good in handling stresses and strains, it is a very suitable material for making live hinges. The live hinges makes it easy to fold the parts, replacing the traditional hinges and reduces part count.

As the chair is foldable, it reduces the storage space and makes it more space optimised and makes it easier in transportation and is stackable.

The live hinges provided helps the chair to be folded easily, reduces part count and make it less space consuming

11.4 Rocking Chair

This chair uses compression of the material as a compliant mechanism. The member present in the chair gives it a spring back motion, which gives it a to and fro movement. It can be used as a relaxing chair with small rocking motion.

The compression member is given on both sides under the seating platform, housed inside parallelograms as a diagonal. When a person sits, the parallelograms compress and this compression is countered by the compression members, which gives it balanced and even motion.

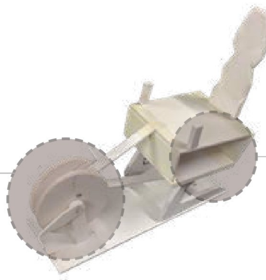
The compression member giving the rocking motion to the chair, when a person sits on it, present on both sides

11.5 Gym Machine

This is an ideation of a gym equipment which tries to achieve its motion through compliant structures. It is an equipment for leg as well as abdomen fat.

The stet of the machine is a compliant structure, which changes its shape when the user sits on it ans starts paddling the pedals in front if it. The pedal system is attached with the seat which pulls it to and fro as the persons pedals it, creating cranking in the abdomen.

The pedals present in the front, connected with the seat though compliant structures

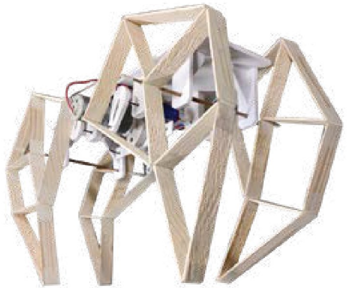


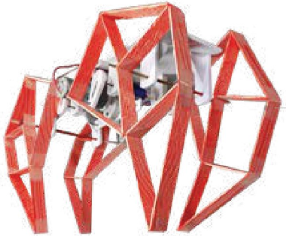
Seating made of compliant mechanism

11.6 Compliant Toy

This is a walking toy ideation, inspired by **Theo Jansen's Strandbeest structure**. This toy uses the power generated by a motor, transferred through camp mechanisms to the legs of the toy. The legs are made from compliant structure , of calculated specific lengths, to give it maximum displacement, which gives it a walking movement.

The number of legs can be different, from minimum of three legs to maximum which can be supported by the power of the motor.



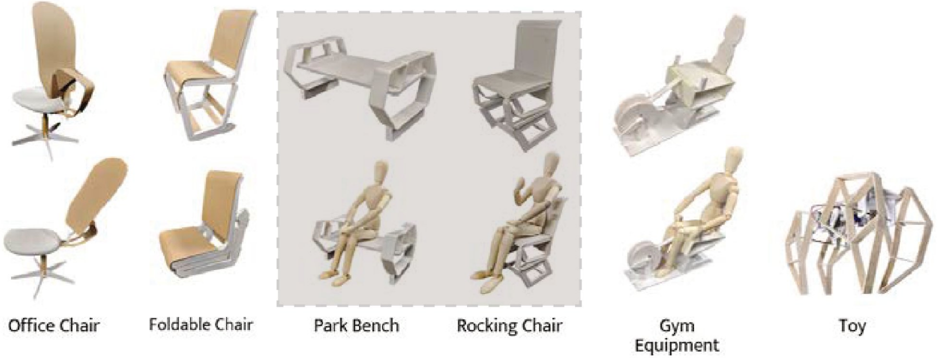


The legs, shown in red colour here are compliant structure which enables a very realistic like leg motion without and joint, completely made up of single piece

12. Refined Ideas

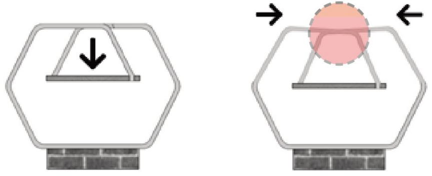
After going through discussions with jury and pointing out the possibilities and challenges with the design, few ideas were further developed and refined.

The idea of park bench and rocking chair were further developed and new advanced ideas were created.

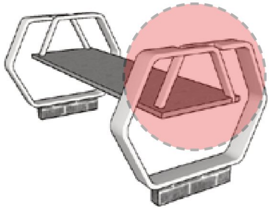


12.1 Problems Identified in Previous Ideas

Park Bench -

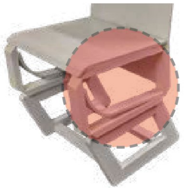


The flexure in the tension members was creating a puncture point at the hand rest which could create severe hand injuries.

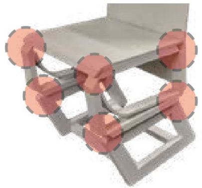


Can be difficult to manufacture due to complex geometry.

Rocking Chair -



Very improper use of compliant structures

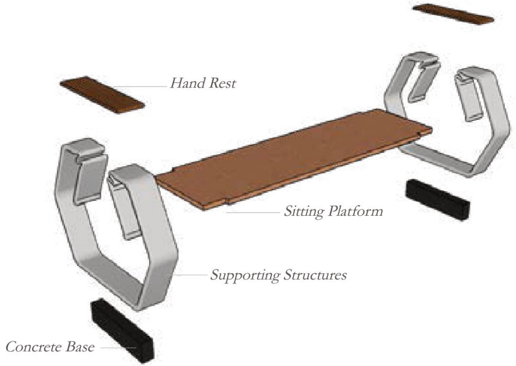


High number of fatigue points increasing chances of failure

12.2 Park Bench 1

This is an updated version of previous public park bench with suspended seating platform. This has more practical use of compliant structure with reduced puncture points.

The bench uses suspended sitting platform, bolted with the supporting structure. These supports have curved profile which gives spring like properties to it.



Easy and simple construction

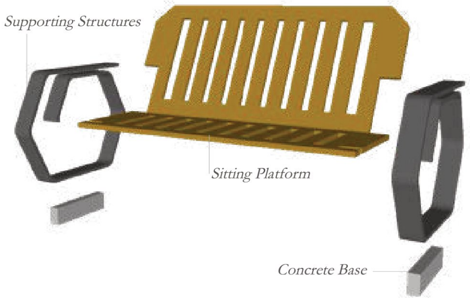
Compliant detail for the dynamic movement

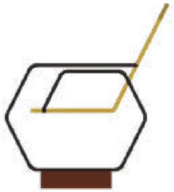
12.3 Park Bench 2

This park bench has similar concept like the previous one but it has a back rest and is slightly different in its complaint structural support than previous one.

The seating platform and backrest is single piece, which are supported on both sides with the compliant structural support.

Easy and simple construction





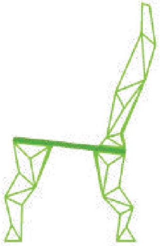
Side profile of the park bench

12.4 Rocking Chair 1

This is a rocking chair concept, integrated with complex compliant structure legs and backrest. This chair changes the shape of its components based on the forces applied while sitting on the chair.

The chair can actually work as a rocking chair when the user shift the centre of mass of the body with a to and fro motion.

Back support which takes the back profile

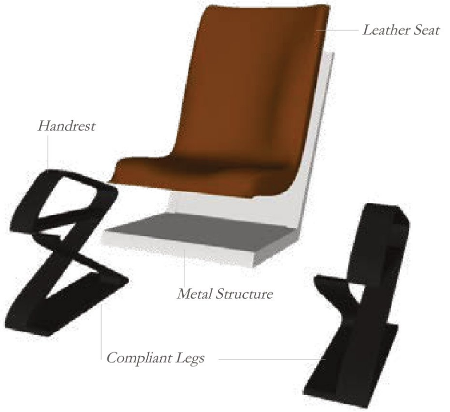


Side profile of the chair

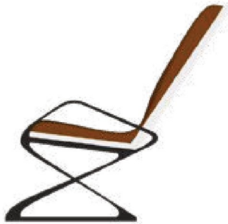
12.5 Rocking Chair 2

A rocking chair concept with simple compliant rocking mechanism. It has structure made up of flexible members, attached together, forming an 'X' shape. This combination counters the forces acting on each other while rocking, providing a limited freedom of movement.

The legs are attached to a metal frame which has a leather seat, making it a very comfortable rocking chair.



Compliant structure providing rocking movement

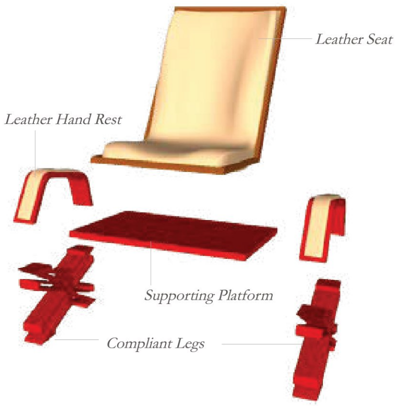


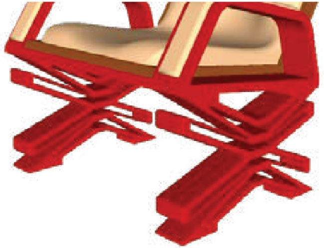
Side profile of the chair

12.6 Rocking Chair 3

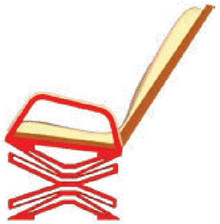
This chair also uses the compliant legs made up of flexible material, but in a totally different design. Similarly like the previous one, the forces acted are balanced by the compression and tension generated in the material, but in a single plane.

This chair also has leather seat with a complete plastic body.





Compliant structure providing rocking movement



Side profile of the chair

13. Final Concept

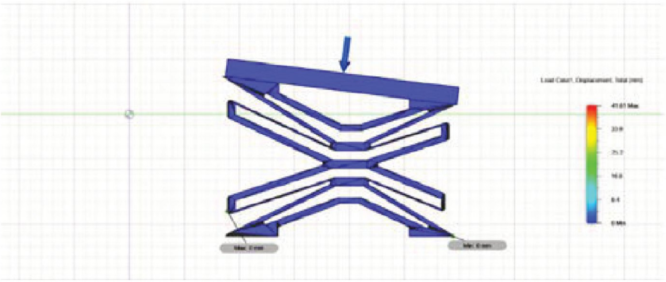
The concept is taken further and developed along with all the detailing

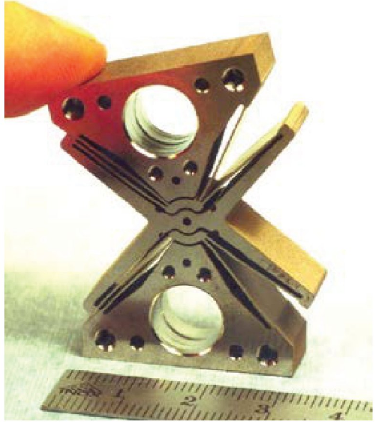
13.1 FEM Calculations

The CAD model was tested for applied load, stresses and deformations in the model to check whether the chair can sustain them or not.

A load of 80 kg is applied on the legs from the top, to check the strength and displacement achieved.

The parts of the legs collapsed to each other with a **maximum displacement of 41mm,** which proves that the current design is failing structurally. Thus a deep study of the applied compliant mechanism was done. This design was inspired by compliant flexure hinge.



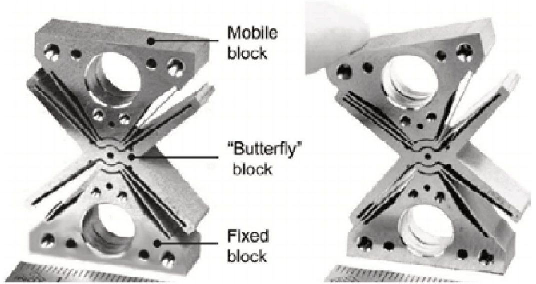


Flexure Pivot for Aerospace Engineering

13.2 Applied Compliant Structures

Flexure Pivot for Aerospace Mechanisms –

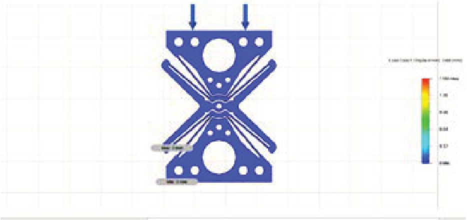
This flexure pivot is a generic high precision flexible pivot dedicated to pointing and scanning space mechanisms. The pivot, as a compliant alternatives for butterfly hinges, gives a precise motion of 15°, both front and backwards.



Deflection range of Flexure Pivot

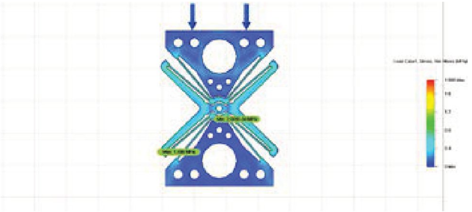
13.3 FEM Analysis of Flexure Pivot

For the analysis, a model of 400mm length, 200mm thickness and 600mm height is taken. The flexure pivot is tested with a weight of 80 kg from the top and different results were studied.



DISPLACEMENT

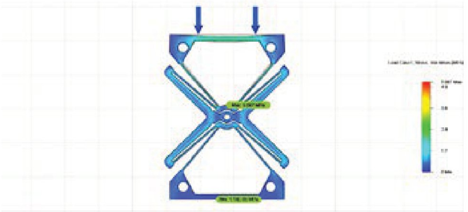
A maximum displacement of 1.5mm is achieved



STRESSES

A maximum stress of 1.9MPa is achieved.

The blue area shows that there are no stresses or almost zero stresses.



After previous simulation, it was found the area under stress. In this model, the area under no stresses were reduce the volume and material used in the hinge.

FACTOR OF SAFETY

A safety factor of 1.5 is achieved when same load is applied on modified model. (A safety factor of 3 is considered for mechanisms and we can achieve that by making the members thicker)

14. Designing of Refined Rocking Chair

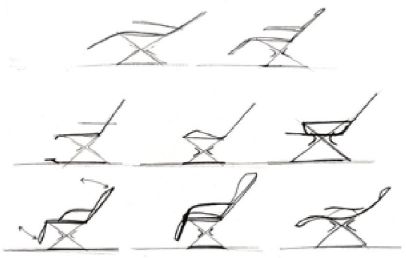
14.1 Mood Board

The mood board shows the design trend followed and the elements taken for the inspiration.

- Sleek
- Modern
- Edgy
- Retro
- Soft
- Black

14.2 Sketches & Ideation

Some quick sketching and ideation for the final form of the rocking chair.



14.3 Dimensions & Proportions

DIMENSIONS & ANGLE OF INCINATION

For the essential anthropometric dimensions to be considered, **Analysis of Anthropometric Dimensions for Sitting Posture and Chair Design by Rizwan M Farooqui and Dr. R. B. Shahu** was referred.

In this diagram on the right, all the anthropometric dimensions are marked which are to be considered for chair design. In the paper, it is also mentioned that an angle of 110° is optimum for backrest while working and for resting chairs, up to 125° is recommended.

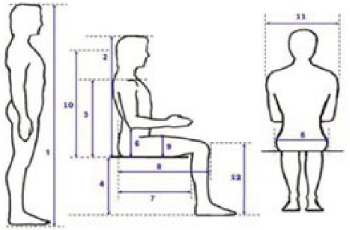
CENTER OF GRAVITY

For the center of gravity, **Determination of Centers of Gravity of Man by John J. Swearingen** was referred.

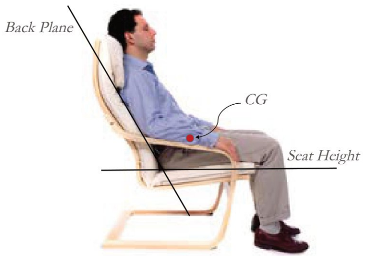
It was mentioned that for a person in resting position, with the legs in air, the CG lies at 9.5inches from the back plane towards the front, 7.5inches above the seat height.

ANTHROPOMETRIC DATA

For the anthropometric data of India, **Indian Anthropometric Dimensions for Ergonomic Design Practice by Debkumar Chakrabarti** was referred.



Dimensions to be considered



Dimensions to be considered

15. Final Concept of Rocking Chair

FLEX Chair

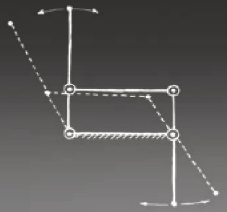
It comes with fixed back angle of 110°
Compliant legs taken from flexure hinge gives it a motion of 30°
Leather seats with injection moulded PP body
ABS hand rests

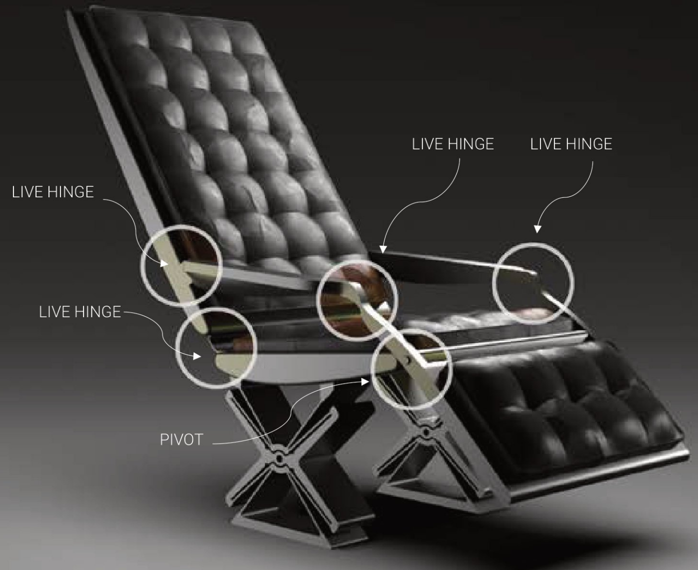
FLEX Chair PRO

It comes with movable back angle of 125°
Compliant legs taken from flexure hinge gives it a motion of 30°
Leather seats with injection moulded PP body
Self adjusting foot rests which comes out as you lean back

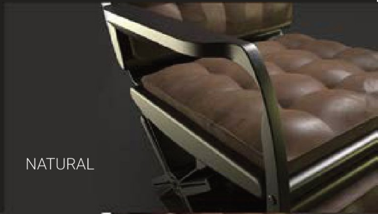
FLEX Chair PRO

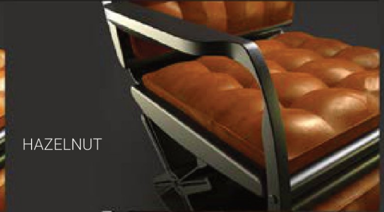
It uses the property of a parallelogram, whose sides remain parallel when angles are changed

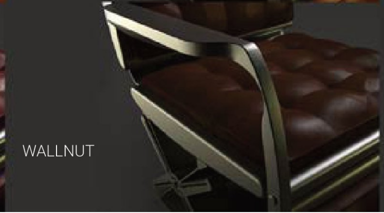


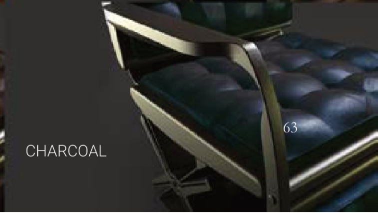


AVAILABLE Colour Options









USER Scenario

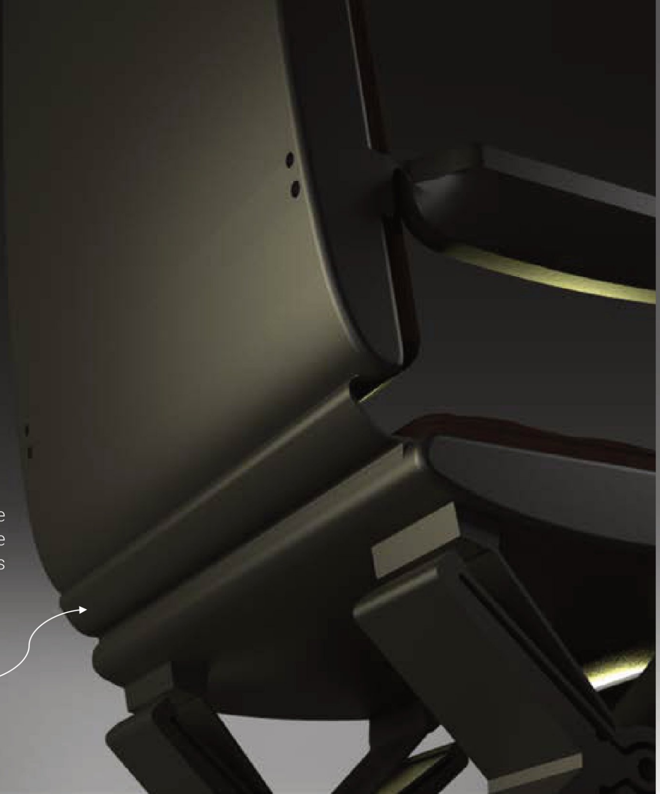
Designed for all the retired but still young inside men, to just sit and relax or to enjoy some reading.

DESIGN Details

The main frame of the seat is provided with ribs to give the structure strength as well the reduce the consumption of material.

DESIGN Details

A live hinge is provided which connects the backrest with the seat, which not only assists the auto retraction of FLEX pro variant, but also helps in packaging.

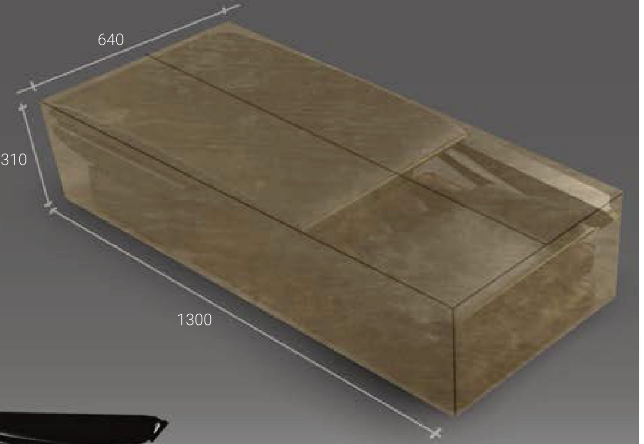


PARTS & JOIERY Details

There are four major parts in pro and five in basic model, along with three leather cushion in pro and two for basic.
These parts are joined together with screws and the leather cushions are snug fit on to the frame.

FOLDING & PACKAGING
Details

Due to the flexible nature of PP material, the whole chair can be packed in a box of dimension 1300mm x 640mm x 310mm. Which optimizes space in transportation in bulk from factory to the outlets.



A COMPLETELY FOLDED FLEX PRO

16. References

Image References

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