HAPPINESS IS... A SPREADSHEET?

It might not have been the most conventional Christmas present, but a spreadsheet that analysed suspension behaviour was too much for **Graham Templeman** to resist

WHEN Race Tech heard about a spreadsheet that analysed suspension behaviour once the user had input the basic information, it seemed like a good idea to see how well it worked. The main attractions for practical racers are that it uses the familiar spreadsheet approach, works on the absolute bare minimum of input data and, at €99, costs less than half of any of its competitors.

The spreadsheet in question is called Dynatune SDM and is the Suspension Design Module for a suite of programs developed by Paul Fickers under the generic name of Dynatune-XL. Together, these provide suspension analysis and a collection of dynamics ride and handling tools.

The website claims that these are based on knowledge acquired over many years on various different vehicle types. A sceptic, looking for proof, would soon find that Fickers' experience is very impressive. A résumé that includes, amongst other things, working as a chassis and dynamics engineer at Stewart Grand Prix, vehicle integration manager for Ferrari, Head of Vehicle Engineering at Maserati and Head of Vehicle Testing for all vehicles in the FIAT Automobiles group, shows that this is obviously not some kid in a bedroom with a computer and a copy of Milliken. In fact the programs have been developed by Fickers throughout his professional career and the journey which started with a VAX computer has travelled via ADAMS and Lotus 123 to its current incarnation in Microsoft Excel.

What you get for your €99 is a spreadsheet that consists of a Master Dashboard where the coordinates for the suspension pick-ups and other data are entered and the key results are displayed. We used the program for a double wishbone set up and needed only to provide 12 suspension pick-ups, and other data such as static settings for camber and caster and rack and spring travel. The output on the Master Dashboard is a table of static results and a series of 30 graphs showing a wide range of vital data such as camber gain with roll and with steering, motion ratio, roll centre lateral migration, steering ratio, Ackerman percentage and so on.

The key results on the Master Dashboard are backed up by a separate Results worksheet in which there are about 80 columns of data showing all sorts of extra information. Here you will find not only the virtual swing axle length but also its longitudinal equivalent and lots more besides. For example the tyre contact patch displacement is shown both laterally and fore and aft: you can also find the theoretical Ackerman angle and the actual angle and the differences between these. Because all of the intermediate calculation results are visible (and can be referred to in workbook formulae) they are available for whatever post-processing the user chooses to do.

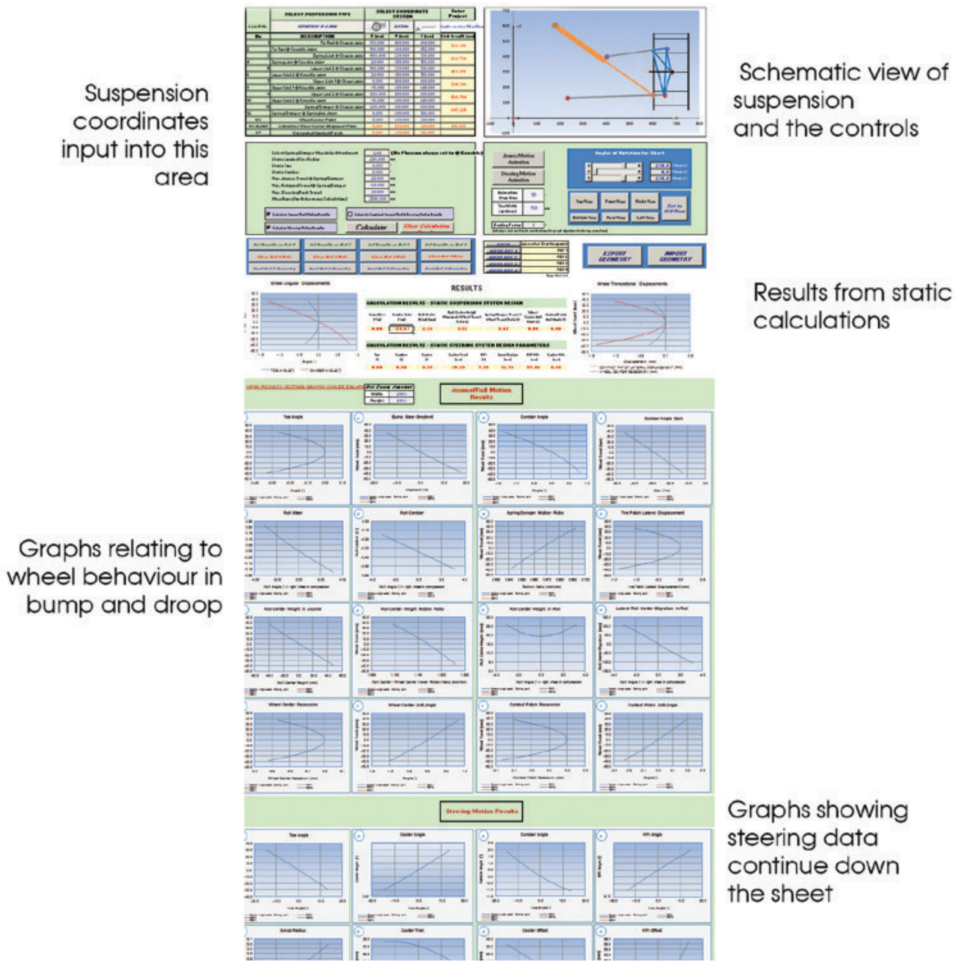
In addition to the output of the current set of results, it is possible to transfer up to four more into a series of Reference Sheets to save them for later. Any set of parameters can also be saved as a geometry set to be reloaded for future reference. This is the old-fashioned equivalent of saving your work as you go and you quickly slip into the habit of creating saved sets.

No doubt for reasons related to the automotive industry background of the spreadsheet's designer, some of the metrics produced are a little unfamiliar and are worth further discussion. One of these is the ratio of roll centre height movement to wheel travel. Given that weight transfer is influenced by the distance between the centre of gravity and the roll centre height, aiming for layout that keeps the ratio close to unity is going to preserve the car's balance under all conditions. So if your proposed layout has a ratio significantly different to 1:1, or the front and rear numbers differ significantly, then it is time for further work.

Another feature of the static output that might seem a little unfamiliar is the way that anti-dive or anti-squat is expressed as a number of degrees at the wheel centre or the contact patch. This is a side effect of the minimalist approach to data input. A proper calculation would need the centre of gravity height and the proportion of the brakes at that end of the car. Armed with such extra information and a bit of trigonometry we could use some of the user-definable worksheet to do the necessary calculations in percentage form.

For people who use Excel on a frequent basis, there is something comforting about using spreadsheet cells rather than a series of dialogue boxes, but the joys of familiarity are lost to a certain extent by the various protections that are built into the spreadsheet. To protect the integrity of the spreadsheet and the intellectual property that it represents, many cells are

BELOW The broad layout of the master dashboard worksheet where data is entered and results displayed



BELOW The static results

RESULTS

CALCULATION RESULTS - STATIC SUSPENSION SYSTEM DESIGN PARAMETERS						
Bump Steer [°/m]	Camber Gain [°/m]	Roll Center Height [mm]	Roll Center Height Movement / Wheel Travel Ratio [-]	Spring/Damper Travel / Wheel Travel Ratio [-]	Wheel Center Anti Angle [°]	Contact Patch Anti Angle [°]
-0.01	-43.86	50.90	1.06	0.65	-1.59	-2.28

CALCULATION RESULTS - STATIC STEERING SYSTEM DESIGN PARAMETERS							
Toe [°]	Camber [°]	Caster [°]	Caster Trail [mm]	KPI [°]	Scrub Radius [mm]	KPI Off. [mm]	Caster Off. [mm]
0.00	0.00	4.93	27.93	9.78	4.14	47.24	6.38

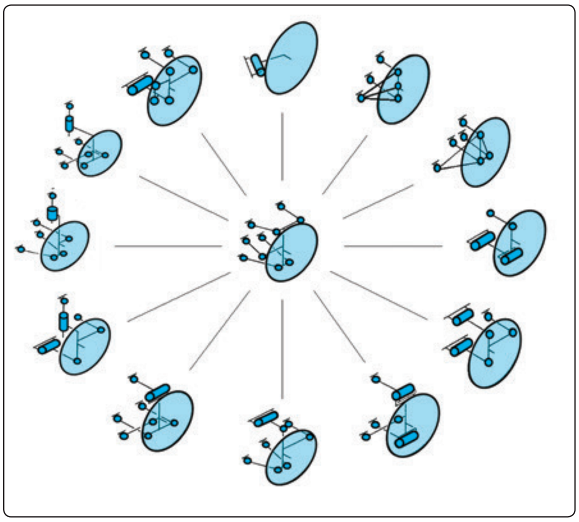
not accessible. This is OK, but it is a shame that some other spreadsheet tools are not available.

One obvious one is that Excel's goal-seeking is disabled so you cannot, for example, ask the machine to find a track rod vertical coordinate that provides zero bump steer. In a similar way, although the user is provided with a blank sheet to use in whatever way he or she wants, the ability to insert extra sheets is not available. The easiest work round is simply to open another spreadsheet and work in that, reserving the User worksheet for collecting key results.

The spreadsheet is based on a generic five-link layout and from these five links, 12 different suspension types can be created. These include double wishbones, McPherson strut, twin parallel link and strut rear suspension popular on front-drive cars and BMW's five-link rear end. From the data entry point of view, this takes a bit of getting used to, because a naming convention that preserves the flexibility to use this small input table to create several different layouts means that the names are not necessarily what you would expect. Luckily there is a geometry file for each of the 12 variants, so these coordinates can be modified to suit. Each time a coordinate is updated, the outline graphic updates, so it is a simple job to identify which link has which label. A short time spent playing around soon allowed the creation of the translation table shown as Table 1 overleaf.

The spreadsheet is not specifically set up to deal with pushrods and rockers but it does the important part of the job. As the translation table shows, we treated the spring damper unit as a pushrod, so that the motion ratio is evaluated. We now need to make sure that the rocker operates in the correct part of its range with the rocker mounting pivot at right angles to the pushrod. Then it simply becomes a matter of multiplying the two motion ratios (pushrod and rocker) together for the calculation of the wheel rate.

Since there was already a suspension model available for the Race Tech 750 project, this presented a good test of the new software. The existing model had been prepared using another piece of budget software, Susprog. The first difference to note is that Dynatune works with a very small data set which simplifies the input process considerably. A good example of this is how the wheel offset is specified. Dynatune effectively needs just one number – the horizontal distance from the centre line of the car to the centre of the wheel. This can be measured relatively easily since modern wheels have their centreline offset marked on them in the shape of an ET number.



LEFT The 12 variants that can be 'built' from the five link suspension

BELOW A simple table was compiled to translate from engineering speak into British English and the blue column was stuck near the computer screen. Speakers of other variants of English will no doubt substitute A Arm, Knuckle and Kingpin as appropriate

TABLE 1

Number	Dynatune Name	'British' English Translation
1	Tie Rod @ Chassis Joint	Steering Rack End
2	Tie Rod @ Knuckle Joint	Track Rod End
3	Spring Link @ Chassis Joint	Bottom Wishbone Rear Chassis
4	Spring Link @ Knuckle Joint	Bottom Wishbone Rear Upright
5	Lower Link 2 @ Chassis Joint	Bottom Wishbone Front Chassis
6	Lower Link 2 @ Knuckle Joint	Bottom Wishbone Front Upright
7	Upper Link 1 @ Chassis Joint	Top Wishbone Front Chassis
8	Upper Link 1 @ Knuckle Joint	Top Wishbone Front Upright
9	Upper Link 2 @ Chassis Joint	Top Wishbone Rear Chassis
10	Upper Link 2 @ Knuckle Joint	Top Wishbone Rear Upright
11	Spring/Damper @ Chassis Joint	Pushrod Top
12	Spring/Damper @ Springlink Joint	Pushrod Lower

This represents the distance of the hub face of the wheel to the centreline of the wheel. So the lateral wheel centre coordinate is:

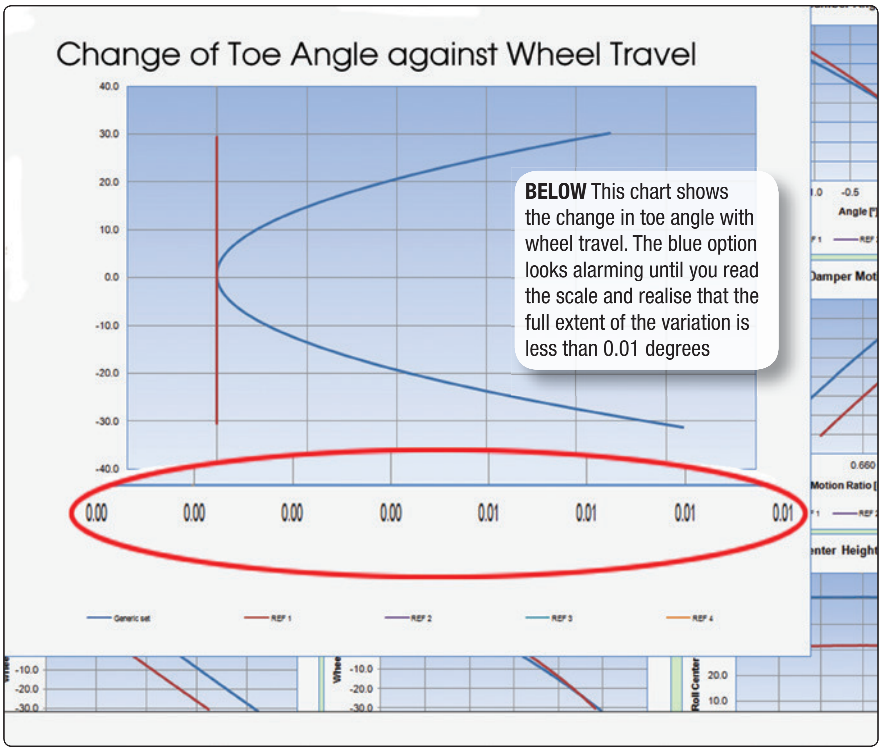
(Distance between hub mounting faces on the car ÷ 2) - ET Number for the wheel

This is much simpler than Susprog, which specifies this by requiring a full set of coordinates to define the upright and also needs the wheel offset.

To test the spreadsheet, the obvious starting point was to compare results from the T5 as designed in Susprog and represented in the Dynatune equivalent. It would not be fair to carry out some form of comparative 'road test' since that implies an equal and considerable knowledge of each package. Rather, Susprog was used to provide a sanity check for the Dynatune numbers. Apart from the axis naming conventions this was straightforward.

The T5 model had been created using an arbitrary system (an option on Susprog) whereas Dynatune strongly recommends the SAE recommended axis system. Nevertheless, the results were all but identical as regards both geometry and output since both programs provide link lengths as a further check of accuracy. The exact format of the output differed in the two packages with Susprog producing tabular results layouts and Dynatune creating 30 graphs in addition to making a huge results table available to you. Susprog does provide the facility to export to spreadsheets but it is a technique that has so far eluded this computer operator! Bearing this in mind, the results seemed to be a pretty good match.

A fairer test was to start from scratch to see how easy it was to home in on a layout that dealt with all the compromises that suspension design inevitably involves. The answer was that it was very easy indeed. Whenever a coordinate was changed it showed up immediately on the slightly inelegant but very effective rotatable outline diagram that cost Ficker an enormous of effort to program it in Excel. The ability to see the key results immediately and then to scroll through the other related graphs helped home in quickly on an acceptable solution. Each of the 30 small charts can be expanded with a single mouse click, although it was necessary to keep an eye on the scaling. The effects of this can be seen in the chart below. ▶



BELOW This chart shows the change in toe angle with wheel travel. The blue option looks alarming until you read the scale and realise that the full extent of the variation is less than 0.01 degrees

After creating a successful generic sports car front suspension, one thing that was investigated was the addition of caster angle to see its effects on camber. The 750 Formula must have been one of the last formulae to make the transition from bias ply to radial tyres and one of the bits of advice that we got from the tyre technicians was that it was important to run more negative camber. There was also a bit of 'conventional wisdom' doing the rounds that rather than adding static camber, it could be added dynamically by increasing the castor angle. So the arrival of the Dynatune spreadsheet was an opportunity to assess the efficacy of this adjustment.

One of the built-in steering motion results graphs shows the change in camber caused by steering input, so this was a simple enough task to investigate and the results are shown in the graph. A reasonable working range for caster angle seems to be somewhere between two and eight degrees. In most circumstances, the lower figure, two degrees, would give very little self-centring; five is the figure used on the current car and personal experience indicated that at eight degrees the feel was beginning to get intrusive. Given that the maximum steering angle normally seen (Mallory Park Hairpin excepted) is in the region of 10 degrees, there is a benefit of an extra half degree of camber from this modification. Whether the side effects justify the change can best be measured on the stopwatch.

Another investigation that was carried out was to look at the rate at which the combined effects of steering and body roll pulled extra negative camber on to the outside wheel. This needed a reasonable degree of spreadsheet skill, because it needed lookup tables to choose the appropriate values from the results table. The calculations were done for 1.3g and 1.8g (dry and wet weather figures) and for a range of corner radiuses from 20m (a hairpin) to 250m (a fast bend). Steering angle was calculated as:

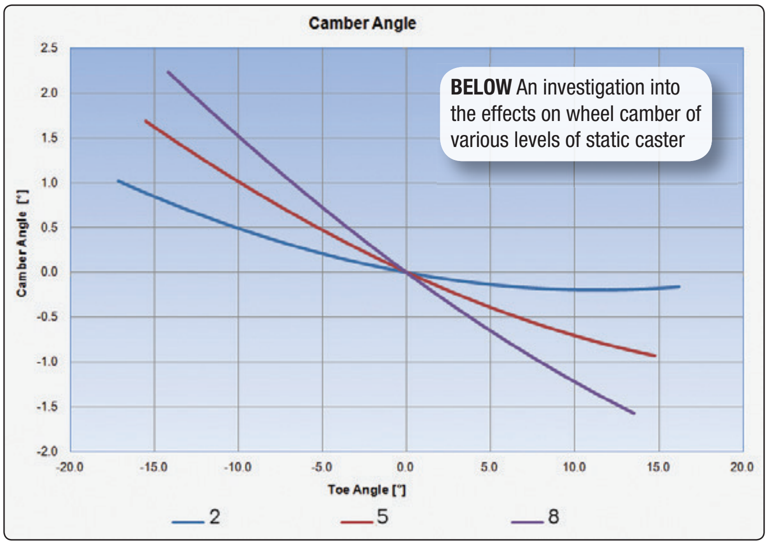
Steered Angle of Front Wheels = 57.3 x (Corner radius ÷ Wheelbase)

As can be seen from the table, it is possible, with a reasonable level of spreadsheet skill, to dig amongst the results to extract further useful information to answer specific questions. Here the answer is that the difference in cornering power in the wet and in the dry does mean less camber gain, but that the difference is fairly minimal compared to the differing requirements of dry and wet-weather tyres. Another bit of information to put away and save for a rainy day.

In the end, this piece took much longer to write than is normal, for the simple reason that there was always something else that could be investigated using the spreadsheet. That simple fact speaks volumes for how easy to use the program is and how informative it can be. But it does raise the issue of how big a time sink the ride and handling spreadsheet could be!

TABLE 2 Investigation of camber increase with body roll and steering input

Corner Radius	Steering Angle for Corner Radius	Camber Gain from Body Roll	Camber Gain from Steering	Total Camber at 1.8g	Total Camber at 1.5g
20	7.16	-0.98	-0.54	-1.52	-1.24
30	4.78	-0.98	-0.38	-1.36	-1.08
40	3.58	-0.98	-0.29	-1.27	-0.99
50	2.87	-0.98	-0.23	-1.21	-0.93
60	2.39	-0.98	-0.2	-1.18	-0.90
70	2.05	-0.98	-0.17	-1.15	-0.87
80	1.79	-0.98	-0.15	-1.13	-0.85
90	1.59	-0.98	-0.13	-1.12	-0.84
100	1.43	-0.98	-0.12	-1.1	-0.82
110	1.3	-0.98	-0.11	-1.09	-0.81
120	1.19	-0.98	-0.1	-1.08	-0.80
130	1.1	-0.98	-0.09	-1.08	-0.79
140	1.02	-0.98	-0.09	-1.07	-0.79
150	0.96	-0.98	-0.08	-1.06	-0.78
160	0.9	-0.98	-0.08	-1.06	-0.78
170	0.84	-0.98	-0.07	-1.05	-0.77
180	0.8	-0.98	-0.06	-1.05	-0.77
190	0.75	-0.98	-0.06	-1.05	-0.77
200	0.72	-0.98	-0.06	-1.04	-0.76
210	0.68	-0.98	-0.06	-1.04	-0.76
220	0.65	-0.98	-0.06	-1.04	-0.76
230	0.62	-0.98	-0.05	-1.03	-0.75
240	0.6	-0.98	-0.05	-1.03	-0.75
250	0.57	-0.98	-0.05	-1.03	-0.75



BELOW An investigation into the effects on wheel camber of various levels of static caster