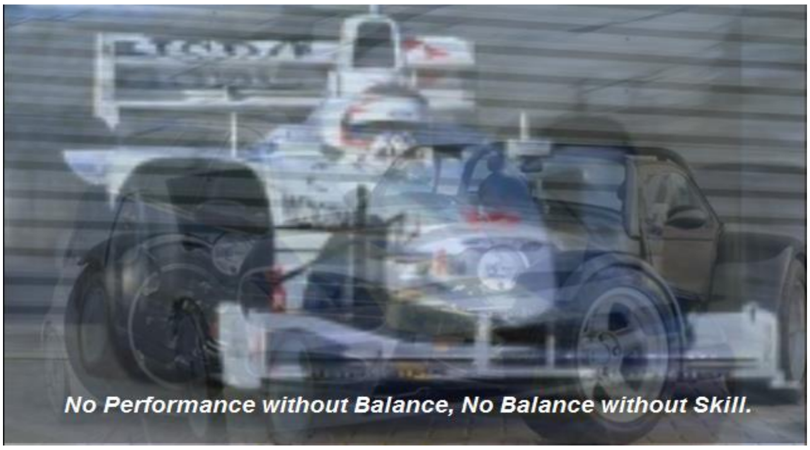
DYNATUNE-XL SIMULATION TOOL SUITE

THE 5 "MUST KNOW" FUNDAMENTALS OF SUSPENSION DESIGN

"No Performance without Balance, No Balance without Skill"



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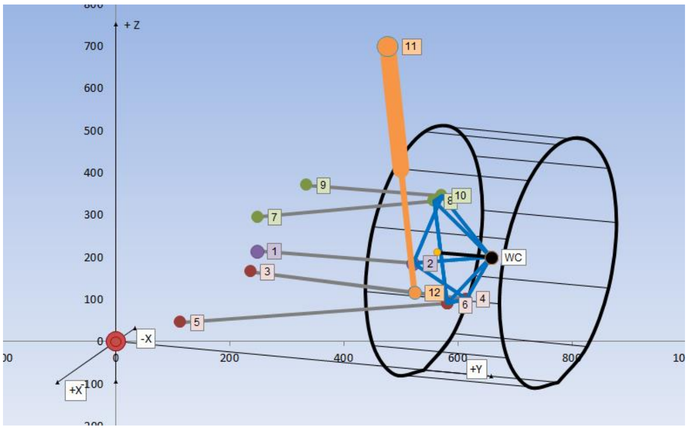
The following list of the 5 most overlooked Basic Suspension Design Fundamentals come with the **DYNATUNE-XL SUSPENSION DESIGN MODULE**. Although this document has been specifically written with the **DYNATUNE-XL** User Community in mind, the content will greatly enhance the understanding of Suspension Geometric Analysis of anyone who is interested in the topic.



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THE 5 FUNDAMENTALS:

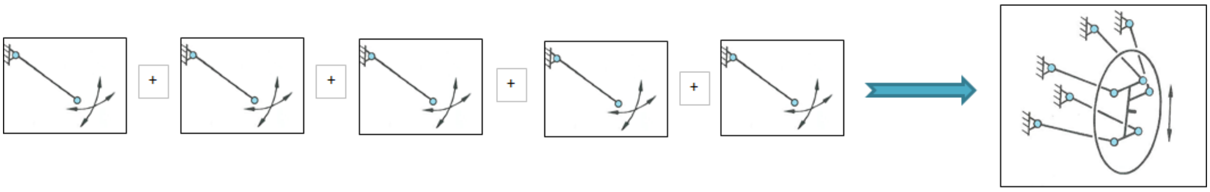
- **1: BASIC FUNDAMENTALS OF INDEPENDENT SUSPENSION SYSTEMS.**
- **2: THE 3 FUNDAMENTAL ARCHETYPES OF INDEPENDENT SUSPENSIONS.**
- **3: THE FUNDAMENTALS OF HOW TO ANALYZE SUSPENSION GEOMETRY.**
- **4: THE FUNDAMENTAL EFFECT OF LOADS ON GEOMETRIC BEHAVIOR.**
- **5: WHY YOU SHOULD NEVER ONLY OPTIMIZE FOR KINEMATICS.**

Note: The paper does assume some general understanding of Kinematic Suspension Terminology

This document is building up on articles from the **DYNATUNE-XL FAQ** webpage for customers:
http://www.dynatune-xl.com/support-sdm.html

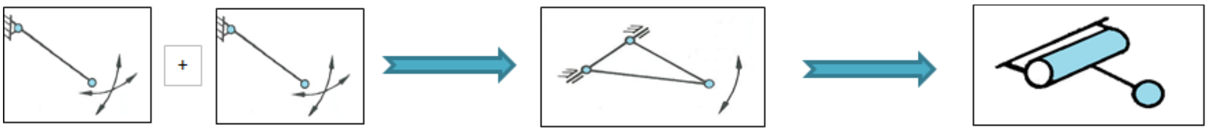
1: BASIC FUNDAMENTALS OF INDEPENDENT SUSPENSION SYSTEMS

- A “free floating object in space” can move in 6 possible ways: #3 translations in X, Y, Z and #3 rotations around X-axis, Y-axis & Z-axis.
- A "free floating object in space" can be fixed to a "ground" by using a max of 6 separate links, each with spherical joints at both ends.
- The above explained theory can be transferred directly onto a Suspension Upright/Knuckle which is being held by several suspension Links: By using only 5 of the 6 above mentioned links and by transforming the 6th link into a "spring", the movement of "free floating object" (aka the Upright/Knuckle) can be reduced to just 1 Translational Degree of Freedom: (Vertical) Wheel travel. All other movements are restricted by the links.

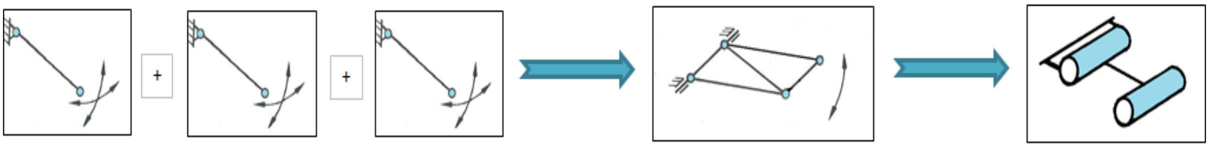


- Single links can be combined creating other suspension links with more than 1 constraint:

1. By combining the end of two links one can create A-Arms:

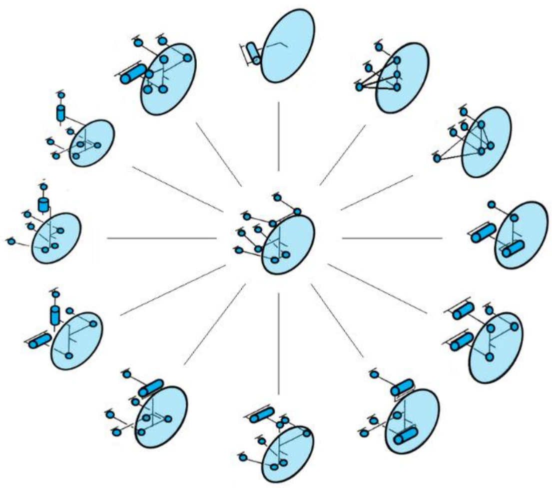


2. Or by combining 3 single links one can create H-Arms:



- By “cleverly” combining links one can create many known Suspensions (clockwise from 12 o'clock):

1. Trailing Arm (Ford Sierra)
2. 3-Link Trailing Arm Rear Suspension (Toyota RAV4)
3. Blade Control Link SLA (Ford Focus)
4. Historic H-Arm "Double" Wishbone Rear Suspension
5. Typical Double Wishbone (SLA)
6. Historical F1 Double Wishbone/Trailing Arm Rear Suspension
7. Wishbone Multi-Link Suspension with 2 separate Lower Links
8. Quadra Link with Upper Wishbone Multi-Link Rear Suspension
9. McPherson Strut Suspension
10. McPherson Strut Suspension with 2 separate Lower Links
11. McPherson Quadra Link Rear Suspension (Lancia Delta Integrale)
12. Integral Link Rear Suspension (BMW 5Series)



Center: Generic 5 Link Suspension

2: THE 3 FUNDAMENTAL ARCHETYPES OF INDEPENDENT SUSPENSIONS.

Independent Suspension Systems can be catalogued into 3 different Archetypes which are SOLELY defined by the characteristics of the "Instantaneous Axis of Rotation" during vertical movement of the suspension system.

1) 2-Dimensional Suspension Architecture – Also known as "IN-PLANE" or "PLANAR" Suspensions.

- A 2-D Suspension can be analysed with 2-dimensional tools like a piece of paper and or elementary software code based on the very technical drawing principles for in-plane geometric motion analysis.

- The Instantaneous Axis of Rotation of such a 2-D Suspension is characterized by a dominant movement in vertical direction with – depending on the suspension configuration – at times more or less pronounced lateral movements. The instantaneous Axis of Rotation does define in the axle rear and side view planes the corresponding suspension Roll & Pitch Centre points.

- Typical representants of such 2-D Suspension Architectures are classic Double Wishbone Lay-outs and McPherson Strut Configurations.

2) 2.5-D Suspension Architecture – Also known as "SPHERICAL" Suspensions.

- A 2.5-D Suspension can only be analysed with significant additional effort using classical 2-D procedures & tools. When using the 2D-based computer software code, the same restrictions apply unless one would divert to full vector algebraic analysis.

- The Instantaneous Axis of Rotation of a 2.5-D Suspension is characterized by the fact that the axis will ALWAYS through one specific suspension point and will perform around that point a Spherical/Cone-like Motion. Hence the name "Spherical" Suspension.

- In Spherical Suspensions Bump Steer, Camber Gain and Roll Centre Height are strictly coupled. One cannot change one without affecting the other.

- Spherical Suspension are using 3-Links. Representants are BMW E36 & Toyota RAV4

3) 3-D Suspension Architecture – Also known as "MULTI-LINK" Suspension

- A fully 3-Dimensional Suspension can only be analysed with a computer with full vector algebraic analysis.

- The Instantaneous Axis of Rotation of a 3-D Suspension is characterized by the fact it is truly moving free in "space" AND that the axis usually is additionally characterized by a typical thread pitch motion. A vertical wheel movement is not only creating a pure rotation around the axis but also a significant fore/aft movement. Like the thread on a bolt.

- The Thread Pitch Motion does in fact describe the instantaneous amount of coupling between Lateral and Longitudinal Wheel movement and their resulting effects on Toe and Camber Characteristics

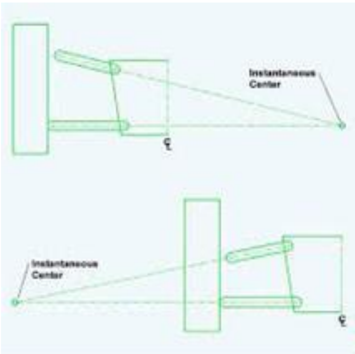
- In a 2-D and 2.5-D Suspension Architecture the Thread Pitch motion is close to zero or very low,

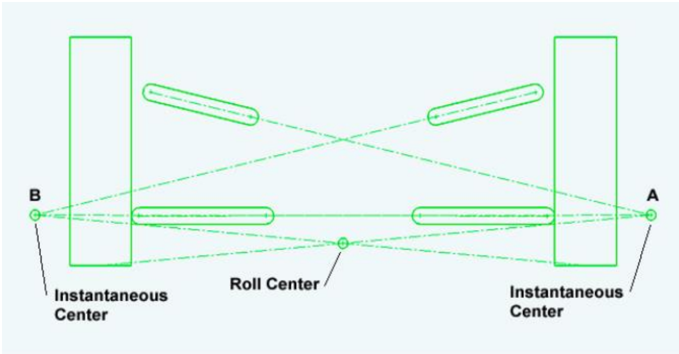
- Not all "Marketing" Multi-Link Suspensions are in fact Multi-Link Suspensions.

3: THE FUNDAMENTALS OF HOW TO ANALYZE SUSPENSION GEOMETRY

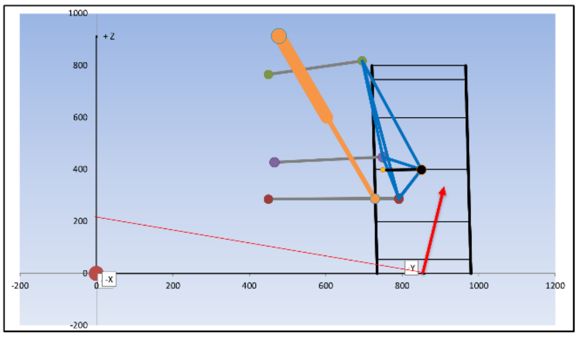
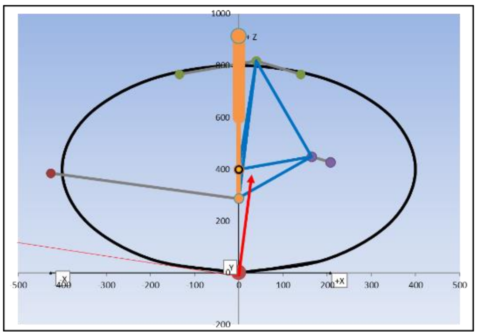
The “Classic” Approach to Suspension Kinematic Analysis is based on using elementary geometric procedures to analyse 2-Dimensional movements of suspension components and as such investigate their influence on the overall suspension system. For Multi-Link Suspension Analysis does serve a completely different approach.

- The most well-known “classic” method to calculate and “visualize” suspension characteristics like Roll Centre Height, Camber Gain, Anti-Lift & Anti-Dive is drawing lines through the link joints and using basic mechanical engineering procedures to calculate instantaneous centers of movement(s).





- As we have just learned in Fundamental #2, this method can only be applied on 2-D Suspension types. 2.5-D & 3-D Suspensions cannot (or only with some more or less severe limitations) be analysed.
- In fact, when trying to Analyse or even Optimise a 3-D Suspension, one must move away from “thinking in wishbone lines” and revert mentally to focus solely on the Upright/Wheel assembly Vector Movement (= How much does the wheel move in each direction per discrete step of vertical travel).
- For instance, the rear-view Y-Z “Vector” movement of the Contact Patch does fully address the location of the Instantaneous Centre of Movement & Roll Centre Height. Like-wise does the side-view X-Z “Vector” Movement of the Contact Patch define the Brake Anti-Angle.

- All relevant Suspension Characteristics can be calculated out of the 3-Dimensional “Vector” Movement of either the Wheel Centre or the Contact Patch Points:
  - Contact Patch X-Z Vector Movement = Braking Anti-Angle & Pitch Centre Location
  - Contact Patch Y-Z Vector Movement = Roll Centre Position
  - Wheel Center X-Z Vector Movement = Traction Anti-Angle & Pitch Centre Location
  - Wheel Center Y-Z Vector Movement = Track Width / track Width Change
  - Wheel Z-Axis Rotation = Toe / Bump Steer
  - Wheel X-Axis Rotation = Camber / Camber Gain
  - Wheel Y-Axis Rotation = Caster Angle / Caster Angle Change

4: THE FUNDAMENTAL EFFECT OF LOADS ON GEOMETRIC BEHAVIOR.

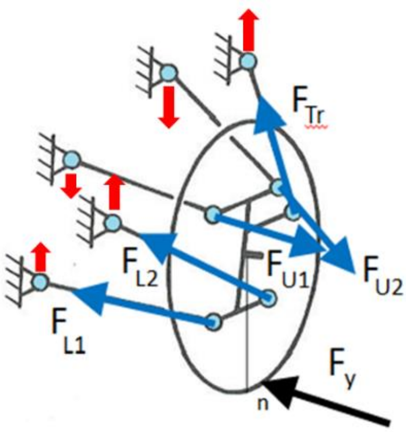
The Kinematic Suspension Analysis Method does typically not consider the effect of Suspension Loads on Geometric Behavior as the most analysis tools do generally assume that all suspensions components are infinitely stiff (rigid elements) and/or that there are no loads in the suspension links.

As Suspension do see in real life considerable loads and as a result of that can see a non-neglectable amount of deformations the effects of suspension loads must absolutely be considered.

The following 2 Dominant Effects to consider are:

1) Geometric (Link-) Load Transfer:

- Geometric (Link-) Load Transfer is addressing the part of the Load Transfer caused by the 3-Dimensional Position of the Suspension Links in the Vehicle. It is an effect entirely caused by Geometric Position of the Links.



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- Any Lateral (or Longitudinal) Force at the Contact Patch will create (**in blue**) reaction forces in the Suspension Links. These Link Forces can from their side create at their respective chassis attachments (**in red**) Vertical Force omponents which will influence the amount of load that at the end must be provided by the Springs and Anti-Roll Bars.

- In fact, Geometric Link Load Transfer and Suspension Roll Centres / Pitch Centres are equivalent. The lower the RCH, the lower the Link Load Transfer and vice versa.

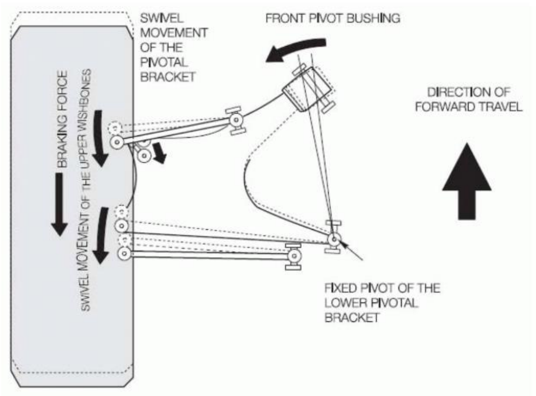
2) Suspension Link Stiffness / Compliant Deformation:

- As many Suspensions are equipped with Bushings and even when equipped with very stiff rose joints any load on a suspension component will cause a deflection of that components. The sum of all deflections and corresponding movements of the geometric suspension hard points will affect the geometric behaviour.

- Hence it is inevitable to consider these elastic deformations which in Suspension Linguistic are being referred to as Elasto-Kinematics.

- Elasto-Kinematic Suspension Behaviour can (even to a very high degree) improve, compensate or worsen the desired Kinematic Characteristics and thus positively, neutrally or negatively affect the ultimate handling of the vehicle.

- In the scheme below, depending on the Basic Geometry Lay-Out and the Stiffness of the Bushing(s), the Braking Force could cause either Toe-In, Toe-Out or No Toe Change at all.



- Typically, complex (and very expensive) multi-body simulation tools are being used to analyse Elasto-Kinematics.

- The **DYNATUNE-XL SUSPENSION DESIGN MODULE** does provide a very efficient First Order Elasto-Kinematics Analysis Tool by allowing Compliant Suspension Links.

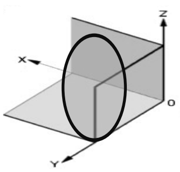
Execute a Jounce Motion ONLY Calculation for correct Compliance numbers

Pneumatic Trail	20.0	mm
Toe Aligning Torque Stiffness	0.425	°/kNm
AT Stiffness Definition iso SAE: (+) AT creating Toe-Out		
Track Rod Link Stiffness	10000.0	N/mm
Spring Link Stiffness	10000.0	N/mm
Lower Link 2 (or 2nd A-Arm leg) Stiffness	10000.0	N/mm
Upper Link 1 Stiffness	10000.0	N/mm
Upper Link 2 (or 2nd A-Arm Leg) Stiffness	10000.0	N/mm

All Compliance Data refer to Design Position

Input Parameters for Dynatune Ride & Handling Tool

- The **DYNATUNE-XL SUSPENSION DESIGN MODULE** does provide a complete table of the to be expected Elasto-Kinematic effects on the most important Suspension Characteristics like Toe, Camber Caster and Wheel Centre & Contact Patch Position (Values in Orange are Industry Standard Considered Important).

	SUSPENSION COMPLIANCE TABLE					
	Vertical Load @ CP	Braking Load @ CP	Acceleration Load @ WC	Longitdinal Impact Load @ WC	Lateral Load @ Outside Wheel @ CP WITHOUT Pneumatic Trail	Lateral Load @ Outside Wheel @ CP WITH Pneumatic Trail
Toe Compliance [°/kN]	-0.016	0.030	0.012	-0.012	0.033	0.024
Camber Compliance [°/kN]	-0.006	0.009	-0.003	0.003	0.017	0.017
Caster Compliance [°/kN]	0.008	-0.055	0.009	-0.009	-0.019	-0.017
Contact Patch X Compliance [mm/kN]	0.071	-0.577	0.193	-0.193	-0.173	-0.161
Contact Patch Y compliance [mm/kN]	0.092	-0.141	0.029	-0.029	-0.231	-0.221
Wheel Center X Compliance [mm/kN]	0.016	-0.199	0.132	-0.132	-0.042	-0.046
Wheel Center Y Compliance [mm/kN]	0.049	-0.081	0.008	-0.008	-0.114	-0.104

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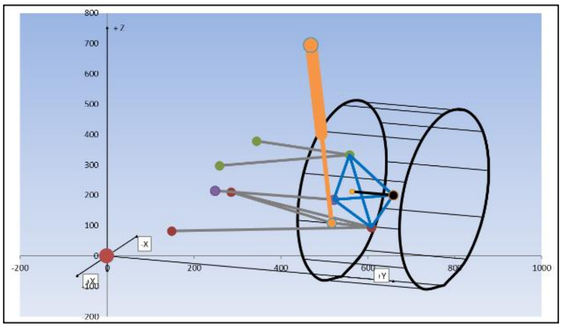
5: WHY YOU SHOULD NEVER OPTIMIZE ONLY FOR KINEMATICS

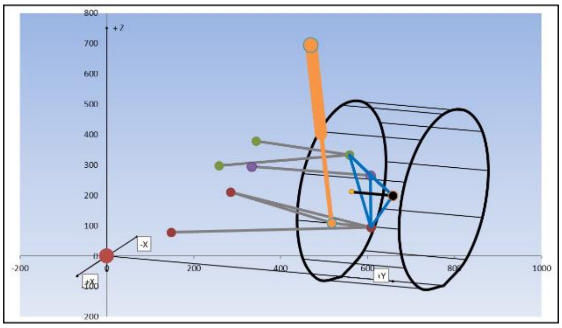
As we have learned that Elasto-Kinematics can/do play an important role in the Suspension Performance, it would be unwise to neglect them. As the following example will show, optimizing for kinematics only can cause significant – though unintended – shortcomings as systems with identical Kinematic Characteristics can have completely different Elasto-Kinematics.

- The following 4 Suspension Layouts do have identical Kinematic Characteristics: x2 Versions do have an Upper & Lower A-Arm Concept and x2 Versions do have an Upper & Lower L-Arm Concept (where one leg of the wishbone is positioned in Axle-Centre Line). All links do have the same Stiffness.

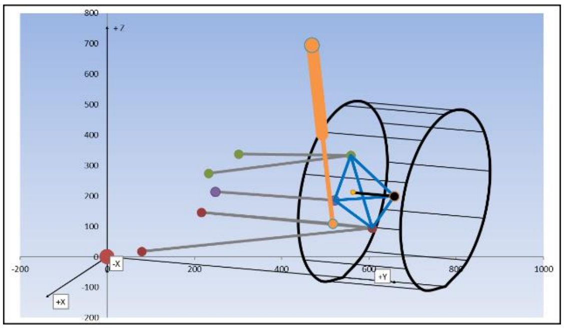
  Both A-Arm as L-Arm concept do have an alternative version with the Track-Rod located in front and behind the Wheel Centre:



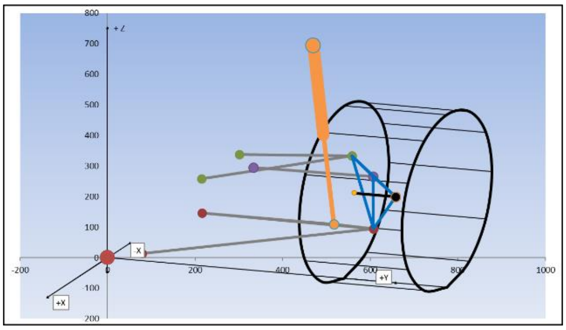
A-Arm / TR front



A-Arm / TR rear



L-Arm / TR front



L-Arm / TR rear

- It is of vital importance to re-confirm the fact, that the kinematic characteristics of ALL of the above variants are **absolutely** identical:

RESULTS @ REFERENCE WHEEL POSITION	0.00	mm in Jounce

CALCULATION RESULTS - STATIC SUSPENSION SYSTEM PARAMETERS						
Bump Steer [°/m]	Camber Gain [°/m]	Roll Center Height [mm]	Roll Center Height Movement / Wheel Travel Ratio [-]	Spring/Damper Travel / Wheel Travel Ratio [-]	Wheel Center Anti-Angle [°]	Contact Patch Anti-Angle [°]
0.02	-21.21	47.93	0.986	0.745	0.00	0.00

CALCULATION RESULTS - STATIC STEERING SYSTEM PARAMETERS					Steering Ratio	N/A	-
Toe [°]	Camber [°]	Caster [°]	Caster Trail [mm]	KPI [°]	Scrub Radius [mm]	KPI Off. [mm]	Caster Off. [mm]
0.00	0.00	4.76	25.42	14.04	3.75	78.75	0.42

As the following tables will show, the differences between the variants can be quite significant

- A-Arm & TR front:

SUSPENSION COMPLIANCE TABLE	Vertical Load @ CP	Braking Load @ CP	Acceleration Load @ WC	Longitdinal Impact Load @ WC	Lateral Load @ Outside Wheel @ CP WITHOUT Pneumatic Trail	Lateral Load @ Outside Wheel @ CP WITH Pneumatic Trail
Toe Compliance [°/kN]	0.004	-0.011	0.042	-0.042	-0.022	-0.032
Camber Compliance [°/kN]	-0.008	-0.001	-0.001	0.001	0.038	0.038
Caster Compliance [°/kN]	-0.006	-0.164	-0.008	0.008	0.006	0.008
Contact Patch X Compliance [mm/kN]	-0.029	-1.020	0.160	-0.160	0.007	0.003
Contact Patch Y compliance [mm/kN]	0.045	0.007	0.027	-0.027	-0.239	-0.247
Wheel Center X Compliance [mm/kN]	0.005	-0.160	0.204	-0.204	-0.027	-0.042
Wheel Center Y Compliance [mm/kN]	0.006	0.003	0.019	-0.019	-0.042	-0.047

- A-Arm & TR rear:

SUSPENSION COMPLIANCE TABLE	Vertical Load @ CP	Braking Load @ CP	Acceleration Load @ WC	Longitdinal Impact Load @ WC	Lateral Load @ Outside Wheel @ CP WITHOUT Pneumatic Trail	Lateral Load @ Outside Wheel @ CP WITH Pneumatic Trail
Toe Compliance [°/kN]	0.002	-0.009	0.033	-0.033	-0.001	-0.011
Camber Compliance [°/kN]	-0.008	-0.001	-0.002	0.002	0.036	0.037
Caster Compliance [°/kN]	-0.006	-0.165	-0.004	0.004	0.001	0.002
Contact Patch X Compliance [mm/kN]	-0.029	-1.019	0.156	-0.156	0.010	0.007
Contact Patch Y compliance [mm/kN]	0.042	0.009	-0.007	0.007	-0.220	-0.220
Wheel Center X Compliance [mm/kN]	0.001	-0.156	0.177	-0.177	0.007	-0.005
Wheel Center Y Compliance [mm/kN]	0.003	0.005	-0.019	0.019	-0.030	-0.025

- L-Arm & TR front:

SUSPENSION COMPLIANCE TABLE	Vertical Load @ CP	Braking Load @ CP	Acceleration Load @ WC	Longitdinal Impact Load @ WC	Lateral Load @ Outside Wheel @ CP WITHOUT Pneumatic Trail	Lateral Load @ Outside Wheel @ CP WITH Pneumatic Trail
Toe Compliance [°/kN]	0.005	-0.029	0.075	-0.075	-0.033	-0.044
Camber Compliance [°/kN]	-0.010	0.063	-0.003	0.003	0.060	0.060
Caster Compliance [°/kN]	0.005	-0.189	-0.020	0.020	-0.053	-0.050
Contact Patch X Compliance [mm/kN]	0.043	-1.198	0.207	-0.207	-0.384	-0.395
Contact Patch Y compliance [mm/kN]	0.063	-0.384	0.104	-0.104	-0.376	-0.388
Wheel Center X Compliance [mm/kN]	0.016	-0.207	0.309	-0.309	-0.105	-0.131
Wheel Center Y Compliance [mm/kN]	0.009	-0.053	0.089	-0.089	-0.063	-0.071

- L-Arm & TR rr:

SUSPENSION COMPLIANCE TABLE	Vertical Load @ CP	Braking Load @ CP	Acceleration Load @ WC	Longitdinal Impact Load @ WC	Lateral Load @ Outside Wheel @ CP WITHOUT Pneumatic Trail	Lateral Load @ Outside Wheel @ CP WITH Pneumatic Trail
Toe Compliance [°/kN]	0.003	0.006	0.017	-0.017	-0.002	-0.014
Camber Compliance [°/kN]	-0.011	0.060	-0.003	0.003	0.059	0.061
Caster Compliance [°/kN]	0.006	-0.199	0.002	-0.002	-0.063	-0.062
Contact Patch X Compliance [mm/kN]	0.038	-1.193	0.154	-0.154	-0.367	-0.364
Contact Patch Y compliance [mm/kN]	0.058	-0.366	0.034	-0.034	-0.348	-0.349
Wheel Center X Compliance [mm/kN]	0.005	-0.154	0.144	-0.144	-0.035	-0.040
Wheel Center Y Compliance [mm/kN]	0.003	-0.049	0.019	-0.019	-0.040	-0.031

- As one can see, for a selected few metrics the differences do range from an almost 100% change in magnitude to even a change of direction. A suspension could for instance change from creating toe-out under lateral load to toe-in or from creating toe-out to toe-in under braking loads. The range of trade-offs is so much bigger and more complex than with Kinematics only.

- Even when dealing with very rigid suspension components, one should NEVER solely optimize only for Kinematics but ALWAYS consider compliance effects and try to "use" them in a favourable manner.

- The REAL performance of Suspensions systems is located in their tunability of the Elasto-Kinematics.

DYNATUNE – XL

DYNATUNE-XL is the registered name of a suite of core skill **MS EXCEL ®** based Engineering and Simulation Tools.

The **DYNATUNE-XL** Tool Suite does provide Professional Engineering Tools covering the most Important Aspects of Vehicle Dynamics. All Tools aim to achieve a Maximum of Results with a Minimum of Input Data allowing quick Setup Checks or - if wanted - more complex Generic Parameter Studies. Being a fully **MS EXCEL ®** based Tool does significantly reduce the application threshold for many engineers and technicians. MS Excel is available on most computers as part of **MS OFFICE ®** and widely supported in business applications**.**

SOFTWARE REQUIREMENTS & LICENSE MANAGEMENT

Software requirements for **RELEASE 8.0** are **Full** Versions (incl. latest updates) of **MS EXCEL ® 2007, 2010, 2013, 2016** or **2019** or **Office/365** with a **MS Windows ® XP, Windows Vista, Windows 7 Starter, Windows 7, Windows 8** or **10 Operating System**.

All Modules of **DYNATUNE-XL** come as a compiled executable (*.exe) binary file which will call **MS EXCEL®** as a separate stand-alone instance. Source code is copyright protected and safe data handling is guaranteed through secure binary files.

Standard Customer Licenses are typically valid for the use of the workbooks (and ALL user-saved variants) on 1 computer and for 1 user only without a timing constraint.

The protection software does offer to the customer next to the security of encoded binary data handling also - by means of a unique License Key Verification Procedure - a state–of-the-art data protection.

License support is available for the latest releases only and as there is no annual maintenance fee existing clients with older product releases can acquire "upgrading" licenses to the latest version release at special client rates.

Recommended minimum hardware configuration for the **DYNATUNE-XL** Tools are Intel Core i5/i7 CPU (or similar) with 4GB Ram.

All Units in **DYNATUNE-XL** are SI.

DYNATUNE-XL DEMO VERSIONS

DEMO Versions of the following DYNATUNE-XL Modules can be downloaded here:

- DYNATUNE Ride & Handling Module: http://www.dynatune-xl.com/download-demo-rh.html
- DYNATUNE Suspension Design Module: http://www.dynatune-xl.com/download-demo-sdm.html
- DYNATUNE Suspension Tuning Module: http://www.dynatune-xl.com/download-demo-stm.html

DYNATUNE-XL STORE

B2C customers can acquire the various **DYNATUNE-XL** Modules online in our webstore:

http://www.dynatune-xl.com/store/c1/Featured_Products.html

B2B customers are kindly requested to contact us directly.

DYNATUNE-XL CONTACT

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