



**TGM TYRE TOOL
QUICK START**

JULY 2013

Updated 25th July 2013 (Relevant to build 240)

Consider this a concise guide to the TGM. Actual tyre design is largely beyond the scope of this document, though a few pointers are provided.

Firstly, the rTrainer is provided as our example mod. It is distributed along with rFactor 2 SDK in your `rFactor 2\ModDev\Vehicles\rTrainer\` folder. This is a good starting place when creating your own mod / vehicle tyres. For those at a more advanced stage, you may consider unpacking the TGM files available on the website's Dev Corner (<http://rfactor.net/web/rf2/devscorner/>) and basing your own tyres off the most similar tyre example that we offer.

A multiple tab text editor (such as Notepad++) is recommended to edit physics parameter files. A tool like WinMerge can also prove invaluable to make text file comparisons. You may also find a spreadsheet application (such as LibreOffice.org) or other design tool invaluable to assist in the initial analysis and design of your tyres.

Some abbreviations

- AI – Artificial Intelligence
- CTD – Crash to Desktop
- DOF – Degrees of Freedom
- LD – Lookup Data
- QSA – Quasi-Static Analysis
- QSM – Quasi-Static Model

TBC

The TBC must reference one or more TGM file(s) – (every instance must point to a single TGM). The TBC is used for AI physics, while the TGM overwhelmingly defines the player tyre physics.

Although we still obtain the 'starting temperature' from the TBC, as well as the rim radius. We also obtain suspension pick-up points and set ride heights via the TBC, meaning a strong correlation between the static loaded radius of the TGM and TBC is ideal to achieve the best results. In other words the cars' static garage ride height should not vary when switching between tire models (possible to verify by pressing ALT+T in developer mode). It should also be noted that this dependence is likely to change in the future. Aside from these attributes, the TBC is pretty much exclusively used for the AI.

TGM

The TGM is in essence a brush model, using a 6-DOF rigid ring to simulate frequency modes. A brush model being one through which the tyre surface essentially made up of a bunch of bristles, each capable of providing surface interactions with the ground. In our TGM model, a highly sophisticated quasi-static model is tested over a wide range of conditions to supply adequate information to generate a detailed lookup table. This resultant data is able to be processed quickly enough for the real time model to sufficiently run in a real time environment at high sampling rate, providing accurate behavioural results.

There are 4 main sections to the TGM file;

1. The [QuasiStaticAnalysis] (QSA) section, used to generate testing ranges for the lookup table, also defining the bounds of what the lookup data table is. So it's rather important not to change these values, unless you are doing so in order to generate a new lookup table dataset. Altering these entries without properly generating a new lookup table may result in CTD's, or inaccurate behaviour of your tyres whilst running the real time model.
2. [Node] you will find a lot of these entries in the TGM file, they are the physical locations and properties for each node. These enable rF2 to calculate mathematically how your virtual tyre dimensions and stiffness properties. Note that changes made within, require regeneration of the entire LD (lookup data) table in order to be experienced in the real time model. The exception to this being the thermodynamics model, whose definable parameters include, specific heat, thermal conductivity and the mass required for these calculations (derived by the density and volume). Note however, that changing mass without generating a new LD table, will result in an inaccurate tyre behaviour (especially at higher speeds), so changing mass is ideally accompanied by regeneration of the LD table.
3. [Realtime] defines properties specific to the real time model. This is a separate model from the QSA model, though requires data generated from the QSA model to fulfil it's obligation. These entries primarily define the surface/tread rubber properties in ground contact, such as grip, abrasion rates, and so on.
4. [LookupData] is data generated by ttool (discussed in depth later), there's no need to touch this section. This is essentially a representation of testing results obtained used to define the physical properties of the tyre, such as carcass rigidities, growth rates, etc, and how these change over a wide range of conditions (as dictated to, by the [QuasiStaticAnalysis] section).

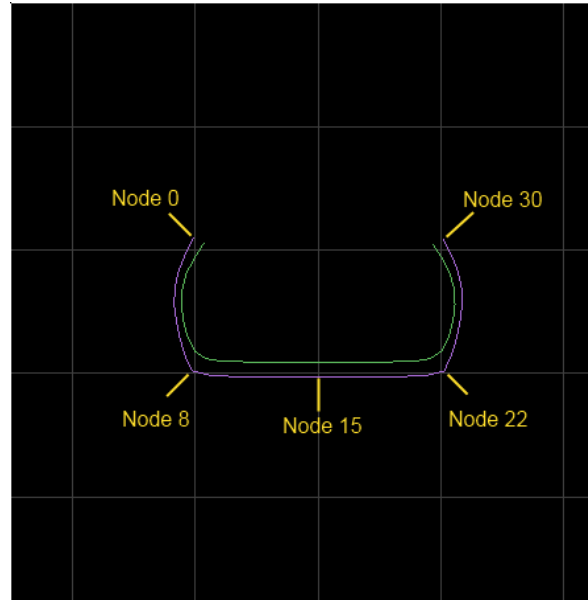
All units within the TGM are SI units, i.e. Temperature in Kelvin, Density in kgm^3 , Pressure in Pascal, etc.

Definitions

[Nodes]

Geometry = Location of the node X (lateral displacement from centreline), Y (vertical displacement from centre), T (Thickness of the node). X, Y define the outer surface of the tyre, while the inner co-ordinates are derived from the thickness values. As we assume a tyre to be perfectly round there is no need to define a Z axis, this allows us to create a cross section profile. As seen below.

This image was taken from ttool, with a previous generation of rTrainer tyre. Here the purple line represents the connected outer nodes, as defined by the first 2 values within "Geometry=" for every node. The inner green line is derived from the thickness at each node. The yellow marked positions were added manually to denote easily identifiable nodes, and to show the ordering. In this particular tyre, nodes 0 and 30 connect to the wheel rim. Nodes 8 and 22 mark the extremities of the tread area. While node 15 is the exact centre of the tyre. The number of nodes and position are fully adjustable, though it's recommended to stay in the range of about 33-49 nodes, depending on your hardware and requirements. The more nodes, the better the potential accuracy of the model, at the expense of longer the table generation times (and slightly larger file sizes, though this should not be a concern). You can expect an approximately linear increase in computation times with the number of nodes, but you will probably want to add circumferential sections ("NumSections=") to accompany increases in the number of nodes. Thus, doubling the lateral nodes, and sections would result in an approximate 4-fold increase in computation times. However, a positive aspect of NumSections, is that these can be added at a later stage in development with relative ease. To get the most out of your TGM it is mathematically more efficient to ensure nodes are rather smoothly and evenly distributed. The exception being that nodes of slightly closer proximity may be desired in regions that demonstrate greater flexibility (such as the lower/outer side-wall in radials, i.e. nearer the tread).



Reasonable placement of the first and final nodes (that connect to the rim) can be achieved choosing a location anywhere between the outer of the tyre bead (i.e. excluding the bead altogether), the inner radius of the bead or even the rim height. Granted you should compensate for the loss in mass of the tyre if you model it further away from the rim (by adding the bead area mass back to the 'wheel' mass in the PM file). My preference is to model the tyre from the rim itself. The main reason being that the bead does demonstrate some flex even if relatively minor, and that even the rim itself demonstrates some flex, which is not currently modelled. Another reason is that it becomes easier to account for the mass of the bead and produces better visualization of the tyre. A couple of trade-offs to consider, is that the bead area is relatively stiff, so if modelled you might require running a lower DT multiplier in TTool, which will increase QSA test times. The other being that the bead is still an area of low flex, and so computing what happens here may be a little wasteful to that end. In such cases, adding extra nodes might help to compensate, but again, will lead to longer lookup data generation times. If done correctly, either method should yield satisfactorily accurate results.

AnisoCarcassConductivityMult = Directional heat conductivity multiplier at the carcass level. X (lateral), Y, (depth), Z (longitudinal).

Material = All material properties are subject to the following format (Temperature (for which all following properties are valid), Density, Young's Modulus, Poisson's Ratio, Damping Factor (not implemented yet! leave at -1) , Specific Heat, Thermal Conductivity). The final 2 values can be altered without requiring regeneration of the lookup data table and tested with immediate effect in-game, as these form part of the thermodynamics model, density also has an effect on thermodynamics, though requires a new lookup table to form a better description of the tyre.

BulkMaterial = Fills out the tyre with this type of material for areas where there are no other materials present.

TreadMaterial = Surface contact properties are defined by this material. Note that the tread density is currently ignored for the ring model, instead BulkMaterial defines this, but this variable still remains important for the thermodynamics model and may gain further importance in the future as the TGM model evolves.

TreadDepth = Usable depth / thickness of tyre tread. Slick tyres generally have tread depth of about 3-5mm, while 6-10mm is more common for street tyres. Off-road tyres could be substantially deeper, depending on their requirements (potentially 20mm). Note that a much lower tread thickness is standard practice in the sidewall regions, which typically exhibit little to no signs of wear other than the occasional scuffing.

RingAndRim = 1st variable defines whether mass contained within the node is calculated as part of the 6 DOF Rigid Ring (1.0) or as part of the rim (0.0). The rigid ring itself is defined as approximately half way up the sidewall and inclusive of the tread area. The second variable, is the spring rate of the nodes' connection to the rim. Essentially this should represent the spring rate of the bead/rim itself (depending on where you modelled the tyre from). There should be only 2 nodes connected to the rim, those being the first and final nodes. Failure to adhere will probably cause TTool to fail upon loading the file.

PlyParams = (1st value represents the angle at which the ply layer is laid relative to circumferential centreline i.e. 0 degrees is perfectly forward / rearward, such plies are rarely seen in 4 wheel car / truck tyres but more common for motorcycle tyres, very low angles are typically seen as the belt ply in drag racing tyres as well. While 90 degrees represents a perfectly radially wound ply, which are common carcass plies in budget radial tyres and LRR (Low Rolling Resistance) tyres.

The 2nd value, represents the ply material thickness, this should not be the individual strand thickness, but rather the cumulative thickness averaged over the area of the node. What is meant by this is to use the area of the strand, and also consider spacing of the strands. e.g., if the strand is perfectly round then its area is always going to be $\sim 0.785398 \times$ that of its diameter ($\pi \cdot r^2 / d^2$) this is then further reduced by any spacing between plies, if the ply diameter is 0.61mm, and the gap between the ply strands are 1.0mm we multiply the previous result by $0.61 / (0.61 + 1.0) = 0.378882$. Following the above example, $0.61\text{mm} / 1000 = 0.00061$, $0.00061 \times 0.785398 \times 0.378882 = 0.000181\text{m}$ would be the average thickness of our layer using such plies. Keep in mind that this is further complicated by the fact that as you move from bead to tread, the strand spacing changes, particularly in the case of radial carcass plies.

The 3rd value, is a 'connect flag'. 1 = Connect to previous node, 2 = Connect to next node, 3 = Connect to both previous and next node. This flag can help create smoother transitions between different tyre sections. Note that any number of plies can be used within a single node. Ordering is non-crucial at this stage, however, for conventions sake, we recommend to put the outer most layer last (i.e. belt or under-tread cap ply) as final entry for each node.

PlyMaterial = Carcass construction properties are defined by this material. Any number of plies can be included to represent belts, tread cap plies, body plies, etc.

[MirrorNodesAbove]

This is an optional entry. This entry should only ever be used for symmetrical tyres. When present, it essentially takes the nodes above this line, and mirrors them to complete your tyre, so you only have to specify half of the nodes. In order to use this variable, create your half tyre, add this line “[MirrorNodesAbove]” without quotation marks, and then save the file using ttool. It will have automatically generated the remaining nodes on your behalf.

[QuasiStaticAnalysis]

*Basically defines the test boundaries of the lookup data table. Any number of tests can be run, but changing this without regenerating the lookup data table, may result in the real-time model failing to run properly, crashing rF2. Specifying more tests here considerably increases the time require to generate the lookup data, though does provide an overall more accurate tyre over a wider range of conditions. As a result, doing so is recommended towards the end of the development of a tyre. Using ttool it is possible to generate a 6 test tyre that will run in the real time section of ttool as well as mod mode, this could be useful for doing specific experiments. Some examples might include bench testing (using ttool) the tyre at various slip angles within narrow temperature, pressure and speed ranges, where the tyre remains somewhat accurate. It's harder to justify in mod / developer mode, but if you need to quickly compare tyre structure changes this is one way to proceed, just keep in mind the compromises in doing so. For retail mode the minimum tests are 48 (2 pressures * 2 temperatures * 2 speeds * 6 standard predefined tests).*

The defaults are;

NumLayers=2 // Currently fixed at 2, while 3 may work in the QSA section, it does not work for the real-time model, causing unexpected behaviour. The computations also quickly become expensive, in other words stick with 2 layers until further notice.

NumSections=100 // Number of 'cross sections' around the circumference, having made the assumption that a tyre is perfectly round, these are automatically generated based on the value entered here. There must be an even number of sections. Increasing this improves the accuracy of results, but also requires more computation time to complete each test. For testing purposes it's generally not recommended to push too far above 100, if you're extremely happy with your tyres and you have a powerful computer (CPU namely), you might try up to about 120 or so for your final revision, though it should somehow correlate to the number of nodes you have. From personal observation and experimentation using a value where the middle of the sidewall approximates a square (so much as possible), seems to yield reasonable results. That is where the distance between adjacent middle sidewall nodes approximately match the distance between the sections at this point. The general effect of changing the NumSections is to slightly change observed stiffness's of the tyre.

RimVolume=0.014 // Rim volume, used for total tyre air volume calculations. Upon inspection of The Quasi Static Model in ttool, the calculation 'Bead Enclosed Volume (L)' is provided, which generally should serve as the upper limit of what you might use for the RimVolume variable. However, Bead Enclosed Volume (L) assumes a perfectly cylindrical rim profile, which is not typically the case. The rim usually taking up a smaller volume, hence the recommendation to generally go with a lower value, probably in the order of 1-6% depending on how profiled the rim is. This variable can be changed without causing conflicts with the LD table.

RealtimeCamberLimit=45 // Helps to efficiently translate the geometry into the realtime brush model, basically so we don't waste bristles on the sidewall. For most usages we believe that 45 to be a good compromise, but this angle would need to be increased for motorcycle racing (and no that doesn't mean we support this at the moment). Increasing this would also come in handy for anyone wanting to have a go at creating a 2 wheel stunt driving vehicle ;). This variable can also be changed without the need to regenerate the LD table.

GaugePressure=60000 // To achieve the most realistic experience you should carefully choose the test ranges for the tyre. In general we recommended 5 distinct gauge pressure tests. The minimum pressure could be chosen to simulate a flat tyre (not currently implemented). In such a case it would mean the tyre should demonstrate accurate behaviour at very low and 0 pressures, but may be an unnecessary time expenditure for a condition that is rarely seen on track. The data outside the range of these predefined bounds are extrapolated, and interpolated between so even if you don't create a 0 pressure data point the relative behaviour should still be reasonably accurate at this point, for the few times it will actually be seen on track.

GaugePressure=120000 // A suggested value for the second data point might be the typical cold pressure that is likely to be used.

GaugePressure=160000 // I like to use something in between typical cold pressure used for the tyre as this value and a typical warm pressure, you can add more entries for better accuracy, but the table will take longer to generate. In the case of any series which uses tyre warmers, you could use expected pressures after a safety car period, perhaps from a circuit which requires the lowest pressures of the season. Such circumstances are usually seen at low speed tracks.

GaugePressure=190000 // A test running somewhere near the hot optimum real life pressure would be a good idea too. Realistic hot and cold pressures should help ensure a more accurate overall experience.

GaugePressure=240000 // The max should be something slightly higher than you will ever be likely to reach. Again keep in mind not to run too many of these in early development of your tyres, as the lookup table generation time may well exceed what is acceptable for you.

CarcassTemperature=283.15 // Should approximate the minimum temperature this tyre is ever likely to be subjected to (at full carcass depth).

CarcassTemperature=363.15 // Something near the optimum here might be a good idea..

//CarcassTemperature=433.15 // Should be the maximum temperature this tyre is likely to ever be subjected to. You might consider disabling this test until your tyres are at a late development stage.

RotationSquared=0 // Minimum speed should probably always be 0.

RotationSquared=26667 // Add up to 4 rotation speeds for better accuracy at varying rotational speeds, more results in rapidly diminishing returns.

//RotationSquared=53333 // Again I would only run a 0 Rotation and max typical rotation speed in early development.

RotationSquared=80000 // Maximum lookup table speed, should approximate top speed of the vehicle tyre is intended for in (radians/sec)² (consider going a bit higher if this tyre might be used for something faster in the future). A good way to determine this value, if you have details of the fastest vehicle to use these tyres would be to use the following. (maximum engine RPM/60 * 2 * PI / Maximum Gear Ratio)² e.g., might look something like (8000/60*2*PI/2.96)²=80104

This clearly works well on driven wheels, but may require some tuning on tyres which might have a significant difference in radius on a non-driven wheel (front tyres on a top fuel dragster for example).

NumNodes=31 // Total number of nodes. The more nodes you create, the more accurate the test results. If you do have very good hardware, and you're happy with the general behaviour of the tyre you've created, you may consider increasing the number of [Node](s) to around 40. This value is generated from the number of [Node](s) listed below the QSA (QuasiStaticAnalysis) section. So any change to the number of nodes after development of a tyre will have to be very carefully undertaken. Realistically though, this often requires a partial redesign of the tyre at the new node resolution. Increasing the number of nodes early in development, may come at a time when the time required to generate lookup tables is a concern, however if you plan your time carefully, you can still perform many tasks in the background while the TGM is generating. So it would probably be best to start with a decent number of nodes in your TGM, rather than increasing them at some point, especially if you find one of our TGM's to be a good starting point, which are typically encompassing 49 nodes.

VolumeLoad=0 // Not yet relevant to build 240.

LoadCamber=0 // Not yet relevant to build 240.

LoadInclination=0 // Not yet relevant to build 240.

LoadDeflection=0 // Not yet relevant to build 240.

TotalMass=10.558957270550053 // total tyre (and ring) masses and inertia's as automatically calculated by ttool upon saving a TGM file.

TotalInertiaStandard=(0.9865952331376638,0.629654560048139,0.6296545600481429)

RingMass=9.873669634213842 // You can alter this, relative to the totals, by changing where you have defined your ring from the first "RingAndRim=()" variable. Again the outputs here are automatically generated by ttool upon saving a file.

RingInertiaStandard=(0.9536807920631629,0.5898999023566385,0.5898999023566396)

[Realtime]

These parameters are only in effect running the real time model; they do not affect the QSA model (Quasi-Static Analysis) what-so-ever. Changes in these lines can be tested immediately in-game using the developer executable by simply clicking 'race' and driving on track, they can also be tested immediately in TTool by reloading the TGM file. Most of the variables here adjust the properties of the tyre tread rubber which is in contact with a driving surface.

StaticBaseCoefficient = Base grip coefficient for static friction. Keep in mind this is essentially an absolute peak, perfect conditions, values over 3 are not uncommon for modern racing compounds. Static covers bristles that are static relative to the track surface. Keep in mind that during normal cornering, even toward the peak slip angle, various parts of the tyre contact patch are likely to be static. In other words, toward maximum speed, in a straight line, the majority of the contact patch will actually be static (but not necessarily entirely). Toward the other extreme in a large angle drift, it's probable that none of the contact patch is static (on the rear tyres), everything condition between will be a blend.

SlidingBaseCoefficient = Base grip coefficient for sliding friction, i.e. Something of a peak coefficient when the rubber is in a sliding state. See WLFParameters and Sliding(Adhesion/Micro/Macro)Curve entries below to vary the friction coefficient over different sliding speeds. It is important to remember that the nodes and resultant LD table primarily define at what point a bristle transitions between static and sliding, while the temporary bristle springs also have a say in this.

AbrasionCurveWLFStartStep= (WLF lookup start, and step value) Defines each WLF step for which the following AbrasionVolumePerUnitEnergy values are used.

AbrasionVolumePerUnitEnergy= m^3/J volume of rubber sheared per Joule energy, max 32 values based on the WLF values.

DegradationPerWearFraction = Degradation based on wear fraction, max 32 values. Essentially a grip multiplier.

DegradationCurveParameters = (<activation_temperature_K>,<heat_history_step_Ks>) where heat history is essentially a linear progression of temperature over activation point multiplied by time. i.e. if the tyre bristle is 30 degrees over the activation temperature, for 30 seconds, the result is a heat history of 900 Ks.

DegradationPerUnitHistory = Degradation per heat history step, up to a maximum of 32 values. Essentially a grip multiplier.

TemporaryRingMassInertia = Tyre ring mass, tyre ring inertia (x,y,z) This is a temporary variable, recommended to use the values RingMass=, RingStandardInertia=() from the [QuasiStaticAnalysis] section, that are generated upon saving a TGM file.

TemporaryRingDamper = Tyre ring damping for x,y,z,p,q,r (lateral, vertical, fore/aft (should probably always be the same as vertical), pitch, yaw, roll (should be the same as yaw). Temporary until internal damping characteristics are finalized.

TemporaryBristleSpring = Bristle spring rate for (Lat, Vert, Long). Temporary until contact patch model finalised. Once a TGM is generated through the run automated tests, this effects the stiffness of the bristles in the real time model (which are in contact with the road). This should be adjusted so

that the real time model approximates the stiffness as seen in the QSA model. For the vertical component this can be done relatively simply by adjusting this value until the load for a given deflection in the real time section matches that obtained in the QSA section. Keep in mind at present, the tyre should probably be a tiny bit softer in real time than QSA, due to computational reasons, perhaps in the order of <5%. In other words, you may see it fit to use the bristle spring rate as a compensation for this effect. The lateral spring can also be adjusted in the real time section until the amount of flex seen is similar to that of the ring itself and a similar rule would apply to the longitudinal spring rate. These variables have a significant impact on the peak slip angles.

TemporaryBristleDamper = Damping for (Lat, Vert, Long). Changes the damping effect of the tyre bristles in contact with the road surface, this also has a large effect on rolling resistance, and thus heat generation.

MarbleEffectOnEffectiveLoad = Fraction of load available to produce grip when driving on maximum marble saturation.

TerrainWeightOnContactTemperature = Ratio of track temperature influence vs tyre surface temperature used for WLF equations. I.e. How much track temperature to use as opposed to actual tyre temperature for grip and wear, should probably be under 0.15 (15%) in general, which would give an 85% weight to the actual tyre surface temperature.

WLFParameters = Glass transition temperature T_g , is rather critical and changes with compound. On the other hand, the remaining variables are pretty much the same for all rubbers, with the exception of butyl rubber (not typically used for tread compounds). The default values fit into the following shift factor WLF equation:

$$\log_{10}(aT) = -8.86 ((Tq - Tg - 50) / (51.5 + Tq - Tg))$$

Where T_g is the Glass Temperature, T_q is the current temperature and aT is the shift factor. This constructs what is known as a master curve, where the shift factor horizontally shifts the curve based on temperature, this fits into the 3 following sliding curve parameters below:

SlidingAdhesionCurve = Adhesion is defined as friction that occurs when microparticles are physically in contact with each other. (min sliding speed ($\log_{10}(aT v)$), grip multiplier (for min), peak sliding speed, grip multiplier (for peak), max sliding speed, grip multiplier (for max)). Where aT is the shift factor (see above under WLFParameters) and v is the current sliding velocity.

SlidingMicroDeformationCurve = Same as above for microroughness component of driving surfaces.

SlidingMacroDeformationCurve = Same as above for macroroughness component of driving surfaces which are a result of larger surface deformations in the tyre.

StaticRoughnessEffect = Terrain roughness influence on static friction. Rough terrain reduces static friction, by reducing surface contact. Roughness is the sum of the Roughness= variable in the track surface .TDF file, the defaults being (0.50,0.25), or 75%.

GrooveEffects = Maximum groove influences grip here for: (static friction, sliding adhesion, sliding micro-deformation, sliding macro-deformation).

DampnessEffects = fully damp track (at threshold of standing water or more) influence on grip for same things as GrooveEffects (static, sliding, micro, macro grip).

StaticCurve = The static friction grip fraction relative to temperature curve in the format of (cold temperature, static grip multiplier @ aforementioned temperature, peak temperature, grip multiplier @ peak temperature, hot temperature and grip multiplier for said temperature). The values are blended together to form a wide smooth curve.

RubberPressureSensitivityPower = Rubber contact pressure sensitivity (power, offset, nominal maximum, normalize (1=yes,2=no)). This adheres to the following formula, $(\text{BristleContactPressure} + \text{Offset})^{\text{Power}}$, and if normalized (recommended) will provide a peak multiplier of 1.0 at 0 contact pressure.

IgnitionParameters = Ignition temperature of rubber in Kelvin, heat power factor, nominal max of $\text{area} * \text{temperature_over_ignition}$. A lower ignition temperature will produce skid marks and tyre smoke earlier, while an increase to the nominal max will make it more difficult to achieve maximum smoke saturation, producing a smoother transition.

SizeMultiplier = A multiplier to the geometrical width, and radius. Recommended to use only as a temporary solution or for very minor geometrical corrections. The default size information is contained within the [Node](s) and the [LookupData] section contains data about how those change due to various conditions such as rotation speeds.

ThermalDepthAtSurface = The depth of the temperature sample layer used for contact properties (i.e. grip and wear); if provisional second layer is disabled, tread will never be allowed to get thinner than this value. Not recommended to push below the default value of 0.0001, as the accuracy of the thermal conduction may suffer. Higher values will reduce temperature fluctuations felt in tyre surface temperatures which are used for contact properties. Lower values would increase the conductance, increasing fluctuations but as stated may create accuracy problems if the rate of conductance is too quick for the physics sampling rate.

ThermalDepthBelowSurface = (if provisional code enabled) the depth of the second layer; value should be \geq surface layer but not too big; tread will never be allowed to get thinner than these two layers.

BristleLength = An optimisation tuned to aid collision detection, no other physical effects. It could be considered the maximum possible deflection that a bristle can experience. A safe value would approximate the maximum possible tyre radius (usually achieved at maximum temperature, speed and air pressure), minus the rim radius.

InternalGasHeatTransfer= (base, mult, power) - heat transfer coefficients to internal gas cavity = $base+(mult*(vel^{power}))$, where vel is linear velocity of tire.

ExternalGasHeatTransfer = (base, mult, power) - heat transfer coefficients to external air = $base+(mult*(vel^{power}))$, where vel is linear velocity of tire.

GroundContactConductance = (base, mult). Thermal contact conductance coefficient to ground = $base+(mult*pressure)$, where pressure is contact pressure. This is responsible for a significant portion of tyre cooling, bringing about a high correlation between variances in tyre temperatures following track temperatures.

TireRadiationEmissivity = Thermal radiation emissivity for external tire surface. 0.0 is a theoretically perfectly white surface, 1.0 is a theoretically perfect black surface. Typical external tyre rubber should be in the range of 0.9 – 0.95 according to various literature.

InternalGasSpecificHeatAtConstantVolume = (temperature (K), specific heat at constant volume (J/(kg*K))). 719 J/(kg*K) is an approximation for dry air, but the value changes slightly depending on temperature. You can add or remove entries for this table as you see fit, however you may have other issues if the internal gas reaches 500 degrees Kelvin, which is why our default tables do not exceed this value. Different inflation gases will clearly have different specific heat values.

The Tyre Tool

Now we get to the good stuff, from the application launcher, select the final tab 'advanced' within you'll find another 4 tabs within, select the 3rd one (Developer CLI). From here you'll need add "+ttool" (no quotes) as a command line parameter, and select 'Save Parameters'.

Another useful command line parameter is "+multiple" (minus quotes), I almost consider this mandatory when using +ttool as it allows you to run multiple rFactor 2 instances, allowing you to generate a tyre in the background while, say, attending a league race in rFactor 2. If doing so, please be advised that a tri-core or greater processor is highly recommended, otherwise obtaining respectable performance may not be possible. You can also play with the windows task managers application priority settings to ensure ttool does not significantly impair system performance, ultimately I have found this to be unnecessary though (at least on quad and hexa core CPU's). If you really want to prioritize ttool, I have often run it at a real time priority with very little disruption to my normal usage of other basic non-intensive applications.

Return to the main tab (simulate), and select the developer icon, this will initialize tyre tool.

To open a file, you must place a .TGM file in your `\rFactor 2\pTool\` folder. If this folder does not exist, create it. Once a TGM is correctly placed in this folder, type the file name (i.e. rtrainer.tgm) and click load. The file should now be loaded correctly, if so you'll see a geometrical shape change in the cross section display and some numbers change in the lower part of the user interface.

Once you've loaded an appropriate TGM file, the most useful part will be the quasi-static testing section. Here you can define test conditions, temperatures pressures, etc. If you want to run a single test. Select 'iterations per frame' and enter a number such as 20. You can then view results in the 'Quasi Static Model' section, such as loads or radius, etc.

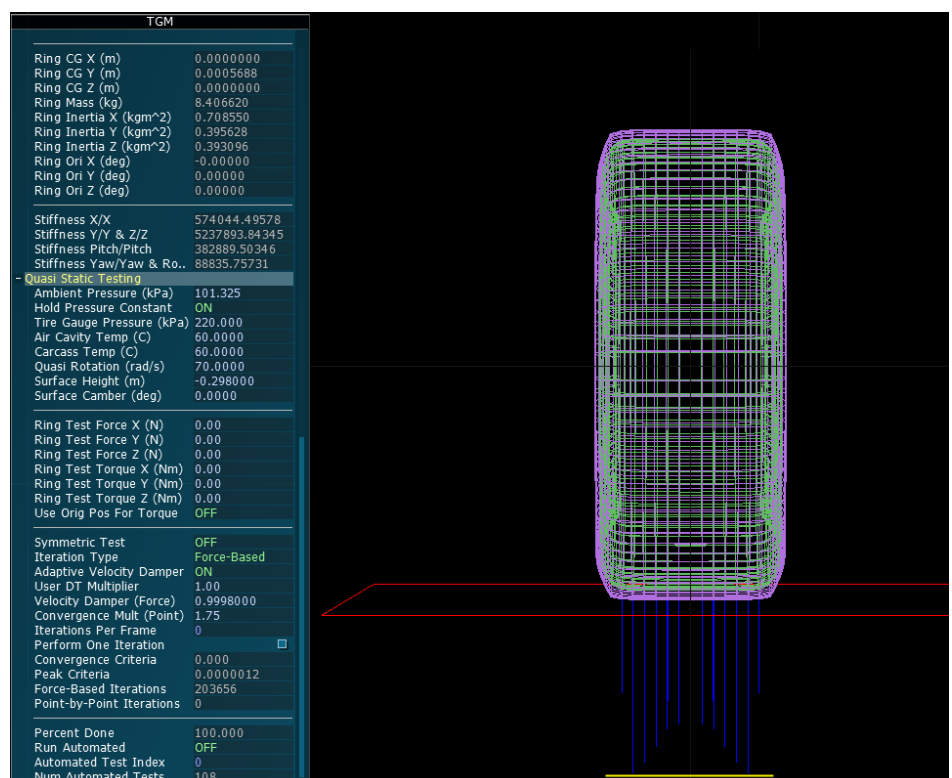
To help visualize the tyre, on the left side under the [Quasi Static Model] section, select "Display 3D".

As an example of running a simple vertical deflection test:

1. Open a tyre .tgm file.
2. Select "Display 3D" ← just so you can see what's going on more clearly.
3. Scroll down to the bottom of the list on the interface.
4. Type 10 under 'iterations per frame', which defines how many computations are made before the graphical displays are updated. Higher numbers run the current test more quickly by skipping graphical updates. Conversely, lower values will keep you more up to date graphically but the test will take longer to perform.
5. You should see the 3d model moving a bit as well as the cross section display on the right.
6. Under [Quasi Static Testing] you will see the test conditions to which the tyre is being subjected to, such as pressure, temperature, height of the ground plane (Surface Height), etc.
7. Near the bottom of the list, once "Percent Done" is 100, click 'perform one iteration' to stop testing and scroll upward to the 'Quasi Static Model' section.
8. Here are some displays such as 'Load (N)' and 'Peak Radius' among a few other useful bits of information.
9. Now that you know the peak radius scroll downwards to the QS Testing section once more. This time enter a Surface Height, and make this 1cm smaller value than the peak radius from the previous test. Also make sure to enter this as a negative number to denote the surface below the tyre centre.
10. Type 30 under 'iterations per frame', once percent done is 100, you can scroll up and check the tyre load.

Congratulations, you have just completed your first vertical deflection test. Note that your tyres are likely to be slightly stiffer than would be considered realistic due to computational reasons (primarily due to a finite number of physical nodes). One solution could be to compensate for this by using softer 'bristles' in the [realtime] section. This means the QSA model should probably be slightly stiffer than real life tyre 'spring' rates, perhaps in the order of 3-15%, the more nodes, the more accurate the results should be.

To compensate for this discrepancy adjusting the 'TemporaryBristleSpring=(, ,)' middle value. This is contained in the real time section and can be tuned until the desired spring rate is achieved. This is a step to be done after generation of the lookup data, which we'll discuss next. Your test should look something like this:



In this example I used more 'real world' conditions. The red square here is the ground plane, the blue lines stretching downward below it, are used for visual representation of the effective loads that the each node is exerting onto the ground plane (the yellow line is something I added manually). Ideally in your tyre design you'll want a fairly consistent loading across the contact patch for realistic given loads and pressures, while the importance of testing varying rotation speeds should not be forgotten.

The above example shows a partially unoptimized contact patch, where the middle of the tyre has a much lower contact pressure than the nodes slightly further away. This kinda of behaviour could well be realistic if the tyre pressure is too low for the vertical load on the tyre, though in these cases the transition is usually a bit smoother. This also illustrates why adding more nodes generally helps create a better tyre design, as it allows more control, increases computational accuracy, and helps highlight where different tyre sections transition.

Anyway, so what now? Let us begin with a quick recap of the TGM. Some properties primarily in terms of stiffness's are defined within the lookup table, which is generated from data contained within the [Node]s, and tested under the conditions defined under [QuasiStaticAnalysis]. So to properly adjust the size of the tyre you must redefine the geometrical shape of the tyre, and regenerate the [LookupData] which allows the model to be run in real time. Once this table is generated you can analyse it in the Realtime Testing parameters section at the top of the ttool menu, at this point the tyres are also ready to be tested in game. Remember it's also good practice to keep backups of your TGM files and note changes between them when testing different versions.

In order to generate a set of [LookupData], you will need to load an appropriate tyre .tgm file you have created or modified, and select run automated near the very bottom of the list.

Note: If at any time the meshes 'explode' or the tyre shakes violently during this test, or you notice negative stiffness values, you will need to reduce the DT Multiplier to a value less than 1.0. This costs more time to run each test, so using near the highest value you can get away with is advisable. I generally select the highest value BEFORE the tyre meshes vibrate and run about 0.05 below that value as a bit of leeway. Generally steel belted tyres will not require a DT multiplier less than 1.0, and kevlar belted tyres might require a slightly lower value, I had to use 0.85 for a previous generation FR3.5 tyres for example. If the DT multiplier is substantially too high, the ttool may crash. In essence, if an analysis crashes or results in really weird vibrations, or a collapsing tyre, try lowering the DT multiplier a fraction as this is the usual culprit.

Pressing CTRL+D allows you to toggle certain graphics to optimise the processing speed of these tests.

It is important to remember the automated tests run are in accordance with the "[QuasiStaticAnalysis]" section of the TGM file. You can include more tests to make it more precise over a greater range, the cost is more tests = more time required to fully generate the lookup tables. During the early stages of tyre development we recommend the default number of tests, of course feel free to adjust the test ranges if they're not appropriate for the tyre you're working on.

The standard run automated test (which will undertake a total of 72 tests), with the current build 240 ttool, will typically take 4 hours depending on your processing power (there are plans to enable multi-threading in ttool at some point which could cut this time substantially). Once complete, save under a different file name, and copy the lookup data table information. Alternatively, backup files are created by ttool (i.e. QuasiStaticPartialResults_72_72.tgm) the contents should be stored within these files, once completed you can analyse how your new tyre behaves in the real time section. If

ttool crashes at some point during the automated testing phase, these partial results can be very useful. Create a copy of the file, place it in your pTool main folder, and load the file. If the file is for example “QuasiStaticPartialResults_60_144.tgm”, you can resume the test by scrolling to the bottom of the UI, entering the test index “60” and setting run automated ON. Keep in mind the reason ttool crashed is likely to be DT multiplier was set too high, so it's a good idea to reduce this, below what you had used last time (by around 0.05), and continue the test from there. Keep in mind if you push too close to the maximum DT multiplier possible, there's a chance of table corruption and you might need to re-run the entire set of tests again.

Note: Saving a file currently strips out [realtime] segment of the TGM file, this section is required to deliver accurate testing results when analysing a tyre in the real time testing section of ttool. This issue will be eliminated with the next rFactor 2 SDK release.

You can also manually stop an automated test. First, disable 'Run Automated'. Then note down the current 'Test Index' save the file under a name like rTrainer_test23.tgm (so you don't forget the test index it was up to). Then later reload the file, enter the test index near the bottom and enable 'run automated', it will continue from where you left off. Remember making excessive backups is better than keeping too few, it's also a good idea to keep notes on test results and how you've changed you tyres over various versions, and the impact that changing certain tyre attributes has on those test results.

Concluding Remarks

Each compound and each size of tyre requires its own TGM file, which could undoubtedly become quite cumbersome for some mods with large permutations. The important thing is to start small and familiarise yourself with the .TGM before branching off too far. On the other hand, wider experimentation can also yield its own benefits too. This can help making distinctions between tyre design differences clearer, so there is always a difficult balancing act.

For most tyres, you will pretty much require a new lookup table, although you may be able to get away without re-building the lookup data between minor compound variations for the same tyre sizes. In such cases, grip coefficients, wear, glass temperature, etc. can be tuned under the [Realtime] section. Likewise if there are very subtle tyre size changes you may try the SizeMultiplier found under the [Realtime] section. We do not recommend using this multiplier for tyres of greater size differences than a few millimetres except for use as place holders. As we move forward, it's possible some variables will be made to be more easily overridden to help reduce the need for inclusion of significant numbers of TGM files for simple compound variations.

Wet tyres definitely require their own TGM files, and should probably have their own lookup tables generated for more accuracy, primarily as their tread depth is likely to be deeper (about 1-4mm thicker than slicks), and are also made of a softer rubber compound. Our recommendation would be concentrating initially on the dry tyres, and sticking mostly sticking with 1 compound until you're comfortable, then moving on, as spreading your focus out too much will usually hinder your progress.

If you're stuck at this point, the preferred starting point is to make the geometrical shape as realistic as possible. The first step here finding out as much about the true size of the tyre you're working on. Depending on your resources, contacts, this will range from some simple sizes such as '325/40 R18', and photo-graph's, to the preferred method of getting a 2d profile of the actual tyre, at 0 pressure and attached to the rim. If you physically have access to the tyre, options such as laser scanning (obviously somewhat expensive) or any number of 2d profiling options might exist. The other preferred starting point is simply to do research on tyres in general, it's a very deep, technical and complicated subject. Read some books, or some technical articles on the subject for inspiration.

Hopefully this guide has been a helpful starting point, feel free to ask any questions on the forums, and we may use this feedback to help improve any future versions of this tutorial.

TTool Glossary

Realtime Test Parameters This section basically represents a bench test of your tyres.

Run Physics → Runs the real time model based on current properties.

Run Single Timestep → Runs a single time step (1/Sample Rate second). This also disables “Run Physics” should you have had this switched on previously.

Sample Rate → Adjustable between 1 and 10,000. I probably wouldn't play with this too much, very low sampling rates are extremely unstable.

Time Mult → Adjustable between 0.001x and 100x. Time multiplier to run the test at an accelerated rate, or slower to help analyse certain attributes. Note that you probably won't be able to run 100x as the CPU usage can become astronomical.

Thermodynamics and Wear → Enable or disable thermodynamics model and tyre wear model, as wear is inextricably linked with temperature, they form a single variable. You can switch this off or on to observe the effects of wear on tyre performance as well as heating and cooling properties of your tyre.

Rigid Ring Dynamics → This should probably always be switched on. This enables the rigid ring dynamics model which is the main carcass flex, you can disable it to reduce CPU demands if you want to test some particular bristle properties in isolation, but you should only do this if you know what you're doing.

Free Rolling → Attempt to automatically adjust the tyre rotation speed until it more or less matches up with the travelling speed of the road so as to minimize slip.

Static Coeff → Static friction coefficient adjuster (does not work in build 240, you must alter this property in the [Realtime] section of the TGM).

Sliding Coeff → Sliding friction coefficient adjuster (does not work in build 240, you must alter this property in the [Realtime] section of the TGM).

Long Vel (m/s) → Forward travelling speed of the road relative to the tyre.

Lat Vel (m/s) → Lateral travelling speed of the road relative to the tyre will induce some sideways slip angle (assuming the tyre is actually touching the road).

Rotation (rad/s) → Tyre rotation speed in radians per second.

Rotation (m/s) → Another way to express tyre rotation speed, speed is applied at the 'Nominal Radius'.

Nominal Radius (m) → This should be set to the current tyre radius

Width (m) → Wheel rim width adjuster.

Deflection (m) → Vertical deflection of tyre on ground.

Slip Angle (deg) → Set or view the current lateral slip angle.

Slip Ratio (%) → Set or view the current longitudinal slip ratio.

Camber (deg) → Set the rim camber angle relative to road surface.

Gauge Pressure (kPa) → Adjust the tyre gauge pressure.

Temperature (C) → Initial tyre temperature for all nodes and their respective depth layers. This will be dynamic if 'Thermodynamics and Wear' model is enabled.

Realtime Test Results

Vertical Force (N) → Vertical force exerted between tyre and ground plane.

Long Force (N) → Longitudinal force exerted between tyre and ground plane.

Lat Force (N) → Lateral force exerted between tyre and ground plane.

Aligning Torque (Nm) → Aligning torque of the tyre relative to ground plane.

Overturning Torque (Nm) → Overturning torque of the tyre relative to ground plane.

Roll Resist Torque (Nm) → Torque of the tyre along the rolling resistance axis relative to ground plane.

Bristle Vertical Power (W) → Power lost due to vertical bristle damping.

Bristle In-Plane Power (W) → Power lost from lateral and longitudinal bristle damping / flex.

Bristle Sliding Power (W) → Power released from bristles sliding against the ground plane which is primarily expelled as heat.

Bristle Abrasion Rate (m/s) → The current rate of tyre abrasion in terms of metres of tread worn per second.

Bristle Average WLF Transform → Average WLF value for all the bristles currently in ground contact.

Bristle Average Heat History (Ks) → Average heat history of those bristles currently in ground contact.

Ring Damping Power (W) → How much power is being lost to damping of the tyre ring. Basically, power lost in the sidewall flex and associated damping.

Max Lat Tread vs. Ring Def (m) → The maximum lateral displacement of any individual bristle relative to the rigid ring.

Max Long Tread vs. Ring Def (m) → The maximum longitudinal displacement of any individual bristle relative to the rigid ring.

I/O

File Name → The filename of the TGM you wish to load / save, this must be in the pTool\ folder in your working rFactor 2 directory.

Load File → Load the file with the file name mentioned above.

Save File → Save the file name with the pre-mentioned file name, you may name it whatever you wish, but it should end with .tgm extension please!

Quasi Static Model

Display 3D → Display the QSA model in the viewer, as opposed to the real time model. This option also enlarges the cross section window of the nodes within the middle of the contact patch.

Bead Enclosed Volume (L) → A calculation for the air volume that resides within a theoretical perfect cylinder as calculated from the inner nodes that attach to the rim.

Current Air Volume (L) → Current total air volume in the tire cavity that spans between the tyre and her hosting wheel rim.

Cross Section Nodes → Displays the number of nodes that the current TGM incorporates.

Peak Radius (m) → Peak tyre radius in metres. In other words, displays the current maximum radius of any individual node in the tyre.

Peak Half Width (m) → Maximum current lateral offset from the 0 co-ordinate (centre of the wheel).

Peak Width (m) → Maximum current lateral offset between the 2 most laterally distant nodes.

Load (N) → Tyre vertical load exertion on the ground plane.

Ground Force X (N) → The amount of force the ground is exerting on the tyre in the lateral direction.

Ground Force Y (N) → The amount of force the ground is exerting on the tyre in the vertical direction.

Ground Force Z (N) → The amount of force the ground is exerting on the tyre in the longitudinal direction.

Ground Torque X (Nm) → The amount of torque the ground is exerting on the tyre in the pitch orientation.

Ground Torque Y (Nm) → The amount of torque the ground is exerting on the tyre in the yaw orientation.

Ground Torque Z (Nm) → The amount of torque the ground is exerting on the tyre in the roll orientation.

Total CG X (m) → Total tyre lateral centre of gravity offset relative to centre co-ordinates.

Total CG Y (m) → Total tyre vertical centre of gravity offset relative to centre co-ordinates.

Total CG Z (m) → Total tyre fore/aft centre of gravity offset relative to centre co-ordinates.

Total Mass (kg) → Total tyre mass as calculated by ttool.

Total Inertia X (kgm²) → Total tyre inertia in pitch.

Total Inertia Y (kgm²) → Total tyre inertia in yaw.

Total Inertia Z (kgm²) → Total tyre inertia in roll.

Total Ori X (deg) → Total tyre orientation change from its origins for Pitch.

Total Ori Y (deg) → For Yaw.

Total Ori Z (deg) → And for Roll.

Ring CG X (m) → Tyre ring lateral CG offset. The ring essentially encompasses the tread and about half of the sidewall.

Ring CG Y (m) → For vertical CG offset.

Ring CG Z (m) → For longitudinal CG offset.

Ring Mass (kg) → Total mass of the tyre ring in kilograms as calculated by ttool.

Ring Inertia X (kgm²) → Pitch ring inertia as calculated by ttool.

Ring Inertia Y (kgm²) → Same for Yaw.

Ring Inertia Z (kgm²) → Same for Roll.

Ring Ori X (deg) → Orientation change of just the ring, pitch.

Ring Ori Y (deg) → Yaw

Ring Ori Z (deg) → Roll

Stiffness X/X → Calculated stiffness of the ring, in lateral terms, where this value represents the force in Newtons to move the carcass 1 meter. Knowing the lateral stiffness and the ring mass, you can calculate the lateral tyre oscillation frequency using the formula;

Frequency=SquareRoot((Stiffness X/X)/(Ring Mass))/(2 π), using which, a tyre of 400,000 N/m stiffness and 7kg ring mass, give an approximate frequency of 38.05hz.

I'm sure most of us are well aware of these effects which are often shown in slow motion during grand prix racing where the inside tyre is set into motion upon clipping a tall curb.

Stiffness Y/Y & Z/Z → Ring Stiffness of vertical and longitudinal movements, as the TGM assumes a tyre to be perfectly round, a single stiffness value is appropriate to both directions.

Stiffness Pitch/Pitch → Pitch stiffness of the tyre ring in Newton metres per radian of rotation.

Stiffness Yaw/Yaw & Roll/Roll → Stiffness of tyre ring to resist yaw or roll rotation in Nm/rad.

Quasi Static Testing This section effectively defines the test conditions for the QSA model.

Ambient Pressure (kPa) → Sets the atmospheric test pressure.

Hold Pressure Constant → Whether to hold the tyre pressure constant. Essentially, to maintain the specified tyre pressure as the tyre changes shape.

Tire Gauge Pressure (kPa) → Gauge tyre pressure in kilopascals.

Air Cavity Temp (C) → Temperature of the air inside the tyre cavity.

Carcass Temp (C) → Temperature used for the entire tyre carcass.

Quasi Rotation (rad/s) → Tyre rotation speed in radians per second.

Surface Height (m) → Height of the ground plane relative to the wheel centre.

Surface Camber (deg) → Angle of the ground plane relative to the wheel.

Ring Test Force X (N) → Applies a test force to the tyre ring in lateral direction.

Ring Test Force Y (N) → Applies a test force to the tyre ring in vertical direction.

Ring Test Force Z (N) → Applies a test force to the tyre ring in longitudinal direction.

Ring Test Torque X (Nm) → Applies a torque directly to the tyre ring in pitch orientation.

Ring Test Torque Y (Nm) → Applies a torque directly to the tyre ring in yaw orientation.

Ring Test Torque Z (Nm) → Applies a torque directly to the tyre ring in roll orientation.

Use Orig Pos For Torque → Whether to use the original tyre position for applied torques or apply them at their new / current positions.

Symmetric Test → Significantly boosts test performance time by the assumption the tyre and test conditions are perfectly symmetrical, thus reducing the need to make a lot of calculations. Do not enable if you want accurate results and have applied lateral force, torque, are using surface camber setting or are testing a non-symmetrical tyre.

Iteration Type → Whether to perform tests with force-based iterations or point-by-point iterations. Point-by-point iterations perform much more slowly as they are calculated node by node. Suggest to leave this at default setting.

Adaptive Velocity Damper → Automatically sets the 'Velocity Damper' to deliver smaller changes as the tyre nears an accurate result.

User DT Multiplier → Time step multiplier, often required to reduce this value slightly to maintain stability in the QSA model if the automatic time steps are not sufficient. This usually needs to be decreased if the tyres you are working with are very stiff or very light for a given stiffness.

Velocity Damper (Force) → Effectively used to dampen forces so that a solution can be eventually reached. Increasing slows the rate at which nodes move, increasing does the opposite, but can lead to instabilities and may need to be accompanied by decreases to the DT multiplier. We recommend not to touch this and use the Adaptive Velocity Damper which will automatically set this.

Convergence Mult (Point) → Convergence multiplier for point-by-point iterations, effectively also adjusts how quickly things can change in a single step for these tests, setting too high can give very unstable results, while setting it too low will increase the time taken to perform.

Iterations Per Frame → How many iterations/time steps to perform before graphical displays are updated. Higher number = less graphical updates which allows faster calculations.

Perform One Iteration → Performs a single iteration / time-step, and sets 'Iterations Per Frame' to 0, it's the best way to pause / stop testing.

Convergence Criteria → Criteria for analysing how close the current tyre test is to completion. In theory once this reaches 0.000 the tyre is stable with no more changes in any node positions, however reaching this point takes an unreasonable amount of time, considering the benefit is negligible beyond a certain point.

Peak Criteria → Another way to express how close to completion the test is.

Force-Based Iterations → How many force-based iterations how been completed thus far.

Point-by-Point Iterations → How many point-by-point iterations how been completed thus far.

Percent Done → Current test % completed, once this reaches 100% the resulting values should be accurate to within acceptable tolerances.

Run Automated → Whether to turn on automated testing, which generates the necessary data for the [LookupData] binary table, by testing the tyre under the specified [QuasiStaticAnalysis] properties.

Automated Test Index → Displays the current test index, important to note down if you want to pause and resume testing at any point.

Num Automated Tests → Displays the total number of tests required to satisfy the [QuasiStaticAnalysis] section. By removing, commenting out, or adding GaugePressure=, CarcassTemperature=, or RotationSquared= lines, from the QSA section you change the total number of automated tests required.

Useful Shortcuts

CTRL+D → Cycle through various display options, switching off the graphics entirely streamlines ttool to complete tests more quickly, the downside is obviously the loss of visual reference. You should only display the minimum you need, when you need it.

CTRL+NumPadKeys → These cycle through various camera / view settings. You can also add the ALT modifier key to move with more precision;

- CTRL + 4 / 6 : rotate around the tyres yaw axis
- CTRL + 2 / 8 : rotate around the pitch axis
- CTRL + 1 / 3 : adjust the camera zoom
- CTRL + 7 / 9 : adjust the camera distance from the tyre
- CTRL + 5 : cycles through various centred the views
- CTRL + Arrow keys : move the camera up, down, left, right.

F12 : take screenshot.

RESOURCES

http://www.nhtsa.gov/staticfiles/safecar/pdf/PneumaticTire_HS-810-561.pdf ← A very useful resource covering many areas of tyre design and principals covering aspects of their behaviour.

http://www.uniroyal-tyres.com/generator/www/cz/cz/uniroyal/pneumatiky/themes/service/downloads/hidden/dl-databook_en.pdf ← Provides a rim dimension standards on page 44, along with some other potentially useful dimensions throughout the document.