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Rear Wheel Steering System for Racing Solar Cars

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Abstract

Some of our students study energy by producing racing solar cars. Of course, they are concerned with solar energy and how to use it efficiently, however they must also study total energy system for making good solar cars. In solar education we try to provide them with an opportunity for learning engineering technologies around the solar energy to realize that solar power is related to other fields and branches. For example, it is important to reduce resistance to motion of a car to save the energy. So they designed a rear wheel steering system and a narrow spat in order to make the drag force be small. The spat is a kind of cover for a tire. They showed the rear wheel steering caused the width of the spat to be more narrow. The drag force, which is a part of the resistance to motion, on two front spat was estimated. From the result, they calculated the total energy saving over the route of the 2013 World Solar Challenge. It is recognized that adding the rear steering system to the car is useful for the race.

Keywords: *Solar Education, Energy Education, Mechanical Engineering, Racing Solar Car, Drag Force Coefficient, Rear Wheel Steering System, World Solar Challenge*

1. Introduction

Solar energy is origin of other forms or types of energy on the earth. When we teach energy to our students, we may have to make them consider that solar energy plays a significant role in many fields and understand that solar power is related to other fields and branches.

One of main purposes of solar education is getting and using solar energy effectively. In our racing solar car team, students have found out the power density of solar radiation is low. So they improve the car with various techniques. The work for their improvement suggests the using solar energy is related to other fields and many technological knowledge is needed for the using that energy effectively. Now teachers try to show the students recognizing that solar energy is included in total system and emphasizing that using energy in the system is related to many fields.

An example of the improvement of the solar car was introducing a rear wheel steering system to the car. This improvement was effective way for reducing the drag force to save the energy, because that force depends on a width of a vehicle spat covering a tire. The knowledge of other fields, example for vehicle dynamics and fluid dynamics, was used to utilize solar energy.

2. The racing solar cars

The racing solar car, which is shown in Fig.1, was designed by our students for the World Solar Challenge (WSC) and participated in the 2013 WSC adventure class. It has a 1.3 kW photovoltaic (PV) system, a 5.2 kWh rechargeable Lithium-ion (Li-ion) battery system, a carbon fiber monocoque, two front tires and one rear tire which contains an in-wheel motor. The motor is a 2.0 kW direct drive one.

After the 2013 WSC, the solar car team members tried to improve the car. For example, reducing resistance to motion of the car became their aim, because it is important for saving energy to reduce the resistance. The

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members thought that one of the solutions to the reducing is adding a rear wheel steering system to the solar car.

When a vehicle turns left or right, for a given turning radius, the larger the steer angle of a rear tire is, the smaller that of the front tires is. So steering a rear tire can make the width of a vehicle spat covering a front tire be more narrow. The fact suggests that the spat's drag force, which is included by the resistance to motion, may be small.

Fig. 1: KAIT (Kanagawa Institute of Technology) racing solar car participated in the 2013 WSC

3. Turning radius and steer angle

We consider the relation between turning radius and steer angle in this section. If a steady-state turning at very low speed is assumed, centrifugal force doesn't act on the car, lateral forces are not needed, and side-slip angle is 0 while front and rear wheels travel in the heading direction of the car and make a circular motion (Abe and Manning, 2009), as shown in Fig.2. α, γ, W and T are given.

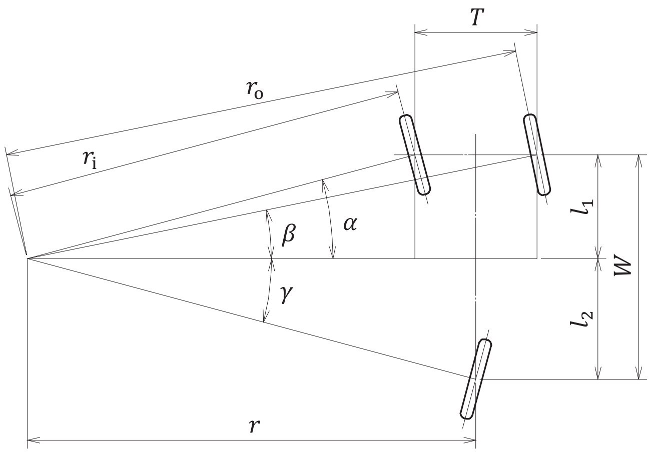

Fig. 2: Turning radius and steer angles (α, β : front; γ : rear) for steady–state turning at low speed

We start by

$$W = l_1 + l_2 = (r - T/2)\tan\alpha + r\tan\gamma = -T\tan\alpha/2 + r(\tan\alpha + \tan\gamma) \quad \text{(eq. 1)}$$

then

$$r = (W + T\tan\alpha/2)/(\tan\alpha + \tan\gamma)\ . \quad \text{(eq. 2)}$$

And from Fig. 2,

$$\tan\beta = l_1/(r+T/2) = (r-T/2)\tan\alpha/(r+T/2) = (1-1/(r/T+1/2))\tan\alpha\ , \qquad \text{(eq. 3)}$$

$$r_o/T = (r+T/2)/(T\cos\beta) = (r/T+1/2)/\cos\beta\ . \qquad \text{(eq. 4)}$$

Putting

$$p \equiv r/T + 1/2 = (W/T + \tan\alpha/2)/(\tan\alpha + \tan\gamma) + 1/2\ , \qquad \text{(eq. 5)}$$

we obtain

$$\tan\beta = (1-1/p)\tan\alpha\ , \qquad \text{(eq. 6)}$$

and a dimensionless radius :

$$r_o/T = p/\cos\beta = p/\cos\tan^{-1}\big((1-1/p)\tan\alpha\big)\ . \qquad \text{(eq. 7)}$$

For the racing solar car, $W = 2000$ mm, $T = 1300$ mm , so $W/T = 1.54$. Figure 3 presents the dimensionless radius : r_o/T for both the inside front steer angle α and the rear one γ at $W/T = 1.54$.

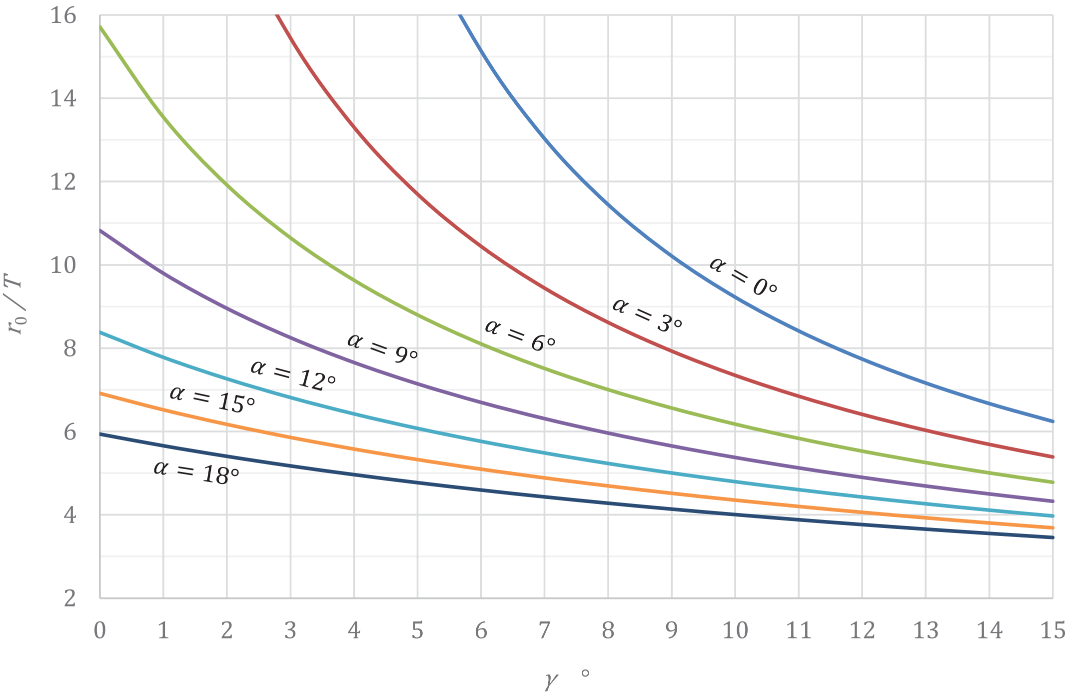

Fig. 3: Dimensionless turning radius r_o/T , inside front steer angle α and rear one γ for steady–state turning at low speed at *W*/*T* = 1.54

According to regulations for the 2013 WSC, the Solar car must be able to make a U-turn in either direction within a 16 m lane, kerb to kerb. If the car has no rear wheel steering system, the maximum value of inside front steer angle α must be 18° or more in order to observe the regulations, because of $r_o/T < (16/2)/1.3 = 6.15$ and Fig. 3. However we can satisfy the regulations at that angle $\alpha = 7.5°$, if the car has the rear steering system and rear steer angle γ is 9°.

4. Drag force on the front spat

In the previous section, we know that the rear wheel steering system is effective against the reducing the front steer angle. So the width of the spat, which covers a tire, may become narrow and the drag force on the narrow spat is smaller than that on the wide one. We assume that the shape of the spat is a streamlined two-dimensional cylinder, and we are going to guess the drag coefficient C_D by the procedure shown in Fig.4.

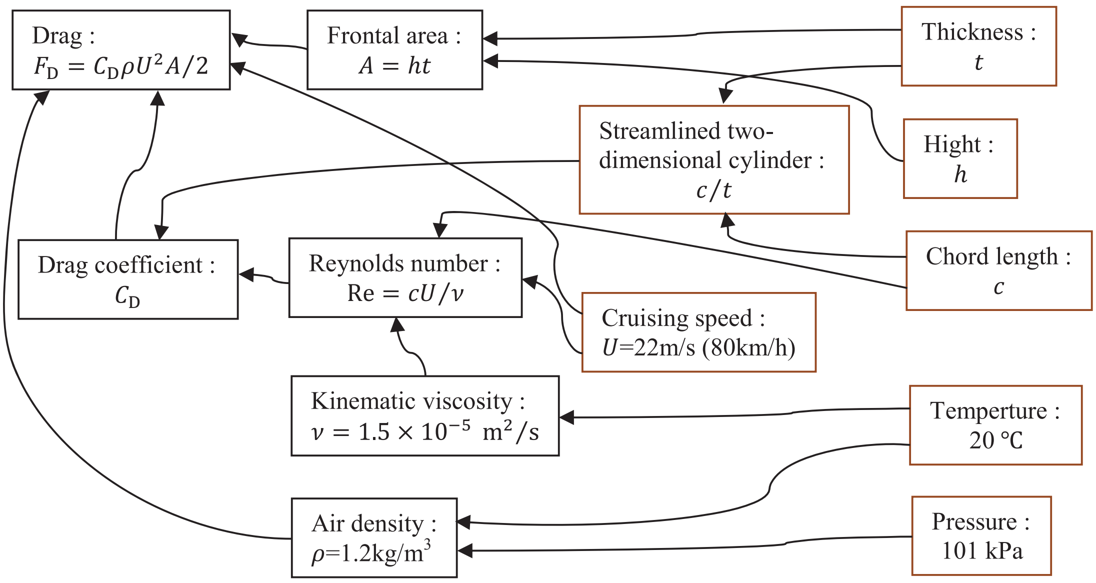

Fig. 4: Procedure for determining drag from the shape of the spat, the cruising speed, air temperature, atmospheric pressure

Reynolds number is defined here by

$$Re \equiv cU/\nu \qquad \text{(eq. 8)}$$

where c is the longitudinal length of the spat, U is the cruising speed of the car and ν is kinematic viscosity of air . The chord length c is approximately 1200 mm. Let the air temperature, atmospheric pressure, the cruising speed be 20°C , 101 kPa and U =22 m/s (80km/h) respectively. So the kinematic viscosity $\nu = 1.5 \times 10^{-5}\ \mathrm{m^2/s}$, the air density ρ=1.2 kg/m^3. Then Reynolds number is

$$Re = 1.2 \times 22/(1.5 \times 10^{-5}) = 1.8 \times 10^6\ . \qquad \text{(eq. 9)}$$

The diameter of the front tire of the solar car $D = 552$ mm and the width of it $B = 103$ mm, then

$$D \sin\alpha + B\cos\alpha = \begin{cases} 174\ \mathrm{mm} & \text{for } \alpha = 7.5° \\ 269\ \mathrm{mm} & \text{for } \alpha = 18° \end{cases} \qquad \text{(eq. 10)}$$

is needed for width of inside spat cavity. If there exists the rear wheel steering system, that is, $\alpha = 7.5°$, the outside width of spat is $t = 190$ mm. On the other hand no rear one, that is, $\alpha = 18°$, the outside width of spat is $t = 285$ mm. Then

$$t/c = \begin{cases} 0.16 & \text{for } \alpha = 7.5° \\ 0.24 & \text{for } \alpha = 18° \end{cases}. \qquad \text{(eq. 11)}$$

We obtain the drag coefficient

$$C_D = \begin{cases} 0.082 & \text{for } \alpha = 7.5° \\ 0.075 & \text{for } \alpha = 18° \end{cases} \qquad \text{(eq. 12)}$$

from Fig. 5 (Granger, 1995; Goldstein, 1965; Shames, 1992; White, 2011). Figure 5 gives drag coefficients for Reynolds number = 10^6, and our one : 1.8×10^6 is not that, however it is likely that the drag coefficient for Reynolds number = 1.8×10^6 is nearly equal to that for $Re = 10^6$. Generally, the drag coefficient of bluff forms depends on the span, but on low-drag forms the effect of aspect ratio is considerably smaller than that on bluff forms (Goldstein, 1965). So the effect of the aspect ratio on the drag coefficient is negligible.

The drag force F_D is expressed by

$$F_D = \frac{1}{2} C_D \rho U^2 A \qquad \text{(eq. 13)}$$

where A is the frontal or projected area. Let the spat height be 308 mm, then

$$F_D = \begin{cases} 0.082 \times 1.2 \times 22^2 \times 0.190 \times 0.308/2 = 1.4\text{N} & \text{for } \alpha = 7.5° \\ 0.075 \times 1.2 \times 22^2 \times 0.285 \times 0.308/2 = 1.9\text{N} & \text{for } \alpha = 18° \end{cases} \quad \text{(eq. 14)}$$

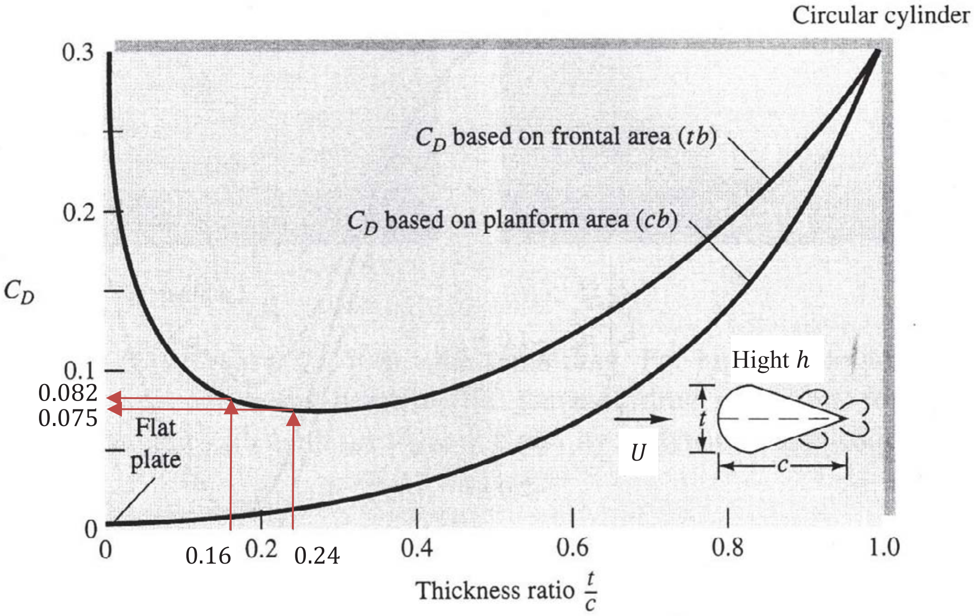

Fig. 5: Drag coefficients for a streamlined two-dimensional cylinder at $Re = 10^6$ (White, 2011)

5. Energy consumption of the rear wheel steering system

The rear wheel steering system consists of a DC 12V geared motor, a screw driven liner actuator, a stroke sensor, a microcontroller. The motor is controlled by feedback. The actuator can push or pull the swing arm of the rear wheel. A part of the system is shown in Fig. 6.

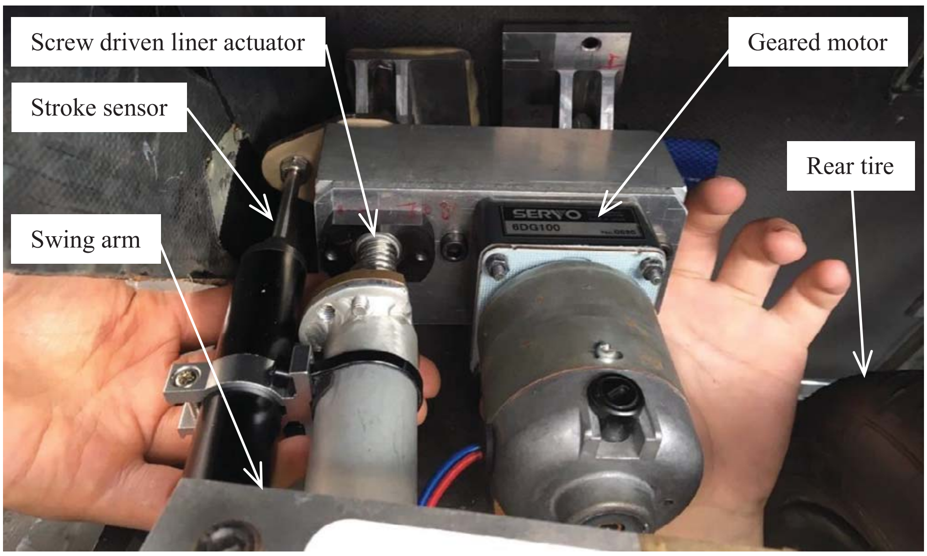

Fig. 6: Putting the rear wheel steering system to the solar car

The solar car team member measured the current of the steering system and Fig. 7 shows the result. The current was approximately 1A, so electric power was 12W and it took 2×6s=12s for one cornering operation.

Then 12×12s=144J is needed for one that operation. Since it is likely that the efficiency of the electric power is 70%, the energy consumption of the rear wheel steering system is $144/0.7 = 206$J. They also researched the number of turning that required the rear wheel steering on the 2013 WSC route. The turnings were 26, so the total energy consumption of the rear wheel steering system is $206 \times 26 = 5.36 \times 10^3$J throughout the race.

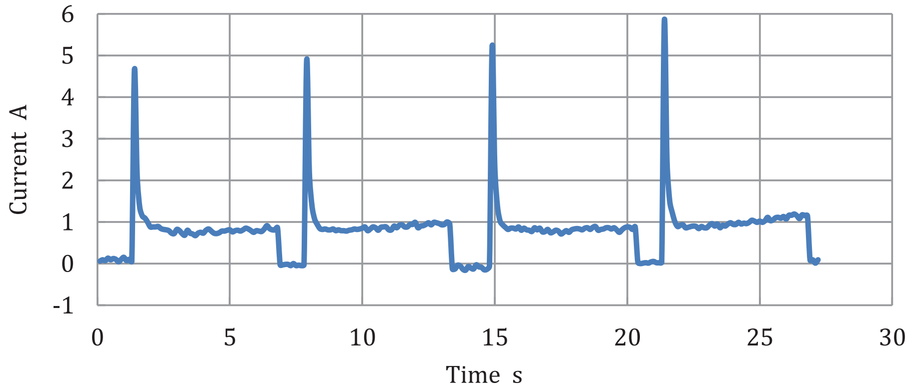

Fig. 7: Current consumed by the rear wheel steering system

6. Effect of the rear wheel steering

We consider the effect of rear wheel steering system here. The travelling distance by no rear steering operation in the WSC route is approximately 3008km. The merit in the rear wheel steering is reducing the resistance to motion. It saves the energy : $2 \times (1.9 - 1.4) \times 3008 \times 10^3 = 3 \times 10^6$J, because front spats are two. The demerit is the consumption of electric power of the rear steering system : 5.36×10^3J for the result of previous section. Now we can guess the effect. It is $3 \times 10^6 - 5.36 \times 10^3 \cong 3 \times 10^6$ J energy saving in the race.

7. Conclusions

The racing solar car has been improved. The rear wheel steering system added to the car may make the total driving energy consumption be reduced throughout the WSC. We obtained the following.

If the solar car has the rear wheel steering system and rear steer angle γ may be 9°, we can satisfy the 2013 WSC regulations at the inside front steer angle $\alpha = 7.5°$.

The drag force on the front spat with the rear wheel steering system may be 1.4 N at the cruising speed = 22 m/s (80 km/h). But with no that system the force is 1.9 N.

The effect of the rear wheel steering system throughout the WSC, we estimated, is 3×10^6 J energy saving. Effective solar energy usage induces our students to study many fields related to solar energy practically.

8. References

Abe, M., Manning, W., 2009. Vehicle Handling Dynamics, Elsevier.

Granger, R.A., 1995. Fluid Mechanics, Dover Publications.

Goldstein, S., 1965. Modern Developments in Fluid Dynamics Volume Ⅱ, Dover Publications, New York.

Shames, I.H., 1992. Mechanics of Fluid, third ed. McGraw-Hill.

White, F.M., 2011. Fluid Mechanics, seventh ed. McGraw-Hill.