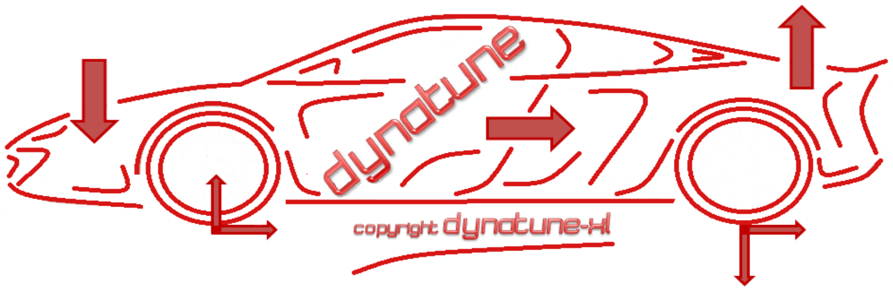





## *DYNATUNE END USER LICENSE AGREEMENT*

DYNATUNE ('the Software Product') and accompanying documentation is protected by copyright laws and treaties, as well as laws and treaties related to other forms of intellectual property.
DYNATUNE-XL or its subsidiaries, affiliates, and suppliers (collectively 'DYNATUNE-XL') own intellectual property rights in the Software Product. The Licensee's ('you' or 'your') License/Software to download, use, copy, or change the Software Product is subject to these rights and to all the terms and conditions of this End User License Agreement ('Agreement').

**Acceptance**

YOU ACCEPT AND AGREE TO BE BOUND BY THE TERMS OF THIS AGREEMENT BY DOWNLOADING, INSTALLING OR USING THE SOFTWARE PRODUCT. IF YOU DO NOT AGREE TO ALL OF THE TERMS OF THIS AGREEMENT, YOU MUST NOT INSTALL OR USE THE SOFTWARE.

**License Grant**

This Agreement entitles you to install the licensed copy of the Software Product. In addition, you may make copies of the Software Product for your own use. This Agreement does not permit the installation of the Software Product on more than one computer at any given time, on a system that allows shared used of applications, on a multi-user network, or on any configuration or system of computers that allows multiple users. Multiple copy use or installation is only allowed if you obtain an appropriate licensing agreement for each user and each copy of the Software Product.

**Restrictions on Transfer**

Without first obtaining the express written consent of DYNATUNE-XL, you may not assign your rights and obligations under this Agreement, or redistribute, encumber, sell, rent, lease, sublicense, or otherwise transfer your rights to the Software Product.

**Restrictions on Use**

You may not use, copy, or install the Software Product on any system with more than one computer, or permit the use, copying, or installation of the Software Product by more than one user or on more than one computer. If you hold multiple, validly licensed copies, you may not use, copy, or install the Software Product on any system with more than the number of computers permitted by license, or permit the use, copying, or installation by more users, or on more computers than the number permitted by license.

**Restrictions on Alteration**

You may not decompile, 'reverse-engineer', disassemble, or otherwise attempt to derive the source code for the Software Product.You may not modify the Software Product other than in the indicated areas or create any derivative work with the source code of the Software Product or its accompanying documentation. Derivative works include but are not limited to translations. You may not alter any protected files or libraries in any portion of the Software Product.

**Restrictions on Copying**

You may copy the Software Product for your personal use. You must however respect the limitations as described in 'Restrictions on Use'

**Disclaimer of Warranties and Limitation of Liability**

UNLESS OTHERWISE EXPLICITLY AGREED TO IN WRITING BY DYNATUNE-XL, DYNATUNE-XL MAKES NO OTHER WARRANTIES, EXPRESS OR IMPLIED, IN FACT OR IN LAW, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OTHER THAN AS SET FORTH IN THIS AGREEMENT OR IN THE LIMITED WARRANTY DOCUMENTS PROVIDED WITH THE SOFTWARE PRODUCT.
DYNATUNE-XL makes no warranty that the Software Product will meet your requirements or operate under your specific conditions of use. DYNATUNE-XL makes no warranty that operation of the Software Product will be secure, error free, or free from interruption. YOU MUST DETERMINE WHETHER THE SOFTWARE PRODUCT SUFFICIENTLY MEETS YOUR REQUIREMENTS FOR SECURITY AND UNINTERRUPTABILITY. YOU BEAR SOLE RESPONSIBILITY AND ALL LIABILITY FOR ANY LOSS INCURRED DUE TO FAILURE OF THE SOFTWARE PRODUCT TO MEET YOUR REQUIREMENTS. DYNATUNE-XL WILL NOT, UNDER ANY CIRCUMSTANCES, BE RESPONSIBLE OR LIABLE FOR THE LOSS OF DATA ON ANY COMPUTER OR INFORMATION STORAGE DEVICE.
UNDER NO CIRCUMSTANCES SHALL DYNATUNE-XL, ITS DIRECTORS, OFFICERS, EMPLOYEES OR AGENTS BE LIABLE TO YOU OR ANY OTHER PARTY FOR INDIRECT, CONSEQUENTIAL, SPECIAL, INCIDENTAL, PUNITIVE, OR EXEMPLARY DAMAGES OF ANY KIND (INCLUDING LOST REVENUES OR PROFITS OR LOSS OF BUSINESS) RESULTING FROM THIS AGREEMENT, OR FROM THE FURNISHING, PERFORMANCE, INSTALLATION, OR USE OF THE SOFTWARE PRODUCT, WHETHER DUE TO A BREACH OF CONTRACT, BREACH OF WARRANTY, OR THE NEGLIGENCE OF DYNATUNE-XL OR ANY OTHER PARTY, EVEN IF DYNATUNE-XL IS ADVISED BEFOREHAND OF THE POSSIBILITY OF SUCH DAMAGES. TO THE EXTENT THAT THE APPLICABLE JURISDICTION LIMITS DYNATUNE-XL'S ABILITY TO DISCLAIM ANY IMPLIED WARRANTIES, THIS DISCLAIMER SHALL BE EFFECTIVE TO THE MAXIMUM EXTENT PERMITTED.

**Limitation of Remedies and Damages**

Your remedy for a breach of this Agreement or of any warranty included in this Agreement is the correction or replacement of the Software Product. Selection of whether to correct or replace shall be solely at the discretion of DYNATUNE-XL. DYNATUNE-XL reserves the right to substitute a functionally equivalent copy of the Software Product as a replacement. If DYNATUNE-XL is unable to provide a replacement or substitute Software Product or corrections to the Software Product, your sole alternate remedy shall be a refund of the purchase price for the Software Product exclusive of any costs for shipping and handling.
Any claim must be made within the applicable warranty period. All warranties cover only defects arising under normal use and do not include malfunctions or failure resulting from misuse, abuse, neglect, alteration, problems with electrical power, acts of nature, unusual temperatures or humidity, improper installation, or damage determined by DYNATUNE-XL to have been caused by you. All limited warranties on the Software Product are granted only to you and are nontransferable. You agree to indemnify and hold DYNATUNE-XL harmless from all claims, judgments, liabilities, expenses, or costs arising from your breach of this Agreement and/or acts or omissions.

**Governing Law, Jurisdiction and Costs**

This Agreement shall be governed by and construed in accordance with International Law and any dispute arising from it shall be subject to the exclusive jurisdiction of the International Courts

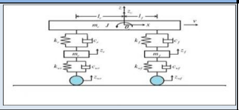
**Severability**

If any provision of this Agreement shall be held to be invalid or unenforceable, the remainder of this Agreement shall remain in full force and effect. To the extent any express or implied restrictions are not permitted by applicable laws, these express or implied restrictions shall remain in force and effect to the maximum extent permitted by such applicable laws.

# DYNATUNE SUSPENSION TUNING MODULE - RELEASE 8.1



**On each worksheet one can click on the pictures in the header which will redirect to the corresponding web page (left) or the related FAQ support page (right). PASSWORD = dyna4xl1989**



**Analytical Model:**

This workbook does allow the calculation of Spring & Damper Setup of a Vehicle. .
The Simulation Model behind it is a classical 5 DOF / 3 PART Spring & Damper Bicycle model with Interactions of the Unsprung Mass of Front and Rear Axles on the Sprung Mass & Pitch Inertia Vehicle Body.
The model itself is based on Fully Linear Differential Equations with a partially Non-Linear Representation of the Damper data. The tire and the road are always connected for Frequency Domain Simulations
and can be disconnected in the Time Domain from Release 8.0 onwards. Non-Linear Bump Stops are NOT considered.
The differential equations of the vehicle system are being solved by numerical integration/differentiation over time with a step size of 0.001 sec.

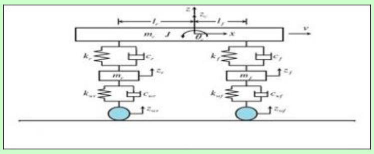
**Input Data:**

Vehicle Data - Masses, Weight Distribution & Inertia and if applicable Aerodynamic Downforce
Spring, Tire Stiffness and Percentage Tire Damping - **In RELEASE 8.1 one can add data for a rubber damper top mount**
Suspension Motion Ratio - **In RELEASE 8.1 one can add a Non-Linear Vertical Wheel Force Deflection Curve**
Measured Damper Data for Jounce & Rebound (@ standard damper speeds)
Scaling Factors for Spring Rates and Jounce & Rebound Damping allowing Quick Tuning Sessions
Road Profile Data

EMPIRICAL PITCH INERTIA ESTIMATE FORMULA

Iyy = 0.9 X 0.1269 X WHEELBASE X TOTAL LENGTH x TOTAL MASS

Note: Typically Pitch Inertia = 90% of Yaw Inertia



**Output / Results:**

Front & Rear Body & Wheel Ride Frequencies
Bounce & Pitch Center Location
Percentage Critical Damping Graphs
Frequency Transfer Function Graphs for Body & Wheel Movements with respect to a Sinusoidal Road Input Signal
Dynamic Wheel Loads and dissipated Damper & Tire Energies
Half Sine / Ramp Time History Response Function Graphs for Body, Wheel, Damper Speeds and Dynamic Wheel Loads
KPI / Metrics for Contact Patch Load Fluctuations, Grip, Body Movements & Accelerations

**Automatic Optimization Procedure (RELEASE 8.0.1)**

In order to reduce the analysis time the tool does provide a Fully Automatic Damper Creation and Optimization Feature
allowing the user to create and optimize a damper curve for his specific application in one single click.
By using an STM specific Cost Functioncalled STM Performance Index one can set Calibration Parameters
related towards the intended areas of improvements.
Next to the Fully Automated Routine the user can individually execute Partial Sections of the Optimization Process.

**EXECUTE FULL DAMPER LOOP**
**CREATE & OPTIMIZE**
**FRONT & REAR DAMPERS**

**Data Handling (RELEASE 8.0.1)**

Several Data Copying and Import/Export Data Routines do allow comfortable handling of both Damper as Vehicle Data.
either between the 2 VEHICLE Sheets or towards an external medium.

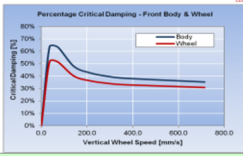
**EXPORT VEHICLE 1 DATA** | **IMPORT VEHICLE 1 DATA** | **COPY DATA TO VEHICLE 2** | **LOAD VEHICLE 2 DATA**

**RELEASE 8.1 - NEW DAMPER TOP MOUNT & NON-LINEAR WHEEL FORCE DEFLECTION CURVE**

**RELEASE 8.1** does provide a feature to add a topmount to the damper (**in effect add another spring in series to the damper**) which is typically standard OEM practice. For Racing applications one can now also provide a (non-linear) vertical Wheel Force Deflection Curve and/or a non-linear Motion Ratio Curve in order to simulate the effects of these non-linearities on typically highly loaded Aerodynamic Racing Cars.

*Front Suspension Data*

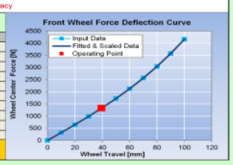
| | | | |
|---|---|---|---|
| Front Unprung Mass (Corner) | 27.5 | | kg |
| Fr. Tire Vert. Stiffness | 290.00 | | N/mm |
| Fr. Tire % Critical Damping | 5.00 | | % |
| Fr. Tire Damping Rate | 299.22 | | Ns/m |
| Instant. Spring/Damper to Wheel Motion Ratio* | | 0.749 | - |
| Calculated Instantaneous Fr. SPRING Rate | | 72.59 | N/mm |
| Fr. Spring Static Deflection / Wheel Travel | 29.59 | 39.50 | mm |
| Fr. WHEEL Rate (incl. Scaling) | 35.57 | | N/mm |
| Fr. RIDE Rate (incl. Tire) | 31.68 | | N/mm |
| Fr. Damper Top Mount Stiffness (0 = Deactivate) | 1000.00 | | N/mm |
| Fr. Body Frequency | 2.582 | | Hz |
| Fr. Body Ride Frequency (incl. Tire) | 2.437 | | Hz |
| Fr. Wheelhop Frequency | 17.318 | | Hz |




NOTE: Increasing Non-Linearity will affect Analysis Accuracy

| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| 0.0 | 0.700 | 0.0 |
| 10.0 | 0.705 | 320.8 |
| 20.0 | 0.715 | 648.4 |
| 30.0 | 0.730 | 987.7 |
| 40.0 | 0.750 | 1343.7 |
| 50.0 | 0.775 | 1721.6 |
| 60.0 | 0.805 | 2127.3 |
| 70.0 | 0.840 | 2567.0 |
| 80.0 | 0.880 | 3047.7 |
| 90.0 | 0.925 | 3577.2 |
| 100.0 | 0.975 | 4163.8 |

☑ USE FRONT WHEEL FORCE DEFLECTION CURVE



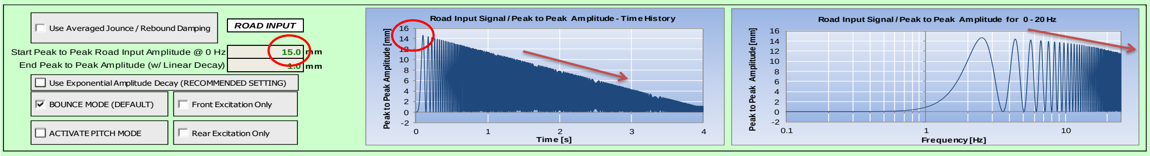

**The additional Topmount and increased Non-Linearities can affect the simulation results. At the end of this README section one can find examples of erratic simulation results and their root cause**

**4 POSTER SWEEP SINE TEST (FREQUENCY DOMAIN - TRANSFER FUNCTION):**

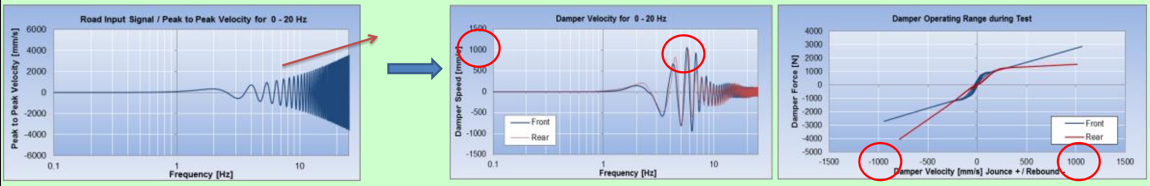
The 4 Poster Sweep Sine Test replicates virtually some of the tests that ary physically executed on hydraulic 4 (or 7) poster rigs. The car is usually excited with some kind of sinusoidal road input in a range of 0 to 25 Hz.
In order to see how the vehicle reacts at various inputs speeds and frequencies, so called Frequency Transfer Function of the vehicle are being created. These FFT functions basically "tell" how much an Excitation does make an object react.
If the object is light it moves more than if it is heavy. If the "Punch" is fast it has a different effect than when it is slow.
A Frequency Transfer Function describes thus the Relationship between an Output Value and an Input Value - in this case typically an amplitude ratio - and is valid for a certain frequency range (Frequency Domain).
Frequency Transfer Functions are usually plotted in logarithmic scales.
In the Automotive World of Vehicle Dynamics this Frequency Range is defined from 0 Hz to 25 Hz as most Suspension and Car-Body related Natural Frequencies typically can be found there.
In order to create a Frequency Transfer Function an artificial sinusoidal signal (in the time domain) is being used that starts at 0 Hz and goes up to around 100 Hz over time (in about 4 "seconds").
The high frequency of 100 Hz is necessary because the algorithm that is being used to create this function - a so called Fast Fourier Transformation (FFT) - does need to have approximately 4 times more frequency for correct results
and create a smooth curve for a range of 0 to 25 Hz. Besides that the algortihm does also need to have sufficient "energy" input in the lower frequency range to create reliable results.

Considering the Signal Requirements, the virtual 4 Poster can in **RELEASE 8.0** be driven with 2 types of road input signals, each with their unique advantages:

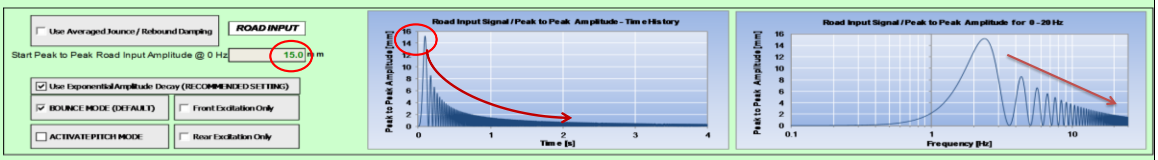
**1 Linear Decaying Amplitude Signal**



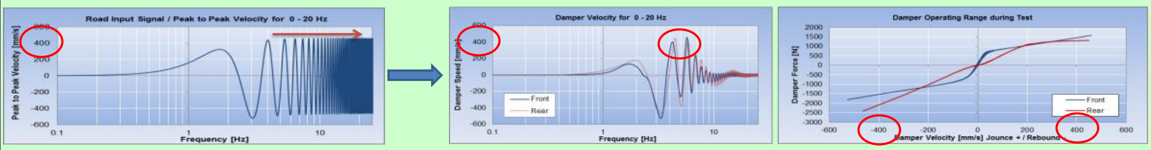

This signal is "Focused" on Peak to Peak Input Displacements and will generate an Input Signal with Non-Constant Peak to Peak Input Speeds as shown below. Damper Speeds are shown too.
Due to the increasing of Peak to Peak Input Speed with increasing Frequency the induced Energy is not constant, which makes this signal less preferable as several parameters (Amplitude, Speed and Frequency) change simultaneously.
However the Signal Initial and Final Amplitude can be adjusted which in certain applications might be an advantage.




In order to adress the increasing Peak to Peak Input Speed of the Linear Signal an alternative signal has been developed with an Exponential Decay of the Input Amplitude over Frequency




Resulting in a constant Peak to Peak Input Speed as shown in the graph below. For Reference also Damper Speeds




This Signal does create a constant Peak to Peak Velocity Input Road Signal which allows rather conveniently to excite the vehicle in the range of interest, especially for specific Damper Piston Speeds.
The initial Start Amplitude of the signal defines the Maximum Value of the Input Velocity AND defines the Amplitude Decay for the complete Frequency Spectrum. The Final Amplitude cannot be manually set as in the Linear Decay Signal.

Both Two Signals can be used simultaneously at both Front and Rear Axle - the so called BOUNCE mode - or with Opposite/180 Degree Out-of-Phase Amplitude Input (Front moving up, Rear moving down) - the so called PITCH mode.
The Frequency Transfer Function can be calculated for both the vertical BOUNCE or the PITCH mode allowing the User to optimize either Heave or Pitch behaviour of the vehicle or finding the best compromise for both.
The Choice of the Road Input Signal is very important for the validity of the results. Please do keep this in mind.

**Some More Info on FFT**

The FFT algortihm is by itself rather a complex algorithm and without going into all details a few key factors one should know/consider:

1) The FFT algorithm is a rather cpu intensive procedure. The "delay" in creating the results is almost solely caused by the "Live Execution" of the FFT code. The less performant your computer is, the more time it will take.

2) The FFT algorithm does require a specific formula number of 2^n data points. For this reason the "simulation time" exist out 4,096 seconds that represent 4096 data points (=2^12) and remains always constant.
This number of data points allows a resolution of around 0.25 Hz in the results.

3) The "standard" FFT algorithm does work in theory only correct on a full linear system. Highly Non-Linear Systems do require Non-Linear FFT algorithms which are very complex.
Since the shock absorber can be both highly non-linear (knee-point) as a-symmetric (jounce/rebound ratio) this does usually creates a few problems for the linear FFT procedure.
Dynatune does allow the user to choose out of two "Damping" Options:

a) BASELINE SETTING
Averaging both Jounce & Rebound Damping over a (Half) Sine Oscillation - This is a commonly used approach which "assumes" that the damping of the vehicle remains "constant" for the oscillation and is calculated as the average of the Jounce and Rebound Damping for that particular operating point. The advantage is that the Transfer Function is more "smooth" and stable, and starts always at 0 Hz with a value of 1. Although this approach should be in theory less accurate than option b) the experience and comparison with real world measurements and data do show that there is a very good correlation.

b) OPTIONAL SETTING - **RELEASE 8.0 NEW FEATURE**
Use the full NON-Linear & A-Symmetric Damper Data as in "real life". This will however lead to a less "smooth" Transfer Function which will potentially also be more difficult to understand. A very high rebound damping will for instance "pull" the car down during the frequency sweep. Changes in Jounce/Rebound Damping can influence the Transfer Function significantly. It is highly recommended to use the Exponential Decay Road Input.
In real life the effects will be less dramatic since in particular suspension compliances and for instance rubber topmounts will "smoothen out" these non-linearities.
This option is recommended to be used only by experts for in depth analysis.

4) Similar to point 3) the Tire must always be in contact with the road as a "Lifting-Off" would introduce a rather severe non-linearity in the system. In fact in the 4 Poster Ride Model the Tire is always connected to the road and "pull the car back" in situations where it would normally lift off. This is purely done to allow robust FFT post-processing

**HALF SINE / RAMP INPUT TEST (TIME DOMAIN):**

**RELEASE 8.0 NEW FEATURE:**
A Half Sine Event has been added allowing to simulate Kerbing Events.

In the Half Sine / Ramp Input Test, the movements of wheel and body can be analyzed over time after passing a ramp (smooth 1/2 sinusoidal resp. smooth 1/4 sinusoidal).
The amplitude of the Half Sine or the height of the Ramp can be modified (either up or down). Length is also adjustable.
By the Defined Length of the Half Sine / Ramp and by adjusting the Vehicle Speed, the time for passing the obstacle and as such the Frequency Content of the events are being changed.
The calculated "Frequency Content" is usefull for relating the results of this test to the 4 Poster Sweep Sine test procedure results.
The test procedure is also particularly usefull (actually it is a MUST) for finding the best compromise/ratio between jounce & rebound damping, keeping the overall damping constant whilst looking at different vehicle speeds (= excitation frequency) and represents the "real world" test for any tuning made with the 4-Poster Sweep Sine Test Procedure.

**RELEASE 8.0 NEW FEATURE:**
It is important to know that the Time Domain Ride Model in RELEADE 8.0 is more sophisticated than the Frequency Response Model. In particular the tire can loose contact with the road.

**TUNING CONTROL CENTRE**

In between the Frequency Domain and Time Domain Calculation Sections one can convenienty find the "Tuning Control Centre". Here the User can scale Front & Rear Spring Rates and Jounce & Rebound Damper Rates.
The effect of changing one single parameter or several ones at once can instantly can be reviewed. Typically we would recommend to use one Vehicle Worksheet as "Scaling Sheet" and use the other Vehicle Worksheet as a Reference Setting Sheet. In the Comparison Sheet the main differences between both Setups can be evaluated and used for further tuning steps.

| | | | | | | |
|---|---|---|---|---|---|---|
| ***SPRING & DAMPER SCALING FACTORS*** | Fr. Jounce Damping Scaling Factor | 0.652 | CALCULATE / F9 | Rr. Jounce Damping Scaling Factor | 1.110 | ***SPRING & DAMPER SCALING FACTORS*** |
| | Fr. Rebound Damping Scaling Factor | 1.326 | | Rr. Rebound Damping Scaling Factor | 0.842 | |
| | Fr. Spring Rate Scaling Factor | 1.000 | | Rr. Spring Rate Scaling Factor | 1.000 | |

The Spring & Damper Scaling Factors mutiply the spring rates and the measured damper data by the selected factor - for jounce & rebound separately.

**General Notes on the Workbook:**

The default calculation setting of the workbook is set to automatic recalculation. Since hower both the real time resolution of the differential equations for the Sweep Sine & Ramp Sine Test as the FFT post processing procedure are quite cpu intensive the sheets can be slow in updating (depending on the hardware of the computer). One can set the default calculation mode to manual calculation on the sheets, but in order to update the results one must either press key F9 (default Excel) or use the Calculation Button on the sheets.

**RESULTS**

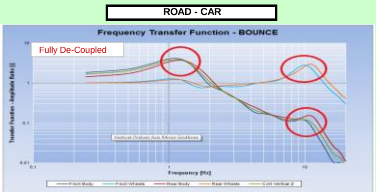
The "Lower Part" of the Vehicle 1 & Vehicle 2 Worksheets provide all the classical metrics and characteristics that are being used by the automotive engineers. Natural frequencies, Pecentage Critical Damping and other interesting metrics like Bounce and Pitch Centers. These are commonly used terms which can be found in literature and are therefor not further explained. There is a presentation on the FAQ page about them.

The Focus of the Tool is on the "Upper Part" of the Worksheets which are providing the results for FREQUENCY DOMAIN with the 4 Poster Frequency Sweep and below the scaling dashboard all results for the TIME DOMAIN with Ramp and Half Sine functions.

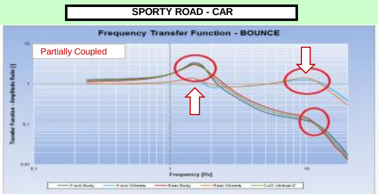
The dominant graph for the 4 Poster Test is the Frequency Transfer Function. The graph does basically show "how much" the Body or the Wheel of the vehicle reacts to a defined road input at a Range of Frequencies.
At 0 Hz this function starts at 1 and typically shows "peaks" near the Natural (Heave and Pitch) Frequencies of Sprung and Unsprung masses. Below some are examples for "good" Target Transfer Functions

**EXAMPLES FOR "GOOD" TARGET TRANSFER FUNCTIONS:**

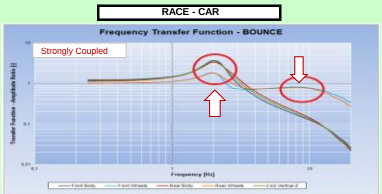
ROAD - CAR




SPORTY ROAD - CAR



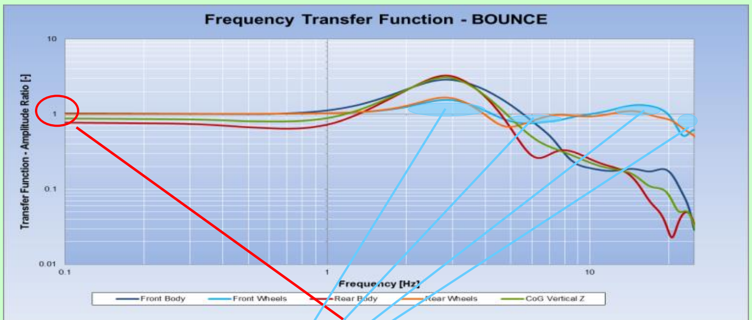

RACE - CAR




If Front Body FFT, Rear body FFT and Centre of Gravity FFT transfer function are very similar it does mean that the Car Body moves in vertical direction from Front to Rear Axle in a verey similar way. This is good for comfort and if both axles have also similar FFT plots they move similarily which should be good for grip. The "sportier" a car becomes - in effect the higher the Spring and Damping Rates become - the lower become the Peak Wheel FFT Values (right red cricles) at Wheel Hop Natural Frequency. They do become however more pronounced at Body Natural Frequency due to the fact that the system becomes more "coupled". The more the FFT Funtion of the Wheels does follow the Body the more the system is "Coupled". An Oscillation System existing out of 2 Springs (Suspension & Tire) is Fully De-Coupled when Spring Rates Differ by a Factor of 10x (which on a Road Car is typically the case).
Next to the visual appearance of the curves there are several metrics in the tool that allow judging the quality of the setup based on specific characteristics of the Frequency Transfer Function.

**Example Results Explanation**

The First important Graph of the 4 Poster Test is the Frequency Transfer Function




| FRONT | Body | Wheel | |
|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.75 | 2.75 | Hz |
| Dynamic Overshoot @ Peak Resonance Freq. | 2.88 | 1.55 | mm/mm |
| % Crtical Damping @ Peak Res. Freq (-3dB) | 37.52 | 46.92 | % |
| Dynamic Wheel Load Indicator 0 - 25 Hz * | | 5[illegible]06 | Hz |

* Area under/above of wheel curves with respect to value 1

**Note:** If the Frequency Transfer Function at 0.1 Hz is not Starting at 1, it does usually mean that the amount of Damping is in general too high for the amount of Spring Rate. Looking for instance at the Rear Body Value of 0.8 - which is lower than 1 - one can generally say that the amount of Rebound Damping is significantly higher than the amount of Jounce Damping. If vice versa the Start Value is significantly above 1, the amount of Jounce Damping would be higher than the amount of Rebound damping (forcing the Rear Body to move more Up than Down resulting in an overall Higher Dynamic Ride Height over one Frequency Cycle.) **This Phenomenon is the Key for understanding FFT Graphs.**

a) **Peak Resonance Frequency:** The Frequency in the Frequency Response Function with the highest Amplitude. Depending on the amount of Damping these frequencies can be different or fall together. In this particular case the dynamic overshoot of the front wheel is higher at the natural body frequency than at the to be expected wheel natural frequency. This happens usually with racing cars

b) **Dynamic Overshoot @ Peak Resonance Frequency**: This metric does indicate how well damped the body or wheelis when excited with the natural frequency of the system. In general once can say, the more damped the system is the lower & wider are the peak curves. If one would be a passenger in the car sitting near the front axle it would mean that for any vertical movement of the road by 1mm the passenger would move 2.88 mm.

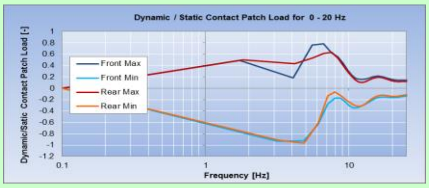
c) **% Critical Damping @ Peak Frequency:** Out of the FTF one can extract by using the -3dB rule the percentage critcal damping of the system at that frequency. This method depends however on the shape of the FTF and the resolution of frequencies steps in the Fast Fourier Transformation. The values can differ sometimes slightly from the damping percentages calculated with the classical method.

d) **Dynamic Wheel Load Indicator 0 - 25 Hz**: This metric does indicate how close the Wheel Transfer Function remains close to the Value "1" in the Frequency Range from 0 - 25 Hz. This metric can be used as a first indication for the general amount of grip of the tires in the range from 0 - 25 Hz. In the RELEASE 8.0 various additional metrics have been developed to explore in greater detail Grip Performance.

**RELEASE 8.0 Upgrade**

Several New Graphs and Metrics have been added

Now in RELEASE 8.0 a "Second" Important Graph is giving the user an good indication on the Maximum and Minimum Dynamic Contact Patch Loads encountered during the test in the range from 0 - 25 Hz.
The Graph is a "Contour" Plot of all the Maximum and Minimum Dynamic Contact Patch Loads during the test. It is a very effective way of looking at how the Setup and thus the Tire does behave over the whole Frequency Range.




| | FRONT AXLE | | | REAR AXLE | |
|---|---|---|---|---|---|
| Max. Dyn./Stat. CPL | 0.783 | - | Max. Dyn./Stat. CPL | 0.633 | - |
| Min. Dyn./Stat. CPL | -0.932 | - | Min. Dyn./Stat. CPL | -0.967 | - |
| Diss. Energy in Dampers | 135.19 | Ws | Diss. Ener. Dampers | 154.16 | Ws |
| Diss. Energy in Tires | 67.38 | Ws | Diss. Energy Tires | 88.93 | Ws |
| Dyn. Tire Load Integral | 955.05 | NHz | Dyn. Tire Load Integral | 909.55 | Ws |

=Surface Area of the Dynamic Tire Load in the Frequency Plot

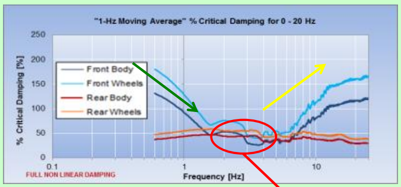
**Frequency Domain Perf. Index *** 1043.29 -

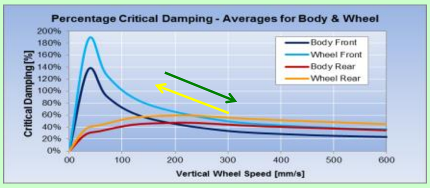
* Value does depend on PI Factor settings

EXPLAINED IN AUTOMATIC OPTIMIZATION SECTION

Whenever the minimum Dynamic Contact Patch Load is below "-1", the wheel would start to lift in real life. This condition should be avoided. This New Graph and these New Metrics do allow a back to back comparison of various setups and will give a good indication of the amount of "work" the Tire has to endure. The Dyn. Tire Load Integral, the amount of Dissipated Energy for Tires and Dampers is calculated over the duration of the test from 0 - 25 Hz.
The less energy is consumed in the tire, the better the vehicle will handle road undulations or - alternatively - if desired, specific setups can be created to generate more energy consumption in the tire in order to heat it more/quicker up.
There can (and will) be differences between the Min Dyn./Stat. CPL metric and the Dynamic Wheel Load Indicator from the FFT Function. As the latter is an approximation based on the assumption that the contact patch load will be better the closer the Transfer Function is to 1 for the wheel, it is recommended to always preveal the New Dynamic Contact Patch Load Metric which is more accurate.

Another New "Third" Interesting Graph is the "Percentage Critical Damping" Moving Average during the 4 Poster Test.




When Full Non-Linear Damping is activated Jounce and Rebound damping can alternate during a frequency cycle quite severly. This graph represents a "1 Hz Moving Average" and thus filters out all the singular peaks and allows to display the amount of "averaged" Percentage Critical Damping during the 4 Poster Test. In fact, the graph does offer an interesting "Visualization" of the % Critical Damping over the Frequency Range giving the user good information of Levels of Damping at the various interesting key frequencies. Most of all this Graph does show how the % Critical Damping Value does change from "Static" to "Dynamic" and how it does change through the Frequency Spectrum.
Quite Interesting to see is that for instance Front Body & Wheel start at low Frequence around 150% Critical Damping which with increasing Frequency deminuishes to around 50% Crtical Damping. Around 7 Hz it does start to rise up ending at 25 Hz around the same values as at the start. Basically the Damper Speed Force Graph is in the first part crossed from left to right and in the second part vice versa.

If we do take the results from the FFT graph above it, is interesting to see that indeed the FFT calculated % Critical Damping at 2.75Hz comes very close to the "Moving Average" Procedure Value around 3 Hz - as indicated in the Red Circle

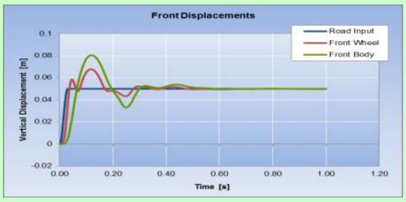
| FRONT | Body | Wheel | |
|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.75 | 2.75 | Hz |
| % Crtical Damping @ Peak Res. Freq (-3dB) | 37.52 | 46.92 | % |

Note: Between 35% and 45% Critical Damping at the Peak Resonance Frequency has emperically proved to be a good compromise between Body Control and Tire Grip.

**TIME DOMAIN - Ramp & Half Sine**

Although the Frequency Domain results are a good indication, the only correct way to verify a setup is a simulation in the Time Domain. One can select from a "RAMP" event, representing road obstacles like access ramps or one can select "HALF SINE" events representing obstacles like "Curb Strikes" in racing or "Sleeping Policemen" on ordinary roads.

The first important graph is showing the various displacements of Road, Wheel and Body. In addition to this visual representation various metrics - like "Peak Overshoot" & "Time to 95% Damped Oscillation" allow accurate performance evaluation of the resulting vehicle movements. On top of that a "comfort metric" indicates the maximum acceleration induced to the vehicle body




**Time Domain Performance Index *** 744.710 -

* Value does depend on PI Factor settings

EXPLAINED IN AUTOMATIC OPTIMIZATION SECTION

| | Front Body Results | |
|---|---|---|
| Time to 95% dampened oscillation | 0.472 | s |
| Dynamic Peak Overshoot | 1.610 | m/m |
| Time to reach Peak Value | 0.120 | s |
| Maximum Vertical Acceleration | 62.95 | m/s² |

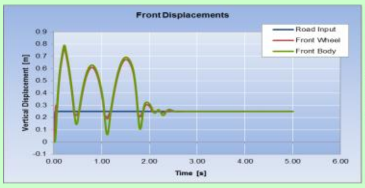
**TUNING GUIDANCE: THE LOWER THE NUMBERS THE BETTER FOR MECHANICAL GRIP**

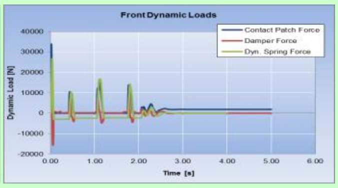
The second graph of interest displays the Dynamic Loads. Contact Patch Load, Spring and Damper Forces are shown over Time, allowing proper understanding of what component takes what load at what time.

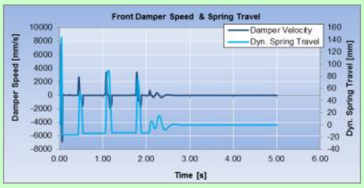

| | Front Wheel Results | |
|---|---|---|
| Max. Dynamic Contact Patch Load | 8386.4 | N |
| Wheel Lift Time | 0.078 | s |
| Dynamic Contact Patch Load Integrator * | 234.50 | Ns |

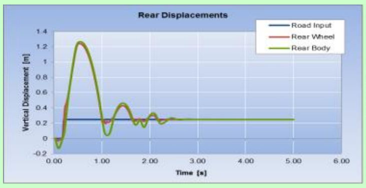
Several Upgraded Metrics like maximum Dynamic Contact Patch Load Integrator and new Metrics like Wheel Lift Time do help the user by providing objective measures for grip judgement.
The Contact Patch Load Integrator does consider Wheel Lift Time.

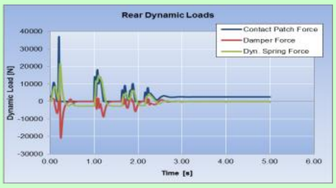
Especially for Rallye / Off-Road Applications the Time Domain Ride Model has been significantly enhanced with respect to the Frequency Domain Model. Next to the Capability of dealing with Zero Contact Patch Load, the model does now also permit to "Jump" with Suspension and Wheel Position correctly positioned at the "Zero Spring Load" Rebound Position. An Example of such an event is shown below for Front and Rear Axle.

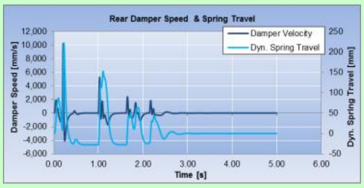



Furthermore are graphs available showing Translational and Rotational Displacement, Velocity & Acceleration for the Center of Gravity.

**COMPARISON SHEET**

The Workbook does also provide a COMPARISON Sheet on which the most important GRAPHS & METRICS of the VEHICLE 1 and VEHICLE 2 Sheets are being confronted.
For the Convenience of the User, the Metrics which are better in one Vehicle Setup than in the other Vehicle Setup are highlighted in Green Cells with White Font. This does give an instant overview of the Quality of one setup versus another.

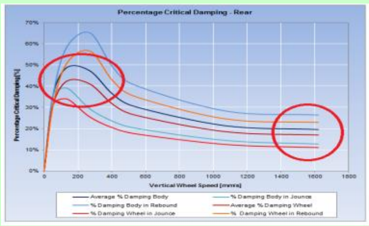
## *10 EASY STEPS TO HAPPY TUNING SESSIONS ... MANUALLY .....*

**STEP 1** START WITH **CLASSIC SETUP**: DEFINE TARGET RIDE FREQUENCIES IN LINE WITH TYPE OF CAR - ENTER ALL DATA ON THE LEFT SIDE OF THE SHEETS
Some General Indications:

| | |
|---|---|
| Road Car | 1.1 - 1.3 Hz |
| Sporty Road Car | 1.3 - 1.5 Hz |
| Sports Car | 1.5 - 1.7 Hz |
| Super Car | 1.7 - 2.2 Hz |
| Race Car | 2.2 - 2.8 Hz |
| Formula Car | > 3.0 Hz |

Historic experience indicates that it is good to have the Rear Ride Frequency about 10% higher than Front Ride Frequency. See STEP 3

**STEP 2** DEFINE SPRING & TIRE RATES RANGE THAT COMPLY WITH STEP 1




**STEP 3** FIND BEST BOUNCE & PITCH CENTER ACCORDING INDICATIONS ON SHEETS - ADJUST SPRING RATES
If you do this exercise well you will probably find a good starting point for STEP 8

**STEP 4** DEFINE TARGET MAXIMUM PERCENTAGE CRITICAL AVERAGE BODY DAMPING IN LINE WITH TYPE OF CAR
Some General Indications:

| | |
|---|---|
| Road Car | 30% - 40% |
| Sporty Road Car | 40% - 60% |
| Sports Car | 50% - 70% |
| Super Car | 60% - 80% |
| Race Car | 70% - 100% |
| Formula Car | > 80% |

**STEP 5** DEFINE TARGET % CRITICAL DAMPING FOR HIGH DAMPER SPEEDS FOR BODY & WHEEL
Some General Indications:

| | |
|---|---|
| Road Car | Range: Jounce 10% to Rebound 40% |
| Racing | Range: Jounce 20% to Rebound 100% |

**STEP 6** MODIFY "MEASURED" DAMPER DATA TO ACHIEVE STEP 4 & STEP 5

**STEP 7** VERIFY % CRITICAL DAMPING FOR WHEEL. IDEALLY THE WHEEL DAMPING SHOULD FOLLOW BODY
BUT THIS IS DEPENDING ON SPRING RATES AND BODY WEIGHTS NOT ALWAYS POSSIBLE.
MAKE MODIFICATIONS TO DAMPER INPUT DATA UNTIL STEP 1 TO 6 ARE OK. THEN PROCEED TO NEXT STEP

**STEP 8** **4 POSTER SWEEP SINE TEST - OPTIMIZE BODY MOVEMENT & GRIP OVER FREQUENCY -SEE ABOVE FOR EXAMPLES.**
SET POSTER TO STANDARD BOUNCE MODE - IF YOU RUN AN AERODYNAMICALLY SENSITIVE CAR VERIFY ALSO PITCH MODE
**RELEASE 8.0 NEW FEATURE** START WITH "EXPONENTIAL DECAYING AMPLITUDE". THIS WILL GENERATE A ROAD PROFILE WITH CONSTANT MAXIMUM EXCITATION VELOCITY.
VERIFY IF MAXIMUM EXCITATION VELOCITY IS IN LINE WITH WHAT THE VEHICLE USUALLY SEES ON THE ROAD. IF NOT CHANGE START AMPLITUDE.
START WITH "AVERAGED" JOUNCE & REBOUND DAMPING. THIS WILL "SMOOTHEN" THE POSSIBLY LARGE DIFFERENCES BETWEEN JOUNCE AND REBOUND DAMPING
VERIFY IF DAMPER SPEEDS ARE IN DESIRED OPERATING RANGE (USUALLY < 1,5 M/S). AT BODY PEAK RESONANCE FREQUENCIES THE SPEED CAN BE HIGHER THOUGH
**RELEASE 8.0 NEW FEATURE** VERIFY THAT NORMALIZED DYNAMIC WHEEL LOAD REMAINS ABOVE -1. THIS MEANS THAT IN THE REAL WORLD THE TIRE REMAINS ON THE ROAD.
VERIFY THAT BODY TRANSFER FUNCTION STARTS AROUND 1 OR ABOVE. IF NECESSARY ADJUST START AMPLITUDE TO CHANGE DAMPER SPEED & DYNAMIC WHEEL LOAD
IF DAMPER SPEED OR NORMALIZED DYNAMIC WHEEL LOAD ARE OUT OF RANGE ADJUST START AMPITUDE (AND/OR END AMPLITUDE)
START USING SPRING SCALING FACTORS TO MAKE FRONT BODY AND REAR BODY TRANSFER FUNCTION AS "SIMILAR AS POSSIBLE" = MATCHING DAMPED NATURAL FREQUENCIES.
USE NEXT DAMPER SCALING FACTORS TO LOWER FRONT BODY AND REAR BODY PEAKS. TRY KEEPING WHEEL TRANSFER FUNCTIONS AS CLOSE AS POSSIBLE TO 1
NOTE: ON SOFTER SETUPS THE WHEELHOP MODE WILL ALWAYS SHOW UP - SEE EXAMPLES BELOW.
USE METRICS FOR BODY PEAK VALUE. THE LOWER THE PEAK VALUE IS, THE BETTER CONTROLLED IS THE BODY MOVEMENT.
LOOK AT DYNAMIC WHEEL LOAD INDICATOR OF THE TRANSFER FUNCTION AND TRY TO MAKE IT AS LOW AS POSSIBLE. THIS WOULD INDICATE, THAT THE TIRE "FOLLOWS" THE ROAD PROFILE WITH THE SAME AMPLITUDE OVER THE COMPLETE FREQUENCY RANGE AND THEREFORE POTENTIALLY REDUCING CONTACT PATCH LOAD FLUCTUATIONS
CHECK THE MINIMUM DYNAMIC/STATIC CONTACT PATCH LOAD METRIC. THE MORE NEGATIVE THE VALUE, THE MORE THE TIRE WILL BE UNLOADED. TRY MINIMIZING THIS VALUE WHILST KEEPING OTHER METRICS AS GOOD AS POSSIBLE AND FIND THE BEST COMPROMISE.
TRY ALSO MINIMIZING THE MAXIMUM DYNAMIC/STATIC CONTACT PATCH METRIC WHILST KEEPING OTHER METRICS AS GOOD AS POSSIBLE. THIS VALUE IS HOWEVER LESS IMPORTANT THAN THE UNLOADING METRIC AND MIGHT BE "SACRIFICED" FOR A BETTER OVERALL COMPROMISE.
**RELEASE 8.0 NEW FEATURE** DEACTIVATE THE AVERAGING OF JOUNCE & REBOUND DAMPING AND SEE WHAT EFFECTS THE FULL NON-LINEAR DAMPING HAS ON THE RESULTS, ESPECIALLY ON % CRITICAL DAMPING
IF FULL NON-LINEAR DAMPING ACTIVATED DO USE ONLY "EXPONENTIAL DECAYING AMPLITUDE". THIS WILL HELP FFT POSTPROCESSING.
FINE TUNE JOUNCE & REBOUND DAMPING WITH THE SCALING FACTORS. TRY TO KEEP OVERALL DAMPING CONSTANT (F.I INCREASE BUMP DAMPING & REDUCE REBOUND DAMPING)

**STEP 9** **HALF SINE / RAMP INPUT TEST - VERIFY TIME BEHAVIOR & FINE TUNE JOUNCE / REBOUND DAMPING**
**IMPORTANT: INPUTS ARE IN METER (not mm). MAX. SIMULATION TIME = 5s**
DEFINE RAMP/HALF SINE HEIGHT (UP OR DOWN), LENGTH & DEFINE VEHICLE SPEED
TAKE NOTE OF EXCITATION FREQUENCY. THIS WILL INDICATE IN WHAT OPERATING FREQUENCY THE SUSPENSION / CAR WILL BE EXCITED BY THE OBSTACLE
VERIFY IF DAMPER SPEEDS ARE IN DESIRED OPERATING RANGE (USUALLY < 1,5 M/S).
VERIFY THAT SPRING TRAVEL IS IN DESIRED OPERATING RANGE.
VERIFY DYNAMIC WHEEL LOAD. IF DYNAMIC WHEEL LOAD IN REBOUND BECOMES 0 THEN THE TIRE STARTS LIFTING IN THE REAL WORLD WHICH IS NOT GOOD.
IF NECESSARY ADJUST RAMP/HALF SINE PARAMETERS TO YOUR SPECIFIC VEHICLE APPLICATION.
USE SPRING & DAMPER SCALING FACTORS TO MAKE FRONT BODY AND REAR BODY MOVEMENTS AS "SIMILAR AS POSSIBLE"
**ESPECIALLY INVESTIGATE BEST JOUNCE & REBOUND DAMPING COMPROMISE, KEEPING OVERALL DAMPING CONSTANT & KEEPING BODY ACCELERATIONS AS LOW AS POSSIBLE**
**RELEASE 8.0 NEW FEATURE** USE THE NEW METRICS FOR BODY MOVEMENT AND DYNAMIC TIRE LOAD/GRIP INDICATOR TO FIND BEST MATCH FRONT TO REAR

EVALUATE OVERALL BEHAVIOR OVER TIME. ESPECIALLY VERIFY HOW THE REAR BODY OSCILLATION CATCHES UP WITH THE FRONT BODY.
**STEP 10** **GOTO STEP 1 AND RE-VERIFY ALL STEPS.**

NOTE: TYPICALLY MORE DAMPING TENDS TO MAKE THE KPI VALUES ALWAYS BETTER ... BUT ... REMEMBER THESE TEST PROCEDURES DO NOT COVER ALL ASPECTS OF SUSPENSION TUNING
SO DO ALWAYS CONSIDER THE OTHER POSSIBLE IMPLICATIONS ON UNDER/OVERSTEER AND RIDE "COMFORT". AFTER ALL, IT IS ALL A COMPROMISE.

**Fully Automatic Damper Curve Generator & Optimization Procedure**

*EXECUTE FULL DAMPER LOOP*
*CREATE & OPTIMIZE*
*FRONT & REAR DAMPERS*

The Automatic Optimization Procedure is in itself rather straightforward but in detail quite complex and refined. First of all one must understand that the concept of optimization can only be executed towards a GOAL.

The Optimization GOAL in STM is MINIMIZING the **PERFORMANCE INDEX (PI)** Value. The **PERFORMANCE INDEX** is a so called COST FUNCTION. Learn more here: https://en.wikipedia.org/wiki/Cost_function

The **STM PERFORMANCE INDEX** does consider & combine several typical metrics of the 4-Poster Frequency Test Procedure and if desired also a range of Metrics from the Time Domain Obstacle Event Simulations.

These various Metrics in the PI do represent 3 Major Potential Optimization Areas:

1. **Platform Control (Primarily for Aerodynamic / Wing Cars)**
2. **Wheel Control (Primarily for "Classical" Mechanical Grip)**
3. **Driver Comfort (Vertical Accelerations)**

**The Standard Settings - as in the original delivered Workbook - are a general example for Settings for the Fully Automatic Damper Curve Generation & Optimization for a Racing Car**

*STM PERFORMANCE INDEX - CALIBRATION FACTORS*

| | | | |
|---|---|---|---|
| **Platform Control / Aerodynamic Stability** [Recommended Range 0 - 10] | 8.0 | 38.8 | % Contribution to PI-Value |
| **Wheel Control / Mechanical Tire Grip** [Recommended Range 0 - 10] | 10.0 | 42.9 | % Contribution to PI-Value |
| **Driver Comfort / Vertical Accelerations *** [Recommended Range 0 - 10] | 3.0 | 18.3 | % Contribution to PI-Value |

* Time Domain Only

**The Importance of these 3 Contributers in the Performance Index can be scaled in a Range from 0 to 10. 0 does mean that the Contributor will be Neglected and 10 indicates Maximum Importance.**
The Value of the Performance Index will change with the Scaling Factors, so one should set them to a personal preference and keep them constant for correct comparison of various results.

The PI Calculation can be executed for the Frequency Domain or Time Domain or as recommended for both:

☑ Include STM FREQUENCY Domain Performance Index *
☑ Include STM TIME Domain Performance Index *

In which case the x 2 Cost Functions for Frequency & Time Domain can be added and optimized.
It is highly recommended to always use both Frequency & Time Domain in order to achieve best Overall Suspension Performance.

*STM PERFORMANCE INDEX - PI*

| | | |
|---|---|---|
| 4 Poster - Test | 765.20 | - |
| Ride Simulation | 774.12 | - |
| Combined Value | 1539.32 | - |

Expert Users can however also define their own Performance Index for Maximum Tuning Flexibility

☐ Create & Use CUSTOM Performance Index - Only For Experts

In which case up to 2 Cost Function can be defined in Analogy to the 4 Poster Section and the Ride Simulation. One MUST however make sure that the CUSTOM Performance Index / Cost Function CAN be Minimized AND will NEVER become NEGATIVE.

*CUSTOM PEFORMANCE INDEX*

| | | |
|---|---|---|
| Cost Function 1 | 1865.27 | - |
| Cost Function 2 | 251.94 | - |
| Combined Value | 2117.21 | - |

A further fundamental Tuning / Optimization Feature is the possibility to define Target % Critical Damping (or Damping Ratio) for Sprung and Unsprung Masses.
In order to avoid the Optimization Algorithm to iterate towards a Local Optimum, one can add typical reference values. By setting these parameters to 0 there influence will be deactivated.
It is recommended to always specify typical target values for Body and Wheel Damping.

| | | |
|---|---|---|
| Target Front Body % Critical Damping @ Peak Resonance Frequency (-3dB) | 55.0 | % [0 = No Target Value, Deactivated] |
| Target Front Wheel % Critical Damping @ Peak Resonance Frequency (-3dB) | 35.0 | % [0 = No Target Value, Deactivated] |
| Target Rear Body % Critical Damping @ Peak Resonance Frequency (-3dB) | 55.0 | % [0 = No Target Value, Deactivated] |
| Target Rear Wheel % Critical Damping @ Peak Resonance Frequency (-3dB) | 35.0 | % [0 = No Target Value, Deactivated] |

**Recommended Test Procedure Settings**

***Frequency Domain Recommended Test Setting***
*° Bounce Mode w/ Averaged Damping*
*° Exponential Decay - 5 mm Amp.- Average 150 mm/s Input Speed*

***Time Domain Recommended Test Setting***
*° Half Sine - 0.025 m Height - 0.5 m Length - 80 kph - 1 sec Analysis*

The Optimization Procedure does exist out of **2 Sections** with each **2 Optimization Steps**.

In each of the 4 Steps several Front Axle and Rear Axle Iteration Loops will be executed and the progress of the Performance Index and Damper Curves will be "Live" Updated and "Frozen" when the Procedure has finished.

**Section 1:**

*SECTION 1 - CREATION OF A NEW BASE DAMPER CURVE - VEHICLE 1 DAMPER DATA WILL BE OVERWRITTEN !*

In Section 1 a BASE DAMPER Curve will be created. At the End of each Optimization Step 1 & Step 2 the Results will be copied onto the VEHICLE1

**Section 2:**

*SECTION 2 - FINE TUNING OF EXISTING DAMPER CURVE - DAMPER DATA WILL BE GENERATED BY SCALING VEHICLE 1 DAMPER DATA OR DATA GENERATED BY EXECUTION OF STEP 1*

In Section 2 the BASE DAMPER Curve will be modified by setting Damper Scaling Factors on the VEHICLE 1 Sheet. At the End of each Optimization Step 3 & Step 4 the SCALING FACTORS will be copied to VEHICLE 1
If desired the resulting Damper Curve can also be copied to the VEHICLE 1 Sheet and SCALING FACTORS will be set to 1.

**4 STEP AUTOMATIC DAMPER CREATION & OPTIMIZATION ROUTINE:**

**Section 1 - Step 1: A LINEAR SYMMETRIC Damper will be created with Equal Bump & Rebound Forces and a Linear Constant "Rate" over Damper Speed.**

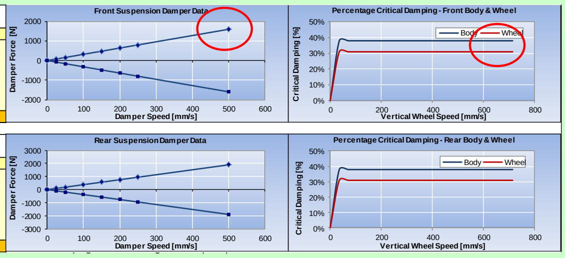
**STEP 1 - CREATE LINEAR & SYMMETRICAL DAMPER CURVE**

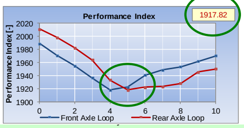
*CREATE LINEAR DAMPER - FRONT*

*CREATE LINEAR DAMPER - REAR*

*CREATE LINEAR DAMPER - FRONT & REAR*

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 78.9 | -78.9 |
| 50.0 | 157.7 | -157.7 |
| 100.0 | 315.4 | -315.4 |
| 150.0 | 473.1 | -473.1 |
| 200.0 | 630.8 | -630.8 |
| 250.0 | 788.5 | -788.5 |
| 500.0 | 1577.0 | -1577.0 |




| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 94.7 | -94.7 |
| 50.0 | 189.4 | -189.4 |
| 100.0 | 378.8 | -378.8 |
| 150.0 | 568.2 | -568.2 |
| 200.0 | 757.7 | -757.7 |
| 250.0 | 947.1 | -947.1 |
| 500.0 | 1894.1 | -1894.1 |

| | | |
|---|---|---|
| Front Damper Start Value | 1192.8 | N [Based on a targeted 30 % Crtitical Wheel Damping] |
| Rear Damper Start Value | 1390.1 | N [Based on a targeted 30 % Crtitical Wheel Damping] |

**SEE RED CIRCLES**

| | |
|---|---|
| 41.43 | % [Critical Front Body Damping @ Damper Start Value] |
| 30.00 | % [Critical Front Wheels Damping @ Damper Start Value] |
| 40.45 | % [Critical Rear Body Damping @ Damper Start Value] |
| 30.00 | % [Critical Rear Wheels Damping @ Damper Start Value] |

If desired the User can set manually a Start Value for Damper Force:

| | | |
|---|---|---|
| Custom Front Damper Force @ Highest Damper Speed Data Point | 1250.0 | N [Compression & Rebound] |
| Custom Rear Damper Force @ Highest Damper Speed Data Point | 1500.0 | N [Compression & Rebound] |

☑ Use Custom Damper Start Values

NOTE: Do make sure that the highest Damper Speed Point is covering up to the Range of 500 mm/s Vertical WHEEL Speed.

The Step 1 Optimization Procedure can be executed manually for Front and Rear Axle only or for Both Axles. At the end of the Optimization the Damper Data will be copied to VEHICLE 1 and **OVERWRITE** Existing Data.

For each Axle Loop the Performance Index will be calculated and displayed graphically (see Yellow CELL in PI Chart). At the end of the Optimization Procedure all Results will be frozen. **SEE GREEN CIRCLES**

**Section 1 - Step 2: The Damper KNEE Point will be Added and Optimized by modifying the 2nd Damper Velocity Point Force**

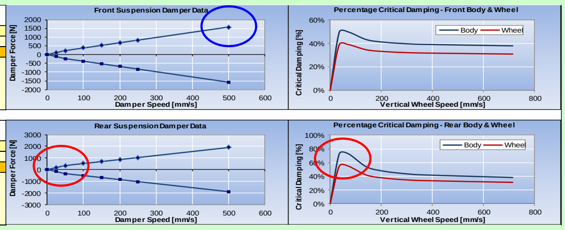
**STEP 2 - ADD & OPTIMIZE KNEE POINT**

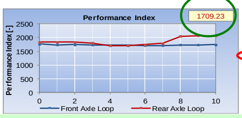
*OPTIMIZE KNEE POINT - FRONT DAMPER*

*OPTIMIZE KNEE POINT - REAR DAMPER*

*OPTIMIZE KNEE POINT - FR. & RR. DAMPER*

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 113.8 | -113.8 |
| 50.0 | 227.7 | -227.7 |
| 100.0 | 377.6 | -377.6 |
| 150.0 | 527.5 | -527.5 |
| 200.0 | 677.5 | -677.5 |
| 250.0 | 827.4 | -827.4 |
| 500.0 | 1577.0 | -1577.0 |




| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 170.9 | -170.9 |
| 50.0 | 341.9 | -341.9 |
| 100.0 | 514.4 | -514.4 |
| 150.0 | 686.8 | -686.8 |
| 200.0 | 859.3 | -859.3 |
| 250.0 | 1031.8 | -1031.8 |
| 500.0 | 1894.1 | -1894.1 |

The Step 2 Optimization Procedure will start from the VEHICLE 1 Damper Data - which can be generated by Step 1 Optimization Procedure or represent Existing Damper Data - and will take the Highest Damper Speed Points as Reference Points for creating a Linear Damper AND keeping their Force Values Constant - **SEE BLUE CIRCLES**

In a next step the SECOND Damper Velocity point - **SEE RED CIRCLES** - will be varied with all other Damper Points (except the Final One) following and various Front & Rear Axle Loops will be executed.

PI Index will be tracked and optimized. **SEE GREEN CIRCLE**

The Step 2 Optimization Procedure can also be executed manually for Front and Rear Axle only or for Both Axles. At the end of the Optimization the Damper Data will be copied to VEHICLE 1 and **OVERWRITE** Existing Data.

**Section 2 - Step 3: The OVERALL % Critical Damping (Jounce & Rebound Combined) will be optimized by scaling the Damper Data Generated in Step 1 or Step 2**

**STEP 3 - FINE TUNING OF % CRITICAL DAMPING**

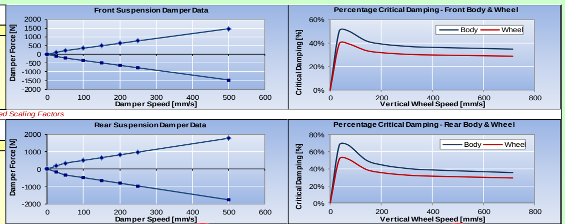
*OPTIMIZE FRONT % CRITICAL DAMPING*

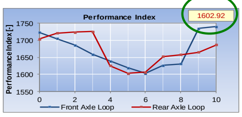
*OPTIMIZE REAR % CRITICAL DAMPING*

*OPTIMIZE FR. & RR. % CRITICAL DAMPING*

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 106.0 | -106.0 |
| 50.0 | 211.9 | -211.9 |
| 100.0 | 351.5 | -351.5 |
| 150.0 | 491.0 | -491.0 |
| 200.0 | 630.5 | -630.5 |
| 250.0 | 770.1 | -770.1 |
| 500.0 | 1467.8 | -1467.8 |

*Note: All Damper Data are considering Applied Scaling Factors*




| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 167.5 | -167.5 |
| 50.0 | 335.1 | -335.1 |
| 100.0 | 493.8 | -493.8 |
| 150.0 | 652.5 | -652.5 |
| 200.0 | 811.2 | -811.2 |
| 250.0 | 969.9 | -969.9 |
| 500.0 | 1763.4 | -1763.4 |

*Set VEHICLE 1 to New Front Damper Data* | *Set VEHICLE 1 to New Rear Damper Data* | *Set VEHICLE 1 to New Fr. & Rr. Damper Data*

| | | | |
|---|---|---|---|
| Fr. Jounce Damping Scaling Factor | 0.931 | Rr. Jounce Damping Scaling Factor | 0.931 |
| Fr. Rebound Damping Scaling Factor | 0.931 | Rr. Rebound Damping Scaling Factor | 0.931 |

The Step 3 Optimization Procedure will also start from the VEHICLE 1 Damper Data - which can be generated either by Step 1 or Step 2 Optimization Procedures or represent Existing Damper Data - and will scale those data up or down with **IDENTICAL** Scaling factors for Jounce and Rebound Damping. **SEE RED CIRCLES**

The Damper Data Table will consider those scaling factors and change the numbers accordingly. **SEE BLUE CIRCLES**

PI Index will be tracked and optimized. **SEE GREEN CIRCLE**

The Step 3 Optimization Procedure can also be executed manually for Front and Rear Axle only or for Both Axles. At the end of the Optimization the Damper Data will be NOT be copied automatically to VEHICLE 1.
By pressing the corresponding Button, the Resulting Damper Data from the Optimization can be copied to the VEHICLE 1 Sheet with an according Reset of Damper Scaling Factors.
You MUST copy the results to VEHICLE 1 if you want to use the results as a Starting Point for another (manually started) STEP 2, STEP 3 or STEP 4 Optimization Loop.

**Section 2 - Step 4: Jounce & Rebound Damping will be Optimized INDEPENDENTLY by scaling the Damper Data Generated in Step 1, Step 2 or Step 3**

**STEP 4 - FINE TUNING OF BUMP & REBOUND DAMPING**

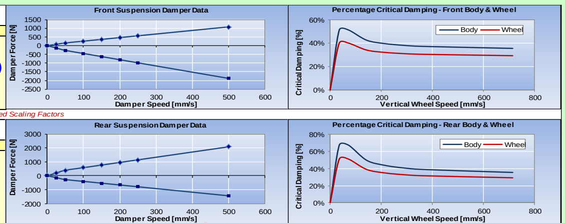
*OPTIMIZE FR. BUMP & REBOUND DAMPING*

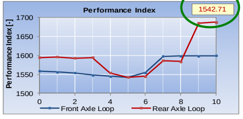
*OPTIMIZE RR. BUMP & REBOUND DAMPING*

*OPTIMIZE FR. & RR. BUMP & REBOUND DAMPING*

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 77.9 | -135.7 |
| 50.0 | 155.8 | -271.5 |
| 100.0 | 258.3 | -450.3 |
| 150.0 | 360.9 | -629.0 |
| 200.0 | 463.4 | -807.8 |
| 250.0 | 566.0 | -986.6 |
| 500.0 | 1078.8 | -1880.4 |

*Note: All Damper Data are considering Applied Scaling Factors*




| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 197.4 | -136.8 |
| 50.0 | 394.7 | -273.7 |
| 100.0 | 581.7 | -403.3 |
| 150.0 | 768.7 | -532.9 |
| 200.0 | 955.7 | -662.5 |
| 250.0 | 1142.6 | -792.2 |
| 500.0 | 2077.5 | -1440.3 |

*Set VEHICLE 1 to New Front Damper Data* | *Set VEHICLE 1 to New Rear Damper Data* | *Set VEHICLE 1 to New Fr. & Rr. Damper Data*

| | | | |
|---|---|---|---|
| Fr. Jounce Damping Scaling Factor | 0.684 | Rr. Jounce Damping Scaling Factor | 1.097 |
| Fr. Rebound Damping Scaling Factor | 1.192 | Rr. Rebound Damping Scaling Factor | 0.760 |

The Step 4 Optimization Procedure will also start from the VEHICLE 1 Damper Data - which can be generated either by Step 1, Step 2 or Step 3 Optimization Procedures or represent Existing Damper Data - and will scale those data up or down with now **INDEPENDEND** Scaling factors for Jounce and Rebound Damping. **SEE RED CIRCLES** The Procedure will however keep the sum of Bump & Rebound Damping Constant.

The Damper Data Table will consider those scaling factors and change the numbers accordingly. **SEE BLUE CIRCLES** Any pre-set Damper Scaling Factors in VEHICLE 1 will be considered and merge into the Final Scaling Factors

**NOTE:** At this point it is worth mentioning that STEP 4 Optimization will need to be evaluated ONLY in the Time Domain Ride Simulations. The FFT in the Frequency domain does limit the differentiation between Bump & Rebound Damping and will therefor produce results with limited suitability for PI Evaluation.

PI Index will be tracked and optimized. **SEE GREEN CIRCLE** **In this example the PI Value Started at 1917 and went consequently to 1709, then to 1602 and finally ending at 1542 after Step 4**

The Step 4 Optimization Procedure can also be executed manually for Front and Rear Axle only or for Both Axles. At the end of the Optimization the Damper Data will be NOT be automatically copied to VEHICLE 1.
By pressing the corresponding Button, the Resulting Damper Data from the Optimization can be copied to the VEHICLE 1 Sheet with an according Reset of Damper Scaling Factors.
You MUST copy the results to VEHICLE 1 if you want to use the results as a Starting Point for another (manually started) STEP 2, STEP 3 or STEP 4 Optimization Loop.

#### …. 10 EASY STEPS TO EVEN HAPPIER TUNING SESSIONS … AUTOMATICALLY …..

**STEP 1** BEFORE STARTING ANY AUTOMATIC OPTIMIZATION DO CHECK THE FOLLOWING:
- VERIFY THAT ALL VEHICLE DATA HAVE BEEN ENTERED CORRECTLY.
- MAKE SURE THAT YOU DO HAVE AN (APPROXIMATE) DAMPER CURVE COVERING THE RANGE FROM 0 TO 500 MM/S VERTICAL WHEEL SPEED
- **CHECK THAT THE SECOND DAMPER VELOCITY DATA POINT IS SET TO THE CORRECT INTENDED KNEE POINT VELOCITY - A TYPICAL KNEE POINT OPERATING SPEED IS 50 MM/S TO 100 MM/S**
- SELECT THE DESIRED FREQUENCY & TIME DOMAIN SIGNALS. THE STANDARD SETTING - AS SUPPLIED IN THE ORIGINAL WORKBOOK - DO 'REFLECT COMMONLY USED RIG TEST PROCEDURES AND ARE A GOOD REFERENCE TO START WITH FOR THE AVERAGE RACE CAR RUNNING ON TARMAC.

**NOTE: THE BASELING SIGNAL SETTINGS - AS DELIVERED IN THE ORIGINAL WORKBOOK - ARE A TYPICAL INDUSTRY REFERENCE SETTING AND AS SUICH HIGHLY RECOMMENDED.**

- COPY YOUR REFERENCE SETTING TO VEHICLE 2 FOR FUTURE COMPARISONS.

**STEP 2** PROVIDE - IF POSSIBLE - APPROXIMATE % CRITICAL DAMPING RATES FOR THE BODY & WHEEL @ NATURAL FREQUENCIES. IF YOU DO NOT KNOW YOU SET ALL TARGET DAMPING TO 0 AND SEE WHERE THE OPTIMIZATION ALGORITHM WILL BRING YOU. ONE COULD IN A NEXT STEP USE THESE RESULTS FOR A DEFINING A CUSTOM DAMPER STARTING POINT AND AFTER HAVING EVALUATED THE % CRITICAL DAMPING CHARTS SET NEW TARGETS FOR WHEEL AND BODY DAMPING RATIO'S.
- SET ALL DAMPING TARGETS @ NATURAL FREQUENCY TO 0 (=DEACTIVATE). EVALUATE RESULTS
- SET WHEEL DAMPING @ NATURAL FREQENCY TO 35% (TYPICAL VALUE). EVALUATE RESULTS
- SET BODY DAMPING TARGET @ NATURAL FREQUENCY TO 35% (SHOULD NOT CONFLICT WITH WHEEL DAMPING) & EVALUATE RESULT
- SET OPTIMIZED TARGETS BASED ON PREVIOUS RESULTS.

**NOTE:** WITH INCREASING SPRING RATES THE BODY-WHEEL OSCILLATION SYSTEM BECOMES MORE COUPLED AND IT DOES BECOME INCREASINGLY MORE DIFFICULT TO SPECIFY INDEPENDENT DAMPOING RATES FOR EACH OF THEM. SEE FFT TRANSFER FUNCTION ABOVE.

**STEP 3** MAKE SURE THAT THE PERFORMANCE INDEX CALIBRATION FACTORS ARE CORRECTLY SET FOR YOUR INTENDED OPTIMIZATION PROFILE,
DEFINE THE CONTENT OF THE PERFORMANCE INDEX CALCULATION AND DO MAKE SURE THAT THE SELECT TESTING PROCEDURES DO MEET YOUR VEHICLE OPERATING CONDITIONS.

- FOR WING CARS THE PRIMARY OPTIMIZATION CRITERIUM IS PLATFORM CONTROL. HERE ONE MIGHT ALSO CONSIDER TO USE THE PITCH MODE FOR ADDITIONAL VERIFICATION.
- FOR NON AERODYNAMIC CARS THE PRIMARY OPTIMIZATION CRITERIUM IS TIRE GRIP OPTIMIZATION
- ONE CAN AND SHOULD CONSIDER TOO A CERTAIN DEGREE ALSO SETTING COMFORT TARGETS AS DRIVER FATIGUE IS ALSO A PERFORMANCE FACTOR IN RACING

**NOTE: THE BASELING PERFORMANCE INDEX SETTINGS - AS DELIVERED IN THE ORIGINAL WORKBOOK - ARE A GOOD COMPROMISE AND STARTING POINT FOR ANY OPTIMIZATIONS.**

**STEP 4** DECIDE WHETHER YOU DO WANT TO OPTIMIZE AN EXISTING DAMPER CURVE OR CREATE A NEW ONE. IF YOU ARE A NOVICE START WITH THE FULLY AUTOMATIC PROCEDURE

**STEP 5** IF YOU DO WANT TO CREATE A COMPLETE NEW DAMPER CURVE FROM SCRATCH THEN RUN A FULL AUTOMATIC CREATE & OPTIMIZATION LOOP.

**STEP 6** IF YOU DO WANT TO OPTIMIZE AN EXISTING DAMPER CURVE RUN ONLY STEP 3 AND IF DESIRED STEP 4 FOR THE DESIRED AXLE(S)
STEP 3 & STEP 4 DO NOT MODIFY THE DAMPER CURVE IN VEHICLE 1 BUT OPTIMIZE ONLY THE AMPER SCALING FACTORS. THIS DOES ALLOW EASY FURTHER MANUAL MANIPULATIOM

**STEP 7** ANALYZE THE RESULTS AND RE-EVALUATE ALL STEPS FOR ANY POTENTIAL ADJUSTMENTS. IF NEEDED RUN AGAIN STEP 1 TO STEP 6 WITH ADJUSTED PI SETTINGS

**STEP 8** IF YOU HAVE SUCCESSFULLY TERMINATED A FULL OPTIMIZATION LOOP YOU CAN CONSIDER TO RUN ANOTHER SEQUENCE OF STEP 2, STEP 3 AND STEP 4 MANUALLY IN ORDER TO SEE IF ONE CAN ACHIEVE FURTHER IMPROVEMENTS. BY DOING SO YOU **MUST HOWEVER CONSIDER THE FOLLOWING:**

- THE **STEP 2** OPTIMIZATION PROCEDURE DOES ALWAYS START WITH USING THE ACTUAL DAMPER DATA AND **DOES RESET ALL DAMPER SCALING FACTORS** IN VEHICLE 1.
IF YOU WISH TO RUN STEP 2 YOU **MUST UPDATE THE DAMPER DATA IN VEHICLE 1** BY PRESSING THE UPDATE BUTTONS OF THE LAST STEP 3 OR STEP 4 SIMULATION THAT WAS EXECUTED.
IN CASE OF RUNNING A FULL AUTOMATIC LOOP YOU WILL BE ASKED AUTOMATICALLY AFTER EXECUTION OF STEP 4 OPTIMIZATION LOOP.

- THE STEP 3 & STEP 4 OPTIMIZATION PROCEDURE DO START WITH THE VEHICLE 1 DAMPER DATA **AND DO CONSIDER ALL DAMPER SCALING FACTORS**.
ONE CAN UPDATE THE VEHICLE 1 DAMPER DATA AND RESET THE DAMPER SCALING FACTORS BY PRESSING THE ACCORDING UPDATE BUTTONS.
IN CASE OF WANTING TO EXECUTE AN ADDITIONAL KNEE-POINT OPTIMIZATION (STEP 2) ON THE RESULTING DAMPER DATA OF STEP 3 OR STEP 4 ONE MUST UPDATE THE DAMPER DATA IN VEHICLE 1 AND RESET THE SCALING FACTORS - AGAIN BY PRESSING THE CORRESPONDING UPDATE BUTTONS

**STEP 9** IF YOU DO FEEL THAT CERTAIN ASPECTS OF THE VEHICLE BEHAVIOUR DO NEED SPECIFIC TUNING DO CONSIDER CREATING A CUSTOM COST FUNCTION AND EXECUTE STEP 1 TO 8

**STEP 10** COMPARE YOUR NEW SETUP TO YOUR ORIGINAL START/BASELINE SETUP BY COMPARING ALL PERFORMANCE METRICS.

***Some Final Words of Wisdom.***

° Do make sure that all input data is valid. GIGO (Garbage In = Garbage Out) is applicable to any Software Tool.

° In Particular all Damper Data should cover the normal operating range and provide correct data points for KNEE velocity and high speed impact velocities.

° The KNEE Point is of Key importance for Low Frequency Body Control. Do make sure that the KNEE Point Velocity is in the Ball Parc as otherwise the STEP 2 Optimization might finish at a Local Optimum only.

° Do NOT define conflicting targets, in particular for Body & Wheel Damping Ratio's - The results of the optimization will be more accurate the more the targets are "in-line" with each other.
- For instance if one does increase Spring Rate and Damper Force accordingly the amount of Damping on the Wheel will also go up. Adjust Targets accordingly.

* Several Functions in the STM Performance Index Calculations will provide a value from 1000 to 100000 in case of an error. This does indicate that certain metrics which are used in the PI value cannot be determined.
- These "Errors" do happen when for instance it is not possible to identify "Peaks" in the Transfer Function. A "Flat Curve" will also not permit to calculate % Critical Damping.
- If such happens over (almost) the complete axle loop simulation do check your model. If the Error is related to % Critical Damping then Deactivate then corresponding Target Input ("0")

° When creating a Custom Performance Index (For Experts Only) one <u>MUST</u> make sure that the Final Value is always Positive, cannot produce any errors and does respect the Criterium of Lower Values being Better.

° If for some reason the model does fail do change a front and a rear spring rate and run with F9 a calculation. All should return to normal.

° The Baseline Optimization Routine does calculate PI Values for combined Frequency and Time Domain Test. As a matter of good practice one can (and should) also optimize only one Domain and check the effect on the other Domain and Vice Versa !. By doing so one can gain a good feeling for the sensitivity of the damper setting on the Frequency Domain as on the Time domain independently.

* Although the Numbers from the PI can differ significantly between 2 damper settings it is not necessarily said that the setting with the higher PI Value is all bad. It is very much possible that only 1 metric is not achieving the target value - and potentially in combination with a high scaling factor for that metric - does create a significant potentially over-proportional importance. A small manual change in the damper characteristics could adress this issue and make the setting "on paper" better.

° The Resultsof the Optimization Procedure should be considered as a Good Starting Point for further investigations and potentially extra (manually) executed optimization loops.

° The Optimization Tool is a great feature to get a solid baseline Damper Setting but it is not the Magic Wizzard that is always right. Check Results for Sanity !

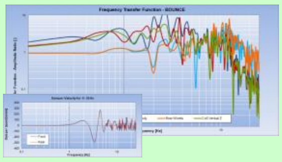
* As the CPU usage during the Optimization Loop is significant, some versions of Excel might briefly indicate in the title bar that Excel is not responding. This is a know "Problem" of Excel 2013 & above Versions.
Do not worry, the Procedure will execute anyway correctly. It is a feature not a fault …

° HAVE FUN !

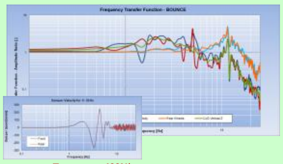
**TYPICAL SIMULATION ERRORS IN RELEASE 8.1 WHICH CAN BE CAUSED BY NON_LINEARITY & TOP-MOUNT SPRiNG & DAMPER 2nd ORDER INTEGRATION**

With the introduction of the damper topmount in RELEASE 8.1 the results can become irratic if the topmount.Stiffness is selected "too low". Below one can see the results for a range of topmount stiffness in the Frequency Domain.

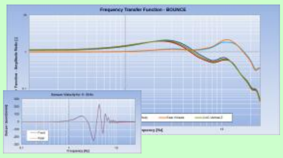

**Topmount 200N/mm**




**Topmount 300N/mm**




**Topmount 400N/mm**



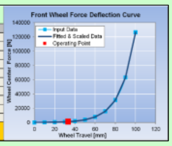

**Topmount 500N/mm**

In the example above the minimal topmount stiffness for numeric stable analyis is 500N/mm for this particular vehicle and suspension setup. Whether this value does give in real life enough performance has to be analyzed consequently.

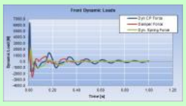
With the introduction of Non-Linear Wheel Force Deflection Curves and/or Non-Linear Motion-Ratio Curves, also the Time-Domain integrator can run into numerical problems if the non-linearity is too severe. Indications of problems are the following:

| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| 0.0 | 0.700 | 0.0 |
| 10.0 | 0.705 | 320.8 |
| 20.0 | 0.715 | 648.4 |
| 30.0 | 0.730 | 987.7 |
| 40.0 | 0.750 | 1975.5 |
| 50.0 | 0.775 | 3951.0 |
| 60.0 | 0.805 | 7902.0 |
| 70.0 | 0.840 | 15804.0 |
| 80.0 | 0.880 | 31607.9 |
| 90.0 | 0.925 | 63215.9 |
| 100.0 | 0.975 | 126431.8 |

☑ USE FRONT WHEEL FORCE DEFLECTION CURVE




1) When introducing very strong non-linearities, the integration algorithm can start to create "oscillations"




2) When introducing very strong non-linearities, the above mentioned integration oscillations can cause a numeric "drift" of especailly displacement variables (which are the results of 2 consecutive integrations and hence will be adding all numeric errors). If Vehicle CoG Heave Travel & Pitch Angle do not return to their start values, then there is a problem.


**If one does experience one of the above problems, one MUST either increase the topmount spring rate or reduce the non-linearity in the wheel force deflection curve.**

***UNPROTECTED SHEET FREE FOR USAGE - CANNOT BE RENAMED***

Can be used as normal Excel Sheet.

***DO NOT DELETE "EXPORT" BUTTON***

***EXPORT COMPLETE USER SHEET***

# DYNATUNE SUSPENSION TUNING MODULE - RELEASE 8.1

Copyright
DYNATUNE-XL


***NOTE:* The Damper Optimizing Procedures Will Modify the Damper Data in VEHICLE 1 (!)**

***Frequency Domain Recommended Test Setting***
*° Bounce Mode w/ Averaged Damping*
*° Exponential Decay - 5 mm Amp.- Average 150 mm/s Input Speed*

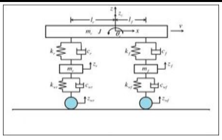
***Time Domain Recommended Test Setting***
*° Half Sine - 0.025 m Height - 0.5 m Length - 80 kph - 1 sec Analysis*

***BLUE = ENTER DATA (SUSPENSION)***
***GREEN = ENTER DATA (CAR & CONTROL)***
***RED = CALCULATED RESULTS - DO NOT TOUCH***

OPTIMIZER README SECTION

***COPY DATA VEHICLE 1 TO VEHICLE 2***

***COPY DATA VEHICLE 2 TO VEHICLE 1***



■ Include STM FREQUENCY Domain Performance Index *

■ Include STM TIME Domain Performance Index *

***STM PERFORMANCE INDEX - PI***

| | | |
|---|---|---|
| 4 Poster - Test | 788.16 | - |
| Ride Simulation | 2200.00 | - |
| (combined) PI-Value | 2988.15 | - |

** It is strongly recommended to consider both Frequency as Time Domain in the Optiminzing Procedure*

■ Create & Use CUSTOM Performance Index - Only For Experts

***STM PERFORMANCE INDEX - CALIBRATION FACTORS***

| | | | |
|---|---|---|---|
| **Platform Control / Aerodynamic Stability** | 8.0 | 46.5 | % Contribution to PI-Value |
| [Recommended Range 0 - 10] | | | |
| **Wheel Control / Mechanical Tire Grip** | 5.0 | 45.8 | % Contribution to PI-Value |
| [Recommended Range 0 - 10] | | | |
| **Driver Comfort / Vertical Accelerations *** | 1.0 | 7.7 | % Contribution to PI-Value |
| [Recommended Range 0 - 10] | * Time Domain Only | | |

| | | |
|---|---|---|
| Target Front Body % Critical Damping @ Peak Resonance Frequency (-3dB) | 55.0 | % [0 = No Target Value, Deactivated] |
| Target Front Wheel % Critical Damping @ Peak Resonance Frequency (-3dB) | 35.0 | % [0 = No Target Value, Deactivated] |
| Target Rear Body % Critical Damping @ Peak Resonance Frequency (-3dB) | 55.0 | % [0 = No Target Value, Deactivated] |
| Target Rear Wheel % Critical Damping @ Peak Resonance Frequency (-3dB) | 35.0 | % [0 = No Target Value, Deactivated] |

***EXECUTE FULL DAMPER LOOP CREATE & OPTIMIZE FRONT & REAR DAMPERS***

| | |
|---|---|
| 33.67 | % [Critical Front Body Damping @ Damper Start Value] |
| 30.00 | % [Critical Front Wheels Damping @ Damper Start Value] |
| 31.46 | % [Critical Rear Body Damping @ Damper Start Value] |
| 30.00 | % [Critical Rear Wheels Damping @ Damper Start Value] |

■ Use Custom Damper Start Values

| | | |
|---|---|---|
| Front Damper Start Value | 1000.2 | N [Based on a targeted 30 % Crtitical Wheel Damping] |
| Rear Damper Start Value | 1422.6 | N [Based on a targeted 30 % Crtitical Wheel Damping] |

## *SECTION 1 - CREATION OF A NEW BASE DAMPER CURVE - VEHICLE 1 DAMPER DATA WILL BE OVERWRITTEN !*

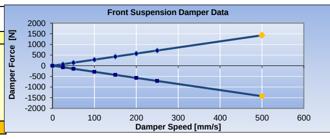
### STEP 1 - CREATE LINEAR & SYMMETRICAL DAMPER CURVE

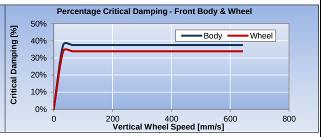
***CREATE LINEAR DAMPER - FRONT***

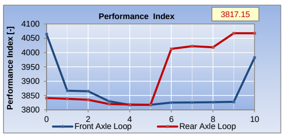
***CREATE LINEAR DAMPER - REAR***

***CREATE LINEAR DAMPER - FRONT & REAR***

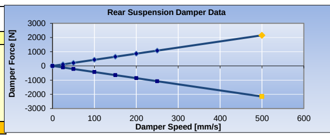
| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 70.7 | -70.7 |
| 50.0 | 141.4 | -141.4 |
| 100.0 | 282.8 | -282.8 |
| 150.0 | 424.2 | -424.2 |
| 200.0 | 565.6 | -565.6 |
| 250.0 | 707.0 | -707.0 |
| 500.0 | 1414.0 | -1414.0 |

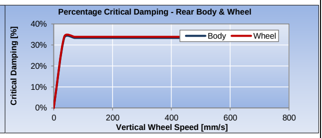



| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 107.7 | -107.7 |
| 50.0 | 215.4 | -215.4 |
| 100.0 | 430.8 | -430.8 |
| 150.0 | 646.2 | -646.2 |
| 200.0 | 861.6 | -861.6 |
| 250.0 | 1077.0 | -1077.0 |
| 500.0 | 2154.0 | -2154.0 |



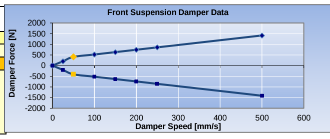

### STEP 2 - ADD & OPTIMIZE KNEE POINT

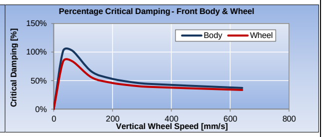
***OPTIMIZE KNEE POINT - FRONT DAMPER***

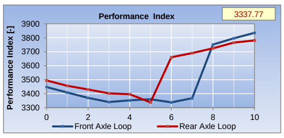
***OPTIMIZE KNEE POINT - REAR DAMPER***

***OPTIMIZE KNEE POINT - FR. & RR. DAMPER***

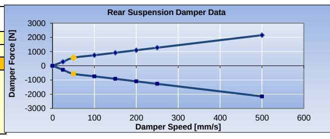
| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 204.1 | -204.1 |
| 50.0 | 408.3 | -408.3 |
| 100.0 | 520.0 | -520.0 |
| 150.0 | 631.8 | -631.8 |
| 200.0 | 743.5 | -743.5 |
| 250.0 | 855.3 | -855.3 |
| 500.0 | 1414.0 | -1414.0 |

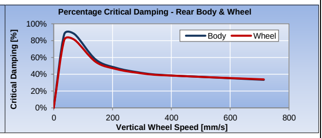



| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 282.7 | -282.7 |
| 50.0 | 565.4 | -565.4 |
| 100.0 | 741.9 | -741.9 |
| 150.0 | 918.4 | -918.4 |
| 200.0 | 1094.9 | -1094.9 |
| 250.0 | 1271.4 | -1271.4 |
| 500.0 | 2154.0 | -2154.0 |




## *SECTION 2 - FINE TUNING OF EXISTING DAMPER CURVE - DAMPER DATA WILL BE GENERATED BY SCALING VEHICLE 1 DAMPER DATA OR DATA GENERATED BY EXECUTION OF STEP 1*

### STEP 3 - FINE TUNING OF % CRITICAL DAMPING

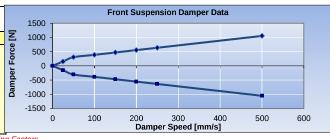
***OPTIMIZE FRONT % CRITICAL DAMPING***

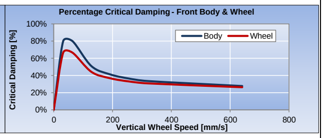
***OPTIMIZE REAR % CRITICAL DAMPING***

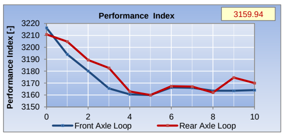
***OPTIMIZE FR. & RR. % CRITICAL DAMPING***

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 152.0 | -152.0 |
| 50.0 | 304.1 | -304.1 |
| 100.0 | 387.3 | -387.3 |
| 150.0 | 470.6 | -470.6 |
| 200.0 | 553.8 | -553.8 |
| 250.0 | 637.0 | -637.0 |
| 500.0 | 1053.2 | -1053.2 |

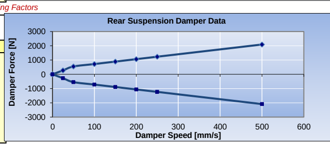
*Note: All Damper Data are considering Applied Scaling Factors*

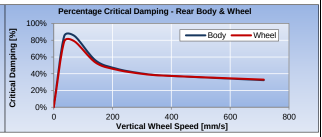



| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 274.2 | -274.2 |
| 50.0 | 548.4 | -548.4 |
| 100.0 | 719.7 | -719.7 |
| 150.0 | 890.9 | -890.9 |
| 200.0 | 1062.1 | -1062.1 |
| 250.0 | 1233.3 | -1233.3 |
| 500.0 | 2089.3 | -2089.3 |




| | | | | |
|---|---|---|---|---|
| Fr. Jounce Damping Scaling Factor | 0.745 | Rr. Jounce Damping Scaling Factor | 0.970 | - |
| Fr. Rebound Damping Scaling Factor | 0.745 | Rr. Rebound Damping Scaling Factor | 0.970 | - |

### STEP 4 - FINE TUNING OF BUMP & REBOUND DAMPING

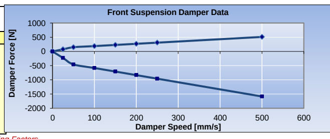
***OPTIMIZE FR. BUMP & REBOUND DAMPING***

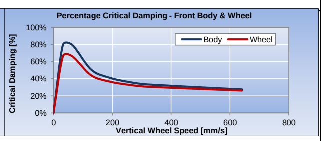
***OPTIMIZE RR. BUMP & REBOUND DAMPING***

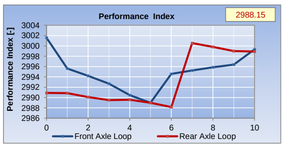
***OPTIMIZE FR. & RR. BUMP & REBOUND DAMPING***

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 73.7 | -228.9 |
| 50.0 | 147.3 | -457.8 |
| 100.0 | 187.7 | -583.1 |
| 150.0 | 228.0 | -708.3 |
| 200.0 | 268.3 | -833.6 |
| 250.0 | 308.6 | -958.9 |
| 500.0 | 510.3 | -1585.4 |

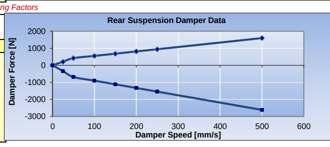
*Note: All Damper Data are considering Applied Scaling Factors*

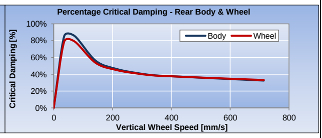



| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 25.0 | 209.4 | -343.3 |
| 50.0 | 418.8 | -686.5 |
| 100.0 | 549.5 | -900.8 |
| 150.0 | 680.2 | -1115.1 |
| 200.0 | 811.0 | -1329.5 |
| 250.0 | 941.7 | -1543.8 |
| 500.0 | 1595.3 | -2615.3 |

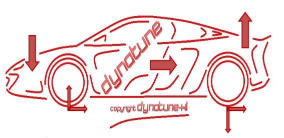



| | | | | |
|---|---|---|---|---|
| Fr. Jounce Damping Scaling Factor | 0.361 | Rr. Jounce Damping Scaling Factor | 0.741 | - |
| Fr. Rebound Damping Scaling Factor | 1.121 | Rr. Rebound Damping Scaling Factor | 1.214 | - |

# DYNATUNE SUSPENSION TUNING MODULE - RELEASE 8.1





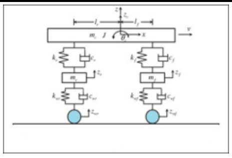

**Vehicle Data**

| | | |
|---|---|---|
| Front Downforce | 1000.0 | N |
| Rear Downforce | 2000.0 | N |
| Wheel Base | 2550.0 | mm |
| Weight Distribution | 45.50 | %Front |
| Total Mass | 715.0 | kg |
| Fr. Wheel Load | 2095.7 | N |
| Rr. Wheel Load | 2911.4 | N |
| Vehicle Pitch Inertia | 675.0 | kgm² |
| Pitch Inertia Sprung Mass | 481.3 | kgm² |

*BLUE = ENTER DATA (SUSPENSION)*
*GREEN = ENTER DATA (CAR & CONTROL)*
*RED = CALCULATED RESULTS - DO NOT TOUCH*

Manual Calculation | CALCULATE / F9

NON-LINEAR WHEEL RATE OPTIMZED



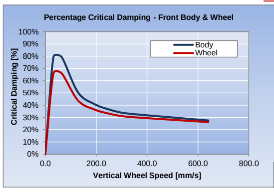
EXPORT VEHICLE 1 DATA | IMPORT VEHICLE 1 DATA | COPY DATA TO VEHICLE 2 | LOAD VEHICLE 2 DATA

**Front Suspension Data**

| | | | |
|---|---|---|---|
| Front Unprung Mass (Corner) | 27.5 | | kg |
| Fr. Tire Vert. Stiffness | 290.00 | | N/mm |
| Fr. Tire % Critical Damping | 5.00 | | % |
| Fr. Tire Damping Rate | 301.12 | | Ns/m |
| Instant. Spring/Damper to Wheel Motion Ratio* | [redacted] | 0.783 | - |
| Calculated Instantaneous Fr. SPRING Rate | [redacted] | 65.30 | N/mm |
| Fr. Spring Static Deflection / Wheel Travel | 41.15 | 52.57 | mm |
| Fr. WHEEL Rate (incl. Scaling) | 39.73 | | N/mm |
| Fr. RIDE Rate (incl. Tire) | 34.94 | | N/mm |
| Fr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | | N/mm |
| Fr. Body Frequency | 2.729 | | Hz |
| Fr. Body Ride Frequency (incl. Tire) | 2.559 | | Hz |
| Fr. Wheelhop Frequency | 17.428 | | Hz |

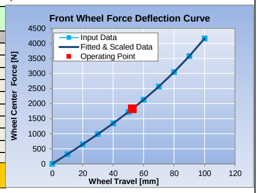
* motion ratio from 0 to 1 (typically max 1:1 = wheel travel)

NOTE: Increasing Non-Linearity will affect Analysis Accuracy



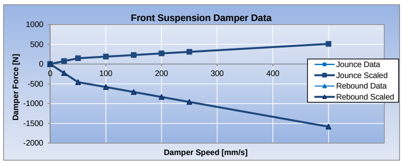

| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| 0.0 | 0.700 | 0.0 |
| 10.0 | 0.705 | 320.8 |
| 20.0 | 0.715 | 648.4 |
| 30.0 | 0.730 | 987.7 |
| 40.0 | 0.750 | 1343.7 |
| 50.0 | 0.775 | 1721.6 |
| 60.0 | 0.805 | 2127.3 |
| 70.0 | 0.840 | 2567.0 |
| 80.0 | 0.880 | 3047.7 |
| 90.0 | 0.925 | 3577.2 |
| 100.0 | 0.975 | 4163.8 |

USE FRONT WHEEL FORCE DEFLECTION CURVE




COPY FRONT WHEEL FORCE CURVE TO VEHICLE 2 | LOAD FRONT WHEEL FORCE CURVE FROM VEHICLE 2

EXPORT FRONT DAMPER DATA | IMPORT FRONT DAMPER DATA | COPY FRONT DAMPER DATA TO VEHICLE 2 | LOAD FRONT DAMPER DATA FROM VEHICLE 2




**Damper Data ID** — Front Suspension Damper Data - Automatically Created & Optimized

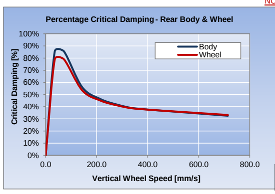
| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] | Damping Rate Jounce [Ns/m] | Damping Rate Rebound [Ns/m] | Rebound/Jounce Ratio [-] |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 73.7 | -228.9 | 2946.7 | -9155.5 | 3.11 |
| 50.0 | 147.3 | -457.8 | 2946.7 | -9155.5 | 3.11 |
| 100.0 | 187.7 | -583.1 | 1876.6 | -5830.6 | 3.11 |
| 150.0 | 228.0 | -708.3 | 1519.9 | -4722.3 | 3.11 |
| 200.0 | 268.3 | -833.6 | 1341.5 | -4168.2 | 3.11 |
| 250.0 | 308.6 | -958.9 | 1234.5 | -3835.7 | 3.11 |
| 500.0 | 510.3 | -1585.4 | 1020.5 | -3170.7 | 3.11 |

**Rear Suspension Data**

| | | | |
|---|---|---|---|
| Rear Unsprung Mass (Corner) | 32.5 | | kg |
| Rr. Tire Vert. Stiffness | 350.00 | | N/mm |
| Rr. Tire % Critical Damping | 5.00 | | % |
| Rr. Tire Damping Rate | 365.80 | | Ns/m |
| Instant. Spring/Damper to Wheel Motion Ratio* | [redacted] | 0.700 | - |
| Calculated Instantaneous Rr. SPRING Rate | [redacted] | 125.97 | N/mm |
| Rear Spring Static Deflection / Wheel Travel | 51.57 | 73.67 | mm |
| Rr. WHEEL Rate (incl. Scaling) | 61.73 | | N/mm |
| Rr. RIDE Rate (incl. Tire) | 52.47 | | N/mm |
| Rr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | | N/mm |
| Rr. Body Frequency | 3.104 | | Hz |
| Rr. Body Ride Frequency (incl. Tire) | 2.861 | | Hz |
| Rr. Wheelhop Frequency | 17.914 | | Hz |

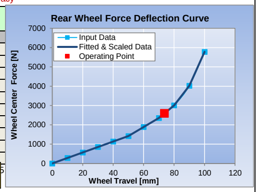
* motion ratio from 0 to 1 (typically max 1:1 = wheel travel)

NOTE: Increasing Non-Linearity will affect Analysis Accuracy



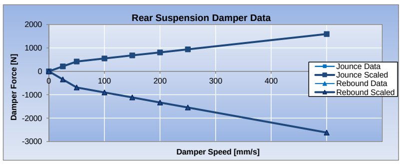

| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| 0.0 | 0.700 | 0.0 |
| 10.0 | 0.700 | 283.8 |
| 20.0 | 0.700 | 567.5 |
| 30.0 | 0.700 | 851.3 |
| 40.0 | 0.700 | 1135.0 |
| 50.0 | 0.700 | 1418.8 |
| 60.0 | 0.700 | 1886.3 |
| 70.0 | 0.700 | 2353.8 |
| 80.0 | 0.700 | 3005.0 |
| 90.0 | 0.700 | 4023.8 |
| 100.0 | 0.700 | 5777.5 |

USE REAR WHEEL FORCE DEFLECTION CURVE




COPY REAR WHEEL FORCE CURVE TO VEHICLE 2 | LOAD REAR WHEEL FORCE CURVE FROM VEHICLE 2

EXPORT REAR DAMPER DATA | IMPORT REAR DAMPER DATA | COPY REAR DAMPER DATA TO VEHICLE 2 | LOAD REAR DAMPER DATA FROM VEHICLE 2




**Damper Data ID** — Rear Suspension Damper Data - Automatically Created & Optimized

| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] | Damping Rate Jounce [Ns/m] | Damping Rate Rebound [Ns/m] | Rebound/Jounce Ratio [-] |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 209.4 | -343.3 | 8375.5 | -13730.4 | 1.64 |
| 50.0 | 418.8 | -686.5 | 8375.5 | -13730.4 | 1.64 |
| 100.0 | 549.5 | -900.8 | 5495.0 | -9008.3 | 1.64 |
| 150.0 | 680.2 | -1115.1 | 4534.9 | -7434.3 | 1.64 |
| 200.0 | 811.0 | -1329.5 | 4054.8 | -6647.3 | 1.64 |
| 250.0 | 941.7 | -1543.8 | 3766.8 | -6175.1 | 1.64 |
| 500.0 | 1595.3 | -2615.3 | 3190.7 | -5230.6 | 1.64 |

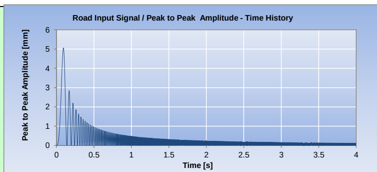
## FREQUENCY DOMAIN ANALYSIS - 4 POSTER SWEEP SINE TEST

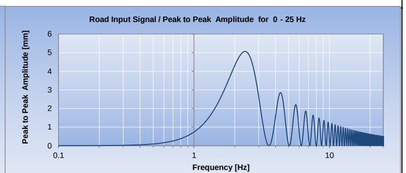
Use Averaged Jounce / Rebound Damping | **ROAD INPUT**

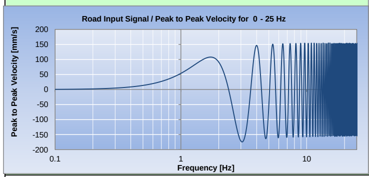
Start Peak to Peak Road Input Amplitude @ 0 Hz: 5.0 mm

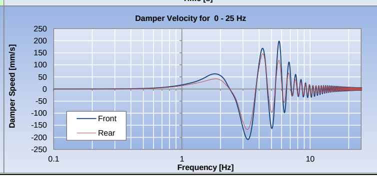
se Exponential Amplitude Decay (RECOMMENDED SETTING)

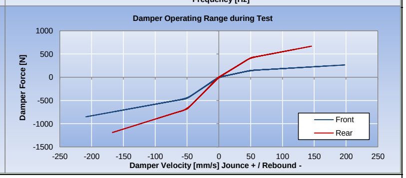
| | |
|---|---|
| OUNCE MODE (DEFAULT) | ront Excitation Only |
| CTIVATE PITCH MODE | ear Excitation Only |

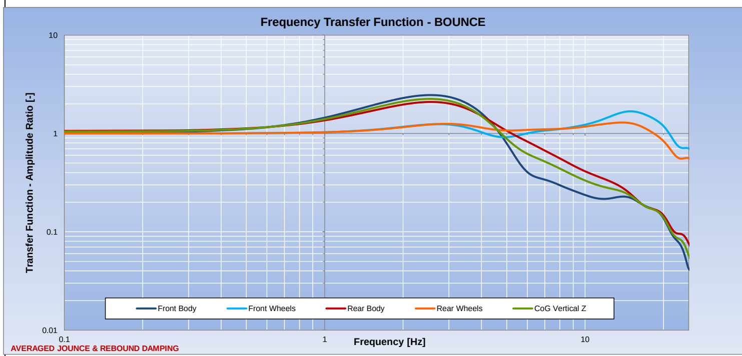


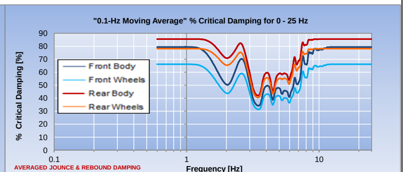



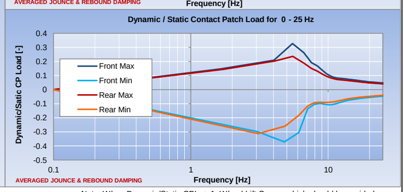




Note: When Dynamic/Static CPL < -1, Wheel Lift Occurs which should be avoided.

| FRONT | Body | Wheel | | CoG | | REAR Body | Wheel | |
|---|---|---|---|---|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.50 | 15.01 | Hz | 2.50 | Hz | 2.50 | 14.01 | Hz |
| Dynamic Overshoot @ Peak Resonance Freq. | 2.46 | 1.68 | mm/mm | 2.25 | mm/mm | 2.09 | 1.29 | mm/mm |
| %Crtical Damping @ Peak Res. Freq (-3dB) | 48.66 | 35.33 | % | 50.61 | % | 55.68 | 65.59 | % |
| Dynamic Wheel Load Indicator 0 - 25 Hz * | | 6.996 | Hz | | | | 5.173 | Hz |

* Area under/above of wheel curves with respect to value 1
Unit = Hz, The lower this value is, the closer the curve remains to 1

Frequency Domain Perf. Index *: 788.16 -
* Value does depend on PI Factor settings

| | FRONT AXLE | | REAR AXLE | |
|---|---|---|---|---|
| - | 0.327 | Max. Dyn./Stat. CPL | 0.236 | - |
| - | -0.371 | Min. Dyn./Stat. CPL | -0.312 | - |
| Ws | 19.99 | Diss. Damper Energy | 22.67 | Ws |
| Ws | 9.12 | Diss. Tire Energy | 10.04 | Ws |
| NHz | 668.97 | Dyn. Tire Load Integral | 563.06 | Nhz |

**SPRING & DAMPER SCALING FACTORS**

| | | | |
|---|---|---|---|
| Fr. Jounce Damping Scaling Factor | 1.000 | Rr. Jounce Damping Scaling Factor | 1.000 |
| Fr. Rebound Damping Scaling Factor | 1.000 | Rr. Rebound Damping Scaling Factor | 1.000 |
| Fr. Spring Rate Scaling Factor | 1.000 | Rr. Spring Rate Scaling Factor | 1.000 |

CALCULATE / F9

**SPRING & DAMPER SCALING FACTORS**

The Spring & Damper Scaling Factors mutiply the spring rates and the measured damper data by the selected factor - for jounce & rebound separately.

# TIME DOMAIN ANALYSIS - VERTICAL RAMP & HALF SINE INPUT TEST

All geometric input units in [m]

| | | |
|---|---|---|
| z- Height Amplitude of Half Sine (Up +, Down -) | 0.0250 | m |
| x-Length of Half Sine | 0.500 | m |
| Velocity over Half Sine | 80.0 | kph |

Set ramp height / amplitude to 0 for test deactivation

| | | |
|---|---|---|
| Simulation Time **(0 - 5s)** | 1.00 | s |

- ■se Smoothed Step/Ramp
- ■se Smoothed Half Sine
- ■ront Excitation Only
- ■ear Excitation Only

**Signal Data**

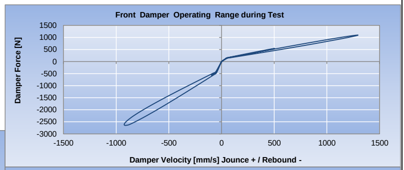
| | | |
|---|---|---|
| Time for Half Sine | 0.023 | s |
| Delay Rear to Front Axle | 0.115 | s |
| Excitation Frequency | 22.22 | Hz |

***HALF SINE***

**TUNING GUIDANCE: THE LOWER THE NUMBERS THE BETTER FOR MECHANICAL GRIP**

**Time Domain Performance Index *** 2200.00 -

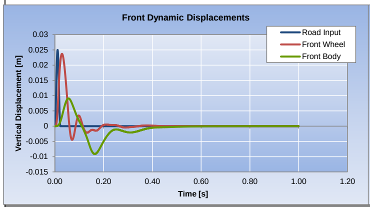
* Value does depend on PI Factor settings

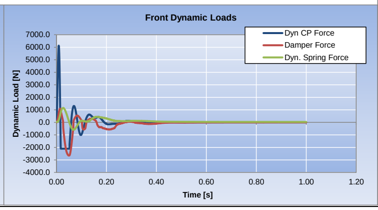


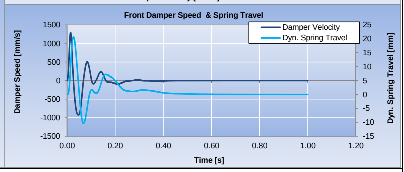

| Front Body Results | | |
|---|---|---|
| **Time to 95% dampened oscillation** | 0.357 | s |
| **Dynamic Peak Overshoot** | 0.365 | m/m |
| **Time to Reach Peak Value** | 0.164 | s |
| **Maximum Vertical Acceleration** | -21.15 | m/s² |

| Front Wheel Results | | |
|---|---|---|
| **Max. Dyn. Contact Patch Load** | 6129.3 | N |
| **Wheel Lift Time** | 0.177 | s |
| **Dyn. CP Load Integrator *** | 316.71 | Ns |

* Integral of the area of the Dynamic Wheel Load Curver over time



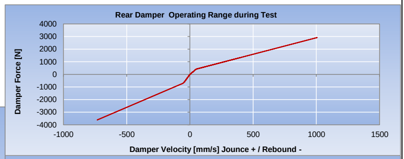



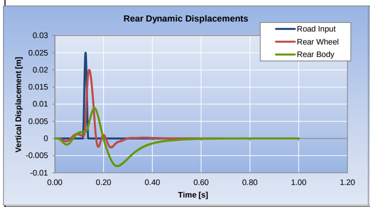

**TUNING GUIDANCE: THE LOWER THE NUMBERS THE BETTER FOR MECHANICAL GRIP**

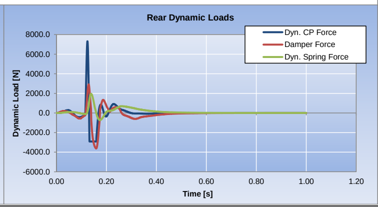
| Rear Body Results | | |
|---|---|---|
| **Time to 95% dampened oscillation **** | 0.296 | s |
| **Dynamic Peak Overshoot** | 0.353 | m/m |
| **Time to Reach Peak Value **** | 0.048 | s |
| **Maximum Vertical Acceleration** | -24.63 | m/s² |

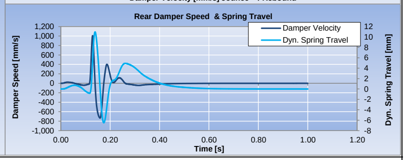
| Rear Wheel Results | | |
|---|---|---|
| **Max. Dyn. Contact Patch Load** | 7317.2 | N |
| **Wheel Lift Time** | 0.138 | s |
| **Dyn. CP Load Integrator *** | 558.02 | Ns |

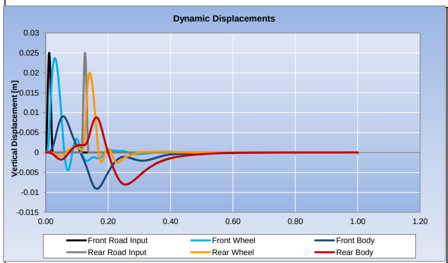
** Without considering delay time due to wheelbase



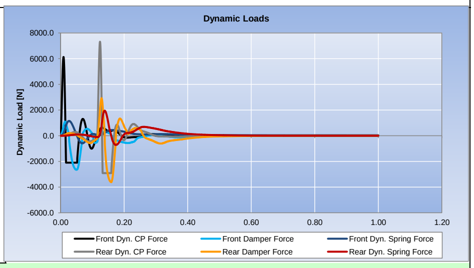



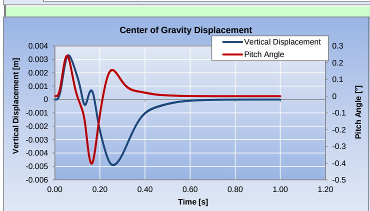

***Front Static Values***

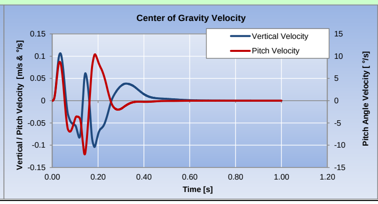
| | | |
|---|---|---|
| CP Load | 2095.72 | [N] |
| Tire Deflection | 7.23 | [mm] |
| Wheeltravel | 52.57 | [mm] |
| Spring Deflection | 41.15 | [mm] |
| Spring Load | 2332.83 | [N] |
| Inst. Wheel Rate | 39.73 | [N/mm] |

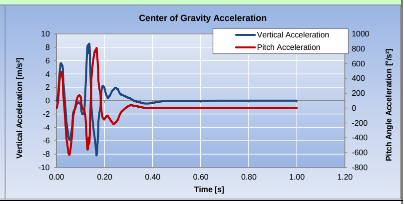
***Rear Static Values***

| | | |
|---|---|---|
| CP Load | 2911.36 | [N] |
| Tire Deflection | 8.32 | [mm] |
| Wheeltravel | 73.67 | [mm] |
| Spring Deflection | 51.57 | [mm] |
| Spring Load | 3703.62 | [N] |
| Inst. Wheel Rate | 61.73 | [N/mm] |



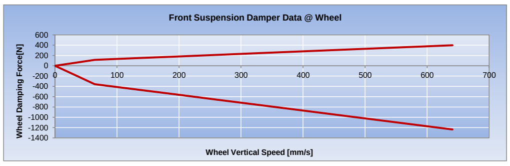



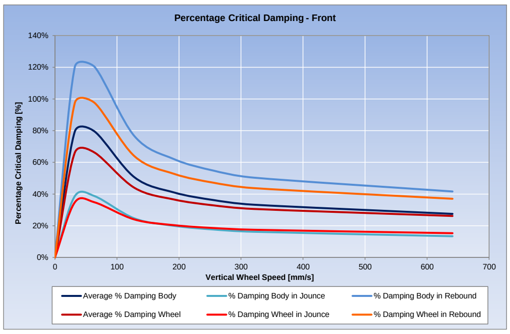



# PRECENTAGE CRITICAL DAMPING CHARTS

| Calculated FRONT Damper Force @ WHEEL (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 32.1 | 57.5 | -32.1 | -178.5 |
| 64.1 | 114.9 | -64.1 | -357.1 |
| 128.2 | 146.4 | -128.2 | -454.8 |
| 192.3 | 177.8 | -192.3 | -552.5 |
| 256.4 | 209.3 | -256.4 | -650.2 |
| 320.5 | 240.7 | -320.5 | -748.0 |
| 641.0 | 398.0 | -641.0 | -1236.6 |

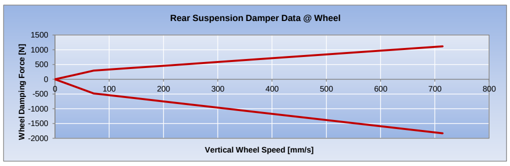



| Front Body % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Body | % Damping Body in Jounce | % Damping Body in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 32.1 | 79.4% | 38.7% | 120.2% |
| 64.1 | 79.4% | 38.7% | 120.2% |
| 128.2 | 50.6% | 24.6% | 76.5% |
| 192.3 | 41.0% | 20.0% | 62.0% |
| 256.4 | 36.2% | 17.6% | 54.7% |
| 320.5 | 33.3% | 16.2% | 50.4% |
| 641.0 | 27.5% | 13.4% | 41.6% |

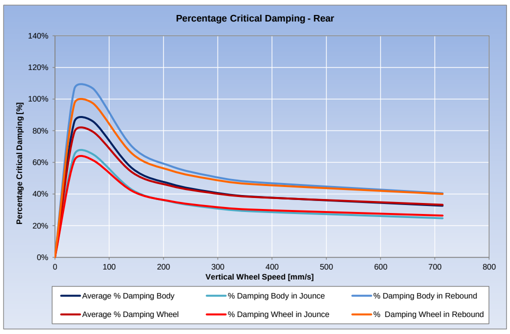



| Front Wheel % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Wheel | % Damping Wheel in Jounce | % Damping Wheel in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 32.1 | 66.1% | 34.8% | 97.5% |
| 64.1 | 66.1% | 34.8% | 97.5% |
| 128.2 | 43.9% | 24.0% | 63.9% |
| 192.3 | 36.5% | 20.4% | 52.7% |
| 256.4 | 32.8% | 18.6% | 47.1% |
| 320.5 | 30.6% | 17.5% | 43.7% |
| 641.0 | 26.2% | 15.3% | 37.0% |

| Calculated REAR Damper Force @ WHEEL (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 35.7 | 146.6 | -35.7 | -240.3 |
| 71.4 | 293.1 | -71.4 | -480.6 |
| 142.9 | 384.7 | -142.9 | -630.6 |
| 214.3 | 476.2 | -214.3 | -780.6 |
| 285.7 | 567.7 | -285.7 | -930.6 |
| 357.1 | 659.2 | -357.1 | -1080.6 |
| 714.3 | 1116.7 | -714.3 | -1830.7 |




| Rear Body % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Body | % Damping Body in Jounce | % Damping Body in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 35.7 | 85.5% | 64.8% | 106.3% |
| 71.4 | 85.5% | 64.8% | 106.3% |
| 142.9 | 56.1% | 42.5% | 69.7% |
| 214.3 | 46.3% | 35.1% | 57.5% |
| 285.7 | 41.4% | 31.4% | 51.4% |
| 357.1 | 38.5% | 29.2% | 47.8% |
| 714.3 | 32.6% | 24.7% | 40.5% |




| Rear Wheel % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Wheel | % Damping Wheel in Jounce | % Damping Wheel in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 35.7 | 79.0% | 61.1% | 97.0% |
| 71.4 | 79.0% | 61.1% | 97.0% |
| 142.9 | 53.6% | 41.8% | 65.3% |
| 214.3 | 45.1% | 35.4% | 54.8% |
| 285.7 | 40.8% | 32.2% | 49.5% |
| 357.1 | 38.3% | 30.2% | 46.4% |
| 714.3 | 33.2% | 26.4% | 40.0% |

# BOUNCE & PITCH CENTERS

| Output Parameter | RESULTS | |
|---|---|---|
| Fr. Ride Frequency | 2.559 | Hz |
| Rr. Ride Frequency | 2.861 | Hz |
| Ratio Rr/Fr Ride Frequency | 1.118 | - |
| Body CoG Pitch Frequency (frequency one) | 3.838 | Hz |
| Body CoG Bounce Frequency (frequency two) | 2.694 | Hz |
| Pitch Center (motion center one) | 0.144 | m * |
| Bounce Center (motion center two) | -5.617 | m * |

The differential equations for the analytical model of the body movement provide 2 solutions, so called Motion Centers ("one" and "two"). The Motion Center that is located at the nearest distance from the CoG (usually solution "one") is called PITCH CENTER and is located within the Wheel Base.The Motion Center that is located at the furthest distance from the CoG (usually solution "two") is called BOUNCE CENTER and is located outside of the Wheel Base.

**Note: Depending on the weight distribution & spring setup, the two motion centers can exchange positions.**

Note 1: Usually the natural Pitch Frequency is higher than the natural Bounce Frequency

Note 2: The sign indicates whether the Motion Center is located fore or aft relative to CoG x-Position

* Positive number = distance from CoG in forward direction

* Negative number = distance from CoG in rearward direction

| Relative to FRONT AXLE | | |
|---|---|---|
| Pitch Center (motion center one) | -1.246 | m ** |
| Bounce Center (motion center two) | -7.007 | m ** |

** Positive Number = In Front of Front Axle

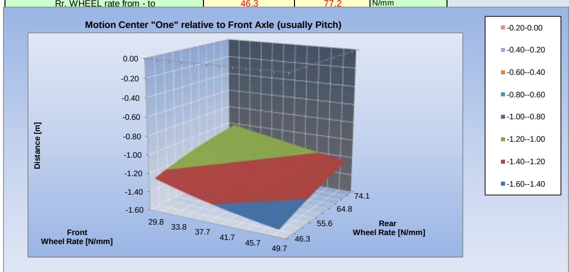
** Negative Number = Behind Front Axle

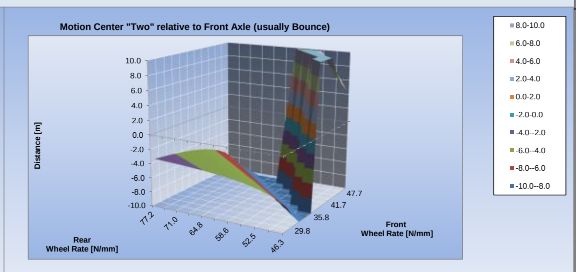
**Tuning Recommendation: Pitch Center should be as close as possible to Front Axle**

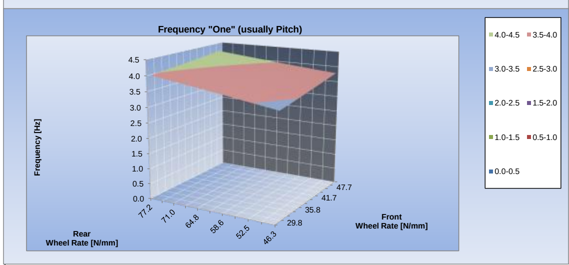
**Tuning Recommendation: Bounce Center should be as far as possible from Front Axle - ideally at least as far away as the equivalent to one wheelbase length**

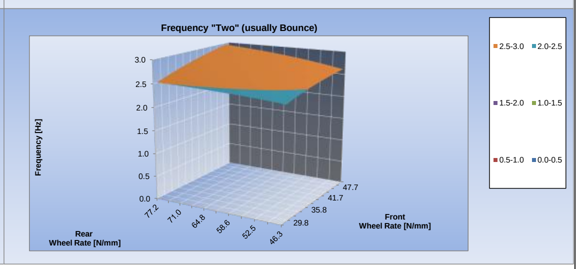
| RANGE CARPET PLOTS FROM 75% TO 125% WHEEL RATE | | | |
|---|---|---|---|
| Fr. WHEEL Rate from - to | 29.8 | 49.7 | N/mm |
| Rr. WHEEL rate from - to | 46.3 | 77.2 | N/mm |

# BOUNCE & PITCH CENTER CARPET PLOTS



# DYNATUNE SUSPENSION TUNING MODULE - RELEASE 8.1



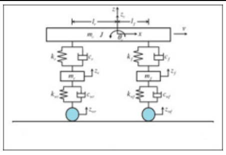
**Vehicle Data**

| | | |
|---|---|---|
| Front Downforce | 1000.0 | N |
| Rear Downforce | 2000.0 | N |
| Wheel Base | 2550.0 | mm |
| Weight Distribution | 45.50 | %Front |
| Total Mass | 715.0 | kg |
| Fr. Wheel Load | 2095.7 | N |
| Rr. Wheel Load | 2911.4 | N |
| Vehicle Pitch Inertia | 675.0 | kgm² |
| Pitch Inertia Sprung Mass | 481.3 | kgm² |

BLUE = ENTER DATA (SUSPENSION)
GREEN = ENTER DATA (CAR & CONTROL)
RED = CALCULATED RESULTS - DO NOT TOUCH

Manual Calculation | CALCULATE / F9

LINEAR WHEEL RATE OPTIMZED



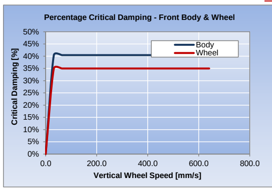
EXPORT VEHICLE 2 DATA | IMPORT VEHICLE 2 DATA | COPY DATA TO VEHICLE 1 | LOAD VEHICLE 1 DATA

**Front Suspension Data**

| | | | |
|---|---|---|---|
| Front Unprung Mass (Corner) | 27.5 | | kg |
| Fr. Tire Vert. Stiffness | 290.00 | | N/mm |
| Fr. Tire % Critical Damping | 5.00 | | % |
| Fr. Tire Damping Rate | 299.65 | | Ns/m |
| Fr. Spring/Damper to Wheel Motion Ratio* | 0.780 | | - |
| Enter Fr. SPRING Rate | 60.00 | | N/mm |
| Fr. Spring Static Deflection / Wheel Travel | 39.02 | 50.02 | mm |
| Fr. WHEEL Rate (incl. Scaling) | 36.50 | | N/mm |
| Fr. RIDE Rate (incl. Tire) | 32.42 | | N/mm |
| Fr. Damper Top Mount Stiffness (0 = Deactivate) | 0.00 | | N/mm |
| Fr. Body Frequency | 2.616 | | Hz |
| Fr. Body Ride Frequency (incl. Tire) | 2.465 | | Hz |
| Fr. Wheelhop Frequency | 17.342 | | Hz |

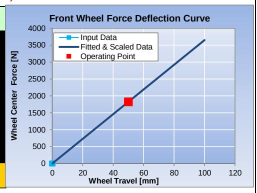
* motion ratio from 0 to 1 (typically max 1:1 = wheel travel)

NOTE: Increasing Non-Linearity will affect Analysis Accuracy



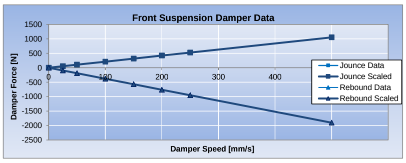
| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| [redacted] | | |

USE FRONT WHEEL FORCE DEFLECTION CURVE



COPY FRONT WHEEL FORCE CURVE TO VEHICLE 1 | LOAD FRONT WHEEL FORCE CURVE FROM VEHICLE 1

EXPORT FRONT DAMPER DATA | IMPORT FRONT DAMPER DATA | COPY FRONT DAMPER DATA TO VEHICLE 1 | LOAD FRONT DAMPER DATA FROM VEHICLE 1



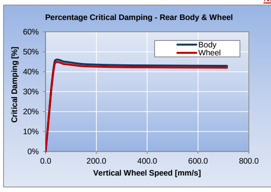
| Damper Data ID | Front Suspension Damper Data - Automatically Created & Optimized | | | | |
|---|---|---|---|---|---|
| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] | Damping Rate Jounce [Ns/m] | Damping Rate Rebound [Ns/m] | Rebound/Jounce Ratio [-] |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 52.5 | -95.1 | 2101.6 | -3804.2 | 1.81 |
| 50.0 | 105.1 | -190.2 | 2101.6 | -3804.2 | 1.81 |
| 100.0 | 210.2 | -380.4 | 2101.6 | -3804.2 | 1.81 |
| 150.0 | 315.2 | -570.6 | 2101.6 | -3804.2 | 1.81 |
| 200.0 | 420.3 | -760.8 | 2101.6 | -3804.2 | 1.81 |
| 250.0 | 525.4 | -951.1 | 2101.6 | -3804.2 | 1.81 |
| 500.0 | 1050.8 | -1902.1 | 2101.6 | -3804.2 | 1.81 |

**Rear Suspension Data**

| | | | |
|---|---|---|---|
| Rear Unsprung Mass (Corner) | 32.5 | | kg |
| Rr. Tire Vert. Stiffness | 350.00 | | N/mm |
| Rr. Tire % Critical Damping | 5.00 | | % |
| Rr. Tire Damping Rate | 365.59 | | Ns/m |
| Rr. Spring/Damper to Wheel Motion Ratio* | 0.700 | | - |
| Enter Rr. SPRING Rate | 125.00 | | N/mm |
| Rear Spring Static Deflection / Wheel Travel | 29.63 | 42.33 | mm |
| Rr. WHEEL Rate (incl. Scaling) | 61.25 | | N/mm |
| Rr. RIDE Rate (incl. Tire) | 52.13 | | N/mm |
| Rr. Damper Top Mount Stiffness (0 = Deactivate) | 0.00 | | N/mm |
| Rr. Body Frequency | 3.092 | | Hz |
| Rr. Body Ride Frequency (incl. Tire) | 2.852 | | Hz |
| Rr. Wheelhop Frequency | 17.904 | | Hz |

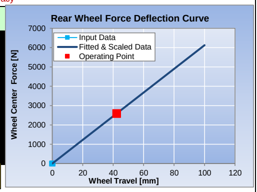
* motion ratio from 0 to 1 (typically max 1:1 = wheel travel)

NOTE: Increasing Non-Linearity will affect Analysis Accuracy



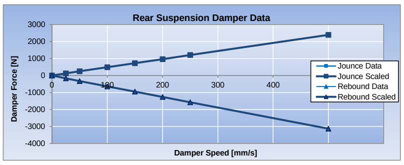
| Wheel Travel [mm] | Motion Ratio [-] | Wheel Center Z-Force [N] |
|---|---|---|
| [redacted] | | |

USE REAR WHEEL FORCE DEFLECTION CURVE



COPY REAR WHEEL FORCE CURVE TO VEHICLE 1 | LOAD REAR WHEEL FORCE CURVE FROM VEHICLE 1

EXPORT REAR DAMPER DATA | IMPORT REAR DAMPER DATA | COPY REAR DAMPER DATA TO VEHICLE 1 | LOAD REAR DAMPER DATA FROM VEHICLE 1



| Damper Data ID | Rear Suspension Damper Data - Automatically Created & Optimized | | | | |
|---|---|---|---|---|---|
| Damper Speed [mm/s] | Jounce Force [N] | Rebound Force [N] | Damping Rate Jounce [Ns/m] | Damping Rate Rebound [Ns/m] | Rebound/Jounce Ratio [-] |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 125.6 | -164.2 | 5025.3 | -6569.2 | 1.31 |
| 50.0 | 251.3 | -328.5 | 5025.3 | -6569.2 | 1.31 |
| 100.0 | 489.2 | -639.5 | 4892.3 | -6395.4 | 1.31 |
| 150.0 | 727.2 | -950.6 | 4848.0 | -6337.5 | 1.31 |
| 200.0 | 965.2 | -1261.7 | 4825.9 | -6308.5 | 1.31 |
| 250.0 | 1203.1 | -1572.8 | 4812.6 | -6291.2 | 1.31 |
| 500.0 | 2393.0 | -3128.2 | 4786.0 | -6256.4 | 1.31 |

## FREQUENCY DOMAIN ANALYSIS - 4 POSTER SWEEP SINE TEST

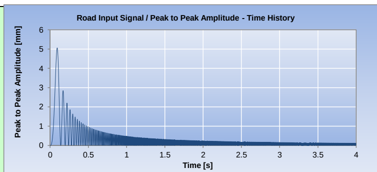
Use Averaged Jounce / Rebound Damping | ROAD INPUT

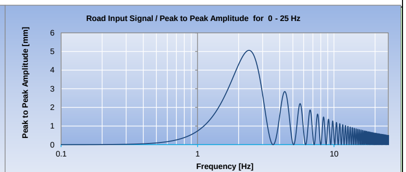
Start Peak to Peak Road Input Amplitude @ 0 Hz 5.0 mm

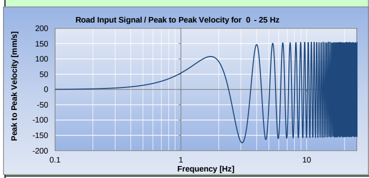
Use Exponential Amplitude Decay (RECOMMENDED SETTING)

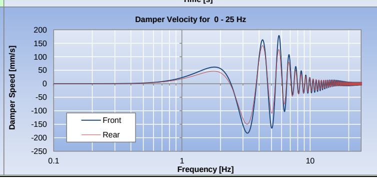
BOUNCE MODE (DEFAULT) | Front Excitation Only

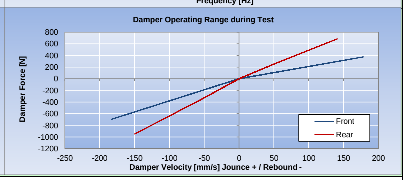
ACTIVATE PITCH MODE | Rear Excitation Only

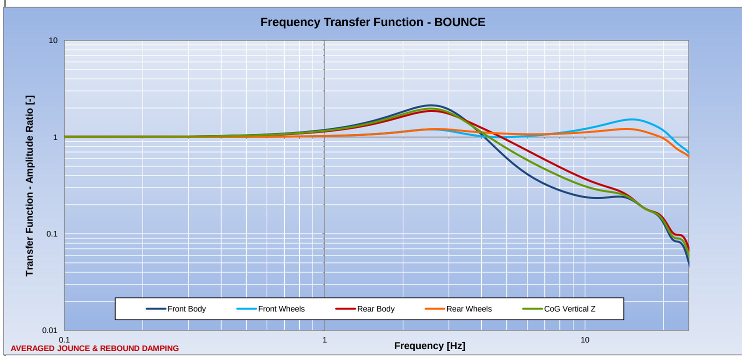


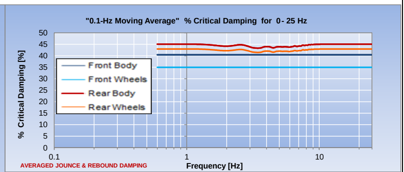


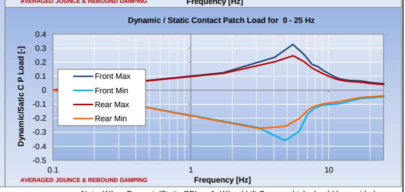












Note: When Dynamic/Static CPL < -1, Wheel Lift Occurs which should be avoided.

| FRONT | Body | Wheel | | CoG | | REAR Body | Wheel | |
|---|---|---|---|---|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.50 | 15.26 | Hz | 2.50 | Hz | 2.50 | 14.51 | Hz |
| Dyn. Overshoot @ Peak Resonance Freq. | 2.13 | 1.52 | mm/mm | 1.97 | mm/mm | 1.86 | 1.21 | mm/mm |
| %Crtical Damping @ Peak Res. Freq (-3dB) | 38.52 | 43.83 | % | 41.85 | % | 49.27 | 67.03 | % |
| Dynamic Wheel Load Indicator 0 - 25 Hz * | | 5.595 | Hz | | | | 3.672 | Hz |

* Area under/above of wheel curves with respect to value 1
Unit = Hz, The lower this value is, the closer the curve remains to 1

Frequency Domain Perf. Index * 1091.99 -
* Value does depend on PI Factor settings

| | FRONT AXLE | | REAR AXLE | |
|---|---|---|---|---|
| - | 0.326 | Max. Dyn./Stat. CPL | 0.246 | - |
| - | -0.360 | Min. Dyn./Stat. CPL | -0.273 | - |
| Ws | 15.77 | Diss. Damper Energy | 18.32 | Ws |
| Ws | 9.26 | Diss. Tire Energy | 10.62 | Ws |
| NHz | 670.20 | Dyn. Tire Load Integral | 571.93 | NHz |

**SPRING & DAMPER SCALING FACTORS**

| | |
|---|---|
| Fr. Jounce Damping Scaling Factor | 1.000 |
| Fr. Rebound Damping Scaling Factor | 1.000 |
| Fr. Spring Rate Scaling Factor | 1.000 |

CALCULATE / F9

| | |
|---|---|
| Rr. Jounce Damping Scaling Factor | 1.000 |
| Rr. Rebound Damping Scaling Factor | 1.000 |
| Rr. Spring Rate Scaling Factor | 1.000 |

**SPRING & DAMPER SCALING FACTORS**

The Spring & Damper Scaling Factors mutiply the spring rates and the measured damper data by the selected factor - for jounce & rebound separately.

# TIME DOMAIN ANALYSIS - VERTICAL RAMP & HALF SINE INPUT TEST

NOTE: All geometric input units in [m]

| | | |
|---|---|---|
| z-Amplitude of Half Sine (Up +, Down -) | 0.0250 | m |
| x-Length of Half Sine | 0.500 | m |
| Velocity over Half Sine | 80.0 | kph |

Set ramp height to 0 for test deactivation

| | | |
|---|---|---|
| Simulation Time (0 - 5s) | 1.00 | s |

- Use Smoothed Step/Ramp`
- Use Smoothed Half Sine
- Front Excitation Only
- Rear Excitation Only

**Signal Data**

| | | |
|---|---|---|
| Time for Half Sine | 0.023 | s |
| Delay Rear to Front Axle | 0.115 | s |
| Excitation Frequency | 22.22 | Hz |

## HALF SINE

TUNING GUIDANCE: THE LOWER THE NUMBERS THE BETTER FOR MECHANICAL GRIP

Time Domain Performance Index 2173.63 -

* Value does depend on PI Factor settings

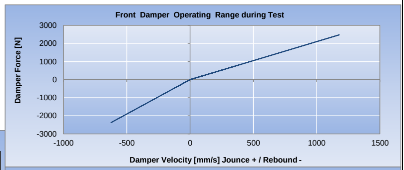
**Front Body Results**

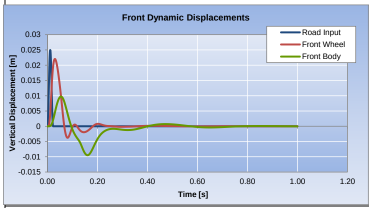
| | | |
|---|---|---|
| Time to 95% dampened oscillation | 0.236 | s |
| Dynamic Peak Overshoot | 0.389 | m/m |
| Time to Reach Peak Value | 0.054 | s |
| Maximum Vertical Acceleration | 25.79 | m/s² |

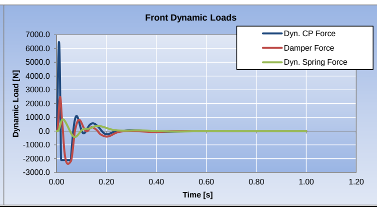
**Front Wheel Results**

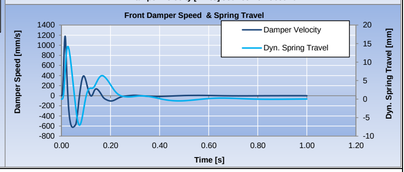
| | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 6472.3 | N |
| Wheel Lift Time | 0.040 | s |
| Dyn. CP Load Integrator * | 319.78 | Ns |

* Integral of the area of the Dynamic Wheel Load Curver over time




TUNING GUIDANCE: THE LOWER THE NUMBERS THE BETTER FOR MECHANICAL GRIP

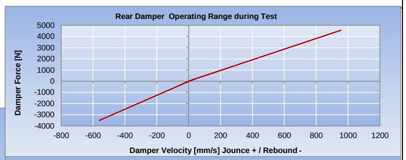
**Rear Body Results**

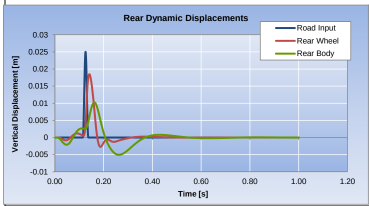
| | | |
|---|---|---|
| Time to 95% dampened oscillation ** | 0.225 | s |
| Dynamic Peak Overshoot | 0.409 | m/m |
| Time to Reach Peak Value ** | 0.047 | s |
| Maximum Vertical Acceleration | 30.96 | m/s² |

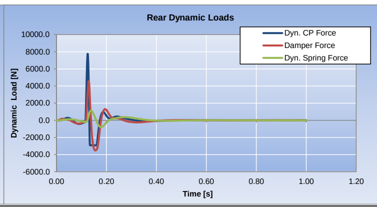
**Rear Wheel Results**

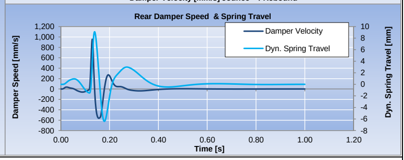
| | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 7759.2 | N |
| Wheel Lift Time | 0.029 | s |
| Dyn. CP Load Integrator * | 562.58 | Ns |

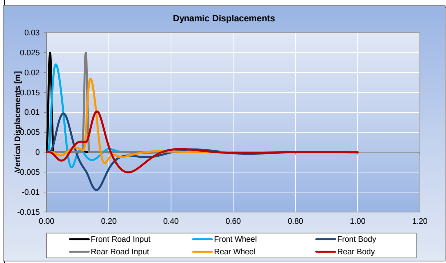
** Without considering delay time due to wheelbase



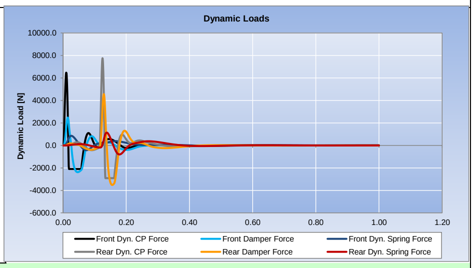



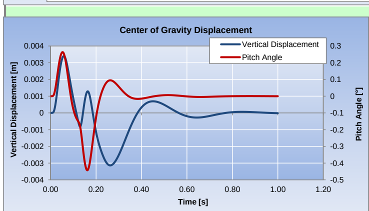

### Front Static Values

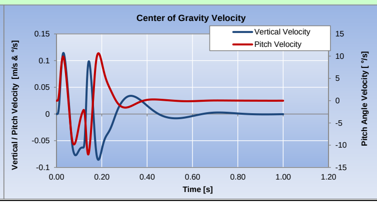
| | | |
|---|---|---|
| CP Load | 2095.72 | [N] |
| Tire Deflection | 7.23 | [mm] |
| Wheeltravel | 50.02 | [mm] |
| Spring Deflection | 39.02 | [mm] |
| Spring Load | 2340.95 | [N] |
| Inst. Wheel Rate | 36.50 | [N/mm] |

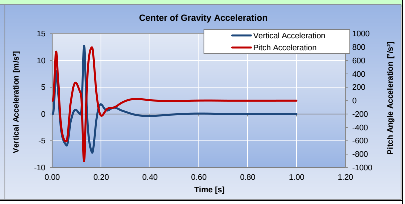
### Rear Static Values

| | | |
|---|---|---|
| CP Load | 2911.36 | [N] |
| Tire Deflection | 8.32 | [mm] |
| Wheeltravel | 42.33 | [mm] |
| Spring Deflection | 29.63 | [mm] |
| Spring Load | 3703.62 | [N] |
| Inst. Wheel Rate | 61.25 | [N/mm] |



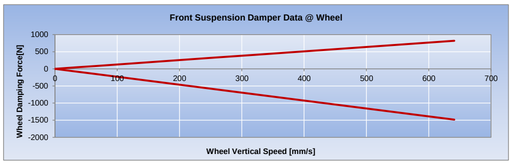



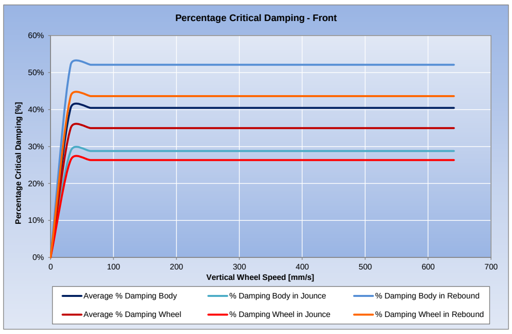



# PRECENTAGE CRITICAL DAMPING CHARTS

| Calculated FRONT Damper Force @ WHEEL (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 32.1 | 41.0 | -32.1 | -74.2 |
| 64.1 | 82.0 | -64.1 | -148.4 |
| 128.2 | 163.9 | -128.2 | -296.7 |
| 192.3 | 245.9 | -192.3 | -445.1 |
| 256.4 | 327.8 | -256.4 | -593.5 |
| 320.5 | 409.8 | -320.5 | -741.8 |
| 641.0 | 819.6 | -641.0 | -1483.6 |

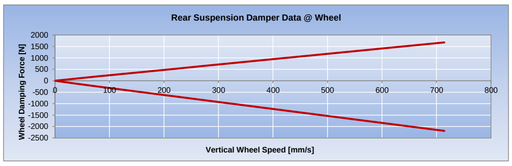



| Front Body % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Body | % Damping Body in Jounce | % Damping Body in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 32.1 | 40.4% | 28.8% | 52.1% |
| 64.1 | 40.4% | 28.8% | 52.1% |
| 128.2 | 40.4% | 28.8% | 52.1% |
| 192.3 | 40.4% | 28.8% | 52.1% |
| 256.4 | 40.4% | 28.8% | 52.1% |
| 320.5 | 40.4% | 28.8% | 52.1% |
| 641.0 | 40.4% | 28.8% | 52.1% |

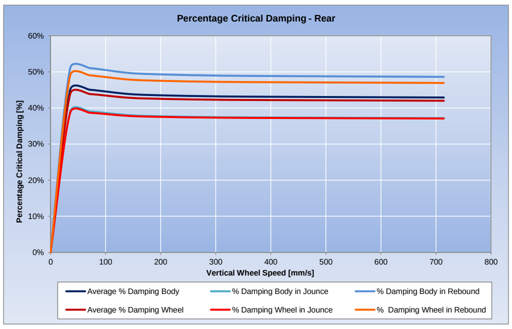



| Front Wheel % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Wheel | % Damping Wheel in Jounce | % Damping Wheel in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 32.1 | 35.0% | 26.3% | 43.6% |
| 64.1 | 35.0% | 26.3% | 43.6% |
| 128.2 | 35.0% | 26.3% | 43.6% |
| 192.3 | 35.0% | 26.3% | 43.6% |
| 256.4 | 35.0% | 26.3% | 43.6% |
| 320.5 | 35.0% | 26.3% | 43.6% |
| 641.0 | 35.0% | 26.3% | 43.6% |

| Calculated REAR Damper Force @ WHEEL (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 35.7 | 87.9 | -35.7 | -115.0 |
| 71.4 | 175.9 | -71.4 | -229.9 |
| 142.9 | 342.5 | -142.9 | -447.7 |
| 214.3 | 509.0 | -214.3 | -665.4 |
| 285.7 | 675.6 | -285.7 | -883.2 |
| 357.1 | 842.2 | -357.1 | -1101.0 |
| 714.3 | 1675.1 | -714.3 | -2189.7 |




| Rear Body % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Body | % Damping Body in Jounce | % Damping Body in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 35.7 | 45.0% | 39.0% | 51.0% |
| 71.4 | 45.0% | 39.0% | 51.0% |
| 142.9 | 43.9% | 38.0% | 49.7% |
| 214.3 | 43.5% | 37.7% | 49.2% |
| 285.7 | 43.3% | 37.5% | 49.0% |
| 357.1 | 43.1% | 37.4% | 48.9% |
| 714.3 | 42.9% | 37.2% | 48.6% |




| Rear Wheel % Critical Damping (considering Motion Ratio & Scaling Factor) | | | |
|---|---|---|---|
| Wheel Vertical Speed [mm/s] | Average % Damping Wheel | % Damping Wheel in Jounce | % Damping Wheel in Rebound |
| 0.0 | 0.0% | 0.0% | 0.0% |
| 35.7 | 43.9% | 38.7% | 49.0% |
| 71.4 | 43.9% | 38.7% | 49.0% |
| 142.9 | 42.8% | 37.8% | 47.9% |
| 214.3 | 42.5% | 37.5% | 47.5% |
| 285.7 | 42.3% | 37.3% | 47.3% |
| 357.1 | 42.2% | 37.3% | 47.2% |
| 714.3 | 42.0% | 37.1% | 46.9% |

# BOUNCE & PITCH CENTERS

| Output Parameter | RESULTS | |
|---|---|---|
| Fr. Ride Frequency | 2.465 | Hz |
| Rr. Ride Frequency | 2.852 | Hz |
| Ratio Rr/Fr Ride Frequency | 1.157 | - |
| Body CoG Pitch Frequency (frequency one) | 3.779 | Hz |
| Body CoG Bounce Frequency (frequency two) | 2.626 | Hz |
| Pitch Center (motion center one) | 0.185 | m * |
| Bounce Center (motion center two) | -4.362 | m * |

The differential equations for the analytical model of the body movement provide 2 solutions, so called Motion Centers ("one" and "two"). The Motion Center that is located at the nearest distance from the CoG (usually solution "one") is called PITCH CENTER and is located within the Wheel Base.The Motion Center that is located at the furthest distance from the CoG (usually solution "two") is called BOUNCE CENTER and is located outside of the Wheel Base.
Note: Depending on the weight distribution & spring setup, the two motion centers can exchange positions.

Note 1: Usually the natural Pitch Frequency is higher than the natural Bounce Frequency
Note 2: The sign indicates whether the Motion Center is located fore or aft relative to CoG x-Position
* Positive number = distance from CoG in forward direction
* Negative number = distance from CoG in rearward direction

| Relative to FRONT AXLE | | |
|---|---|---|
| Pitch Center (motion center one) | -1.204 | m ** |
| Bounce Center (motion center two) | -5.752 | m ** |

** Positive Number = In Front of Front Axle

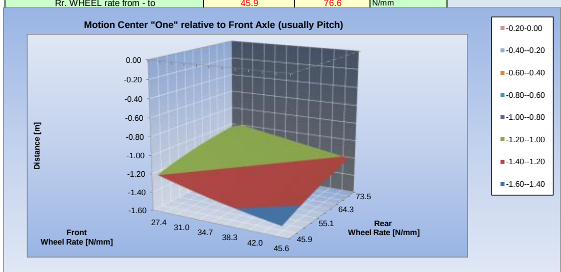
** Negative Number = Behind Front Axle

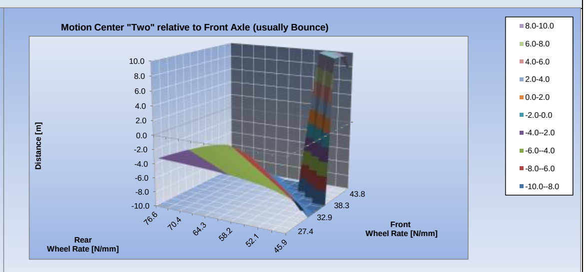
**Tuning Recommendation: Pitch Center should be as close as possible to Front Axle**

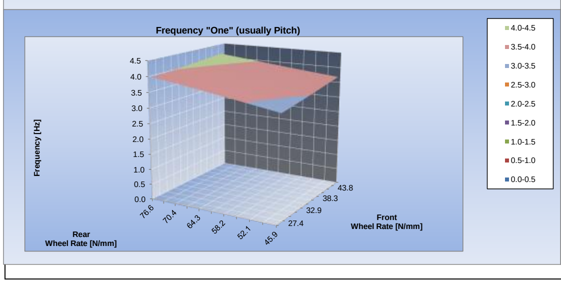
**Tuning Recommendation: Bounce Center should be as far as possible from Front Axle - ideally at least as far away as the equivalent to one wheelbase length**

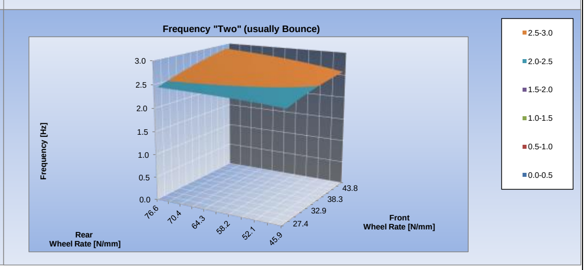
| RANGE CARPET PLOTS FROM 75% TO 125% WHEEL RATE | | | |
|---|---|---|---|
| Fr. WHEEL Rate from - to | 27.4 | 45.6 | N/mm |
| Rr. WHEEL rate from - to | 45.9 | 76.6 | N/mm |

# BOUNCE & PITCH CENTER CARPET PLOTS



# DYNATUNE SUSPENSION TUNING MODULE - RELEASE 8.1



## NON-LINEAR WEIGHT RATE OPTIMZED

### VEHICLE 1

| | | |
|---|---|---|
| Front Downforce | 1000.0 | N |
| Rear Downforce | 2000.0 | N |
| Wheel Base | 2550.0 | mm |
| Weight Distribution | 45.50 | %Front |
| Total Mass | 715.0 | kg |
| Vehicle Pitch Inertia | 675.0 | kgm2 |

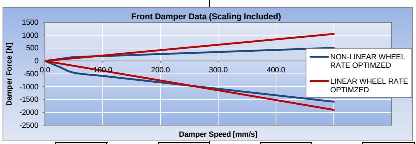
| Bounce & Pitch Center rel. To Front Axle | | |
|---|---|---|
| Pitch Centre | -1.246 | m |
| Bounce Centre | -7.007 | m |

| | Front | Rear | |
|---|---|---|---|
| Body Frequency | 2.729 | 3.104 | Hz |
| Body Ride Frequency | 2.559 | 2.861 | Hz |
| Wheelhop Frequency | 17.428 | 17.914 | Hz |

| | | |
|---|---|---|
| Front Unprung Mass | 27.5 | kg |
| Fr. Tire Vert. Stiffness | 290.00 | N/mm |
| Fr. Tire % Critical Damping | 5.00 | % |
| Fr. Tire Damping Rate | 301.12 | Ns/m |
| Instant. Spring/Damper to Wheel Motion Ratio* | 0.783 | - |
| Calculated Instantaneous Fr. SPRING Rate | 65.30 | N/mm |
| Fr. SPRING Pre-Load (incl. Scaling) | 41.15 | mm |
| Fr. WHEEL Rate (incl. Scaling) | 39.73 | N/mm |
| Fr. RIDE Rate | 34.94 | N/mm |
| Fr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | N/mm |

**SCALED Front Damper Data**

| Jounce Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 73.7 | -25.0 | -228.9 |
| 50.0 | 147.3 | -50.0 | -457.8 |
| 100.0 | 187.7 | -100.0 | -583.1 |
| 150.0 | 228.0 | -150.0 | -708.3 |
| 200.0 | 268.3 | -200.0 | -833.6 |
| 250.0 | 308.6 | -250.0 | -958.9 |
| 500.0 | 510.3 | -500.0 | -1585.4 |

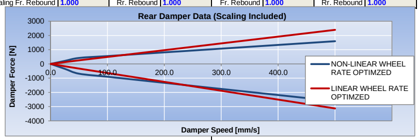


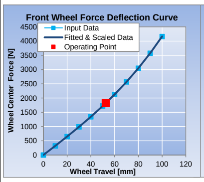

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Scaling Fr. Jounce | 1.000 | Rr. Jounce | 1.000 | Fr. Jounce | 1.000 | Rr. Jounce | 1.000 |
| Scaling Fr. Spring | 1.000 | Rr. Spring | 1.000 | Fr. Spring | 1.000 | Rr. Spring | 1.000 |
| Scaling Fr. Rebound | 1.000 | Rr. Rebound | 1.000 | Fr. Rebound | 1.000 | Rr. Rebound | 1.000 |

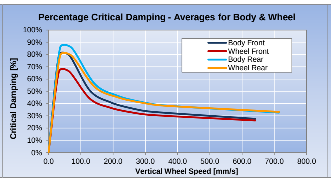
| | | |
|---|---|---|
| Rear Unsprung Mass | 32.5 | kg |
| Rr. Tire Vert. Stiffness | 350.00 | N/mm |
| Rr. Tire % Critical Damping | 5.00 | % |
| Rr. Tire Damping Rate | 365.80 | Ns/m |
| Instant. Spring/Damper to Wheel Motion Ratio* | 0.700 | - |
| Calculated Instantaneous Rr. SPRING Rate | 125.97 | N/mm |
| Rr. SPRING Pre-Load (incl. Scaling) | 51.57 | mm |
| Rr. WHEEL Rate (incl. Scaling) | 61.73 | N/mm |
| Rr. RIDE Rate | 52.47 | N/mm |
| Rr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | N/mm |

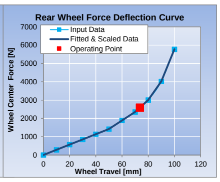
**SCALED Rear Damper Data**

| Jounce Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 209.4 | -25.0 | -343.3 |
| 50.0 | 418.8 | -50.0 | -686.5 |
| 100.0 | 549.5 | -100.0 | -900.8 |
| 150.0 | 680.2 | -150.0 | -1115.1 |
| 200.0 | 811.0 | -200.0 | -1329.5 |
| 250.0 | 941.7 | -250.0 | -1543.8 |
| 500.0 | 1595.3 | -500.0 | -2615.3 |




## LINEAR WHEEL RATE OPTIMZED

### VEHICLE 2

| Bounce & Pitch Center rel. To Front Axle | | |
|---|---|---|
| Pitch Centre | -1.204 | m |
| Bounce Centre | -5.752 | m |

| | Front | Rear | |
|---|---|---|---|
| Body Frequency | 2.616 | 3.092 | Hz |
| Body Ride Frequency | 2.465 | 2.852 | Hz |
| Wheelhop Frequency | 17.342 | 17.904 | Hz |

| | | |
|---|---|---|
| Front Downforce | 1000.0 | N |
| Rear Downforce | 2000.0 | N |
| Wheel Base | 2550.0 | mm |
| Weight Distribution | 45.50 | %Front |
| Total Mass | 715.0 | kg |
| Vehicle Pitch Inertia | 675.0 | kgm2 |

**SCALED Front Damper Data**

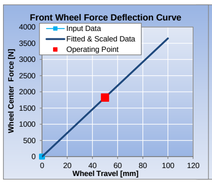
| Jounce Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 52.5 | -25.0 | -95.1 |
| 50.0 | 105.1 | -50.0 | -190.2 |
| 100.0 | 210.2 | -100.0 | -380.4 |
| 150.0 | 315.2 | -150.0 | -570.6 |
| 200.0 | 420.3 | -200.0 | -760.8 |
| 250.0 | 525.4 | -250.0 | -951.1 |
| 500.0 | 1050.8 | -500.0 | -1902.1 |

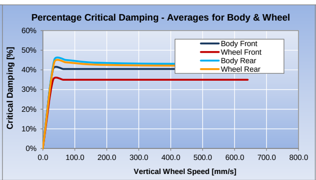
| | | |
|---|---|---|
| Front Unprung Mass | 27.5 | kg |
| Fr. Tire Vert. Stiffness | 290.00 | N/mm |
| Fr. Tire % Critical Damping | 5.00 | % |
| Fr. Tire Damping Rate | 299.65 | Ns/m |
| Fr. Spring/Damper to Wheel Motion Ratio* | 0.780 | - |
| Enter Fr. SPRING Rate | 60.00 | N/mm |
| Fr. Spring Pre-Load (incl. Scaling) | 39.02 | mm |
| Fr. WHEEL Rate (incl. Scaling) | 36.50 | N/mm |
| Fr. RIDE Rate | 32.42 | N/mm |
| Fr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | N/mm |

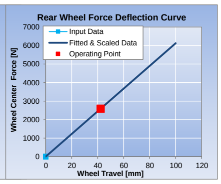
**SCALED Rear Damper Data**

| Jounce Speed [mm/s] | Jounce Force [N] | Rebound Speed [mm/s] | Rebound Force [N] |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |
| 25.0 | 125.6 | -25.0 | -164.2 |
| 50.0 | 251.3 | -50.0 | -328.5 |
| 100.0 | 489.2 | -100.0 | -639.5 |
| 150.0 | 727.2 | -150.0 | -950.6 |
| 200.0 | 965.2 | -200.0 | -1261.7 |
| 250.0 | 1203.1 | -250.0 | -1572.8 |
| 500.0 | 2393.0 | -500.0 | -3128.2 |

| | | |
|---|---|---|
| Rear Unsprung Mass | 32.5 | kg |
| Rr. Tire Vert. Stiffness | 350.00 | N/mm |
| Rr. Tire % Critical Damping | 5.00 | % |
| Rr. Tire Damping Rate | 365.59 | Ns/m |
| Rr. Spring/Damper to Wheel Motion Ratio* | 0.700 | - |
| Enter Rr. SPRING Rate | 125.00 | N/mm |
| Rr. Spring Pre-Load (incl. Scaling) | 29.63 | mm |
| Rr. WHEEL Rate (incl. Scaling) | 61.25 | N/mm |
| Rr. RIDE Rate | 52.13 | N/mm |
| Rr. Damper Top Mount Stiffness **(0 = Deactivate)** | 0.00 | N/mm |



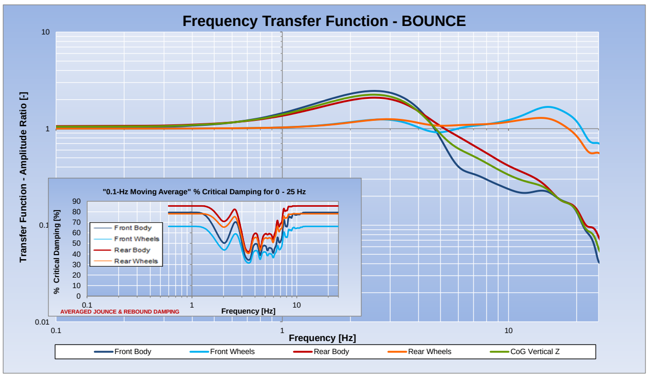




## FREQUENCY DOMAIN RESULTS - 4 POSTER SWEEP SINE TEST

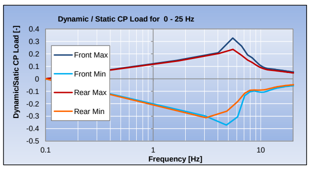
### Vehicle 1

**AVERAGED JOUNCE & REBOUND DAMPING**

| | FRONT Body | FRONT Wheel | | CoG | | REAR Body | REAR Wheel | |
|---|---|---|---|---|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.50 | 15.01 | Hz | 2.50 | Hz | 2.50 | 14.01 | Hz |
| Dynamic Overshoot @ Peak Res. Freq. | 2.46 | 1.68 | mm/mm | 2.25 | mm/mm | 2.09 | 1.29 | mm/mm |
| % Crtical Damping @ Peak Res. Freq (-3dB) | 48.66 | 35.33 | % | 50.61 | % | 55.68 | 65.59 | % |
| Dynamic Wheel Load Indicator 0 - 25 Hz * | | 6.996 | - | | | | 5.173 | - |




| | FRONT | | REAR | |
|---|---|---|---|---|
| Max. Dynamic /Static Contact Patch Load | 0.327 | - | 0.236 | - |
| Min. Dynamic /Static Contact Patch Load | -0.371 | - | -0.312 | - |
| Diss. Damper Energy | 19.991 | Ws | 22.669 | Ws |
| Diss. Tire Energy | 9.123 | Ws | 10.044 | Ws |
| Dyn. Tire Load Integral | 668.967 | Nhz | 563.064 | NHz |




**Frequency Domain Performance Index*** 788.16 -

* Value does depend on PI Factor settings

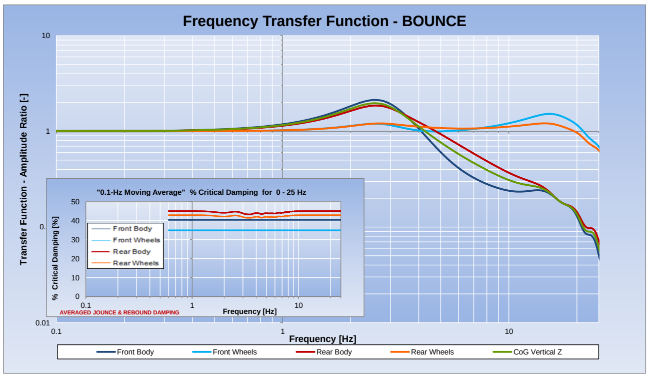
**Exponentially Decaying Amplitude**

Start Peak to Peak Road Input Amplitude @ 0 Hz 5.0 mm

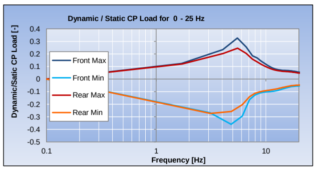
### Vehicle 2

**AVERAGED JOUNCE & REBOUND DAMPING**

| | FRONT Body | FRONT Wheel | | CoG | | REAR Body | REAR Wheel | |
|---|---|---|---|---|---|---|---|---|
| Peak Resonance Frequency in FTF | 2.50 | 15.26 | Hz | 2.50 | Hz | 2.50 | 14.51 | Hz |
| Dynamic Overshoot @ Peak Res. Freq. | 2.13 | 1.52 | mm/mm | 1.97 | mm/mm | 1.86 | 1.21 | mm/mm |
| % Crtical Damping @ Peak Res. Freq (-3dB) | 38.52 | 43.83 | % | 41.85 | % | 49.27 | 67.03 | % |
| Dynamic Wheel Load Indicator 0 - 25 Hz * | | 5.595 | - | | | | 3.672 | - |




| | FRONT | | REAR | |
|---|---|---|---|---|
| Max. Dynamic /Static Contact Patch Load | 0.326 | - | 0.246 | - |
| Min. Dynamic /Static Contact Patch Load | -0.360 | - | -0.273 | - |
| Diss. Damper Energy | 15.772 | Ws | 18.319 | Ws |
| Diss. Tire Energy | 9.264 | Ws | 10.616 | Ws |
| Dyn. Tire Load Integral | 670.199 | NHz | 571.934 | NHz |




**Frequency Domain Performance Index*** 1091.99 -

* Value does depend on PI Factor settings

**Exponentially Decaying Amplitude**

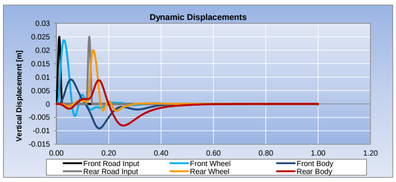
Start Peak to Peak Road Input Amplitude @ 0 Hz 5.0 mm

## TIME DOMAIN RESULTS - HALF SINE / RAMP TEST

### Vehicle 1

| | | |
|---|---|---|
| z- Height Amplitude of Half Sine (Up +, Down -) | 0.025 | m |
| x-Length of Half Sine | 0.500 | m |
| Velocity over Half Sine | 80.000 | kph |

| | | |
|---|---|---|
| Time for Half Sine | 0.023 | s |
| Delay Rear to Front Axle | 0.115 | s |
| Excitation Frequency | 22.222 | Hz |

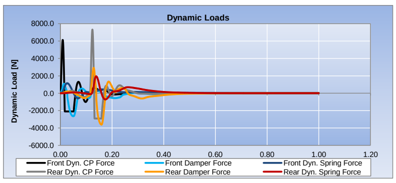



| Front Body Results | | |
|---|---|---|
| Time to 95% dampened oscillation | 0.357 | s |
| Dynamic Peak Overshoot | 0.365 | m/m |
| Time to Reach Peak Value | 0.164 | s |
| Maximum Vertical Acceleration | -21.15 | m/s² |

| Rear Body Results | | |
|---|---|---|
| Time to 95% dampened oscillation | 0.296 | s |
| Dynamic Peak Overshoot | 0.353 | m/m |
| Time to Reach Peak Value | 0.048 | s |
| Maximum Vertical Acceleration | -24.63 | m/s² |

**Time Domain Performance Index *** 2200.00 -

* Value does depend on PI Factor settings




| Front Wheel Results | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 6129.3 | N |
| Wheel Lift Time | 0.177 | s |
| Dynamic CP Load Integrator | 316.71 | Ns |

| Rear Wheel Results | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 7317.2 | N |
| Wheel Lift Time | 0.14 | s |
| Dynamic CP Load Integrator | 558.02 | Ns |

### Vehicle 2

| | | |
|---|---|---|
| Time for Half Sine | 0.023 | s |
| Delay Rear to Front Axle | 0.115 | s |
| Excitation Frequency | 22.222 | Hz |

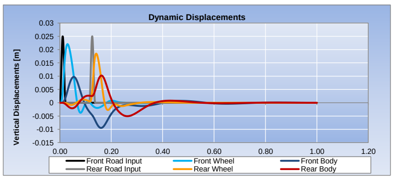
| | | |
|---|---|---|
| z-Amplitude of Half Sine (Up +, Down -) | 0.025 | m |
| x-Length of Half Sine | 0.500 | m |
| Velocity over Half Sine | 80.000 | kph |

| Front Body Results | | |
|---|---|---|
| Time to 95% dampened oscillation | 0.236 | s |
| Dynamic Peak Overshoot | 0.389 | m/m |
| Time to Reach Peak Value | 0.054 | s |
| Maximum Vertical Acceleration | 25.79 | m/s² |

| Rear Body Results | | |
|---|---|---|
| Time to 95% dampened oscillation | 0.225 | s |
| Dynamic Peak Overshoot | 0.409 | m/m |
| Time to Reach Peak Value | 0.047 | s |
| Maximum Vertical Acceleration | 30.96 | m/s² |

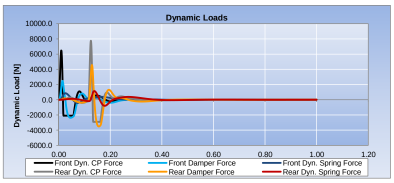
**Time Domain Performance Index *** 2173.63 -

* Value does depend on PI Factor settings




| Front Wheel Results | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 6472.3 | N |
| Wheel Lift Time | 0.040 | s |
| Dynamic CP Load Integrator | 319.78 | Ns |

| Rear Wheel Results | | |
|---|---|---|
| Max. Dyn. Contact Patch Load | 7759.2 | N |
| Wheel Lift Time | 0.03 | s |
| Dynamic CP Load Integrator | 562.58 | Ns |




**MORE FAVOURABLE VALUES HIGHLIGHTED IN GREEN**