Improvementof Car Performance Limits Through Camber Control

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Abstract—In the design and development of car suspension systems, turn ability, comfort, and safety must all be considered simultaneously. Additionally, in light of the environmental concerns that have arisen in recent years, environmental performance has become an issue not only for the powertrain but also for the underbody. However, improving both turn ability and environmental performance through the suspension system alone has proven a considerable challenge in consideration of the mechanism by which a car bends. A large lateral force is generated during cornering according to the slip angle of the tire. The research will be carried out using the CAE analysis tool. Using this analysis tool we will conduct simulation and conduct studies on the performance of camber of the tire.

Keywords—Automobile; Camber Thrust; Cornering force; Suspension

I. INTRODUCTION

The basic ability of a vehicle is to "run", "turn" and "stop". The safeness and comfort during a drive on various road surfaces and speed depends on the performance of these basic abilities of the vehicle. Stability and maneuverability of a vehicle are vital in automotive engineering. The stability of a vehicle is the ability of the vehicle to revert back to a stable state during a drive when faced with crosswinds and irregular road conditions. Maneuverability of a vehicle is the ability of the vehicle to change direction during a drive swiftly based on the steering of the driver. The stability and maneuverability of a vehicle can also be defined as the driving stability of the vehicle. Since the fossil fueled vehicle is the main type of transportation today, the environmental factor in automotive engineering is also vital. By improving the fuel efficiency of the vehicle, the overall carbon emission will be reduced, thus reducing the effect of global warming and greenhouse gas on the Earth. Another main focus of the automotive engineering is the safety performance of the vehicle, especially with the worrying increase of vehicle collision every day. With better safety performance of a vehicle, every driver will be more confident driving every day.

The turning ability of the vehicle is vital in improving the overall driving stability of the vehicle. By improving the cornering ability of the vehicle, the overall driving stability will also improve thus giving the driver a safer driving experience and swifter control of the steering. The double wishbone suspension system is a favorite choice by car manufacturers for conventional vehicle due to the characteristic of the double wishbone suspension system that allow the engineer to manipulate various parameters such as the camber angle, caster angle, toe pattern, scrub radius and many more to achieve a higher cornering limit and better cornering performance of the vehicle [1], [2]. However, when a cornering force is applied to the tire during a cornering motion, conventional double wishbone suspension system will tilt the tire to the opposite side of the turning direction, thus increases the cornering resistance that will affect the overall cornering performance [3], [4]. Therefore, it is considered to be a method that can be used to control the camber [5], [6].

In recent years, many advance technologies [7] such as the AYC (Active Yaw Control) [8], [9], ACC (Active Camber Control) [10], SH-AWD [11], [12] system using electronic control technology have been developed to improve the cornering performance and more importantly the overall driving experience of the vehicle. Unfortunately, these technologies can only be found on super car and concept car because these technologies are too costly and high maintenance is needed to be implemented on the everyday conventional vehicle. Other than that, most of the vehicle equipped with such technologies is often a four-wheel drive vehicle in order to have an optimum performance. These technologies are not suitable for two-wheel drive vehicle due to the limitation of the layout of the vehicle. In order to have an affordable suspension system that will optimize and improve the cornering performance of the vehicle that can fit in various types of vehicle, this research is proposed for a safer and better driving experience in the future.

In the present study, the camber thrust is generated by intentionally adding the camber angle to the tire at the time of cornering. A suspension system that simultaneously improves turn ability and fuel cost performance is examined and shown to increase the cornering force by increasing the camber thrust power according to the slip angle.

Our design is based on a light weight JSAE formula car design of the Kinki University Formula Project team. We will then recreate the JSAE formula car models equip with double wishbone suspension system and another will the new suspension system using the CAE analysis tool ADAMS/CAR 2012 by MSC Software Cooperation and perform simulations to study. We will be able to simulate various experiments and tests using this simulation system. We can save up on precious time, budget and also not risking driver's life and also not risking crashing the formula car by avoiding dangerous test and experiments in real life.

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II. Suspension System

The primary functions of the suspension system are to support the car body and improve traveling comfort. However, increasing the damping force to suppress the free vibration of the vehicle body causes the ride to become rougher due to high-frequency vibrations, while the low-frequency vibrations associated with decreasing the damping force cause the ride to become "fluffy." When pitching increases due to rolling, starting, and braking, as occurs when the car body experiences large right and left inclinations on a convexo-concave road or is subject to a crosswind, maneuvering ability and stability are often compromised. Maneuvering ability, stability, and traveling comfort are mutually conflicting design concerns. The suspension is the most important determinant of maneuvering ability, stability, and chassis performance, which are together referred to as ride quality. The suspension should transmit various forces generated between the wheel and the road, such as driving force, braking force, and lateral force, to the body of the car while ensuring excellent kinematic performance. Therefore, various linking mechanisms have been employed as coupling elements to provide moderate rigidity between the back and front, as well as the right and left, between the wheel and the body. Double wishbone suspension provides high design freedom, and it has been adopted in a student formula vehicle in the present study. Fig. 1 shows the schematic diagram of this double wishbone suspension. The double wishbone suspension system will be the base of the new suspension system in this research and the new suspension system is expected to solve this problem and thus improving the overall cornering performance and of the vehicle. The basic built of a double wishbone is shown in Fig. 1. The double-wishbone suspension can also be referred to as "double A-arms", though the arms themselves need not to necessarily be A-shaped but also L-shaped, or even a single bar linkage. The suspension is fixed to the vehicle body at the leg of the "A" with a bearing to enable an up and down movement of the wheel. The tip of the "A" is installed in the axle housing on the wheel with a ball joint. From this structure we can see that both the A-arms and the side rod stroke around the pivot shaft in other words the suspension jounces (rises). The A-arms will only revolve around the pivot shaft, even though force is applied in the other direction. Therefore, by controlling the geometry of both the A-arms, we can adjust the camber angle parameter and the position of the wheel center. Other than the links and arms, the double wishbone suspension system is also built out of springs and shock absorbers. By changing the layout geometry of the links and the mounting position, we can easily manipulate various parameters such as the camber angle, caster angle, toe pattern, scrub radius and many more to achieve a higher cornering limit and better cornering performance of the vehicle.

The camber thrust is a transverse thrust force generated where the running tire of the vehicle is inclined, and this force is assumed to be the main turning power. If the tire rolls freely in a horizontal plane at the camber angle, the trajectory is an arc BB drawn on the cone APO, as shown in Fig. 2, around the point O. The tire draws the radius R/sin φ centered on point O. Therefore, the power of the tire is applied in the direction of point O, as shown in the figure, if the line motion is applied to the tire with the camber angle. The power caused by the camber angle is designated as the camber thrust. The slip angle

of the car can be decreased when the horizontal power necessary for the turn is supplemented by the camber thrust. The schematic diagram of this mechanism is shown in Fig. 3. Fig. 3 shows the mechanism to reduce the cornering resistance using the camber thrust. When a car makes a turn, the tire takes a slip angle as shown in Fig. 3 (a). By producing a camber thrust in the same direct of the cornering motion, it is possible to generate the lateral force that is needed during a turning motion with a small amount of resistance as shown in Fig. 3 (b). With this, the slip angle can be reduced. A smaller slip angle can reduce the cornering resistance and thus improving the cornering performance of the vehicle as shown in Fig. 3 (c). Resulting improvements of turn ability and fuel cost performance may therefore be expected.
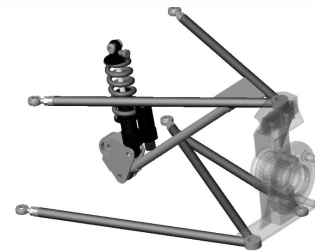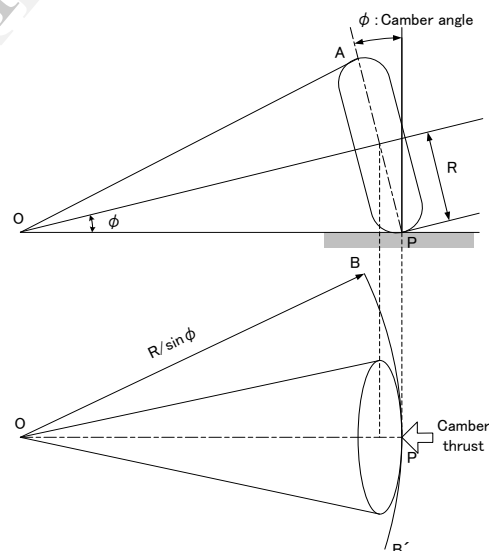

Fig. 1. Double-wishbone suspension system
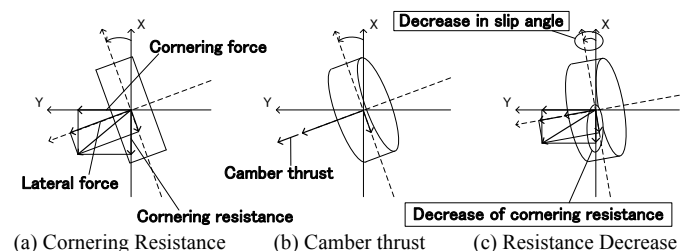

Fig. 2. Geometry and theory of camber thrust

(a) Cornering Resistance   (b) Camber thrust   (c) Resistance Decrease

Fig. 3. Geometry and theory of camber thrust

III. ACCURACY VALIDATION OF VEHICLE CAE ANALYSIS

ADAMS/Car 2012, a product of the MSC. Software Company, was employed as a running CAE analysis tool in the present study. First, the accuracy of the rolling stock motion CAE analysis tool was validated by examining the rolling stock run of the student formula car (hereafter abbreviated as JSAE). The vehicle employed in the running test was an JSAE car developed as a Kinki University formula project in fiscal year 2012. A vehicle photograph and 3D-CAD model are shown in Fig. 4 and Fig. 5, respectively. Table I shows the dimension of the machine, is weighted at 235 kg, has a wheelbase of 1600 mm, tread of 1150 mm, 1170 mm and the weight distribution is 47 % front and 53 % rear. The tires are slick JSAE tires manufactured by Bridgestone.

We have verified the accuracy of the analysis by comparing the actual measurement data of the lateral acceleration and the CAE analysis by the Adams/Car (Vehicle Motion Analysis Tool) of the steering wheel angle of the JSAE vehicle that have adopted the double-wishbone suspension system. A Race Technology Company DL1 mk2 was employed as the running data measuring instrument in this study. The DL1 is a compact, efficient data logging system that records the analysis data of the vehicle on its memory card together with position information. The device recorded acceleration, GPS coordinates, handle slice corner, and suspension stroke at 100 Hz. The SP1-25 steering rudder used in this study was made by the Celesco Company.

In the CAE analysis, the model construction of the FSAE formula machine was conducted using 3D-CAD, as was the setting of the joint and other factors for each part. The General Magic Formula was used as the tire model in the CAE analysis. Fig. 6 shows the vehicle model. As an accuracy validation of the steering angle change due to horizontal acceleration

determined from the CAE analysis, the performance of the car on a pylon slalom course, as shown in Fig. 7, was examined. The results from the FSAE running test and ADAMS/CAR 2012 simulation are shown in Fig. 8 and Fig. 9, respectively. The horizontal acceleration is represented as handle slice corner in both figures. The results of the CAE analysis corresponded well to the actual measurements from the FSAE vehicle, indicating the sufficient accuracy of the model.

Next, the running state in the threshold region was examined, and a steady-state circular test of 7.5 m in radius, as shown in Fig. 10, was conducted for the sake of comparison. The vehicle accelerated gradually from the initial velocity of 0 km/h and experienced failure. The acquired data from the JSAE steady-state circular test are shown in Fig. 11. Moreover, that the consequent maximum accelerations of the running test and CAE analysis are shown in Table. II. The CAE analysis values accurately corresponded to the actual measurement values of horizontal acceleration that showed the performance limits in steady-state circular test.
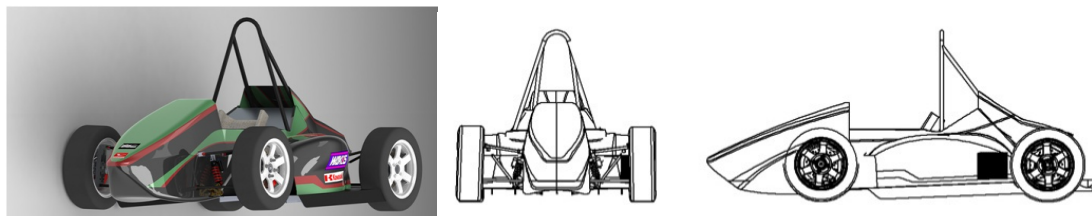

Fig. 4. Photo of JSAE formula machine

Fig. 5. 3D-CAD model of JSAE formula machine

TABLE I. SPECIFICATIONS OF THE JSAE MACHINE

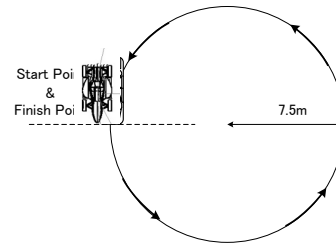| Dimensions	Front	Rear
Overall Length, Width, Height	2506mm, 1364mm, 1128mm	
Wheelbase	1600mm	
Track	1170mm	1150mm
Suspension Parameters	Front	Rear
Suspension Type	Double unequal length A-arm. Pull rod	Double unequal length A-arm. Pull rod
Tire Size and Compound Type	6180/510-13, Bridgestone	6180/510-13, Bridgestone
Wheels	6 inch wide, 1 pc Al Rim, 1.5 inch pos.offset, RAYS	6 inch wide, 1 pc Al Rim, 1.5 inch pos.offset, RAYS
Body Frame		
Frame Construction	Steel Tubular Space Frame	
Material	STKM 13A, STKM 11A steel round tubing.	
Powertrain		
Manufacturer/Model	Kawasaki GPZ500s 2 cylinder / EX500-D1	
Bore/Stroke/Cylinders/Displacement	77mm bore / 58mm stroke / 2 cylinder / 498cc	
Compression Ratio	10.8:1	
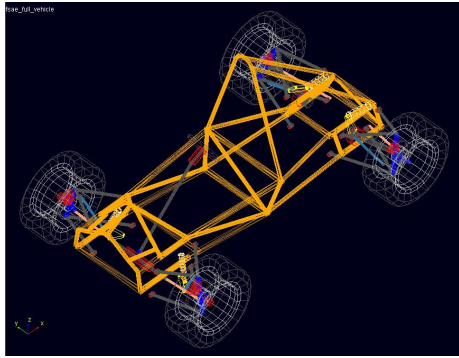
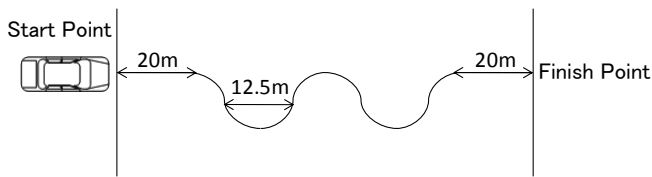Fig. 6.   Comparison of CAE and experimental result

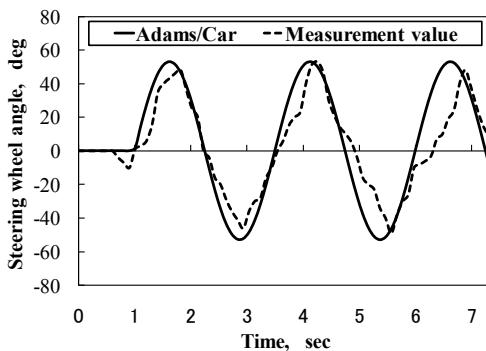Fig. 7.   Pylon slalom tset course

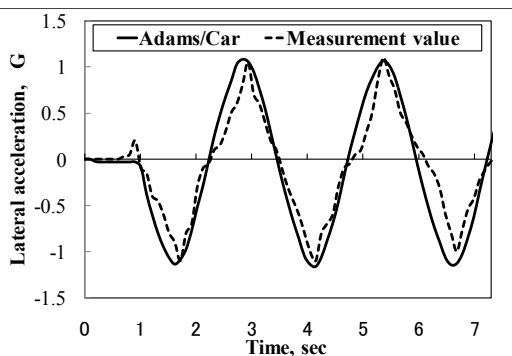Fig. 8.   Comparison of measered and CAE simulation in steering angle

Fig. 9.   Comparison of measered and CAE simulation in lateral acceleration

Next, the running state in the threshold region was examined, and a steady-state circular test of 7.5 m in radius, as shown in Fig. 10, was conducted for the sake of comparison. The vehicle accelerated gradually from the initial velocity of 0 km/h and experienced failure. The acquired data from the JSAE steady-state circular test are shown in Fig. 11. Moreover, that the consequent maximum accelerations of the running test and CAE analysis are shown in Table II. The CAE analysis values accurately corresponded to the actual measurement values of horizontal acceleration that showed the performance limits in steady-state circular test.
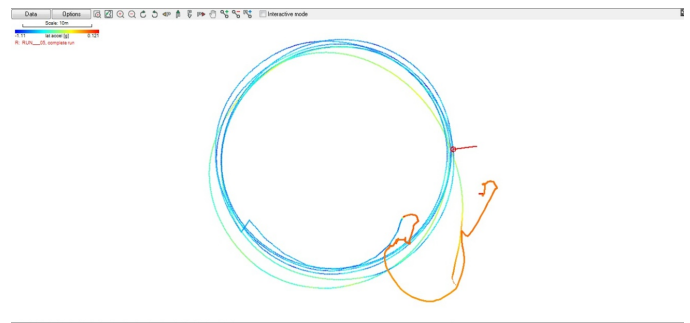

Fig. 10. Steady-state Circular test course

Fig. 11. Pylon slalom tset course

TABLE II.   COMPARISON OF MAX. VELOCITY AND ACCELARATION

	Measurement of JSAE	*ADAMS/Car*
Velocity, km/h	36.5	34.9
Lateral Accelaration ,G	1.27	1.27

IV.   METHOD OF CAMBER ADDITION CAE ANALYSIS

The analytical conditions for acceleration during steady-state circular test are also shown in Fig. 10, along with the initial camber corners added to the vehicle. Performance was assessed by horizontal acceleration, yaw rate, and tire resistance to the critical point. Horizontal acceleration is a working lateral force and can determine the cornering ability high on the body of the vehicle. Moreover, tire resistance determines roughly 30 % of the vehicle's fuel consumption. The direction of the camber addition from the vehicle's rear view is indicated in Fig. 12. As shown in this figure, the direction is designated as 0 when not tilted to either the left or right. The direction is designated as - when tilted toward the inward turning of both wheels and as + when tilted in the turning direction outside the tires. First, the optimal directions of camber addition to the front wheels, rear wheels, and each individual wheel were decided using a parameter decision procedure. Next, the optimal addition corner in the optimal direction of camber addition was determined. The analytical condition was assumed to be a regular yen turn of 7.5 m in radius while gradually accelerating from an initial velocity of 0 km/h.

The results of the CAE analysis when a camber angle of + or -5 degree was added to the front wheels or the rear wheels when rotating are shown in Table III. The rear and front wheels are designated as R and F in the table, respectively. Moreover, the horizontal acceleration represents the maximum lateral acceleration, yaw rate, and tire rolling resistance in the turn. As shown in this table, the lateral acceleration and yaw rate were greatly improved through the addition of an inside camber to

the front wheels in comparison with the F0R0 condition, in which no camber was added to either set of wheels. The rolling resistance of the tire was also decreased. Setting the rear wheels to 0 camber provided the greatest turn ability and fuel cost performance. Although the yaw rate improved greatly under + rear camber, the unsteadiness of the vehicle also increased, likely due to oversteering. From these data, the optimal camber addition was determined to be + for the front wheels and 0 for the rear wheels.

Next, the optimum value of the camber addition corner was examined for the F-R0 condition. The CAE analysis conditions in ADAMS/car 2012 followed those previously described. The assessment considered both horizontal acceleration and running resistance, and the results of the analysis are shown in Fig.13. As seen in this figure, tire rolling resistance decreases as the camber addition corner increases. However, horizontal acceleration is the greatest under a camber addition corner of 8 degree. Increasing the camber angle is thought to reduce the crawler bearing area of the tire, thereby decreasing the tire force. Camber control is predicted to increase horizontal acceleration by approximately 16% and 12% as well as to decrease tire rolling resistance by approximately 13% due to effective use of the camber thrust. The turn ability and fuel cost performance of the vehicle may also be improved due to the advantages of a suspension system that employs the camber thrust

(a) − Camber　　(b) 0 Camber　　(c) + Camber

Fig. 12. Comparison of measered and CAE simulation in lateral acceleration

TABLE III. CAE RESULT OF FRONT AND REAR CAMBER

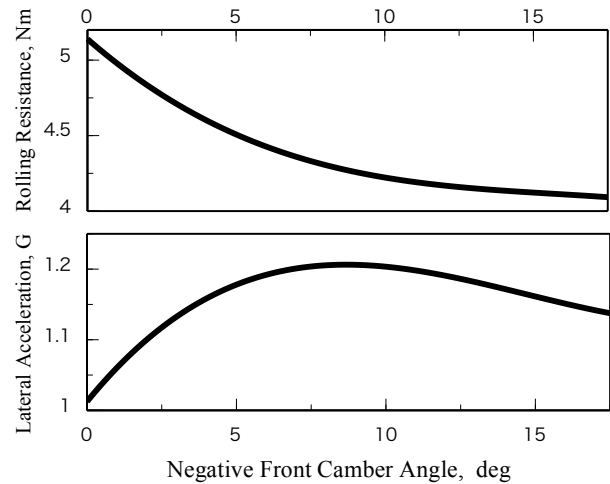| Camber Direction Combination	Lateral Acceleration, G	Yow Rate, deg/s	Rolling Resistance, Nm
F-R-	1.17	70.4	4.53
F-R0	1.18	74.6	4.47
F-R+	1.12	76.6	4.74
F0R-	1.01	65.4	5.24
F0R0	1.02	66.4	5.13
F0R+	1.04	68.6	5.09
F+R-	0.84	58.5	6.35
F+R0	0.86	59.6	6.17
F+R+	0.87	62.1	6.08

Fig. 13. Relation between Front Camber Angle and Rolling Resistance

V. SUMMARY / CONCLUSIONS

The accuracy of the ADAMS/CAR 2012 CAE analysis tool was confirmed using a JSAE student formula vehicle, and the influence of camber addition on running resistance and threshold horizontal acceleration was determined. The results may be summarized as follows:

1. The CAE analysis was confirmed as sufficiently reliable by comparing the results of the running simulations with those of a real driving experiment using the FSAE vehicle with a double wishbone suspension.

2. The most effective camber thrust effect was generated when the front wheels were leaned 8 deg in the direction of the revolution center and the rear wheels had zero camber.

3. The use of a suspension system with effective camber control is expected to drastically increase turn ability and reduce tire resistance by approximately 16%.

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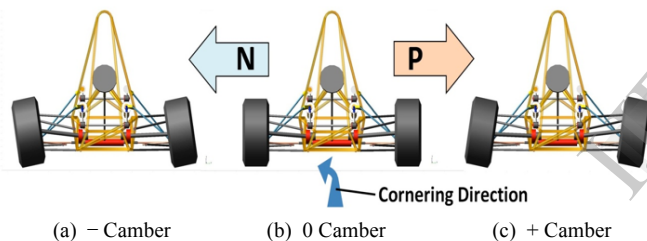
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