Case Study

Design and Analysis of a Chair with Ansys Discovery

Developed and curated by the Ansys Academic Development Team

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Summary

Ansys Discovery is a simulation-driven design tool that combines instant physics simulation, high fidelity simulation and interactive geometry modeling in a single easy-to-use experience. This enables designers and engineers to illustrate a wide variety of concepts in the fields of design, structures, fluids, and heat transfer with the help of simulation.

This case study demonstrates how an iterative design process starting with geometry design to simulation and validation can be carried out using Ansys Discovery. It starts with the design of simple functional chair and uses the simulation results to improve the design by making it more aesthetic, light, and safe. With the support of Discovery, the impact of every design-based decision can be visualized in the results of the simulation model.

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1. Introduction

A chair is a vital piece of furniture found at homes and offices. There are different types of chairs based on their function and utility. For example, the design and material of dining chairs differ from that of swivel chairs found at offices because they satisfy different requirements. Generally, we can define a chair as a seat for one person, typically having four legs, a backrest, and sometimes even hand rests. With regard to design, it is important for chairs to be durable so that they can last several years when used correctly and need to have a good weight bearing capability. Nowadays, people spend a lot of time sitting on chairs at offices, as such it is essential for them to also be ergonomic to provide appropriate support to the spinal cord. One way of ensuring this, is by positioning the backrest of the chair at a 90 degree or higher angle to the seat to provide comfort. Chairs are an integral part of the interior design, therefore it is important for them to be aesthetic as well.

2. Chairs: Common Designs and Materials

As mentioned above, the main parts of a chair consist of a seat, legs, backrest, sometimes hand rests and wheels for swivel function. These parts can be made of the same or different materials. In addition, cushioning can be added for both aesthetic and ergonomic purposes. Chairs can be made up of wood, metal, plastic or stone. The design and material of a chair is decided based on its use and area where it is placed. Some examples of chairs can be seen in Figure 1 below.

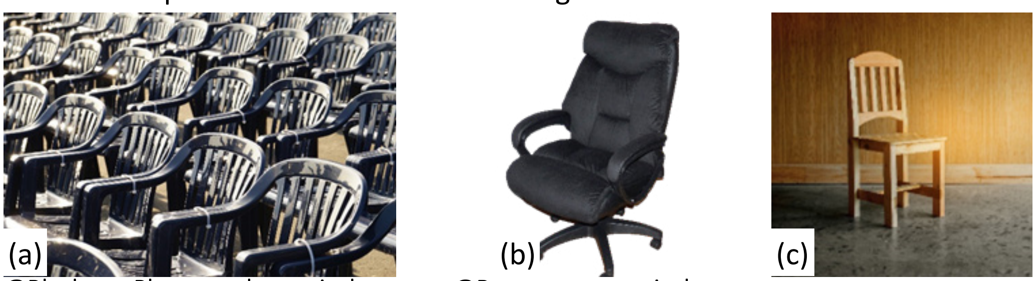

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Figure 1. (a) Outdoor Chairs (b) Swivel Chair (c) Dining Chair

Chairs in Figure 1a are often used at outdoor events like parties are generally made of plastic or metal because they are durable and easy to clean and disinfect. They are designed in such a way that they can be stacked when not in use. Swivel chairs (Figure 1b) are used in offices and homes do not possess four legs like traditional chairs, rather they have a design that allows for wheels to be added at the base for the swivel function. The backrest and seat are cushioned and are generally made of breathable fabric like leather, cotton or mesh like design that can provide comfort despite continuous usage over several hours. The structural components like the base and the wheel are usually made of plastic and metal components. Dining chairs (Figure 1c) are generally made of wood or plastic. They tend to be aesthetically pleasing as they are part of the interior design of a house or restaurant.

3. Structural Design and Analysis Process

The aim of this case study is to design a chair which is safe and can be functional. To do this, we will follow the structural design and analysis process shown in Figure 2, which is used to understand the behavior of structures when external forces are exerted on them. The goal of this process is to find an appropriate safe design that meets requirements like strength, weight reduction, cost reduction, etc.

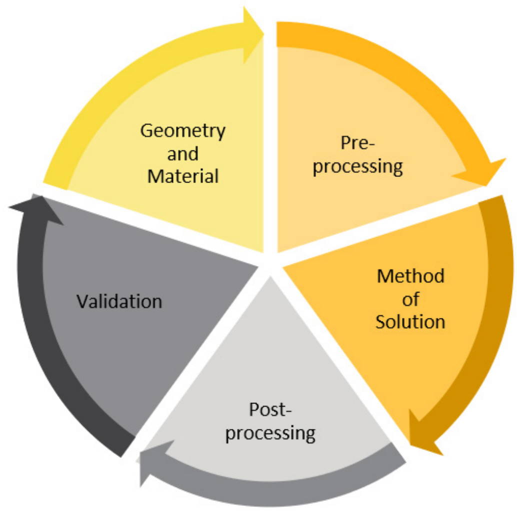

Figure 2. Structural Analysis Workflow

This design and analysis process consists of the following steps:

- Geometry and Material: In this first step the initial physical geometry and the materials to be used are defined.
- Preprocessing: This is the next step, which involves defining the loading conditions (forces, moment, etc.) acting on the model as well as the type of supports and joints between the different components of the model (supports and joints limit the degrees of freedom).
- Method of Solution: There are different types of solution methods that can be used to numerically solve a structural problem. In this case study the finite element method is used.
- Post-processing: Once the model is solved, required outputs like stress, strain and displacement can be evaluated and visualized.
- Validation: The last and most important step is to validate the resulting outputs and check if they seem realistic and if the model meets all requirements to be a safe design.

It important to note that this is an iterative process which may require several cycles of repetition before an optimal design can be found. At the end of each iteration, the engineer or designer can see if the changes in geometry and other aspects resulted in an improvement in the overall design or not. Based on this knowledge, further changes can be made to move the results in the required direction.

4. Design of a Chair with Ansys Discovery

Ansys Discovery is a simulation-driven design tool that combines geometry modeling, instant physics simulation and high-fidelity simulation in a single easy-to-use experience. You can find more information on how to access Ansys Discovery through Ansys Discovery Student Version and Ansys Discovery 3D Design webpage. In this case study, the entire structural design and analysis process of a simple dining chair has been carried out using Ansys Discovery as shown in the following sections.

4.1 Design and Material Definition

Let us start the process by designing a very simple chair comprising of a seat, four legs and a backrest. The initial design will be based on ergonomics, which is the science of optimizing a design with the aim of comfort for human usage. This is carried out by taking into consideration human characteristics like body dimensions, weight etc. Considering the average height of a human being as 170cm, ergonomic analysis suggests that the optimal dimensions of a regular chair are as shown in the Figure 3 [1]. These include the following:

- Height of seat and backrest
- Width of seat and backrest
- Angle of backrest to seat

As a starting point, the thickness and cross-section of the backrest, seat and legs of the chair are defined as in Figure 3.

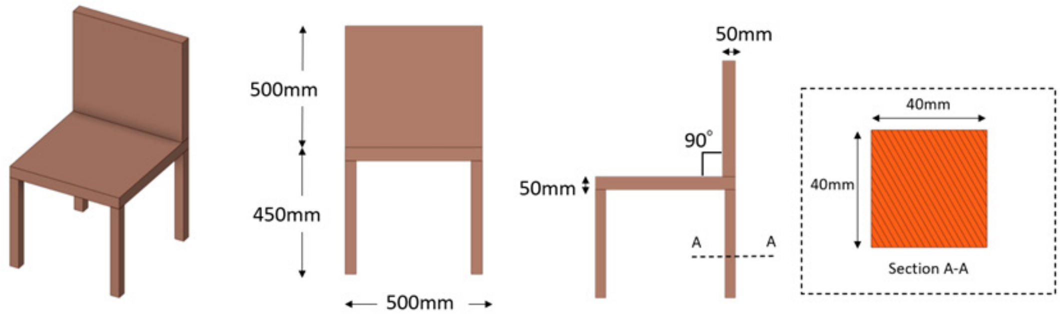

Figure 3. Initial Chair Design

In this case study, we will consider the chair to be made of pine wood. The reason pine wood has been selected is to minimize the cost of the chair as this material is relatively inexpensive. If you would like to explore alternative materials which could be used in the design of a chair based on its usage and requirements (e.g. mechanical properties, cost, environmental impact, manufacturability etc.) Ansys offers a dedicated tool called Ansys Granta EduPack from which you can perform material selection and then export the selected material data to your Ansys simulation.

4.2 Preprocessing

Once the initial geometry and the material have been defined in Ansys Discovery, it is necessary to proceed to the preprocessing stage. In this stage the supports, contact and loading conditions are to be defined. Assuming that all the parts of the chair have been correctly mounted i.e., no component can have rigid body motion when the legs of the chair are stationary, we can define a fixed support at the bottom of the legs of each chair as shown in Figure 4 (a).

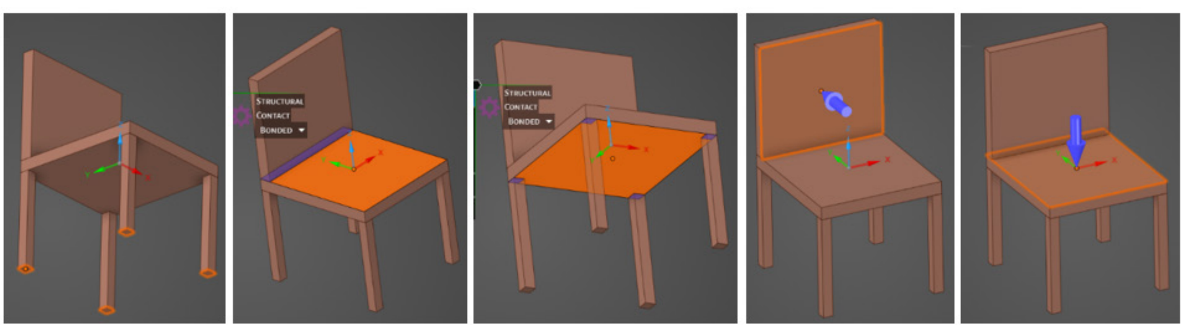

Figure 4. a) Supports, b-c) Contacts, d-e) Backrest and Seat Loading.

Bonded contacts can be defined between the following components as shown in Figures 4 (b-c):

- Backrest and seat
- Seat and legs

Considering a person weighing 100kg sitting on the chair, it is safe to assume that 95% of the weight is on the seat of the chair and 5% on the backrest. In order to produce a safer design, let us assume that the person sitting on the chair exerts their entire weight on the chair and nowhere else (e.g. feet on the ground). This results in a load of 95kg or 931N applied on the seat and a load of 5kg or 49N is applied on the backrest. The directions of the load are as shown in Figure 4 (d-e).

4.3 Solving, Post-processing and Validation

Now that the set-up has been completed, the model can be solved. Figures 5 and 6 display the results of the simulation which have been computed using the GPU solver in Discovery found in the Explore mode with a mesh fidelity of 4mm.

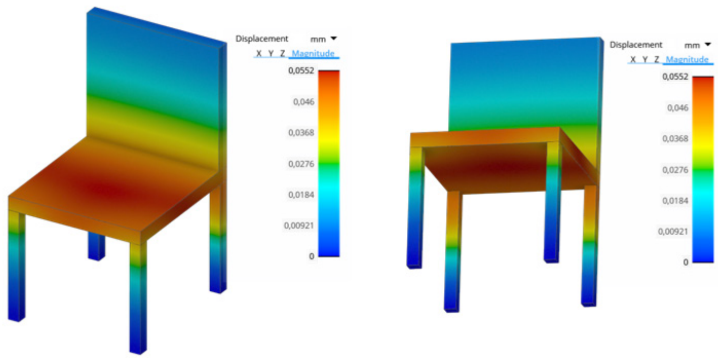

Figure 5. Displacement Contour Plot

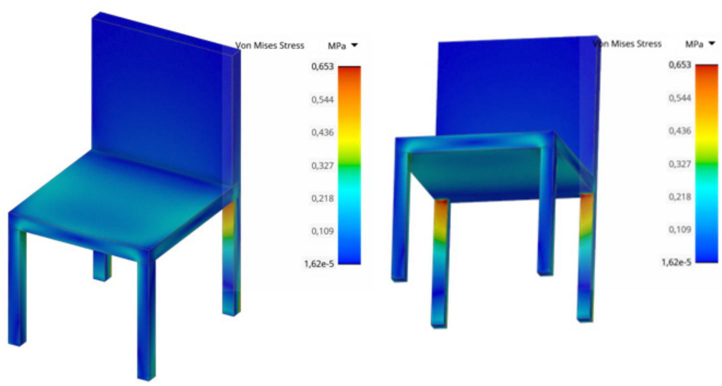

Figure 6. Stress Contour Plot

This case study will focus on displacement (i.e., amount of deformation undergone by the chair), and von Mises Stress (i.e., indication of stress state in the structure). As it can be observed by the contour plot of displacement shown in Figure 5, maximum deformation of 0.05mm can be observed in the seat. This value is so small that it is impossible to feel this displacement while sitting on the chair. Stress Concentration is observed at the inner edges of the legs as show in Figure 6. The maximum value of von Mises Stress is observed to be 0.65MPa.

The reasons for this stress distribution are:

- Weight of the person is concentrated at the middle of the seat, therefore the inner edges of the leg undergo maximum force exertion.
- Stress concentration is often found at sharp edges. This occurs due to sudden changes in the geometry and can be avoided by replacing sharp edges with fillets or chamfers.

Safety factor is a dimensionless constant often used as an indicator to assess the safety of a design under its predefined maximum loading conditions. It is the ratio of yield strength of the material (yield stress of pine wood - 41 MPa) to the maximum stress found in the model (0.65 MPa in this case). In other words, a safety factor value lesser than or equal to 1 indicates plastic deformation under its loading conditions, causing the chair to fail. In this case the safety factor of the chair is 63, meaning it is a very safe design.

When simulation results are computed, it is always important to evaluate them to check if they are within a reasonable range and see if any mistakes were made while setting up the simulation model. This involves doing a sanity check to see if the results meet the expectation. For example, a sturdy wooden chair does not noticeably deflect or warp while sitting on it, indicating that the small displacement obtained in the above model is a reasonable estimate.

4.4 Improved Chair Design

Having assessed the initial design of the chair, we notice that there are several areas of improvement. A key improvement area is the safety factor, which is usually within the range of 1.5 to 3 in non-critical components. The value of 63 obtained from the initial design is unnecessarily high, indicating that we can remove extra material from the chair making it both lighter and cost effective. When assessing where to remove or add material to a certain design, the stress distribution can provide some useful insights on the direction to take. Although material can be removed from all the parts of the model, it can be observed that the backrest is a particularly low stress area. Additionally, removing material from the backrest can aid in improving the design both ergonomically and aesthetically by allowing breathability of the back and making the design more attractive for customers. Another area of improvement observed are the sharp edges in the design, particularly at the legs of the chair which are stress concentration regions. To resolve this problem, fillets or chamfers need to be added to the edges. These also aid in avoiding injury caused due to sharp edges and corners. The improved design can be observed in Figures 7 (a) and (b).

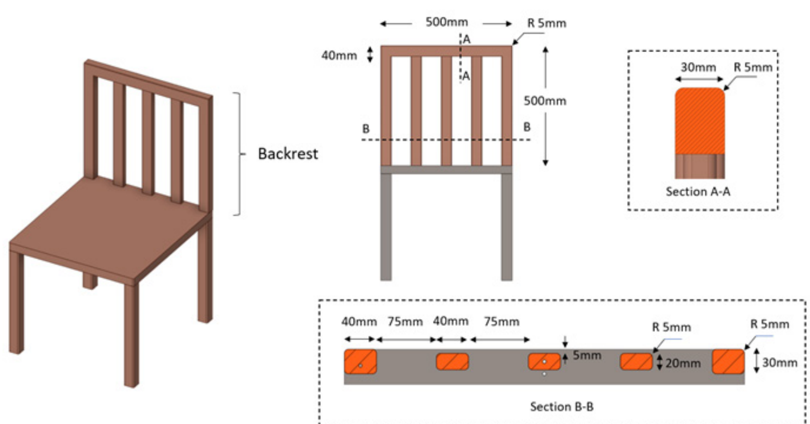

Figure 7. a) Improved Design - Backrest

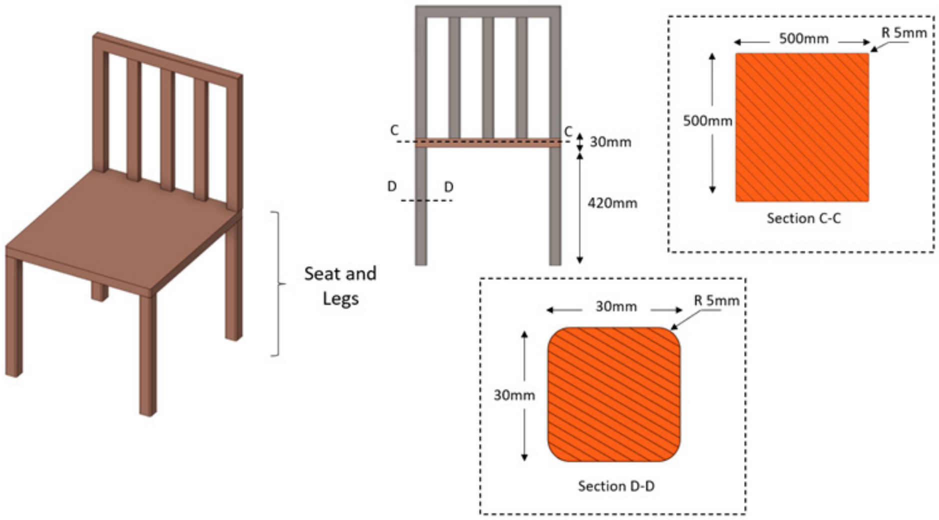

Figure 7. b) Improved Design – Seat and Legs

Starting with the backrest, a frame design with columns has been proposed. To save further material, the thickness of the seat was reduced to 30 mm (from 50 mm) and due to these reductions, the length and breadth of the seat were adjusted to retain the ergonomic dimensions as previously indicated. The cross section of the legs was reduced to 30mmx30mm, and all the edges have been filleted to a radius of 5mm. The length of the legs was also adjusted to retain the ergonomic design. It can also be noted that this chair in addition to having an ergonomic design, is also more aesthetically appealing in comparison to the original design.

4.5 Simulation and Validation of the new Design

The boundary conditions including supports, joints and loading conditions are retained as earlier. It is important to note that the surface area of the backrest has been decreased, therefore the same load is applied to a smaller area. Thus, higher stresses and deflections can be expected. As shown in Figure 8, the maximum displacement has now increased from 0.05mm to 0.29mm. Although the displacement is now 6 times higher than the earlier design, this value is still in the acceptable range as it cannot be noticed by a person sitting on the chair. As expected, the value of stress has also doubled from 0.65MPa to 1.4MPa (shown in Figure 9) leading to a continued safe design (safety factor=29). It can also be seen that stress concentration at edges have decreased and there is a more uniform distribution of stress. By decreasing the seat thickness, leg cross section and removing material from the backrest, the chair has become considerably lighter (from 13.4 kg to 6.4kg), reducing the material cost and making it easier to lift.

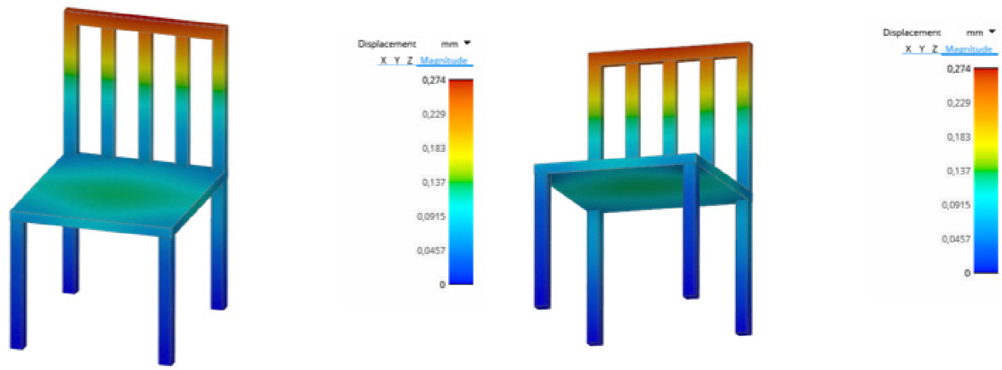

Figure 8. Displacement Contour Plot of Improved Chair Design

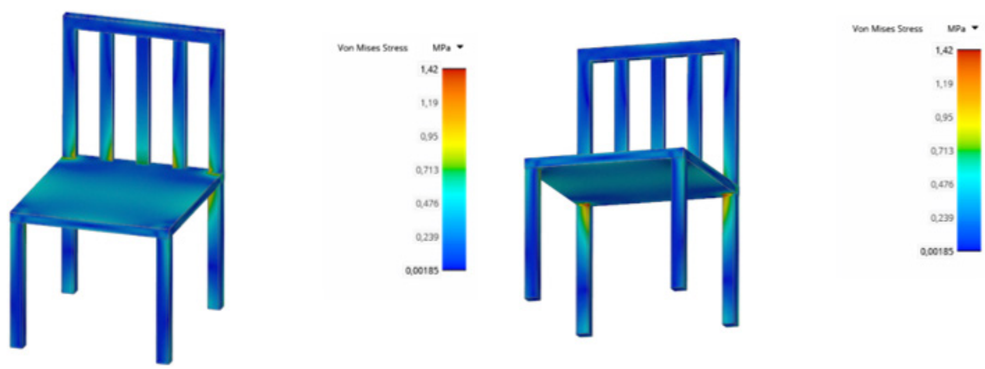

Figure 9. Stress Contour Plot of Improved Chair Design

5. From the Ideal to the Real World

In this investigation a simplified approach was used, while in reality, the model of the chair is more complex as the assembly may involve components like screws, bolts and hinges which are subject to failure. By using bonded contacts, the possibility of failure in these areas are ignored. The chairs may also be subjected to misuse such as people standing on them or overloading them or leaning back on the chair causing the weight to be distributed only on two legs. Therefore, a thorough investigation should also consider these aspects.

6. Further Steps

The structural design and analysis process is an iterative one, although the model obtained from the second iteration is safe, ergonomic, and aesthetically appealing, there are more aspects of the design that could be improved, such as:

- The thickness of the chair seat and backrest can be decreased and tested to see if the design is still safe.
- The angle and shape of the backrest can be changed to adapt better to the human spine.
- The seat can be cushioned instead of having a wooden base.
- Armrests can be added to the model to make it more ergonomic.
- The chair can be made lighter so it can be easily lifted and transported.
- Improve safety of the design through evaluation of misuse load cases that can cause buckling.

7. What does Ansys Discovery bring to the understanding?

In this case study, Ansys Discovery helps the educator illustrate the structural design and analysis process from defining the geometry of the chair to evaluating the required output parameters, in order to determine if the model is safe under the predefined loading conditions. The educator can use Ansys Discovery to explain how the structural analysis process is iterative and can take up to several cycles to reach the required optimal design. It can also be used to indicate how simulation helps speed up the design process and decrease cost as it lowers the need for expensive experiments and prototypes.

References

1. M. Potkány, M. Hitka, M. Debnár, M. Gejdoš, 'Requirements for the internal layout of wooden house from the point of view of ergonomic changes', 2018, 62-63

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