International Conference on Mechanical, Industrial and Energy Engineering 2020
19-21 December, 2020, Khulna, BANGLADESH

ICMIEE20-104

Design and Analysis of Suspension System for Human Exploration Rover

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ABSTRACT
A suspension system is one of the major analytical systems in a vehicle like Human Exploration Rover, a human-powered rover manufactured for human exploration outside the earth. This paper will introduce a perfect geometry, modeling and proper analysis of a double-wishbone suspension system which is manufactured for a human-powered rover. An ideal design of a suspension system includes good stiffness, low weight and low manufacture cost. To minimize the cost and for availability, Stainless steel(SS) material is selected for the designing procedure. In finding the suspension points, the wheelbase and track width are considered at first as the rover should not exceed the limit of 5×5ft tolerance. The modeling and analysis include all the components used in a suspension system with their calculations. Besides, this paper will assist in finding the perfect position of a roll center and minimizing the stability of sprung mass. The study will assist the participants in manufacturing a perfect suspension system for the human manipulated rover in the upcoming Human Exploration Rover Challenge competitions.

Keywords: Suspension system, human rover, double wishbone suspension, roll center.

1. Introduction

The suspension is the system which connects a vehicle to its wheels and allows relative motion between the two and consist of tires, tire air, springs, shock absorbers and linkages [1]. Suspension system isolates the driver from bumps, road vibrations and maintains proximity between the wheels and road surface all the time. A good vehicle bears the characteristic of a good suspension system and better handling [2]. Designing a perfect suspension system is inevitable for a vehicle to attain maximum performance. A perfect design of a suspension system will include a precise suspension geometry for which a vehicle can withstand bump, roll and rebound. On the other hand, to maintain steer and camber attitudes with the road surface, a good suspension system plays an important role. The purpose of designing a suspension system should be to maintain the wheels at an optimum angle with the road surface at any conditions [3]. While designing a suspension system, the dynamic condition of the system is to be always considered. Besides, availability, manufacturability, cost efficiency of materials are also considerable things. There are basically two classifications regarding the suspension system. One is the dependent suspension system, in which any movement of one wheel affects the movement of the other wheel and the system acts as a rigid beam. The main applications of the dependent suspension system are in the rear end of the heavy vehicles. There are several classifications of dependent suspension system of which Leaf Spring Suspension, Panhard rod, Watt's Linkage etc. are noteworthy [2]. The other is the independent suspension system which allows any wheel to move independently without causing any effect to the other wheel. These suspensions are mainly used in passenger cars and light trucks as they have more engine space and better resistance to the vibration of steering. Different types of the independent suspension system are Swing Axle Suspension, Macpherson Strut Suspension, Double Wishbone Suspension, Trailing Arm Suspension, Semi-trailing Arm Suspension, Transverse Leaf Spring Suspension etc. [2].

Among all the suspension systems, the Double Wishbone Suspension System is chosen for the design of human exploration rover for its efficiency. A double-wishbone suspension system is a form of Independent Suspension System, which, allows each individual wheel to react independently to local irregularities in the road surface unlike rigid beam [3]. The Double Wishbone Suspension System consists of two unequal lateral control arm which bears a spring and shock absorber along with it. In maintaining the dynamic stability, the geometry of the suspension system and the design of spring plays the most crucial role [4]. Besides this, negative camber gain can be increased by using a double-wishbone suspension system which can provide full jounce travel, unlike Macpherson Strut. Besides this, easy adjustment of wheel parameter like camber can be assured by this system. The double-wishbone suspension system has the most efficient dynamic properties and load distribution capabilities [2].

The present study will work with the design and analysis procedure of a double-wishbone independent suspension system and will focus on manufacturing the system.

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2. Modeling of Suspension System

2.1. Suspension Geometry

Suspension geometry is obligatory for designing a suspension. There are many essential parameters regarding this geometry, such as wheel camber, roll center, scrub radius, wishbone geometry is noteworthy. In Human rover converging unequal length double wishbones are used. These wishbones are unequal in length, and it will converge to a center point termed as the instant center. There are a series of facilities for using this kind of wishbones which can maintain good control on camber during rolling, provide a stable roll center position, minimize wheel scrub during bump and rebound, maintain good control on camber during bump and rebound [3]. In fig.1, the roll center is shown in below the sprung mass by considering the optimum ground clearance 15.5 inches. In the case of roll center determination, some critical points are considered. Firstly, if the roll center coincides with the sprung mass there will be no roll moment and hence no roll movement, secondly, if the roll center is above the sprung mass the chassis will roll in the wrong way, thirdly if the roll center is below the roll couple and roll movement will increase. Besides this, for better steering control and for better grip 5° negative camber is provided in the upright of the human rover.

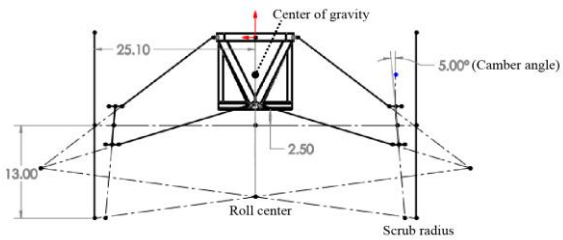


Fig.1 Suspension geometry.

2.2 Computer-Aided Modeling

This modeling process includes modeling of wishbones, pushrods, bell crank, clamps and springs. For modeling of wishbones, at first suspension points are found. The track width is 4.2ft, and the wheelbase is considered as 4.8ft as the Rulebook includes the maximum tolerance of 5ft [5]. Afterward, considering the suitable position for the roll center, the dimensions of the double-wishbone from the front view is obtained. Thus the upright position is found and there create a three-point geometry which therefore provides the 3D dimensions for wishbone modeling. The material used in the wishbone is Stainless Steel(SS). The model of the front wishbone is different from the rear ones as one end of it connects the clamp while the other end connects the ball joint. The 3D model for front and rear wishbones are provided in fig.2.

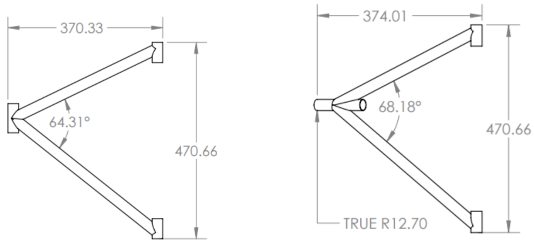


Fig.2. Three dimensional model for front and rear wishbones.

Fig.3 illustrates the push rod whose one end connects the clamp in the wishbones and the other end connects to the bell crank that means push rod is a connecting rod between bell-crank and the wishbones. The pushrod is employed to transfer the load to the spring. In the case of the human rover, Stainless Steel(SS) pipes are welded to prepare the rod for carrying loads of the framework.

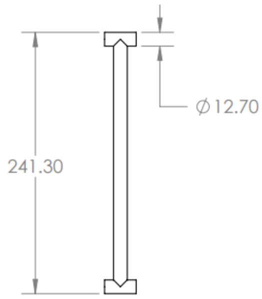


Fig.3 Pushrod.

The bell-crank is a triangular component with three connecting ends which is provided in the purpose of dividing the forces into components. One end of the bell crank connects with the chassis, one end with the pushrod and the other end with the spring. Fig.4 is representing the custom made bell crank used in the human rover. The bell crank is modeled and manufactured using steel plates and SS pipes.

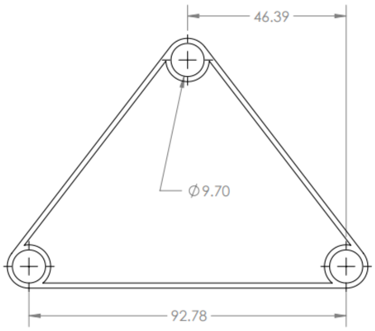


Fig.4 Bellcrank.

Clamps are welded with the frame to hold the wishbones and the pushrods. In the human rover, clamps are modeled with available C channels and drills are done inside it at a definite dimension. A 3D model for the clamp is shown in fig.5.

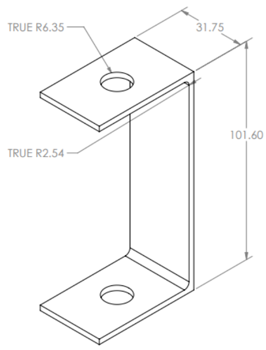


Fig. 5 Clamp.

Fig.6 demonstrates the front and rear uprights. Upright is an obligatory device which makes a connection between the wheel, suspension system and steering system. In the human rover, four Mild Steel uprights are used, and it is to be mentioned that the front upright is different from the rear. While designing the front upright braking force, steering force and the vertical loads are considered.

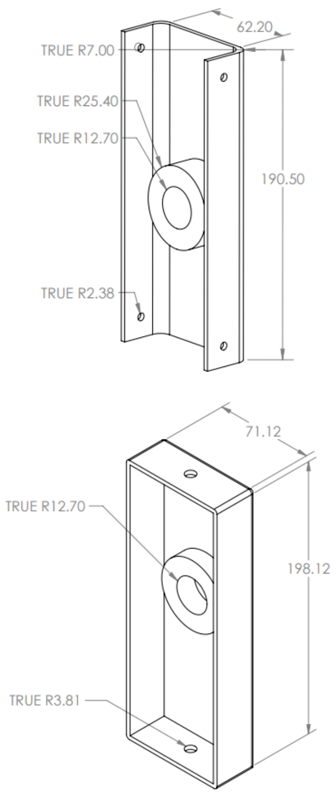


Fig.6 Rear and front uprights.

Besides, in the selection procedure of spring, at first, the free length is found and the compressed length and then Delta 'x' =1.75 inch is found. Then spring stiffness 'k' is found from the equation $k = \frac{F}{x}$ Afterward, the following equations are used to calculate the number of coils needed and diameter of the coils [6]. The equations are:

$$S = \frac{8kFD}{\pi D^3} \quad (1)$$

$$K = \frac{4C-1}{4C-4} + \frac{.615}{C} \quad (2)$$

$$k = \frac{F}{\delta} \quad (3)$$

$$\delta = \frac{8FNC^3}{GD} \quad (4)$$

After calculating it is found that a spring of N=6 and D= ¾ cm is required and thus the spring is selected accordingly. Fig.7 is representing the analyzable model of a spring.

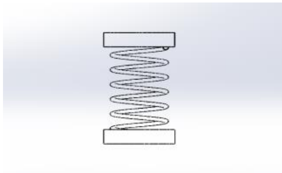
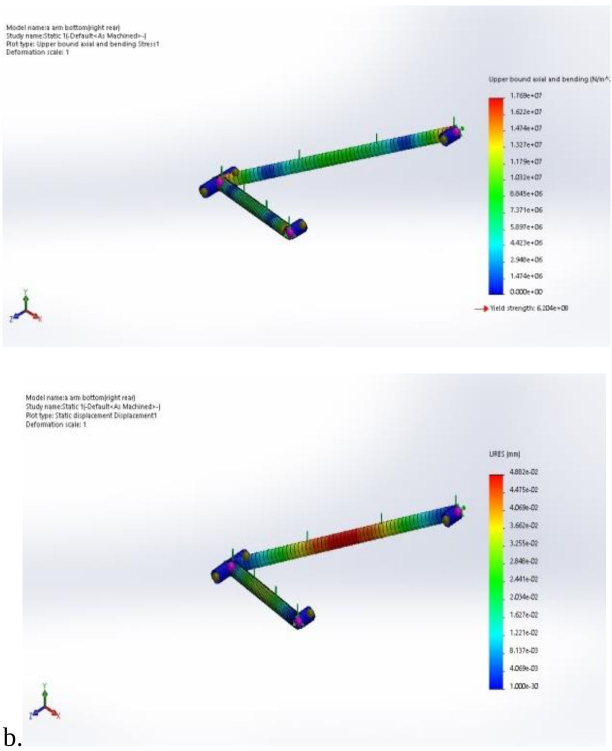


Fig.7 Spring.

3. Results and Discussions

There are three types of analysis which are done to the wishbone before manufacturing. The loadings are plotted along all the three axis. The three types of analysis are- Vertical loadings analysis, Front-impact analysis, Lateral impact analysis. Besides, analysis of pushrods, spring and bell crank is also a part of the suspension system analysis. In case of vertical loadings, the vertical loads are calculated and applied along the Y-axis. In this case, the weight of each side frame (7kg) along with the driver (70 kg) and accessories are considered. Thus, total weight is 85 kg. That implies the total force along the Y-axis will be 833 Newton, and in each side 208.25 Newton load will apply. Fig.8 is showing the stress, and displacement contours and the results are shown in Table 1. It is observed that the maximum displacement is intolerable range for manufacture.

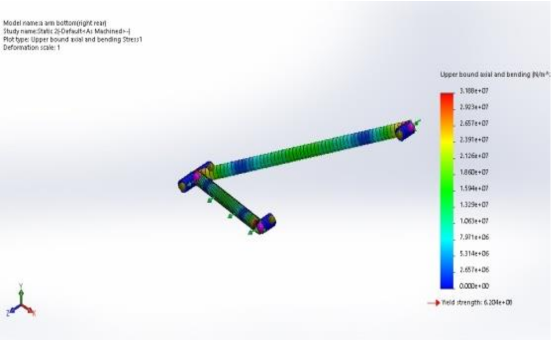
a.



b.

Fig.8 Contours for vertical loadings, (a) stress, (b) displacement.

In case of the front impact analysis, basically, the braking force is calculated. The force will oppose the acceleration of the vehicle. The equation employed for braking force calculation is $F = W * \mu$. Where F is the braking force, W is the weight of the vehicle, and μ is the friction co-efficient of tire/ground [3]. The friction coefficient of tire varies from 0.4 to 0.7 [7]. So, 0.55 is taken, and the total weight of the vehicle is 774.2 Newton. Therefore, the total braking force obtained is 425.81 Newton. The stress and displacement contours are provided in Fig.9, and the results are accumulated in Table 1


a.

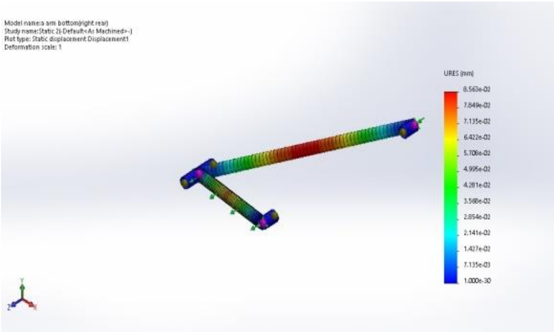
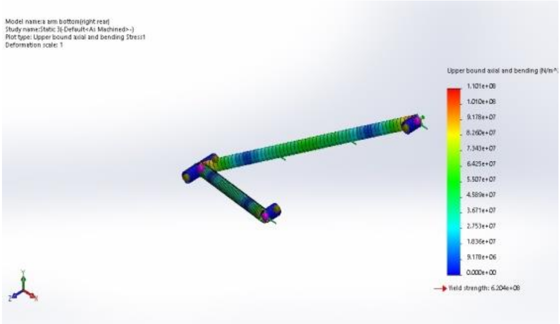

b.

Fig.9 Contours for front impact analysis, (a) Stress and (b) displacement.

In lateral impact analysis**,** the loadings are computed from the cornering forces. In this case, the formula associated with the centrifugal force is considered; $F = \frac{mv^2}{r}$ where m is the total mass of the vehicle, v is the velocity and r is the maximum radius. Here mass is 79 kg, velocity is 10 meters per second and turning radius is 4.57 meter according to the rule book. By calculating, the cornering force is obtained as 1755.55 Newton. The contours for stress and displacements are provided in Figure 9.


a.

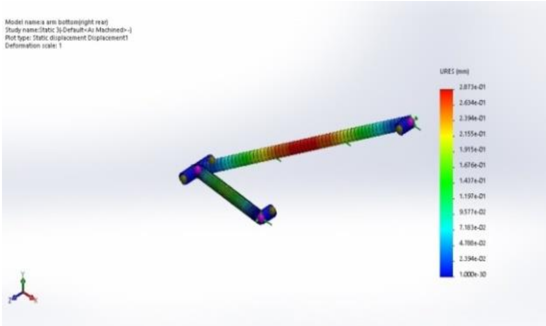
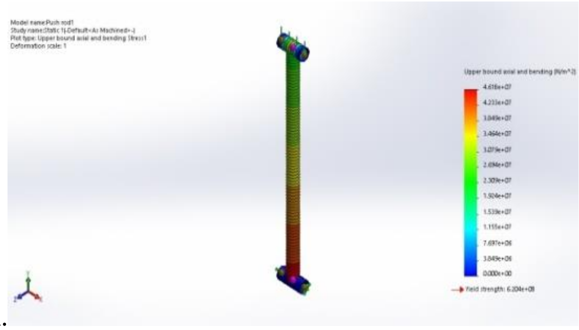

b.

Fig.10 Contours for lateral impact analysis, (a) Stress, (b) displacement.

In the analysis of pushrod, the cosine of the loads are obtained from the bump, and the total weight is measured, and the analysis is conducted. The projection of bump force and the projection of weight (14+70+8=72) kg, which is applied is 848.768 Newton. The contours obtained is shown in fig.11 clarify that the maximum displacement is in the tolerable range.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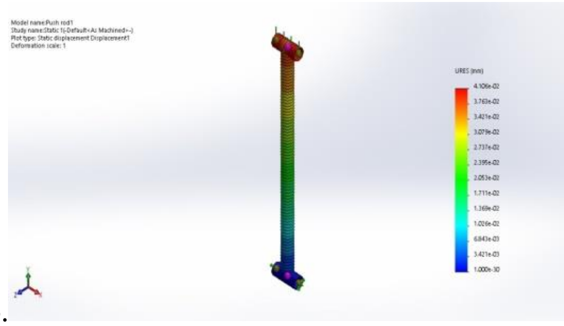
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Fig.11 Contours for push rods, (a) stress and (b) displacement.

In the analysis of spring, 848.77 Newton force is obtained from the weight component, and the bump force component is again resolved into components, and finally, the compressive loads are calculated, and that is 638.684 Newton. The contours are shown in fig.12.

a.

b.

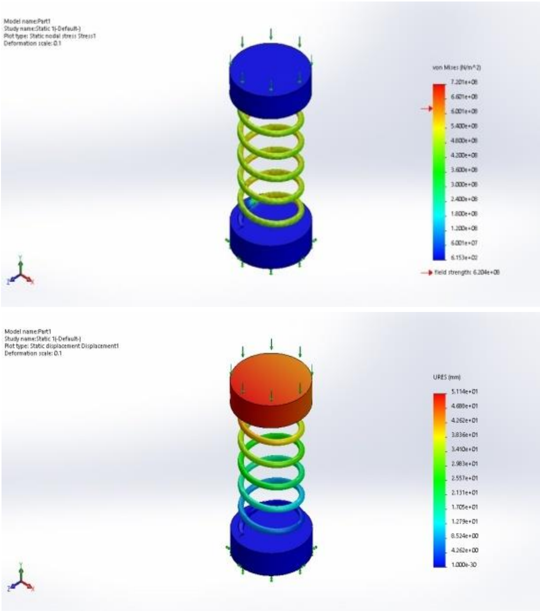


Fig.12 Contours for spring, (a)Stress, (b) displacement.

In the analysis of the bell crank there exist three connecting points. One point is fixed, and the point associated with the pushrod is loaded with 848.77 Newton force, and the other end associated with spring is provided with 638.6836 Newton. The contours shown in fig.13 shows that the design is in the tolerable range.

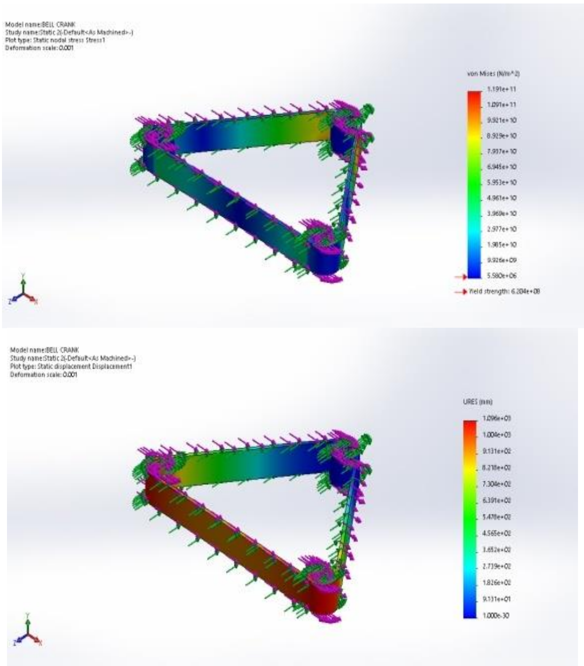


Fig.13 Stress and Displacement contours for bell crank.

Table 1. Accumulation of results.

Analysis name	**Type**	**Minimum value**	**Maximum value**
Vertical loadings analysis	Stress	0.000e+00 N/m^2	1.769e+07 N/m^2
	Displacement	0.000e+00 mm	4.882e-02 mm
	Factor of Safety	3.507e+00	1.000e+00
Front impact analysis	Stress	0.000e+00 N/m^2	3.188e+07 N/m^2
	Displacement	0.000e+00 mm	8.563e-02 mm
	Factor of Safety	1.946e+00	1.000e+00
Lateral impact analysis	Stress	0.000e+00 N/m^2	1.101e+08 N/m^2
	Displacement	0.000e+00 mm	2.873e-01 mm
	Factor of Safety	5.633e+00	1.000e+00
Push rod analysis	Stress	0.000e+00 N/m^2	4.618e+07 N/m^2
	Displacement	0.000e+00 mm	4.106e-02 mm
	Factor of Safety	1.343e+00	1.000e+00
Spring analysis	Stress	6.153e+02 N/m^2	7.201e+08 N/m^2
	Displacement	0.000e+00 mm	5.114e+01 mm
	Factor of Safety	8.616e+00	1.008e+00
Bell crank analysis	Stress	5.580e+06 N/m^2	1.191e+11 N/m^2
	Displacement	0.000e+00 mm	1.096e+00 mm

Table 1 is representing the maximum and minimum values for all the six analyses. It also includes the factor of safety values obtained during the analysis. The maximum displacement values validate that the design procedure is acceptable for manufacturing. Lastly, after a series of the analysis process, the double wishbones, pushrods, clamps, bell crank, uprights are manufactured sequentially. All the components are properly gas welded, and the drilling process is done perfectly in the workshop. The uprights are made with Mild steel due to availability, and all other components are built-in Stainless Steel(SS). All the manufactured components are provided in Figure 14, 15, 16, respectively.

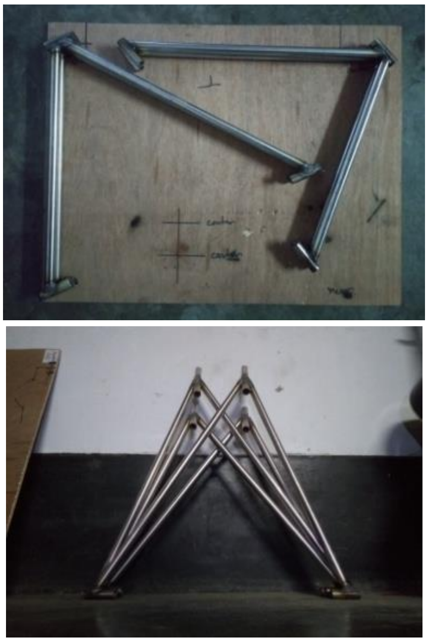
a.
b.


Fig.14 Wishbones after manufacture, (a) rear, (b) front.

a.
b.


Fig.15 Uprights after manufacture, (a) rear, (b) front.

Fig.16 Suspension system mounted with wheel assembly and frame.

4. Conclusions

A suspension system is an inevitable part of a vehicle for better vehicle dynamics. In the suspension system made for the human rover, all the components are custom made in the workshop, and the spring is collected as per the calculations. Due to availability of Stainless Steel and Mild Steel specimen in the local market and due to the cost-efficiency, SS and MS materials are used for the manufacturing process. The suspension system is prepared considering all the design considerations cited in the Rulebook 2019 [5] and the analyses are done with proper calculations. The design and analyses are done using the SolidWorks software and the results obtained exist intolerable range for manufacturing. The manufactured suspension system is employed in the human rover, and the rover took part in “NASA Human Exploration Rover Challenge-2019” without failure.

5. References

1. Jazar, R.N., Vehicle dynamics: theory and application. 2017: Springer.

2. Gillespie, T.D., Fundamentals of vehicle dynamics. Vol. 400. 1992: Society of automotive engineers Warrendale, PA.

3. Seward, D., Race car design. 2014: Macmillan International Higher Education.

4. Dixon, J.C., Suspension geometry and computation. 2009: John Wiley & Sons.

5 NASA Human Exploration Guide Book 2019.

6 Design of Machine Elements by Virgil Moring Faires fourth edition.

7 http://hyperphysics.phy astr.gsu.edu/hbase/Mechanics/frictire.html