MECHANISM DESIGN I – MEE311.1

JUMPING MOBILE ROBOT

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INTRODUCTION

This semester our topic was creating a jumping robot mechanism. Our task is for this robot mechanism to jump vertically and go the farthest distance while in a different position. For the tasks we made our researches about jumping styles, the weight of this robot mechanism and possible errors which may happen. As a result of our researches we determined our rules and boundaries. Adhering to them we started to build sketches, simulate and at the end production.

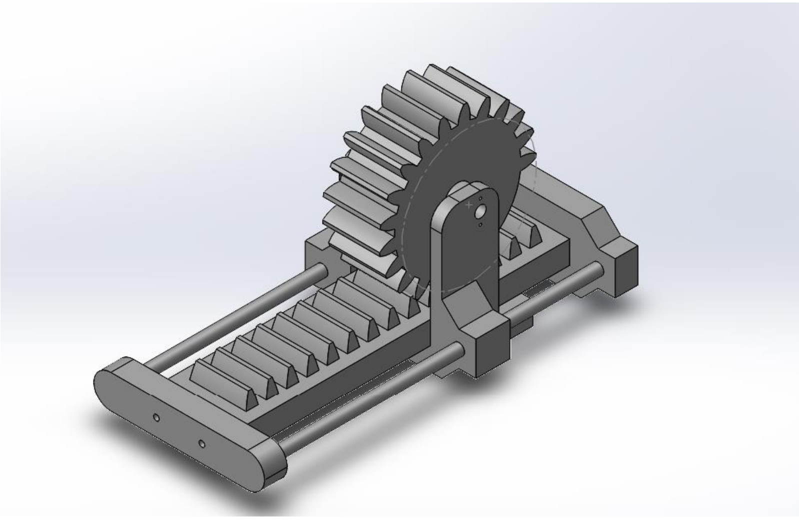
Main Concerns

Jumping Mechanism

Deciding what we should use as a jumping mechanism was a cumbersome process. After 2 weeks of brainstorming we decided that we should use rack and pinion mechanism driven by a rotatory electric motor to store spring potential energy so that we can use that energy to hit ground to make whole vehicle airborne.

We can reach maximum horizontal displacement by chousing our launching angle by 45° with respect to ground. Further calculations will be held in calculations section.

Maximum displacement will be achieved -obviously- by 90° launching angle with respect to ground.

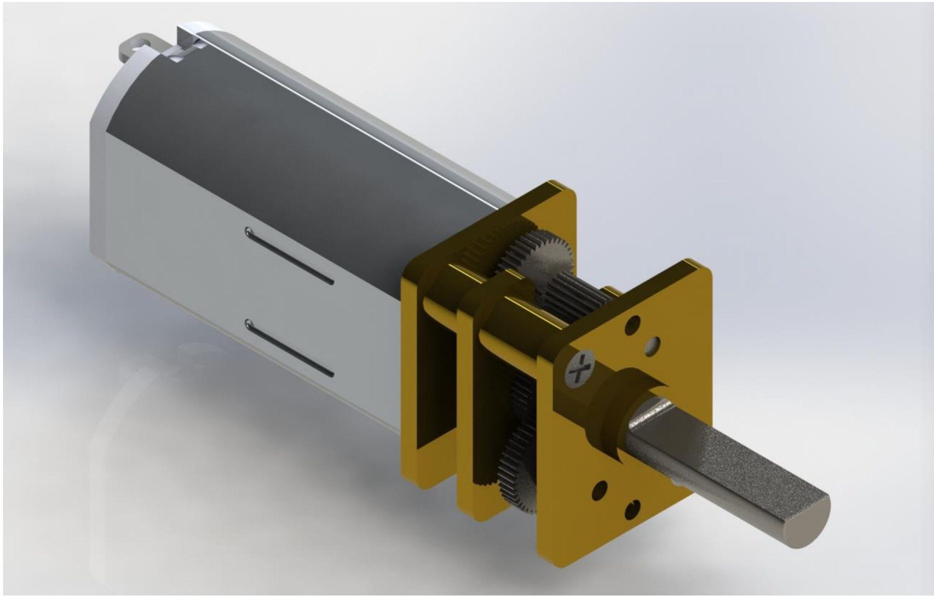


Spring Selection

Spring selection was unexpected hinder to our progress in this project. There isn't much choice for compression springs in common e-shopping websites in Turkey. After firm searching process we decided that we should order our own spring design from manufacturers. Calculations for this spring will be held in calculations section.

Motor

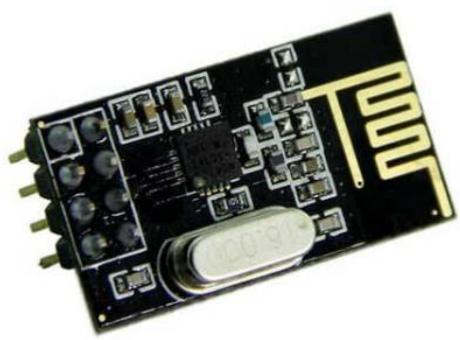
Motor selection was important because we decided to drive the main mechanism by a rotary motion. Initial calculations of the design showed us that simple DC motor didn't produced enough torque to stretch the spring so we decided to bought a geared micro DC motor to produce enough torque.



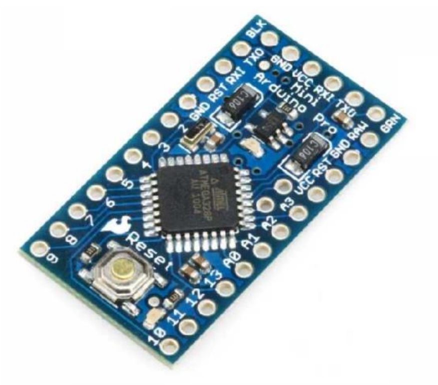
6V Motor with Reduction. Able to provide 12 kg.cm

Control

We decided that control signal should act as a very basic wireless switch for activating the motor and changing between horizontal and vertical mode so we decided that we can use a cheap NRF24L01 wireless wi-fi communication module and Arduino mini pair for both robot and controller.



NRF24L01 wireless communication module.



Arduino Mini

CALCULATIONS

Spring Calculations:

Spring Constant:

We need 3 parameters to calculate the spring constant “k”. First is maximum height h, second is mass of the robot and last one is compression length of the spring. We want this mechanism to gain arbitrary 80cm height as he jumps 90 degree upwards. Just an arbitrary number. From our mechanism design, the free-length of the spring turned out to be 72.5 mm and compressed length was 25 mm. So Δx was 47.5 mm. The calculations carried out as follows;

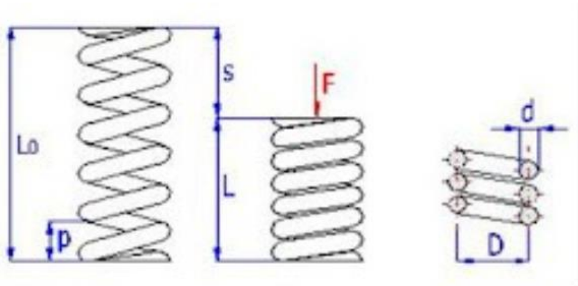
$$2\left(\frac{1}{2}k(\Delta x)^2\right) = mgh$$

$$m = 0.32\,kg, \qquad g = 9.81\,{}^{m}/_{s^2}, \qquad h = 0.8\,m, \qquad \Delta x = 0.0475\,m$$

$$k = 1\,113.0681\ {}^{N}/_{m} = 1.1131\ {}^{N}/_{mm}\ each\ spring$$

Spring Parameters:

We decided that we wanted to manufacture our own spring so we should design a spring that could provide decided spring constant within our constrains. The formulas we followed are;



Round wire spring calculation formula

$$s = \frac{8 \cdot F \cdot n \cdot D^3}{G \cdot d^4}$$

$$\tau = K_s \cdot \frac{8 \cdot F \cdot D}{\pi \cdot d^3}$$

$$k = \frac{G \cdot d^4}{8 \cdot n \cdot D^3}$$

$$K_s = f\left({}^{D}/_{d}\right)$$

We’re choosing D, S, L_0 with respect to our avaliable space and physical design, material is Stainless steel, k is calculated and n is chosen arbitrarly. F is calculated at further torque calculations.

S=0.0475m, $\mathbf{L_0}$=0.0725m, **k**=1113.0681 N/m

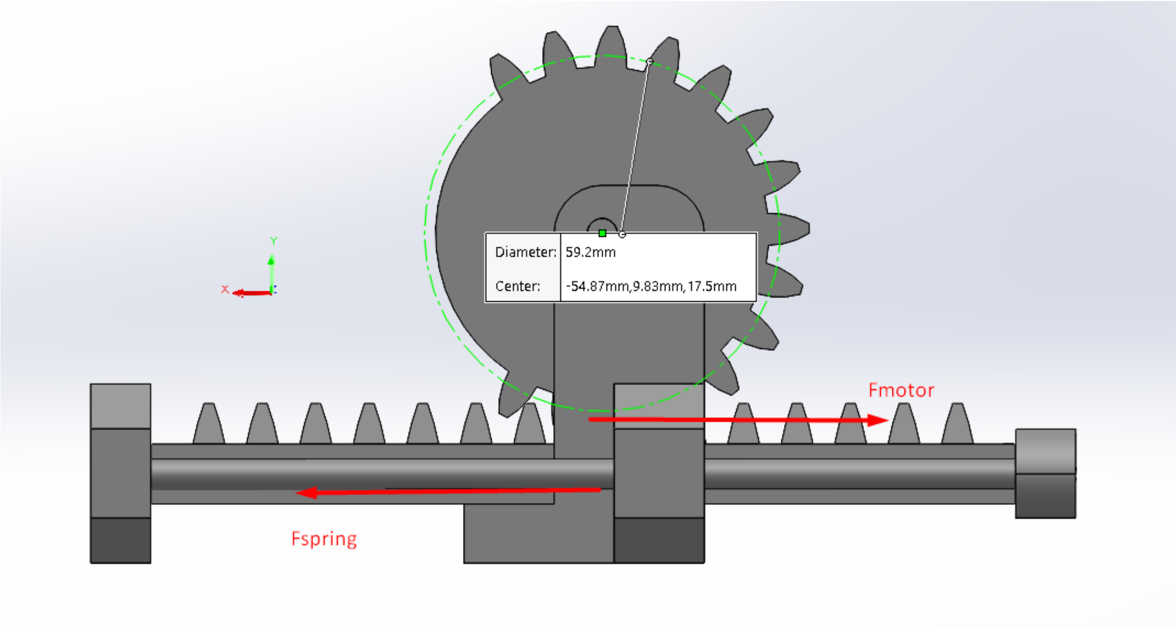
F=52.87N, **n** = 5 **D** = 15mm, **G** = 77.2 GPa

$$\sqrt[4]{\frac{8nD^3k}{G}} = d$$

$$d = 1.18mm$$

Torque Calculations:

We need to see if motor produces enough torque to compress the spring. Our motor is capable of supplying 12 kg cm torque to the shaft. We want system to compress 2 spring by 47.5 mm. So calculations are like following;



$$F_{spring} = k\Delta x, \qquad F_{motor} * \frac{D}{2} = T_{motor}$$

$$k = 1\,113.0681\ {}^{N}/_{m}, \qquad \Delta x = 0.0475\ m, \qquad D = 0.00592m$$

$$F_{Spring} = 52.87\ N$$

$$2 * F_{spring} \leq F_{motor}$$

$$2 * F_{spring} \leq T_{motor} * \frac{2}{D}$$

$$D * F_{spring} \leq T_{motor}$$

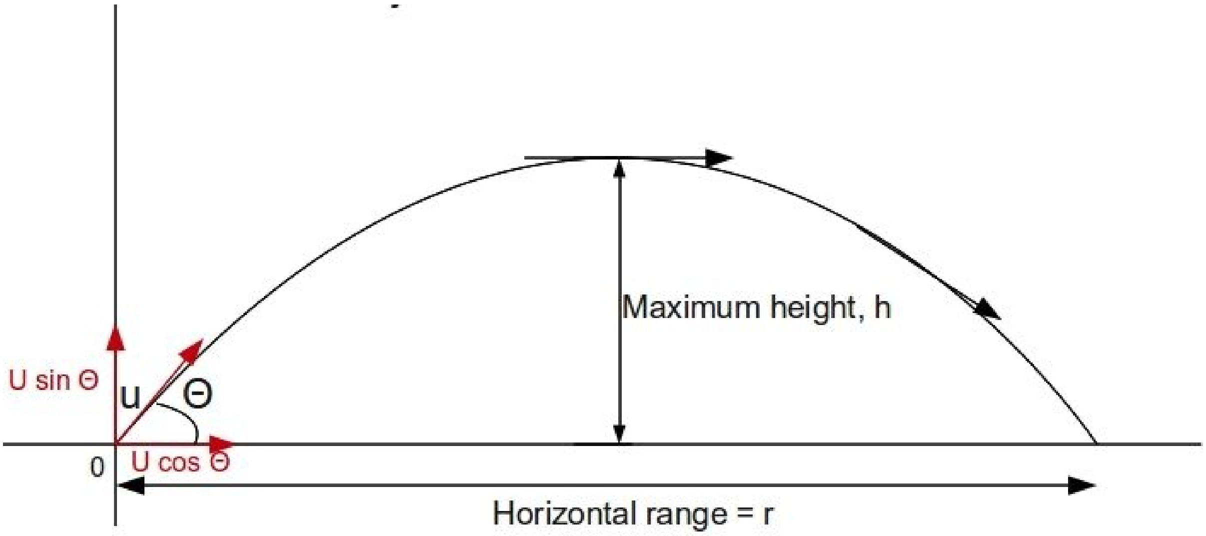
$$T_{motor} \geq 0.6259\ Nm$$

$$\begin{aligned} T_{motor} &= 12\ kg\ cm \\ &= 12 * \ 9.81 * 10^{-2} Nm = 1.878\ Nm \end{aligned}$$

Since 1.878 Nm greater than 0.6259 Nm our motor will compress the spring properly.

Displacement Calculations:

We already decided that we wanted this robot to jump 0.8 m so vertical height is already known. Now we wanted to know how much this robot going to jump horizontally.



Let's convert our spring potential to kinetic energy to find initial velocity;

$$2\left(\frac{1}{2}k(\Delta x)^2\right) = \frac{1}{2}mu^2$$

$$2.21136 = \frac{1}{2}(0.32)u^2$$

$$u = 3.9618\frac{m}{s}$$

$$u\sin\theta = 2.8014$$

Then we can find h_{max} to so that we can calculate flight time

$$V_f^2 = V_i^2 + 2ah$$

$$h = \frac{2.8014}{19.62} = 0.1413\ m$$

$$x_f = x_i + vt + \frac{1}{2}at^2$$

$$-4.905t^2 + 2.801415\ t - 0.1413 = 0$$

$$t = \frac{-2.801415 \pm \sqrt{5.7562}}{-9.81}$$

$$t = 0.5152\ s$$

$$t_{flight} = 1.030\ s$$

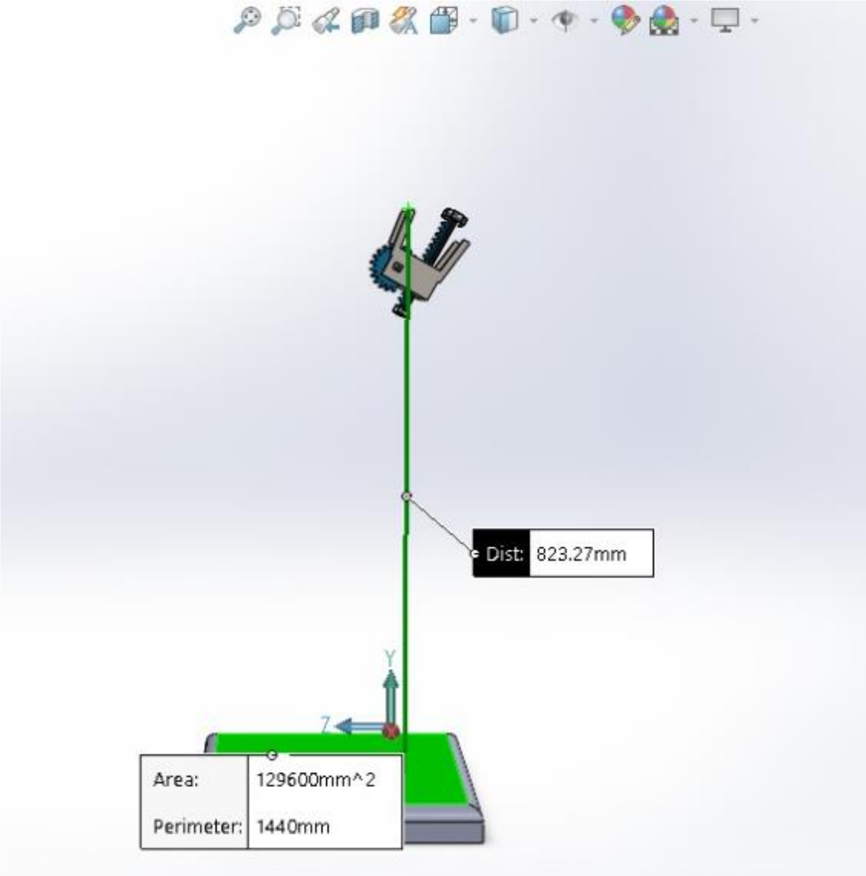
Finally we can calculate horizontal displacement r

$$r = u \cdot \cos\theta \cdot t_{flight} = 2.886\ m$$

SIMULATIONS

Max Height Simulation:

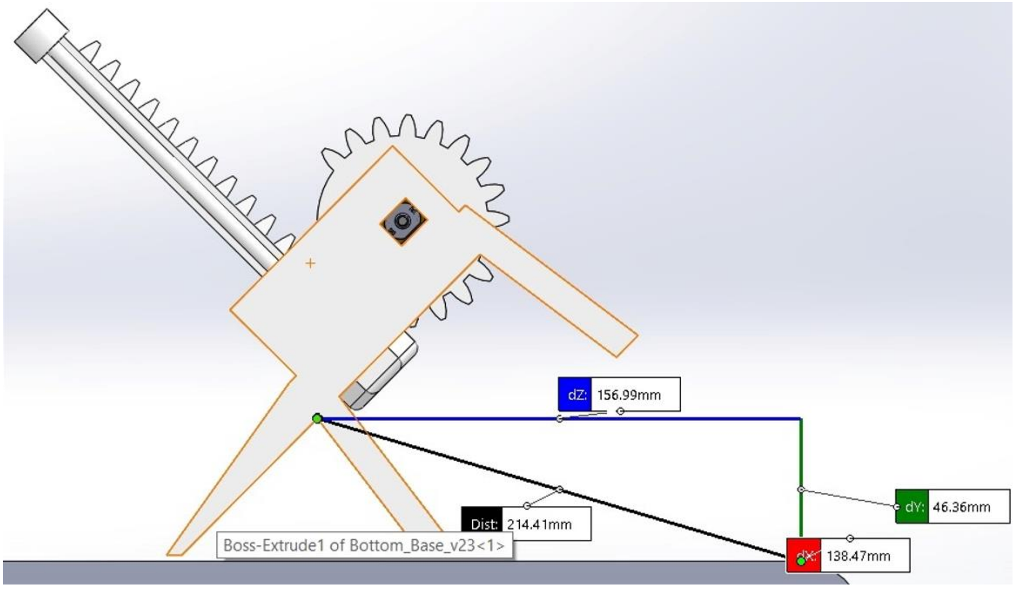
Solidworks has a prebuild spring mechanic so we did simulate the behavior with it.



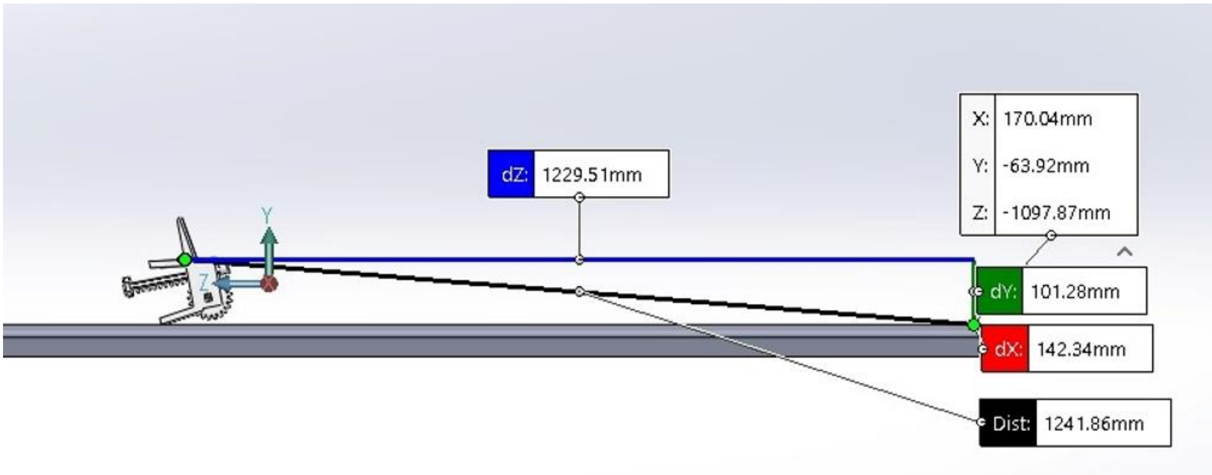
Slight miscalculations occur due to rotation and improper impact angles.

Max Displacement Simulation:

Sadly we had the cut out the horizontal jump mechanic due to time constrains but we simulated the mechanism nonetheless. We added a pair of degenerate legs to our mechanism to sustain 45 degree position.



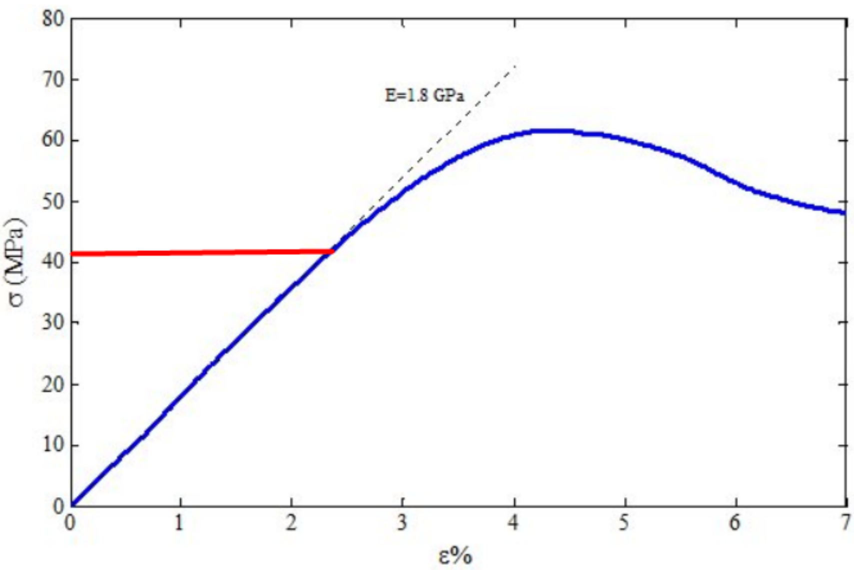
First moment of impact;



Sadly our calculations didn’t hold properly. We assume that this was mainly due to improper impact point. So mechanism couldn’t converted it’s all potential to kinetic energy. Another culprit might be moment of inertia. It might be consuming too much energy for rotation so there could be less kinetic energy for translation.

Drop Test:

Solidworks has a simulation type called drop test. Drop test is a form of FEA method. We can see strain, stress and displacement effects of the impact with this simulation. We used drop test with 820mm height to see if the ABS plastic will endure the impact or not.

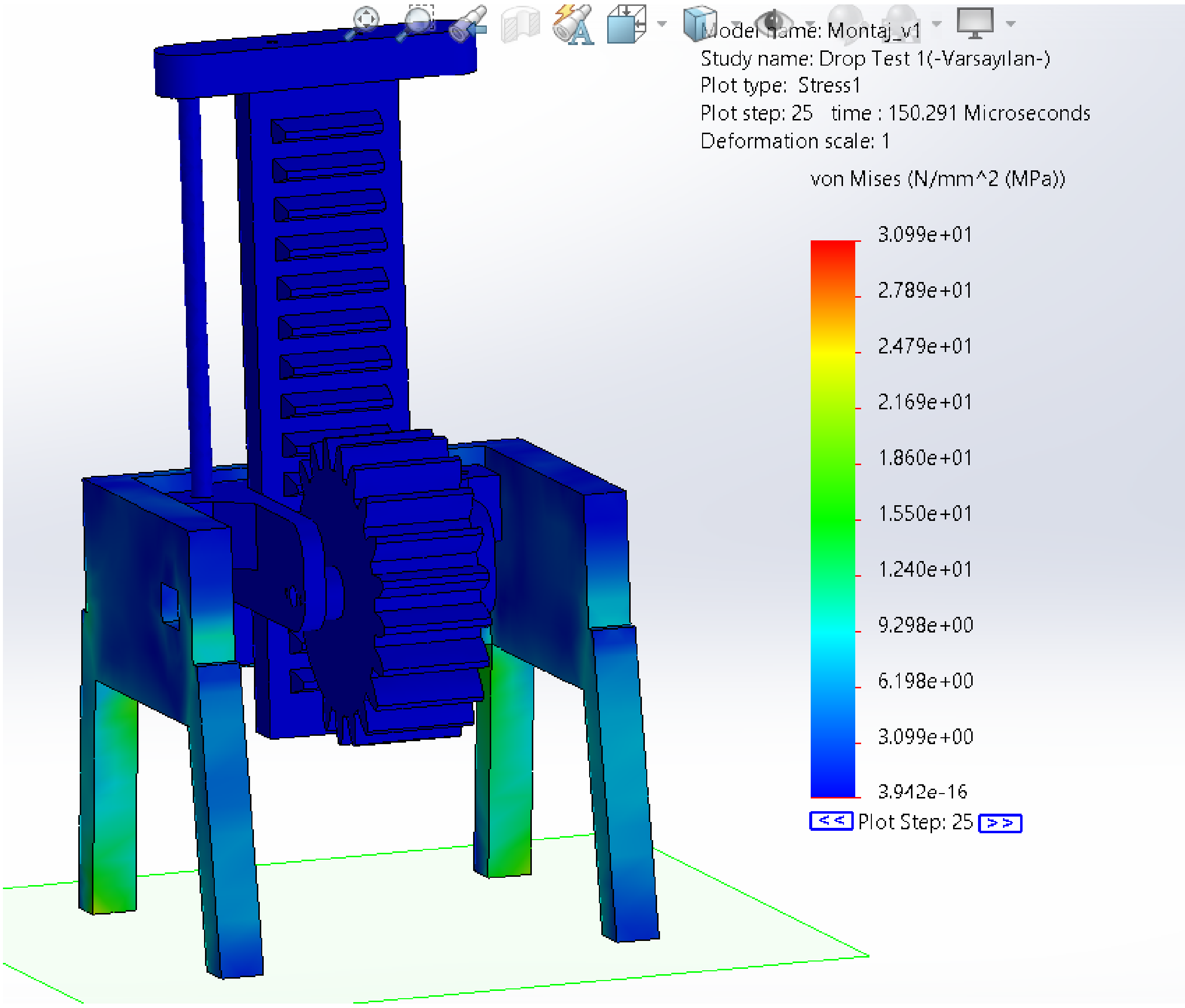


Soltani, Aref & Noroozi, Reza & Bodaghi, Mahdi & Zolfagharian, Ali & Hedayati, Reza. (2020). 3D Printing On-Water Sports Boards with Bio-Inspired Core Designs. Polymers. 12. 250. 10.3390/polym12010250. Figure 5

Plastic limit of PLA+ Plastic Filament is approximately 42 MPa. Following tests will tell if the body will deform or not.

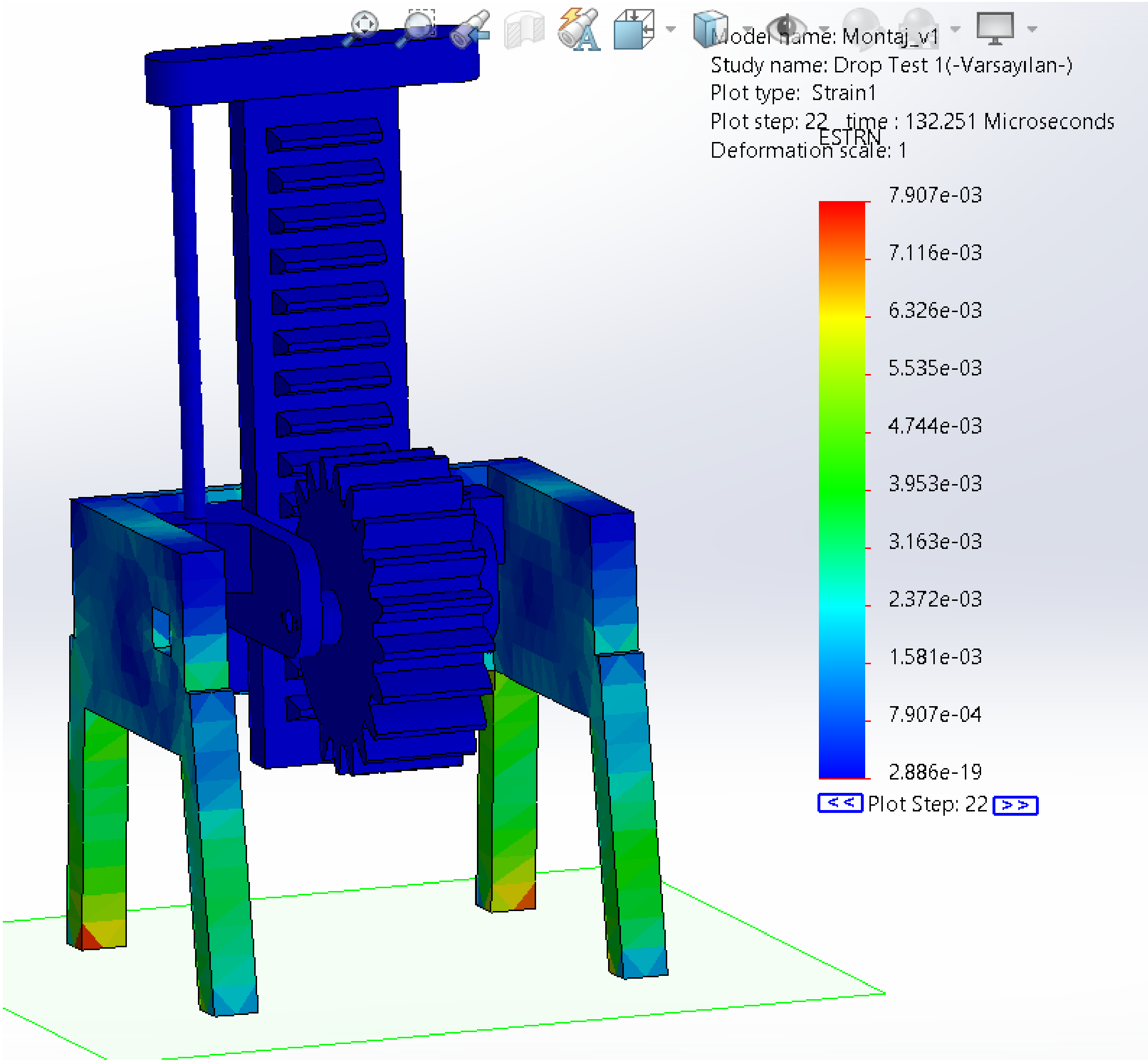
Stress Test:

Plastic limit of PLA+ Plastic Filament is 42 MPa. We used Solidworks drop test Since 30.00 MPa doesn't exceed this value, we're sure that impact of this body won't cause an plastic deformation.



Strain Test:

Strain will tell us how much a part will change its dimensions with respect to its initial shape. Strain is a ratio so it doesn't have a dimension.



Results and Discussions

As a result we successfully simulate our system. Designing of the robot was not difficult but calculations of the parameters like spring coefficient, weight, engine response, gear and moment effects was complicated about design. Eventually we designed and computed all the parameters and by help of SolidWorks simulated whole system. Most valid problem of our project was implementation and manufacturing of mechanism. With the rush of the semester and class we could not produce our design. We thought about different types of manufacture methods but none of them were enough for our deadline time.

Last Render:

This is our last design in Solidworks. Photo is rendered by Photoview360 add-on of Solidworks.