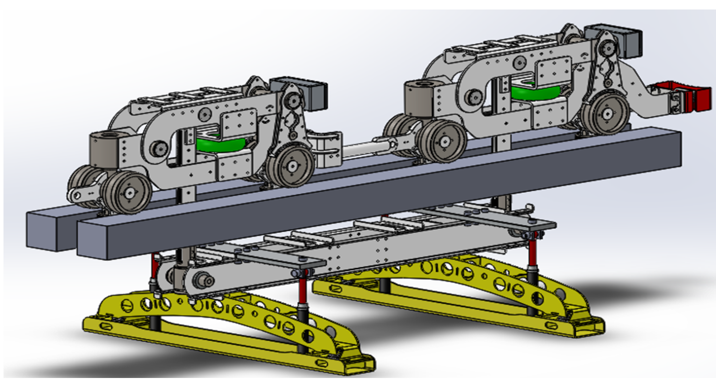
SPARTAN SUPERWAY

The Spartan Superway – Summer 2017 Suspension Team

Research and Development

August 4, 2017



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Abstract

During 2017 summer, the suspension team worked full scale. The suspension team created a new design for the suspension. New pod car's system had rubber bush which was on a middle shaft to keep the cabin stable. But maintenance of rubber bush is high and replacement is hard. So we removed it and replaced with shock-absorber. In order to manufacture suspension simple and strong, 2 types of suspension designs are suggested to handle the rolling from pod car's moving. Prototype of suspension system is currently under production and what next team have to do is actually assemble and test.

Acknowledgments

We express our gratitude to Dr. Furman, Ron Swenson Eric Hagstrom, and Claude for giving us the opportunity to work with them this summer.

I would also like to thank Professor Jung-hwan Ahn, who gave us the opportunity to be an exchange student in San Jose University, and CK for their financial support.

Finally, we would like to thank our families for helping us complete our internship program.

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Executive Summary

ES.1 The Problem Rubber bush of new pod car has limitations:

1. It is difficult to replace.
2. It is expensive to maintain.
3. It is hard to handle vibrations from centrifugal force.

It is difficult to replace, maintain in large structures. There is a need to make this process simple and improve the design process.

ES.2 The Solution

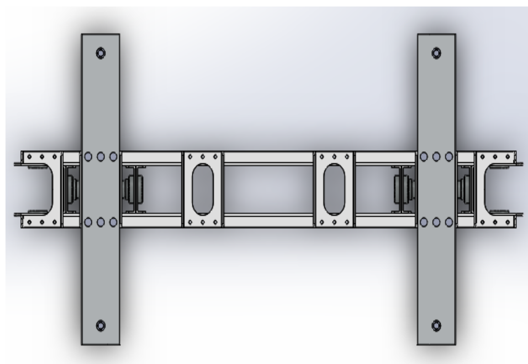


Figure 1. Long Plate

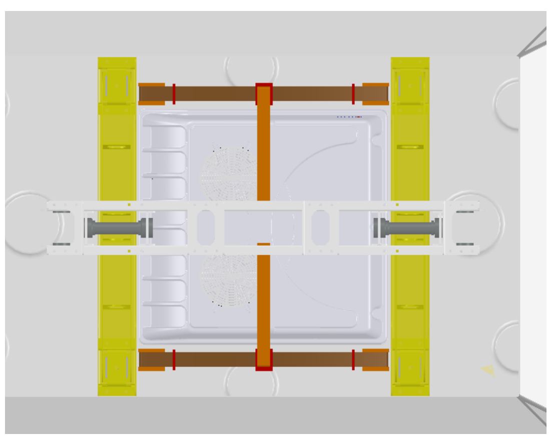


Figure 2. Leaf Spring

Figure 1 & 2 show two types of suspension designs. First, we considered about low maintenance, So We decided to remove rubber bush which was on middle shaft and replace it to shock-absorber and constructions. In order to manufacture simple and strong, it is bolted to dolly plate. Second, instead of shock absorber, it is the another way to make the cabin stable, using Leaf spring. Compared to other suspension system, it is simple to maintain and sturdy. So typically it is used in pick-up trucks and trains. We expect that leaf spring can handle the rolling when it swings.

ES.3 Suspension System Essentials

Our suspension system has the following requirement:

1. Simple design and manufacturing.
2. Easily replacement.
3. Sturdiness to handle rolling of pod car

ES.4 Summary of Key Accomplishments of Suspension System considering essentials

1. Simple design and manufacturing.
2. Easy manufacture using aluminum plate

2. Easily replacement.

1. Long Plate bolted to dolly plate to hang the suspension system

3. Sturdiness to handle rolling of pod car

1. Compact thickness to support the load.

ES.5 Next Steps for Further Research/Design

1. Make Full scale suspension Link structure based on Small Scale
2. Find appropriate spring coefficient to make passengers comfortable
3. Consider link structure to fix leaf spring model

Introduction

The Spartan (Solar Powered Automated Public Transportation System) Super-way is a project designed to develop unique transportation solar powered automated transit network (ATN). These days, more and more grounded vehicles are produced and operated on roads. In proportion to these, transportation accident rate is highly increasing and exhaust gases from automobiles are causing atmospheric contamination. ATN is composed of automated vehicles that run on dedicated guideways carrying passengers from urban to rural areas. The ATN is powered by solar energy. ATN will be a solution to decrease accidents and congestion by grounded vehicles and sustainable transportation. It will also have a safety against of vibrations.

Background and context for the work of the sub-team

When the vehicle enters in to the curved path, it is affected by centrifugal force and rolls within certain degree. Also when people get on the vehicle, it is affected by other vibration. Therefore, our goal is designed to control rolling by centrifugal force and other vibration by suspension system. So we designed 2 types of suspension structure. We designed coil spring type suspension and leaf spring type suspension.

Description of Your Design

Solution 1. Wing Plate

We designed Wing Plate to avoid collision with rail. So we designed it like a wing-shaped to hang shock-absorber higher and give a wide distance between the system and rail. Figure 3 shows a drawing of wing plate. Figure 4 shows a drawing of assembled wing plate with dolly plate.

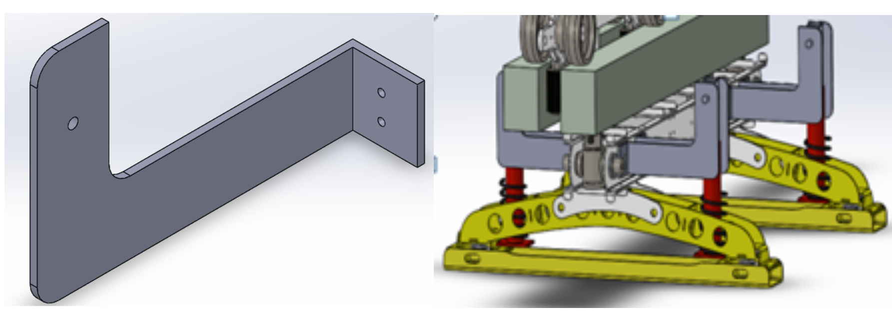


Figure 3&4. Wing Plate

Solution 2. Long Plate

We changed the design because the height of rail is enough short to avoid crush.
Height of the suspension is enough short to avoid crush. In order to manufacture simple and strong, we revised it. It is stick to dolly plate and hard. Figure 5 shows a drawing of nailed Long Plate to dolly plate. Figure 6 shows a drawing of assembled Long Plate with bogie part.

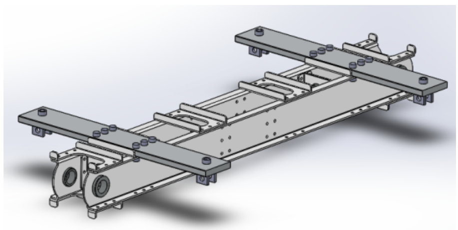


Figure 5. Long Plate

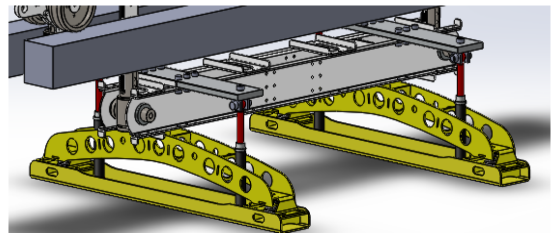


Figure 6. Assembled Long Plate

Solution 3. Leaf spring

Instead of Shock - absorber, we came up with another way to make the cabin stable using leaf spring. Compared to other suspension systems, leaf springs are cheaper, easier to maintain, and sturdy. However, this has the drawback that it is heavy, noisy, and cannot handle small vibrations. we expect that leaf spring can catch the rolling when cabin is swing. Figure 7 shows an overall Leaf Spring part. Figure 8 shows an assembly of leaf spring.

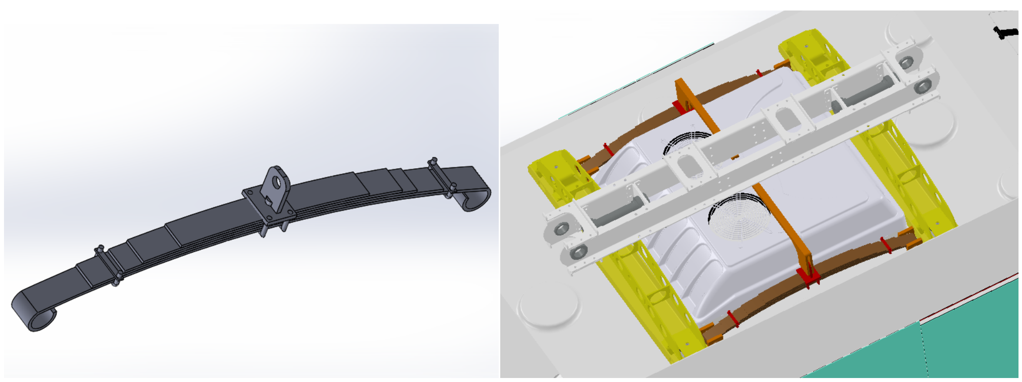


Figure7&8. Leaf Spring

Analysis/Validation/Testing

- Purpose of Simulation

Simulation is used to analyze the suspension behavior against lateral force.

- Method

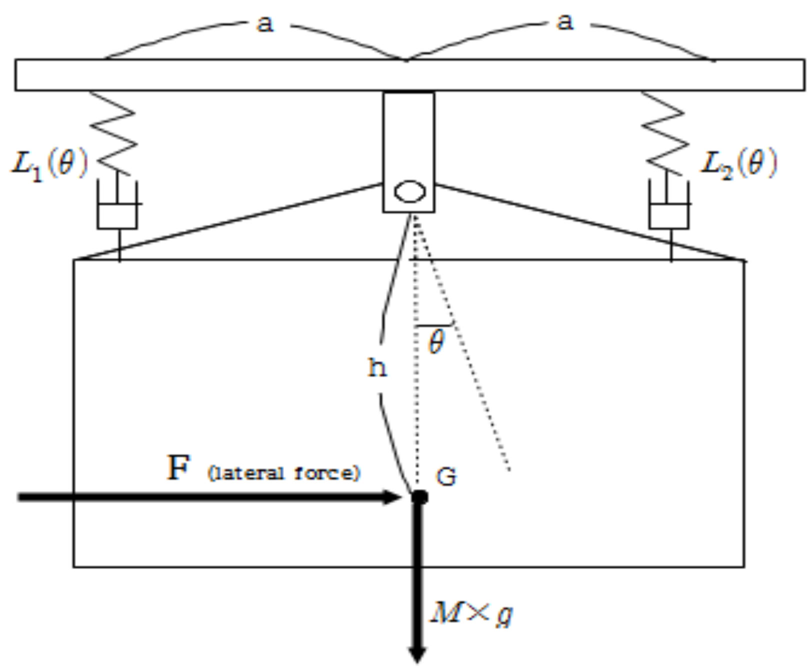


Figure 9. schematic of suspension structure

J : moment of inertia

M : mass

g : Gravitational acceleration

k : spring coefficient

b : damping coefficient

G : center of mass

As shown in the above figure, Because of the link structure of super-way, it only has right and left rolling. And Rolling is affected by lateral force. Lateral force is $\frac{V^2 \cdot m}{r}$. so Lateral force is determined by Radius of rotation and velocity. So if we know the coefficient of suspension, we can anticipate rolling movement of the super-way by simple equation.

- The derivation of the equation

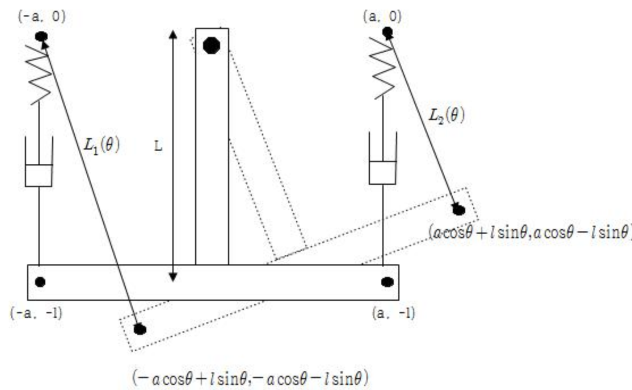


Figure 10. schematic of suspension structure

As shown in the above figure, when the cabin rolls by the lateral force, the suspension is deformed vertically. Then, the suspension is subjected to such a reaction force by the damper and the spring, and the cabin is vibrated back to steady state. Since the cabin has a symmetrical structure when viewed from the front, each point is represented by the trigonometric function of the rotation matrix.

Then, the suspension displacement can be expressed by a trigonometric function, that is, It is possible to express it as a function for theta.

Since the damper and the spring are the velocity function and the displacement function, respectively, the right function must be obtained.

The following is the equation for the appropriate variable for theta.

$L(\theta)_1$= sqrt((a-a*cos(u)+l*sin(u))^2+(a*sin(u)+l*cos(u))^2) - - - - - - - - - - (1)

$L(\theta)_2$= sqrt((-a+a*cos(u)+l*sin(u))^2+(a*sin(u)-l*cos(u))^2) - - - - - - - - - - (2)

$L(\dot{\theta})_1$= ((a*sin(u)+l*cos(u))*(a-a*cos(u)+l*sin(u))+(a*cos(u)-l*sin(u))*(a*sin(u)+l*cos(u)))/sqrt((a-a*cos(u)+l*sin(u))^2+(a*sin(u)+l*cos(u))^2) - - - - - - - - - - (3)

$L(\theta)_2$= ((-a+a*cos(u)+l*sin(u))*(-a*sin(u)+l*cos(u))+(a*sin(u)-l*cos(u))*(a*cos(u)+l*sin(u)))/sqrt((-a+a*cos(u)+l*sin(u))^2+(a*sin(u)-l*cos(u))^2) - - - - - - - - - - (4)

Also, by using the above picture, we can derive the moment equilibrium equation as follows.

$$\ddot{\theta} = \frac{1}{J}(F \times h \times \cos\theta - m \times g \times \sin\theta - k \times (l_1(\theta) - l_2(\theta)) - b \times (l_1(\theta)' - l_2(\theta)'))$$

- (5)

- Simulation by Simulink

The equation (5) is expressed in Simulink.

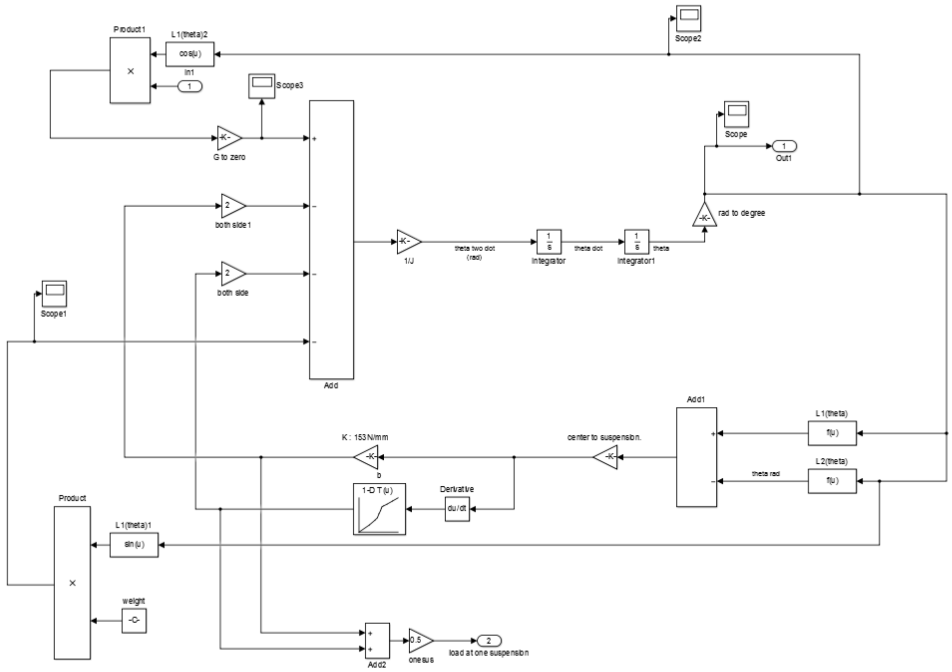


Figure 11. Simulink

And the lateral force is inserted through In1.

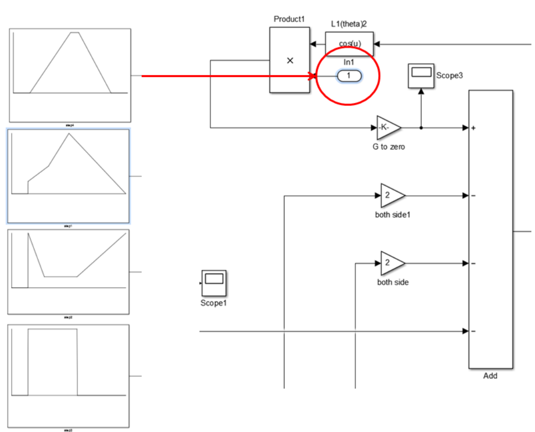


Figure 12. Input lateral force

- Simulink Result

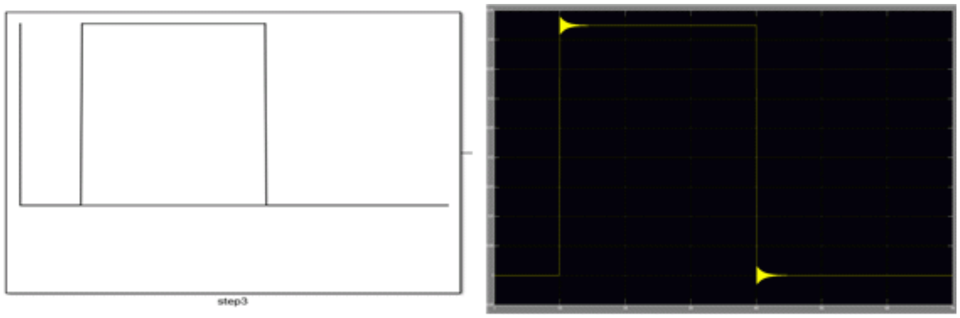


Figure 13. Result 1

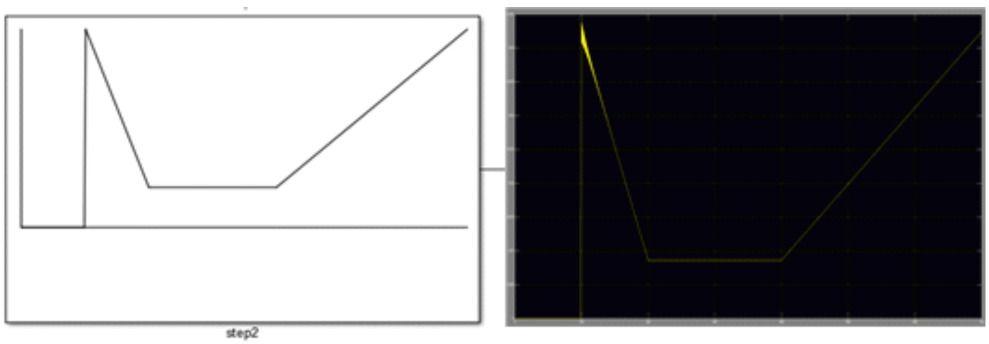


Figure 14. Result 2

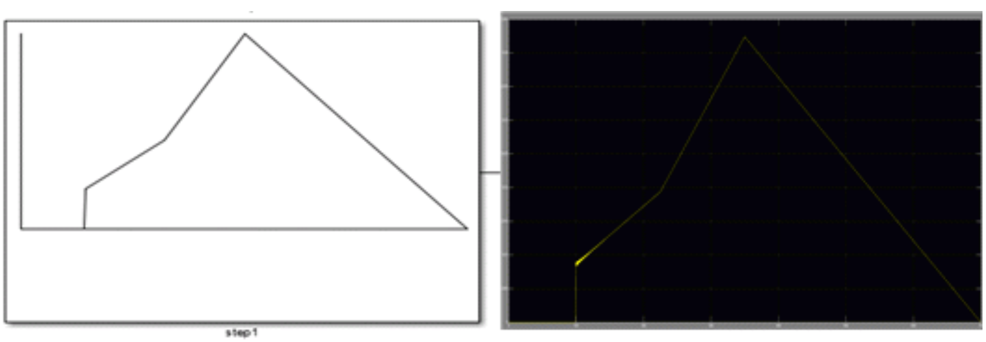


Figure 15. Result 3

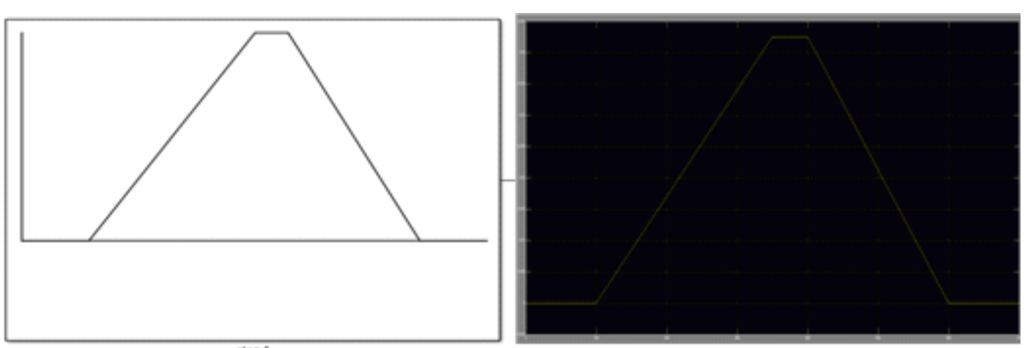


Figure 16. Result 4

The above graphs are the input values and the resulting values. (Figure 13~16) we simulated four types of lateral force. The maximum lateral force was calculated by applying the maximum radius of the super-way (30m) and the maximum speed (40 km/h). The vertical axis of result graph (right graph) indicates the angular displacement of the rotating shaft. The horizontal axis shows time. Results indicate that sudden lateral force can cause severe vibration.

By using this graph, we can control driving cycle and choose Radius of rotation.

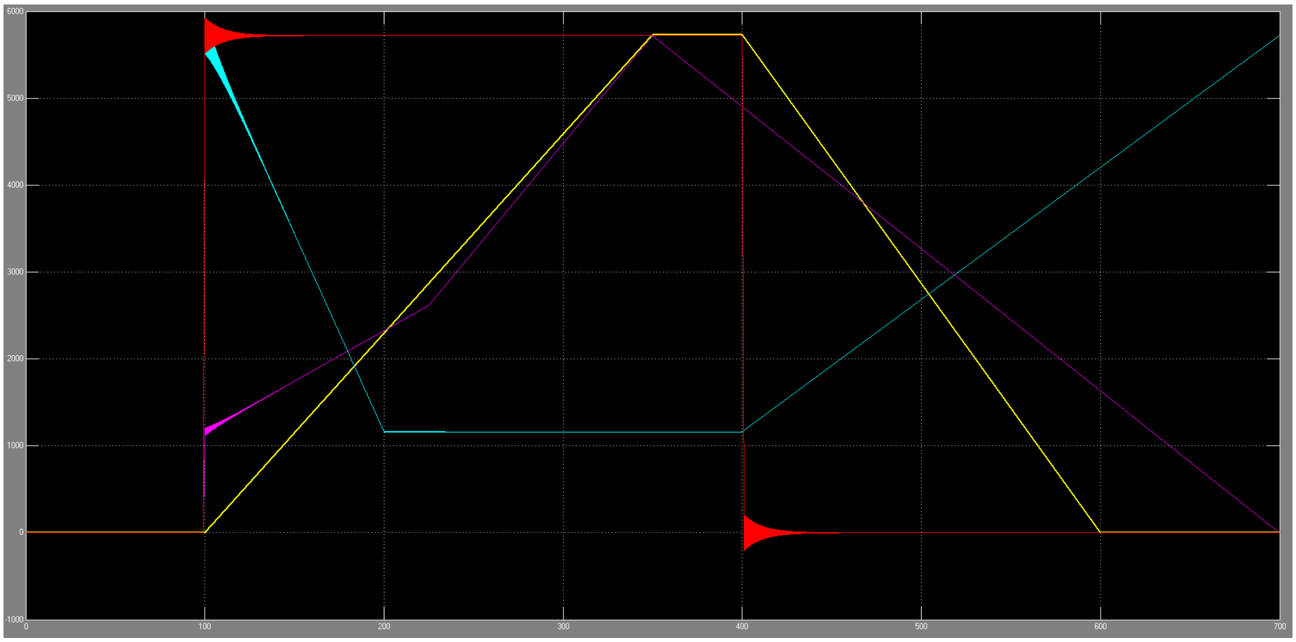
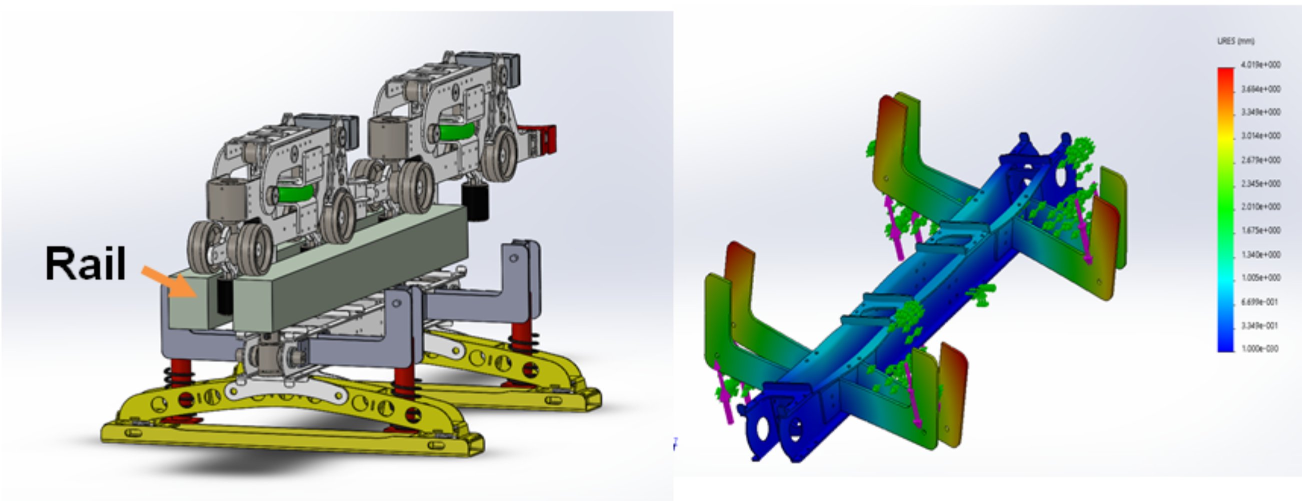


Figure 17. Load of Suspension

As shown in the graph above, the load acting on the suspension as well as the angle can also be calculated. The load can be analyzed for each suspension shape based on the calculated load.

Load Analysis Results

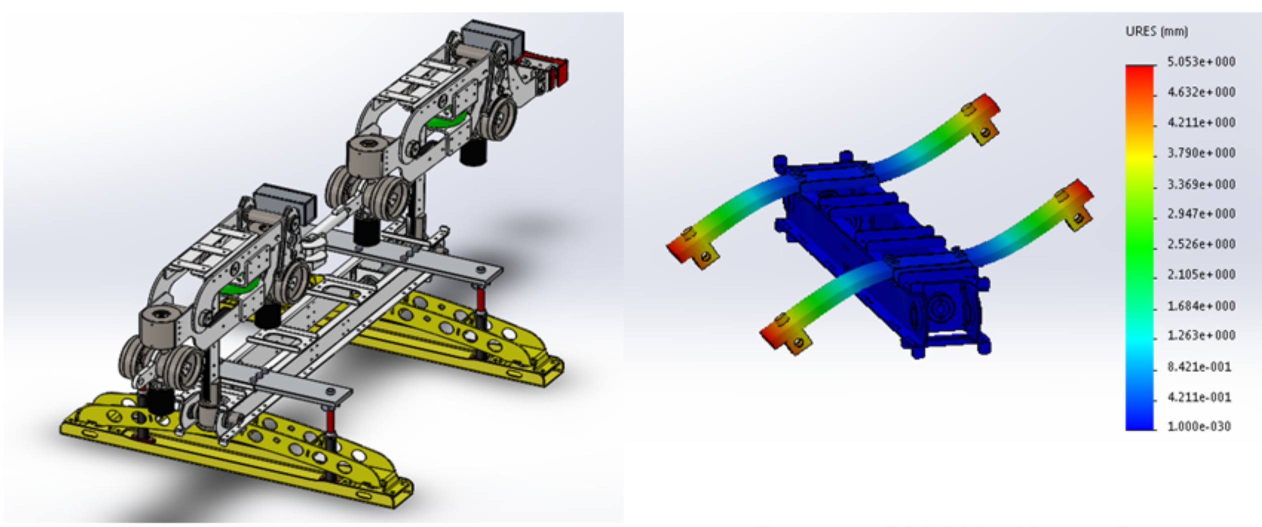
The maximum load acting on each suspension calculated in the above simulation is 5920N. Based on this load, we have analyzed all the suspension designs.



Force = 5920N X_{max} = 4 mm

Figure 18. Analysis Result of Coil Spring 1

The results of the analysis for the first suspension design are as above.



Force = 5920N X_{max} = 5 mm

Figure 19. Analysis Result of Coil Spring 2

The results of the analysis for the second suspension design are as above.

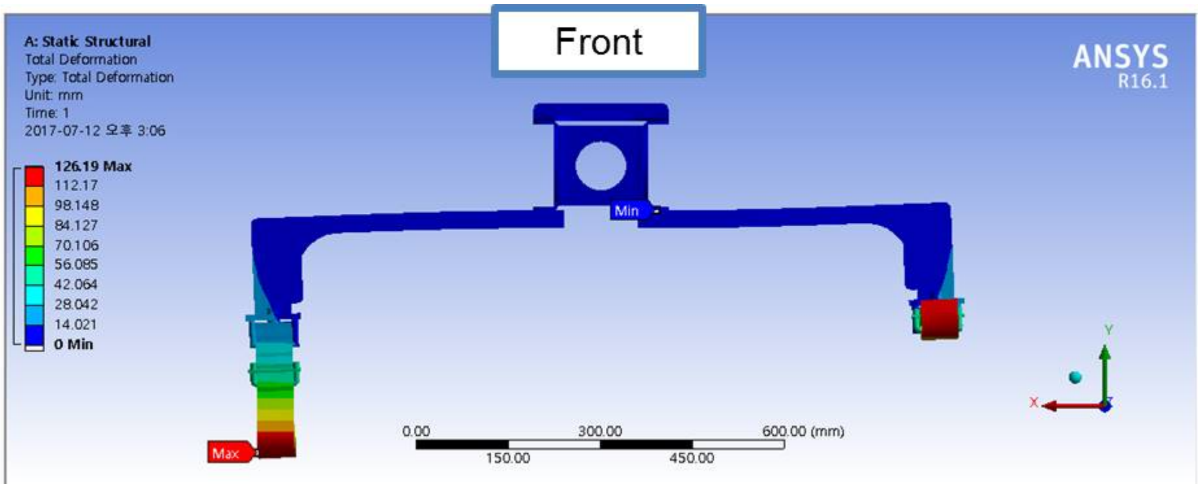


Figure 20. Analysis Result of Leaf Spring 1

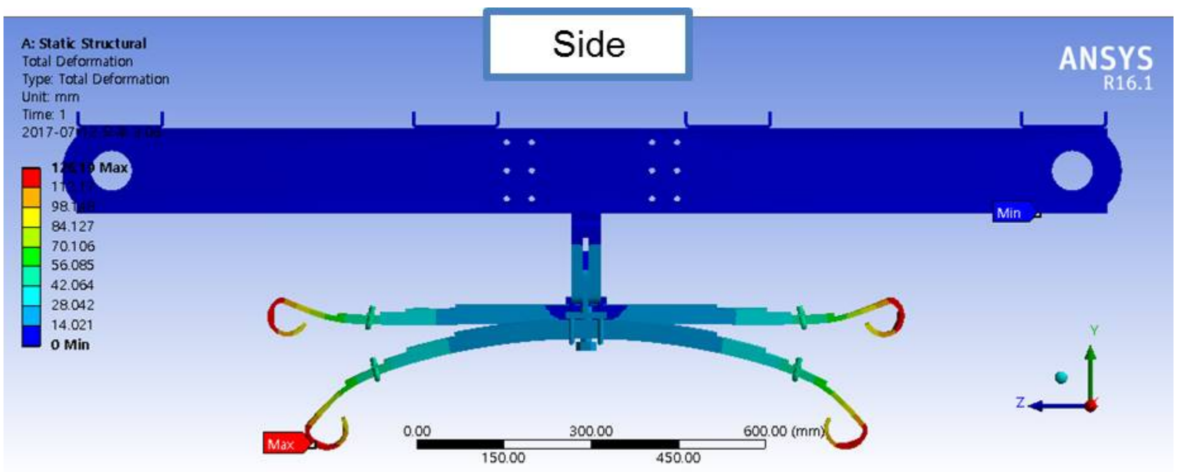


Figure 21. Analysis Result of Leaf Spring 2

The result of the analysis on the leaf spring is as shown above. Due to its structure, the leaf spring is deformed more than the conventional coil spring. However, it has the advantage that it is cheaper than coil spring, and installation and maintenance are much easier.

Procedure / Instruction Manual

Prior to testing full-scale suspensions, we experimented with prototypes by building simple forms of bogie and cabin. The attached file below is the complete assembly picture and drawing file.

1-12 Scale Modeling.zip

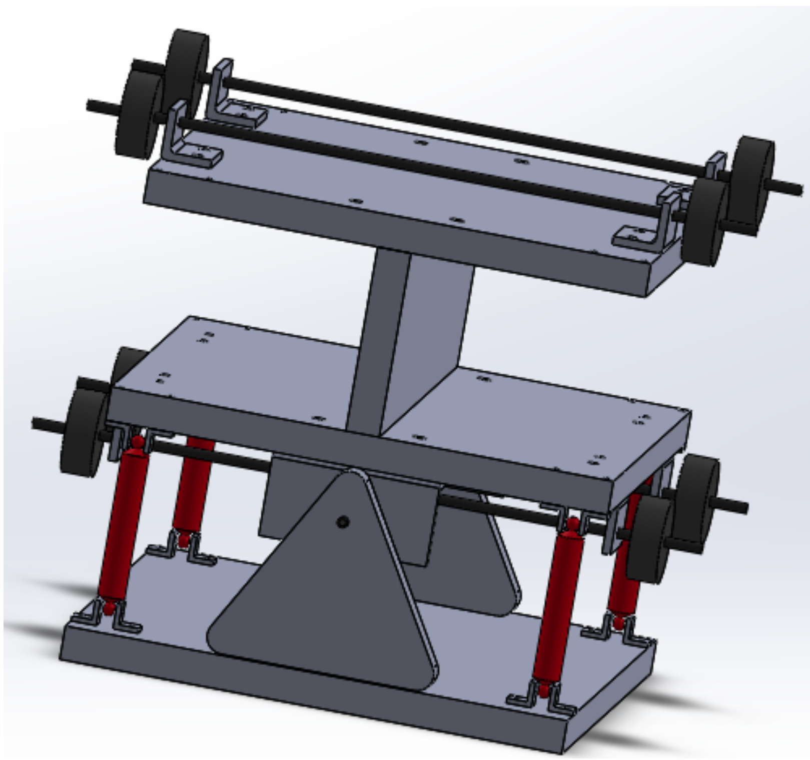


Figure 22. Assembly Model

Money spent on your project

Item	Items	Where	Quantity	EachPrice ($.$$)	Total($.$$)	Supplier
1	Carbon fiber tube	shaft	1	12.99	12.99	Amazon
2	4pcs RC Shock Absorber Springs	shock	1	23.99	23.99	Amazon
3	2 Set Luggage Suitcase Wheels 50*18mm	wheel	4	9.66	38.64	Amazon
4	Hardened High-Strength A514 Alloy Steel, 6" x 12" x 3/4"	Body_Ceterplate	1	79.11	79.11	McMaster-Carr
5	Hardened High-Strength A514 Alloy Steel, 12" x 12" x 3/4"	Angle & Body_Plate	3	125.85	377.55	McMaster-Carr
6	Hardened High-Strength A514 Alloy Steel, 12" x 24" x 3/4"	bottom	1	208.56	208.56	McMaster-Carr
7	Oil-Resistant Buna-N Rubber Round Tube 6" Long, 3/4" OD	bush to fix wheel	1	5.08	5.08	McMaster-Carr
	Total				745.92	

Table 1. BOM

Result and Discussion

As new pod car is designed, our team decided to make suspension system fit better to it. We finally came up with a new design that satisfies all the design requirements, simple to manufacture, low maintenance and strong to support its load. Our final suspension system features to handle swing motion of pod car and it was made from steel for ease of manufacturing, assembly and replace. We removed rubber bush which was on middle shaft in new pod car design because its maintenance was high. Now dampers have role in handling the pose of cabin. To make this possible, we came up with several designs. First system is composed of 4 dampers. Second system handles the vibration in terms of leaf springs.

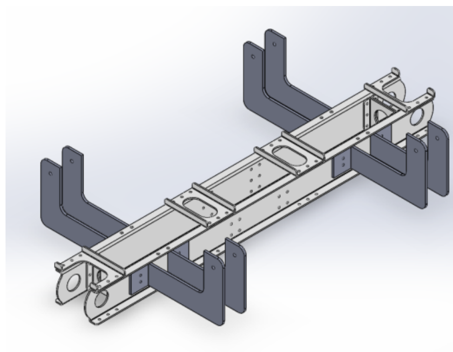


Figure 23. Wing Plate

We first designed suspension system to avoid collision with rail. So we designed it like a wing-shaped to hang shock-absorber higher and give a wide distance between the system and rail. However, we changed this design because the height of rail is enough short to avoid crush. Height of the suspension is 400 - 500mm, enough short to avoid crush. In order to manufacture simple and strong, we revised it to Long Plate. The Long Plate is stick to dolly plate and hard. Brackets are welded to the plate and bolted with shock – absorber as you can see in the figure.

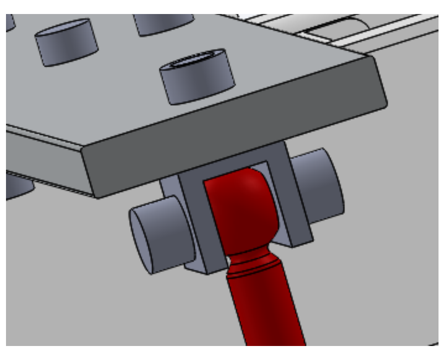


Figure 24. Bracket bolted to damper

Lower part of shock – absorber is connected to Hanger roof plate. Thus, the lower part of the system can swing freely when the pod car is going along the corner of the track.

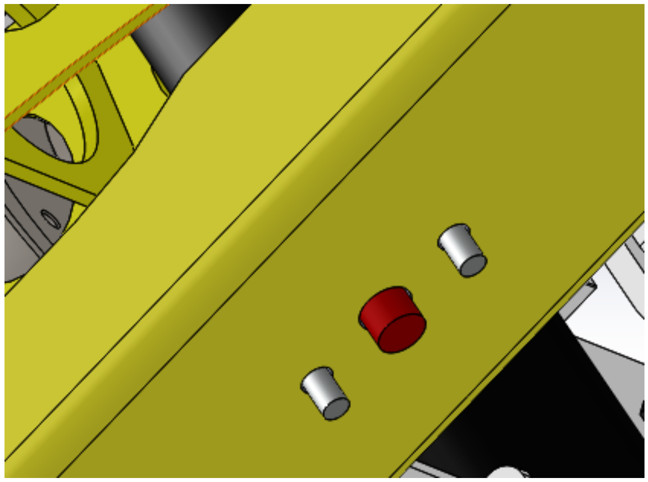


Figure 25. Hanger roof plate connected to damper

To mount the leaf spring on the roof of pod car, we did various trial to mount leaf spring appropriately, efficiently. we should mount under part of leaf spring on the roof of pod car, and the other part of leaf spring under the bogie. Finally, what we came up with was the picture below, and it would easy and strong to endure the load,

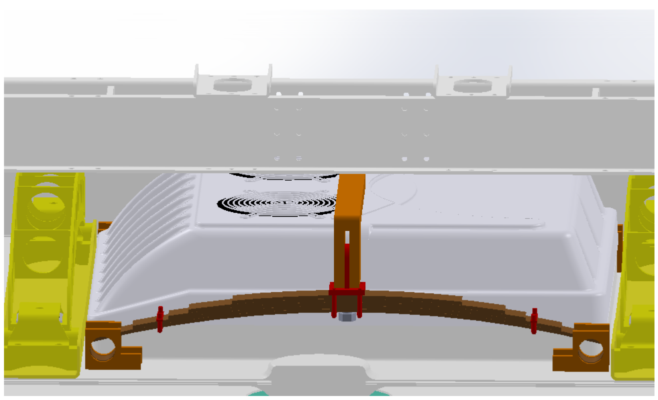


Figure 26. Brackets

we, set up bracket next to Hanger roof plate (Yellow part in Figure2), by inserting pin inside hole, we can fix the leaf spring

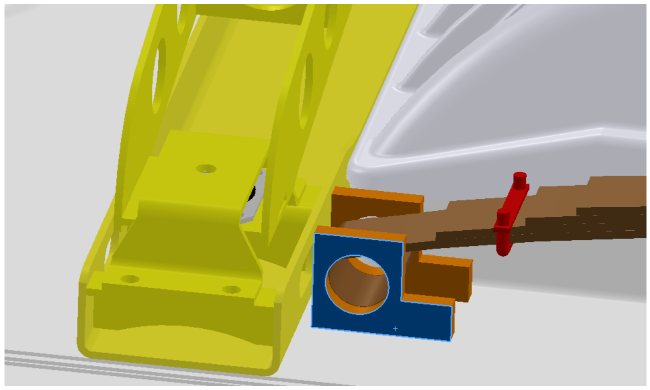


Figure27. Holes on brackets

And the top of leaf spring, also has hole (Red part in Figure3) so upper bracket (orange part in Figure3) can hold the leaf spring while it moves

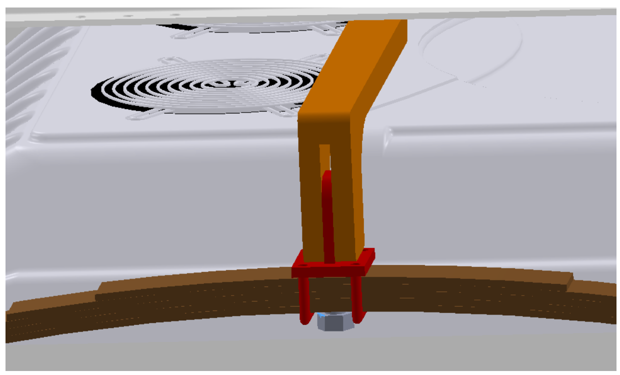


Figure28. Upper bracket

Cars should keep constant position without reference to change of track. We have to use solution tools to certify the secure. Actually, we analyzed this suspension system by Simulink to check its effectiveness. As shown in figure 13 ~ 16, the system would rotate with 2~3 degree when each dampers are forced by 5920N. We finally designed prototype, 1/12 scale of the suspension system using RC car dampers. The structure is shown on figure 22.

Conclusions and Suggestions for Future Work

As we participated in the Spartan super-way project, we took part in suspension system. In order to catch the vibration of Pod car, we though few ways to achieve the goal, first way was using the shock-absorber. To avoid collision with rail, we came up with wing-shaped suspension system. These system was easy to manufacture and analysis with Mat lab Simulink. Second way was using a leaf spring. Compared to other suspension systems, leaf springs are cheaper, easier to maintain, and sturdy. So typically It is used in pick-up trucks and trains. We expect that leaf spring can catch the rolling when pod car's swing. After we designed the shape of suspension system, we tried to analyze that. In order to analyze the behavior of the pod car, several operation patterns were set and the angle of the pod car with time was calculated through simulation. We expect that it could. By using this result, we can control driving cycle and choose Radius of rotation. For future work, Future team should make Full scale suspension Link structure based on Small Scale. And check wheter if it is appropriate or not. Also, after Full sacle spspensuon structure, They need to find appropriate spring coeficient to make passenger compatable, finally, it would be better if they have more time to consider leaf spring model, because leaf spring has many strength in cost, studrdy and easy-maintenance

Reference

[1] O-soon Ahn. The Characteristic Analysis of Progressive Rate type Leaf Spring using FEM, South Korea, Feb 2001

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