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ENHANCING STUDENT RACE CAR PERFORMANCE: SUSPENSION SYSTEM DESIGN AND TESTING

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ABSTRACT

The objective of this paper is to designapushrod suspension system for student race car. The paper analyzed the suspension design process, method of structural analysis of suspension system with the help of Ansys R18.1 software. Some calculation results of structural analysis of suspension components in typical working conditions such as emergency braking and cornering are also presented in this paper.

Keywords: student race car, suspension system, A-arm, pullrod, pushrod.

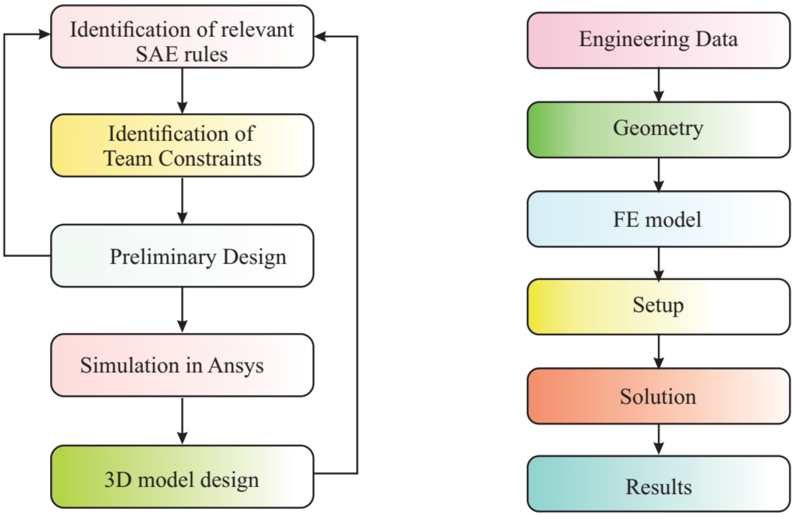
INTRODUCTION

Formula SAE is a student design competition organized by SAE International. The main objective of Formula SAE competition is for students to conceive, design and build a small open wheel racer car according to the competition requirements that is to be compared with other competing designs in order to decide the best overall vehicle. The restrictions on the car are set up to challenge student's imagination and knowledge while giving them a meaningful project as well as good practice working in a team environment. The car must have high performance in terms of acceleration, braking and handling qualities as well as high reliability, low cost and easy maintenance.

Suspension system is the one of the important system in race car. It supports the weight of the vehicle and provides the smooth ride. It allows rapid cornering without extreme body roll and keeps tire in firm contact with the roll and it also prevents excess body squat and body dive. It allows front wheel to turn side to side steering. It also works with the steering to keep the wheels in correct alignment. FSAE suspensions operate in a narrow realm of vehicle dynamics mainly due to the limited cornering speeds which are governed by the racetrack size. Therefore, FSAE suspension design should focus on the constraints of the competition. FSAE suspension designs not only have to be competitive on the racetrack, but the suspensions must also perform well in the static events. For the dynamic events, the designers should concentrate on the geometry so that most ofthe tire will stay in contact with the ground for all normal driving situations: braking, accelerating, and cornering. The suspension system must also be designed so that it is easy to manufacture and is reasonably priced for the cost analysis [1].

Generally, in race a car, double wishbone suspension with either pullrod or pushrod is used owing toease of design and lighter components involved [1]. The objective of this paper is to design the push rod suspension systems for student race car with the help of Ansys R18.1 software.

MATERIALS AND METHODS



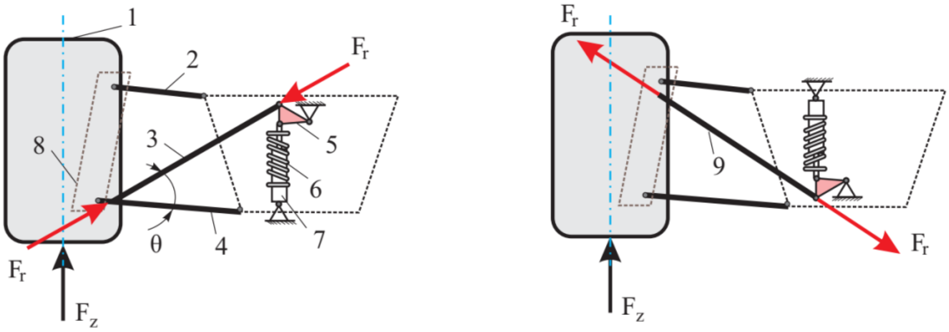
a) b)

Figure 1. Design flow chart (a) and flow chart structural analysis by Ansys software (b)

Nowadays, there are many different approaches to design suspension systems for student race car, however the most common method is the method using CAD software such as Solid work, Adam car, Ansys, Catia ... [2-12]. Figure 1 shows the design flow chart and flow chart structural analysis by Ansys software for designing suspension system.

Identification of relevant SAE rule. Identification of the competition rules relevant to the suspension was the important first step as it dictated the restraints on every subsequent step in the design and ensured the vehicle will be eligible for competitions. In addition to ensuring the general requirements for suspension systems such as ride comfort, controllability, stability of the race car ... the suspension system for students race car must also meet some other requirements such as:*(i)*The vehicle must be equipped with a fully operational suspension system with shock absorbers, front and rear, with usable wheel travel of at least 50 mm, with a driver seated; *(ii)* Officials may disqualify vehicles which do not represent a serious attempt at an operational suspension system or which demonstrate handling inappropriate for an autocross circuit; *(iii)*All suspension mounting points must be visible at Technical Inspection, either by direct view or by removing any covers; *(iv)* All spherical rod ends and spherical bearings on the suspension and steering must be either: mounted in double shear; captured by having a screw/bolt head or washer with an outside diameter that is larger than spherical bearing housing inside diameter[1] etc.

Identification of Team constraint. Team constraint greatly effect son the suspension design process. For example: the team has set the goal that the car should be lighter than the previous car, tomeet those requirements, FEA analysis will reduce the weight of each component as mochas possible and to choose a suitable material for the design; if the team has the goal to make as many parts as possible in the university workshop so the manufacturing process haste be taken into account in the design process.



a) Pushrod suspension ***b) pullrod suspension***

Figure 2. Suspension system for student race car

1. Tire; 2. Upper A-Arm; 3.pushrod; 4. Lower A-Arm; 5. Cockpit; 6. Spring; 7. Damper; 8. Upright; 9. pullrod

Preliminary design. Some of the major considerations at this stage were wheelbase/track lengths, ride height, type of suspension, roll stiffness, type and shape of overall structure and space for driver. In order to receive the preliminary designof suspension for Thai Nguyen University of Technology (TNUT) race car, most of the components from the previous car will be used as a baseline and adjustment made from that design based on previous design flaws and adjustments needed. In addition, some designs of suspension system of other universities are analyzed.

Table 1 shows the structure of the suspension system of FSAE of several universities. Literatures [2-12,15,16]showed most race cars use so-called double wishbone suspension or sometimes called double A-arm suspension. However, various combinations of pushrod and pullrod suspensions have been used in the front and the rear. For example, as mentioned in [2], formula one cars generally use pushrod in the front and pull rod in rear. As evident from [3, 4, 5] this combination is quite popular in formula student vehicles too. Some student formula vehicles like [6, 7, 8], have used a reverse combination i.e., pullrod in front and pushrod in rear. Many formula student cars as in [9, 10, 11] also use either pushrod or pullrod suspension in both front and rear axles.

The advantage of using push orpull rods is that it reduces unsprung weight by moving the spring and damper inboard the vehicle. The main difference between push and pull rods is the forces acting on the push and pull rod (Figure 2). In a pushrod setup, the push rod is under compression as the vertical wheel force pushes on the push rod as the wheel jounces. In a pull rod setup, the vertical wheel force pulls on the pull rod as the wheel jounces. Each of these setups has its benefits and drawbacks. The center of gravity (CoG) is lower in pull rod suspension while it is harder toaccess the spring and damper as it sits so low in the car. Push rod setup, on the other hand, has a higher CoG while making access to the spring and damper much easier as it sits so highin the car. Buckling of the push rod also has to be considered as the load is compressing the push rod there is a risk of it buckling.

Table 1. Type of suspension of student race car

Team	Race car	Type of suspension
Moscow Automobile and Road Construction State Technical University, Russia	FSM4 Rebel FSM5	double unequal length A-arm suspension with push rod in both front and rear axles
Moscow State Technical University "MAMI", Russia	Iguana Evo 4 Iguana Evo 5	double unequal length A-arm suspension with pull rod in both front and rear axles
Bauman University, Russia	BRT-2	double unequal length A-arm suspension with pullrod in front and pushrod in rear
University of Missouri-Rolla, USA	UM - Rolla	double unequal length A-arm suspension with push rod in both front and rear axles
RMIT university, USA	RMIT Racing	double unequal length A-arm suspension with push rod in both front and rear axles
University of Western Australia	REV 2011	double unequal length A-arm suspension with pull rod in both front and rear axles
Thai Nguyen university of Technology, Viet Nam (TNUT)	TNUT 2014	double unequal length A-arm suspension with push rod in both front and rear axles

Wheel alignment have a great influence on suspension design. In order to choose the appropriate wheel alignment for TNUT race car the authors studied and analyzed the wheel alignment of some student race cars (table 2). The results shown in Table 3.

Table 2. Wheel alignment

Team	Camber (deg)	Castor (deg)	King-pin Angle (deg)
Instituto SuperiorTechnico [17]	-2,5	4	5,9
Kempten USA[18]	-3	10	8,5
University of Alberta [19]	-1	4,8	3,1
South Dakota State University[20]	-1	8	7
Royal Institute of Technology [21]	-1	5,3	9,2

After selecting the suspension type, thanks to the graphical method of determining the displacement of the suspension elements in the compression and return journey. From the requirements for elastic and damping elements of suspension system, we select damping with basic parameters such as total length, weight, damping coefficient of damping and spring stiffness.

Simulated by Ansys software. After having the preliminary design of the suspension system, the author proceeded to analyze suspension structure with the aid of Ansys R18.1 software. The steps of analyzing suspension structure are carried out according to the diagram of Figure 1b. The results of structural analysis were used to improve 3D models to obtain the optimal design of the suspension system.

RESULTS AND DISCUSSION

Structural analysis allowing us to choose the optimal design of the suspension system. From above study, thedouble unequal length A-arm suspension with push rod in both front and rear axles was chosen as the preliminary design of suspension system of TNUT race car. In this part, the results of structural analysis of the main components of the suspension system such as control A-arms, pushrod and rockerfor three cases: static load, while race car cornering and emergency braking are presented. Some input parameters of race carusing for structural analysis shown in Table 3.

Table 3. Specifications of the car

Wheel base (mm)	1550
Wheel track front (mm)	1240
Wheel track rear (mm)	1200
Camber (deg)	-10
Castor(deg)	3,50
King-pin Angle(deg)	40

In order to analyze the structure of FSAE suspension system with the aid of Ansys R18.1 software, first of all the authors select and set material parameters; next we build geometric models; set finite element model (FEA model); then assigning loads and constraints for the FEA model; following that, FEA analysis is done for the control A-arms, push rod and rocker and the results are checked.

To determine the force for the finite element model, the authors proceeded to calculate the force for each suspension component as illustrated in Figure 3-4.

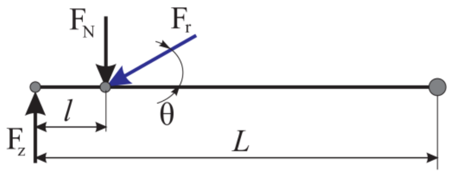


Figure 3. Free body diagram of the forces acting on the pushrod

Figure 3 shows the diagram for determining the force acting on the push rod F_r. In this case, the value of F_r is determined as follows:

$$F_r = \frac{F_N}{sin\theta};(1)$$

$$F_N = \frac{F_z.L}{L-l};(2)$$

$$F_r = \frac{F_N}{sin\theta} = \frac{F_z.L}{sin\theta(L-l)};(3)$$

Where: F_z - Normal forces on the wheel center; L- length of the A-arm; l- distance between upright mounting and push rod mounting points; F_N-normal force on the push rod mounting point (N); θ- Angle to the push rod from horizontal; F_r- force acting on the push rod (N).

The forces acting on the node points of lower and upper A-arms have been calculated for the case emergency braking by using diagrams (Figure 4), the results is shown in Table 4.

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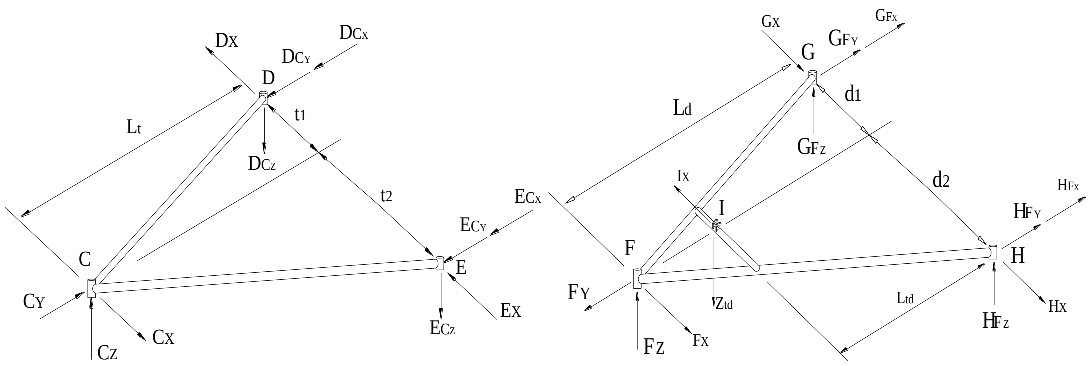


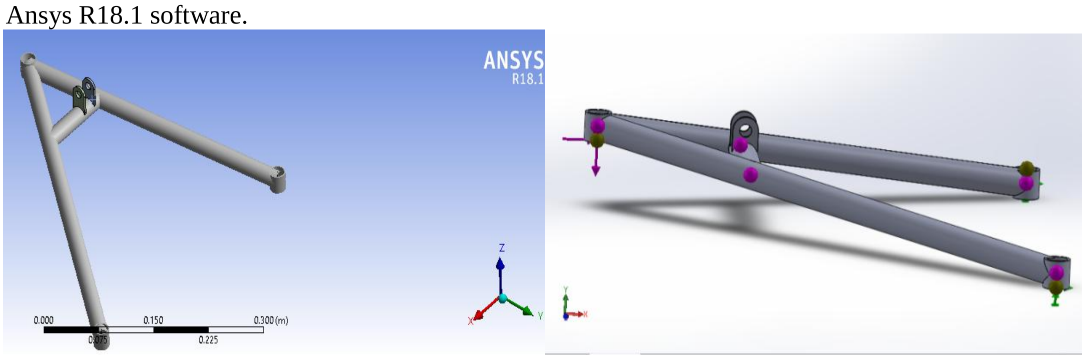
a. Upper A-arm *b. lower A-arm*

Figure 4. Diagram of forces acting on A-arms while emergency braking

Table 4. Results of calculation

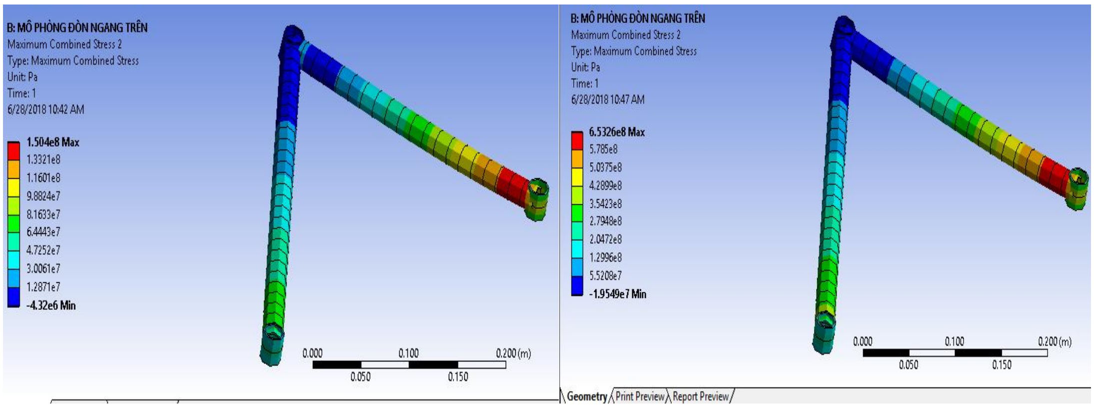
	Points	Emergency braking	Cornering
Upper A-Arm	C	C_y=124 (N), C_x=313(N);C_z=417(N)	C_z=1087 (N) C_y=1019(N)
	D	D_{cy}=92(N); D_{cx}=222(N) D_z=308 (N); D_x=157 (N)	D_{cz}=801 (N) D_y=751(N)
	E	E_{cy}=32(N); E_{cx}=181(N); E_x=157(N); E_z=109(N)	E_{cz}=286(N) E_y=286(N)
Lower A-Arm	F	$F_y = 351(N)$ $F_x = 313(N)$ $F_Z = 417(N)$	$F_z = 1087(N)$ $F_y = 2106(N)$
	G	$G_{Fy} = 256(N); G_{Fx} = 288(N)$ $G_x = 157(N)$; $G_Z = 61(N)$	$G_{Fz} = 158(N)$ $G_{Fy} = 1537(N)$
	H	$H_{Fy} = 95(N); H_{Fx} = 288(N)$ $H_x = 157(N)$ $H_{Fz} = 32(N)$	$H_{Fz} = 59(N)$ $H_{Fy} = 569(N)$

Figure 5 illustrates the FAE model and the result of assigning loads and constraints of the front lower A -arm using Ansys R18.1 software.



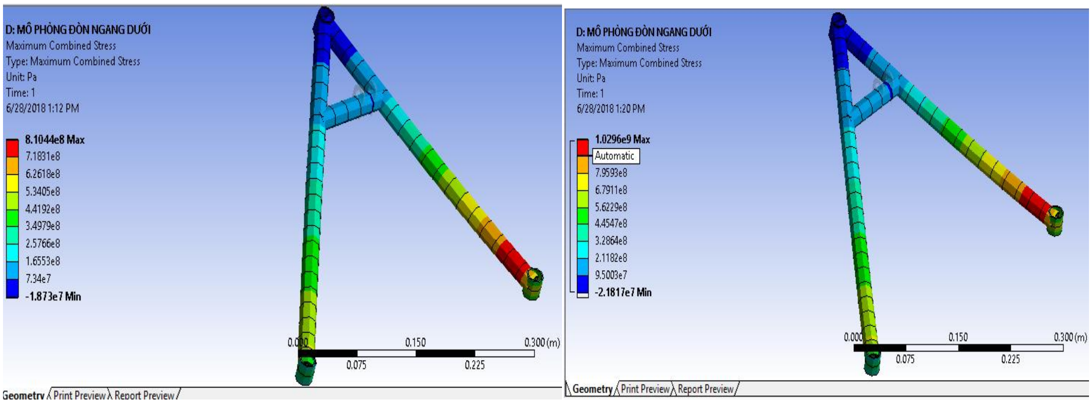
a) FAE model *b) assigning loads and constraints*

Figure 5. Front lower control A-arm

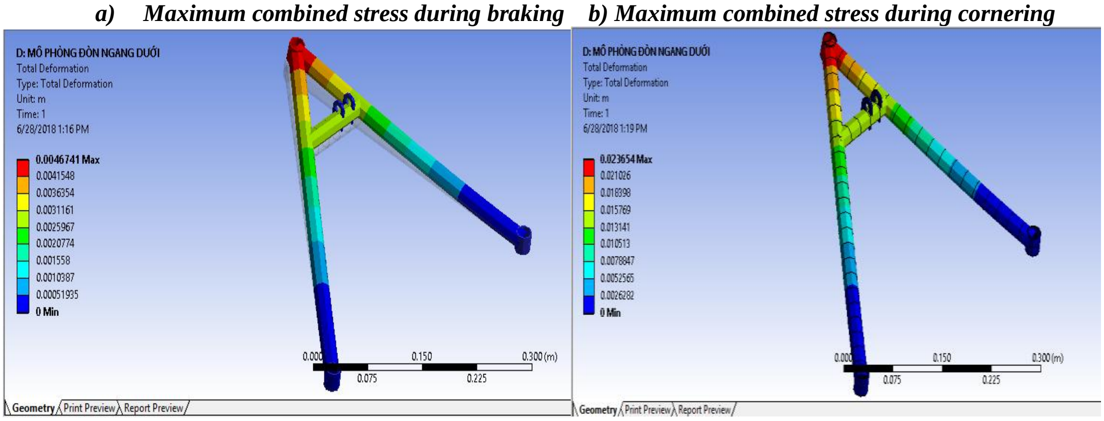


a) During braking *b) During cornering*

Figure 6. Front lower control A-arm FEA results



a) Maximum combined stress during braking *b) Maximum combined stress during cornering*



c) Deformation during braking *d) Deformation during cornering*

Figure 7. Front lower control A -arm FEA results

In figures 6-7 show the simulation results of the Stress and deformation analysis on the upper and lower control A-arm during race car emergency braking and corneringand in figure 8. shows thestress analysis on the pushrod and rear rockers. It is observed from FAE analysis (figure 6 and figure 8) that, while race car cornering and emergency braking, the maximum combined stress of front lower A-arm is equal to1,0296.10^8Pa and 8,1044.10^8Pa, respectively. During braking the maximum total deformation is 0,00467m and while race car cornering the value ofmaximum total deformation is equal to 0,002365 m.

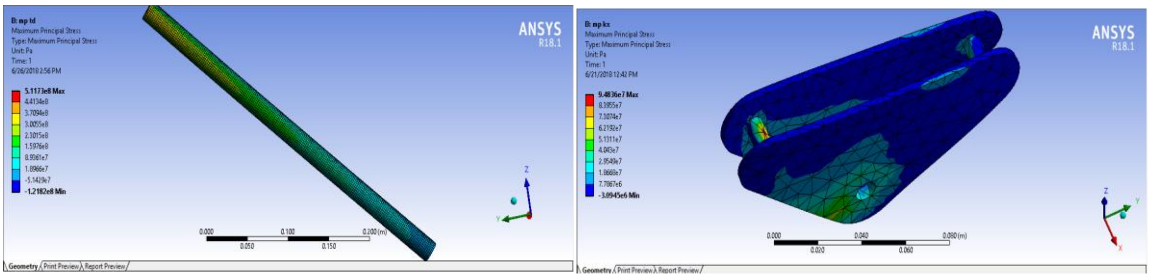


Figure 8. Stress analysis on the pushrod (a) and rear rockers (b)

Performing the same structural analysis, when changing the structure or material of the suspension components, it will quickly obtain the results of stress and deformationof the components corresponding to the selected structure and materials. Thus, based on the structural analysis by using Ansys R18.1 software, it is possible to select the optimal design and material parameters of the components of suspension system of the student race car.

CONCLUSION

This article presented a method for designing student race carsuspension systems, including the selection of parameters and methods structural analysis of the main components of the suspension system with the aid of Ansys R18.1 software. Some main conclusions can be drawn as follows:

a) Currently, most student race cars use double A-arm with pushrod or pullrod suspension in both front and rear axles. However, the pushrod suspension will be more convenient in arranging the component of the suspension system and facilitating at Technical Inspection.
b) In addition to ensuring the general requirements for suspension systems such as ride comfort, controllability, stability of the race car ... the suspension system of student race car must also meet other requirements in the FSAE rulebook and the team constrain. This can make the suspension structure more complicated. Therefore, to shorten the design process, it is necessary to apply CAD software.
c) To analyze the suspension structure, a finite element method can be used with the help of Ansys R18.1 software. This software allows to quickly analyze the structure of suspension components and choose the optimal structural parameters of the FSAE suspension system.

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