Background to Mercedes W196 physics

I have to admit that when Bob asked me to help with the physics for the W196 I didn't know much about the car at all other than it had been dominant in the 54 and 55 seasons. From there it was a huge, but incredibly interesting, learning curve in gathering technical data on the car and understanding something about its dynamics. Perhaps surprisingly for a car of its era, there is a large amount of technical data available and a number of really useful books covering the car have been written – there is a list of relevant references at the end of this note for anyone who is interested.

Bob and I agreed on what we wanted for the car and there were really three main requirements for the physics

(i) Driving the car should be challenging at every level so that there would always be more to work towards. GPL was a role model in this respect and if we get to even half way to how that presents an on-going challenge then this goal will have been met.

(ii) Driving the car should be fun, rewarding the driver who is works towards getting the most out of the car.

(iii) The physics should be as representative as possible of the car as it was and we would use accurate technical data, to the extent that this was available, as a basis.

The W196 is very different to anything done in rF previously with the principal differences being the high ratio of power to tyre grip and the swing axle rear suspension. In addition the slip angle at which peak lateral loads are developed are higher than for more modern cars included in rF.

There wasn't a lot of detail on the tyres except that lateral load levels of between 0.75 g and 1 g had been reported. We started at 0.75 g but this proved very difficult to get a good feel with in rF. The best that could be done at this level was very demanding to drive and we never got to anything that could be considered acceptable. From there the grip levels migrated upwards and we decided on a 1 g level as being the most we could get away with. We acknowledge that this is slightly too high to be historically accurate but is what we chose for the first release of the mod to allow a bit more fun. The grip levels will be reduced in the final release of the mod when we do all the cars and hopefully by then those who want to drive the cars will be more familiar with low grip tyres in rF. Something else a little different in these tyres compared to most of what's in rF is that we have chosen to use reasonably high sensitivity of friction factors to vertical load as is typical of most available tyres as available data suggests this is a more realistic approach. It also affects the way set up changes work and has a subtle but important influence on driving close to the limit.

There isn't any direct info on slip angles for peak lateral load for the tyres used on the W196 but there are a large number of references to the values being between 10 and 20 degrees for typical tyres of the time. We chose to go with 10-12 degrees, higher would have been preferable but the extra rotation demanded of the car and the inevitably lower cornering stiffness makes the dynamics more of a challenge to get right. A number of options were considered for slip curves and different curves were used front and back to reflect the different size tyres and also to affect balance across the range of slip angles in a particular way. The slope of the curve is lower initially for the rears but this means that, when including the additional vertical load, the actual cornering stiffness at low slip angles is closer to that at the fronts. The effective slope at the rears is also affected by application of throttle which reduces the slip angle for peak lateral load. The net effect of the different curves is to give a car that is responsive to initial steering input but understeers approaching it's limits (at low and medium throttle levels or higher speeds) and the oversteer tendency on higher throttle at lower speed is controlled. Hopefully this means it is easy enough to drive below the limit but challenging to drive approaching the limit, requiring precise setting up at corner entry to get to the apex at the right speed and yaw angle so that throttle can then be used to control the car on exit. The car doesn't tolerate corner entry that is too fast as the understeer means it won't be at the right angle at the apex and being too fast at that point means throttle can't be used to rotate the car sufficiently.

We appreciate there will be many who believe the understeer is overdone, however, the nature of the tyre model – or at least the way we've been able to use it to date – is such that removing some of the low thrust understeer seems inevitably (assuming there isn't too much fudging of parameters) to lead to excessive tail happiness on corner exit. There is very little photographic or video evidence of the W196 being well sideways on corner exit so for now we have probably erred towards too much understeer in the low thrust condition. Hopefully the challenge that presents in terms of controlling the car will be seen as something to have fun with rather than being a frustration. This is something we are working on to improve by time the complete car set is released (and that will include a number of cars that were visibly tail happy and can be driven like that).

The sensitivity of slip angle for peak to vertical load is relatively small, in the tyres as defined, compared to what might be seen as typical in rF. There is some data available that suggests that for bias-ply tyres the slip angle for peak may actually decrease with increasing vertical load hence the approach adopted is to allow for only a small amount of sensitivity.

The current release does not include any speed sensitivity for the tyres. This is probably wrong but we have been unable to unearth any significant evidence indicating by how much it is likely to be wrong. There is reference in Ludvigsen's "Last of the Silver Arrows" to a reasonably significant reduction in cornering power at high speeds but its not clear the extent to which this is directly related to the tyres. The preceding comments may, however, simply be an excuse for not yet finding a satisfactory solution to retaining reasonable driving feel at lower grip levels! In any event, this issue has been left open for further investigation before release an update with the full car set.

The thermal characteristics have been set to ensure operating temperatures of between 50C and 70C for most tracks. The tyres probably get up to temperature a bit quicker than they should but there is not any significant information on what heat up rates would have been. The optimum temperature is set as 57C. The optimum pressure is around 200 kPa (29 psi) but does vary with vertical load. The temperature and pressure sensitivity is not particularly strong, with the starting condition giving grip levels around 97% of the final levels (this is more sensitive than many rF mods but not approaching GPL's <95% starting condition). The low sensitivity has been selected since we have not found any information suggesting temperature sensitivity was a major issue for the tyres. The sensitivity to temperatures above peak is more significant and, if you can drive the car hard enough to see a temperature of 20C above the optimum the drop off in grip will be significant (>10% for the rears).

The tyres play a large role in the desired handling but the suspension also has a major influence. The front is a "conventional" double wishbone suspension with the top members slightly shorter than the bottom members. This means that for a given chassis roll angle the outside front loses negative camber and the inside front gains negative camber (including tyre deformation, there is very nearly 1 degree camber change per degree chassis roll).Both the fronts therefore lose lateral load capacity with increasing cornering load factor but the effect for the more heavily loaded outside front is greatest. This promotes understeer with increasing cornering load.

The swing axle at the rear behaves very differently to a double wishbone suspension. In cornering the lateral load on the outside rear imposes a moment that is in the opposite direction from that associated with the vertical load, i.e. it wants to pull the axle down rather than push it up. The tendency is opposite on the inside rear but since the forces are lower than at the outside, it is the situation at the outside that dominates. Although the axles are pivoted relatively low and at the car centreline, there is still a significant resulting jacking force that tends to raise the rear as the cornering force increases. The common pivot location for the axles means that both sides must experience the same camber change (in practice slightly different due to deformation of the tyres). The jacking force, in raising the rear therefore causes a reduction in negative camber for both tyres. Although this is favourable to grip for the inside rear, the negative effect for the outside rear dominates and there is a net loss in potential cornering force for the rear. This causes an oversteering tendency. This is typically weaker than the understeer tendency described above for the fronts since the geometry is such that the camber changes in cornering are less at the rear (for a neutral longitudinal situation the camber change is something less than 0.5 degree per degree of body roll, i.e. less than half of that observed at the front).

The situation changes somewhat as longitudinal acceleration comes into play. Acceleration tends to improve (in the sense of allowing improved cornering) the camber angles at the rear while worsening those at the front. This might be expected to contribute to understeer. However, the longitudinal loads on the rear tyres reduce their lateral capacity so the application of throttle is likely to introduce more oversteer than it mitigates through the camber change. Braking tends to reduce lateral grip at the rear through both effects but the associated camber change can improve the situation at the front.

The way the suspension affects camber changes as mentioned above, and bearing in mind that the car is relatively softly sprung by modern standards so pitches and rolls a fair amount, means that the camber sensitivity of the tyres has a major effect on behaviour. A tyre running at a camber angle generates a lateral load (even at zero slip angle) through camber thrust. Hence for a given slip angle a tyre with favourable camber will generate more side load than a tyre at zero camber. Data for real tyres shows this effect is most pronounced at small slip angles but then drops off as the slip angle for peak is approached. This phenomenon, called "roll-off", does not appear to be fully modelled in rF and the gain in grip at higher slip angles is appears to be overemphasised. Our initial intention was to provide the tyres with realistic camber stiffness values (based on available bias/cross-ply tyre data) but this made for larger effects approaching the slip angles for peak and introduced a more significant understeering tendency – due to the way the fronts lose camber - approaching peak lateral load. To achieve more realistic behaviour at the limit we have used camber sensitivity values that we believe reflect a lower than realistic initial camber stiffness. Nevertheless, the car does seem to retain some of the characteristics imparted by Mercedes' unique approach to the suspension.

Available information and photographs suggests the suspension was set to give a small amount of negative camber for the static condition so this setting has been fixed at -2.5 degrees. A normal running camber of -3 degrees has been reported for the rears and this is the default in the set up but can be increased to -5 degrees to allow for the natural variation that would occur when starting long races with full, i.e. up to 175 kg, fuel. Perhaps the front should allow some camber change in the settings to cater for this but the effect of fuel load on front ride height is much less than at the rear (the fuel tank location had the fuel mass essentially over the rear axle).

The suspension geometry was developed using a number of available drawings as a guide. At the time it was started we didn't understand the mysteries of the CorrectedInnerSuspensionHeight (CISH) parameter (we still don't!) and how the suspension should be set out for the default situation. Hence we chose not to have CISH =-1 (default) but to position the final vertical locations of the suspension attachments to the chassis by adjusting CISH. The only way to be sure this was reasonably accurate was by testing and extensive tests were run measuring tyre loads, camber angles, body roll etc to make sure the actual behaviour was as per the correct suspension layout. The CISH was therefore set to ensure that (i) the camber angles match those predicted for the geometry, (ii) the tyre vertical load vs suspension deflection curves in cornering match those predicted - including the unusual characteristics of these curves, introduced by the swing axles, for the rears – and (iii) the lateral load transfer ratios for given spring settings matched those predicted. This involved a significant amount of additional analysis and, although the results of (iii) were, for a number of reasons, never entirely satisfactory, we believe the CISH value gives the suspension overall characteristics similar to that of the original (whether or not the chassis side pick-ups are indeed correctly located!).

The front steering geometry is defined to minimise bump steer and have no Ackermann effect. It is not accurate in the latter as the actual steering is understood to have included a small amount of anti-Ackermann. This will be addressed in a revision before release of the complete 1955 car set. Depending on driver feedback we'd also be prepared to consider a front suspension with geometry optimised through Carfactory, but giving relationships between key parameters that remain largely historically correct, for the final release.

Its also worth mentioning that the W196 used torsion bars, rather than linear springs, front and rear. There isn't a facility to model this directly in rF so we elected instead to use long linear springs positioned vertically directly over the spindle in each case. The intent was to allow the spring rate to define the wheel rate and to ensure linear load-deflection behaviour over the full range likely to be encountered (not historical obviously but would ensure predictable behaviour). Measurements revealed, however, that even in this situation the wheel rates were not equal to the spring rates so some correction factors had to be applied. The corrections used were established by test to ensure that the wheel rates reported in the set up are close to the actual wheel rates. The ranges allowed for front and rear are similar to those reported for the actual cars and three options are provided for each (significant tweaking of set up parameters at the track before a race was not yet happening in 1955). A single anti-roll bar setting is allowed at the front (this based on historical information). We are not certain that the stiffness selected provides additional front roll stiffness exactly matching that of the original but believe the effect to be similar.

Available information covering the chassis (mass, tracks, wheelbase etc) has been used where possible to define parameters in the hdv file. Some of these variables changed with Mercedes' ongoing development of the W196 but we have tried to use values we think are generally representative without trying to fix it down to the configuration used in one particular race.

The aero drag has been set based on Cd figures published for the open wheeler and also considering the maximum speeds at Spa. The car does not include any lift or downforce as there is no data indicating the likely situation. If any reliable evidence one way or another comes to light on this topic it can be included in the final release.

The W196 used a ZF diff. Before wear this gives between 40% and 50% locking for the power side (based on data published in Pomeroy's book). Unlike ramp and clutch diffs, the cam and pawl ZF was not adjustable so ideally we should probably only have one setting. However, these diffs are understood to have suffered reasonably rapid wear and locking capability diminished with wear. We have taken this into account – i.e. used it as an excuse – to allow for lower diff locking settings that will accommodate a wider range of preferences from drivers. The factors allowed are 25%, 35% and 45% for the power side. For reference, GPL with a 45 deg ramp angle and three clutches gives a locking factor of about 30% so the 35% and 45% settings do mean a degree of finesse is needed.

The ZF was effectively open in coast but a small amount of preload (20 Nm) and a minimum of 10% locking is included for friction effects. This corresponds to a 60 deg coast ramp with one clutch in GPL (for which most of us started with 30 deg coast and at least one clutch giving locking factors typically around 20% or higher). Recognising that in sims we don't get all the cues to help with running a minimally locking diff in coast, we have allowed for up to 30% locking (something a bit less than 30/3 coast for GPL).

The engine torque curve is based on published data for the M196 as late in the 1955 season. The engine could rev to over 9000 rpm (the use of desmodromic valves made it tolerant of some abuse) but the drivers were told not to run at 9000 rpm for more than 4 secs at a time and running at 8700 rpm was restricted to 20 seconds per event. Ideally we would want the engine to include damage that would ensure failure when run too long at rpms approaching 9000 and beyond. This will be included in the final release but for now we have taken the decision to restrict rpm via a limiter to 8750 rpm. We think this will make for fair racing without requiring too much attention to looking after the engine.

The fuel consumption has been set to match that published and should be around 7-8 miles per imperial gallon.

The gearbox as is includes nine final drive ratios covering the range known to be used. In addition it includes a wide range of individual gear ratios, probably many more individual gearsets than were actually produced for the cars. However, we understand that Mercedes carefully investigated the requirements for each track in advance and would optimise the gearing accordingly. Given that we're likely to run at a wider range of different tracks it seems reasonable to allow for more options in our gearing. In many cases however an acceptable solution will be found by changing just the final drive without any need to change individual gears.

The steering travel was originally set considering wheels with 360 deg (or less) travel and was such as, at maximum, to correspond to the actual tyre angle. Newer wheels with >360 deg travel demand more angle change to ensure a reasonable level of sensitivity. Hence the maximum allowable tyre angle has been increase to 40 degrees. This is unrealistic as a maximum and clashes with the bodywork but allows one to use a >360 deg travel wheel without making other adjustments. There doesn't appear to be any real solution to this but at least one doesn't actually use anything close to the 40 degrees in practice and the range used remains reasonable. Steering sensitivity has a strong effect on how the car feels to drive so is actually an important set up parameter.

FFB has been set to work with standard rF approach or RealFeel. The actual cars had around 6 degrees caster. We have chosen to limit this to 3 degrees maximum to accommodate RealFeel. You may want to reduce this further to have less of a centreing spring effect at small slip angles. There will be a small additional understeering tendency with reduced caster but probably not enough to influence a preferred FFB feel.

Although we've tried to include what we think is the best available technical data covering the car where possible, there obviously remains much we don't know, are unsure of or are just plain wrong in. We think that releasing the single car now is a great way to get feedback on the physics that we can use to improve the final car set so would very much appreciate your comments and suggestions for improvements.