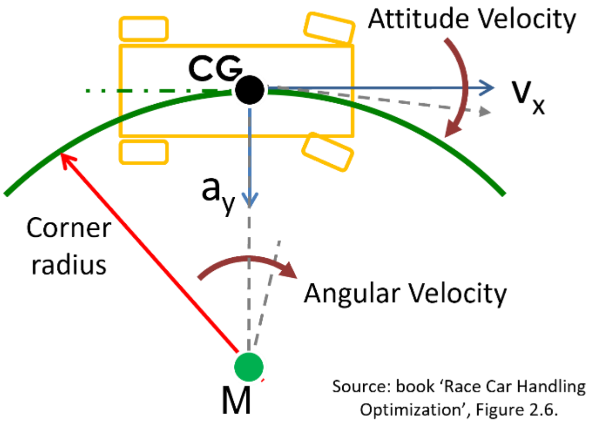
Yaw is yaw, right? Or not…?

When responsible for the dynamics of a 4WD EV, it is of utmost importance that understeer and oversteer are measured correctly so that the electric power is distributed correctly across the four wheels. So during my judging at Formula Student NL meeting in July '25, I asked this to all teams, and guess what: none of them gave the correct answer… That motivated me to write this blog.

Have you ever studied the data sheet of your Data Acquisition equipment, like a data logger including a GPS-receiver, thoroughly? The data sheet most likely states that the data logger produces the signals of the 6 degrees of freedom, including the rotation around the Z-axis. We call this yaw. And the datasheet of the optional GPS-receiver will also claim that it produces a yaw signal. So you get two yaw signals, but is there any difference between them? Well, you could say 'yaw is yaw', but that is not true.

Let's first look at the yaw signal from the data logger. Strictly speaking it is the yaw of the data logger itself. But we are interested in the yaw of the car, and therefore it is wise to install the data logger in (or as close as possible to) the CG. The yaw measured in this way is called the 'Attitude Velocity' (AttVel), as it tells us about the attitude of the car in top view.



The yaw data coming from the GPS-receiver is a different, bit more complex story. I purposely call it the GPS-receiver rather than GPS-module since it only receives and processes the signals from the GPS-satellites. It does not send any signal to the satellite. Your GPS-receiver selects the best receiving signals from a multitude of GPS satellites which are orbiting around earth at 35,786 km altitude, which is the geo-stationary orbit. Each satellite does one orbit in 24 hours, like earth, and that makes that they stand stationary relative to earth. The only thing GPS satellites are doing is transmitting their coordinates (relative to earth) and a time signal. Not the satellite, but your GPS-system itself calculates the path it makes from the coordinates, received from satellites. It does so by 'Circle Method Derivation'. In this way your GPS-system calculates its path, velocity and corner radius of its own receiver. Since we want to know the data of the CG of the car, it makes sense to place the receiver in the CG, as we do for the data logger! The yaw measured in this way is called the

‘Angular Velocity’(AngVel), it tells us about the angular velocity of the GPS-receiver (read ‘the CG of the car’) around the center of the corner.

So: Attitude Velocity is about the movement of the car around its own CG, and Angular Velocity is about the movement of the CG around M!

The Attitude Velocity and the Angular Velocity are both expressed in [deg/sec] or [rad/sec]. These two only have the same value in case of a steady state trajectory by the car through the corner. But when the attitude is changing from understeer to oversteer or vice versa, both yaw values are different.

Concluding that the car ‘is neutral because AngVel = AttVel’ is a common mistake: imagine a car is in a steady oversteer situation during mid-cornering, like drifters do with full opposite lock. Then the AngVel is equal to AttVel, but the car is in full oversteer. Comparing the two equal yaws should NOT result to the conclusion that the car is neutral, but it only is an indication of change in one or both of them.

And concluding that the car is oversteered when Attvel is larger than AngVel is incorrect too: when a car might have been understeered during corner-entry and transient phase, but during mid-cornering it is correcting itself towards neutral behavior, then the AttVel is larger than AngVel for a short while. This could lead to the wrong conclusion that the car is oversteered, where it is just correcting itself into less understeer.

When overlaying both signals you see that the AttVel often shows a more squiggly line than the AngVel: not only the inertia of the car in longitudinal direction is larger than the inertia around the Z-axis, resulting in a more stable AngVel, but the driver has a large influence on the AttVel too with his steering wheel and throttle.

This leaves us with two questions remaining.

First question is: “What is the value of the AttVel and AngVel signals.”? The AttVel provides useful information concerning the attitude or the stability of the car. Analyzing this signal in combination with the steering and throttle input might lead to some serious conversations with the driver. And what about the AngVel? Well, in theory you need to know this to calculate the corner radius, but what the heck, your GPS-system has already been doing that. Still you can use it for a sanity check: if your car is doing a 180 degree corner with a radius of 30 meter, that car might be cornering for let’s say 3 seconds. This should result in a AngVel of 3 sec per 180 degrees, which is 60 degrees/sec or approximately 1 rad/sec. This is a very good short exercise for students to quickly learn to judge whether the DA-system produces meaningful data. A result of e.g. 20 radians/sec in this example should activate all alarm bells. (really happened to a student of mine)

Second question is: “If I cannot compare AttVel vs AngVel to determine under/oversteer, then how am I supposed to determine this”?

There are basically three answers to this question.

The first option is that you calculate this, e.g. for a bicycle model of the car with the aid of the AttVel:

Neutral steering angle $\delta_{neutral}$ = AngVel [rad/s] * wheelbase [m] / v_x [m/s].

Compare this value with the actual measured steered angle of the outer front wheel (not from the steering wheel!): $\delta_{understeer} = \delta_{steer} - \delta_{neutral}$. Be aware that these are in radians. In simple words: if the front wheel steers at a larger angle than required in a neutral steered car, $\delta_{understeer}$ gets a positive sign, meaning understeer. A negative sign indicates oversteer. In our book 'Race Car Handling Optimization' you will find more methods to measure and calculate over/understeer.

The second option is a bit more accurate since it takes the slip angles into consideration. You can choose between using a bicycle model of the car, or to use the four wheel model. Calculate the slip angles of the front and rear tyres, and compare these with each other. In case the front slip angles are larger than the rear slip angels the car is understeered. The major challenge with this method is that the lateral velocity v_y is required to calculate the slip angles, not all DA-systems provide the proper function to generate the instantaneous value (not the total value!) of the integral from a_y.

The third option is to calculate the under/oversteer gradient. However, although this gives you an interesting insight in the behaviour of the car, it does not provide a real understeer angle in degrees.

To get the best overview of the cars behavior is to use all three methods simultaneously, and compare the results. For students with their laptop skills: a piece of cake!

Wanna know more? Please let me refer you to our book:

Race Car Handling Optimization (ISBN 978-3-658-47190-3).

About the author: Ton Serné is mechanical engineer, former racing driver & team manager, specialized in Vehicle Dynamics. Co-author of the book *Race Car Handling Optimization*, guest lecturer at the Minor Motorsport Engineering at Fontys University of Applied Engineering, Eindhoven, Netherlands, member of the jury in Formula Student, and many more assignments, see LinkedIn.