2013 Automotive Simulation World Congress

Significance of Numerical Simulations in the Journey of Tire from Rubber to Road

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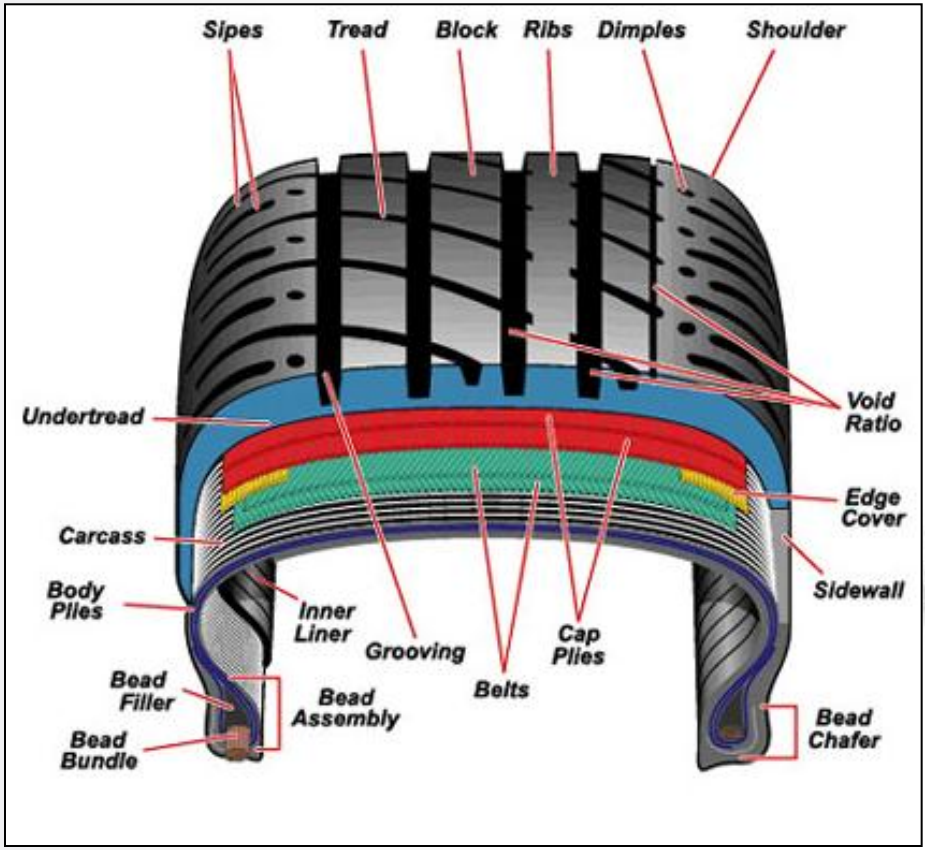
ANSYS

Outline

- Introduction
- Tire Manufacturing & Design
- Simulating Tire Manufacturing Processes
- Simulating Tire Design & Performance
- Summary

Introduction

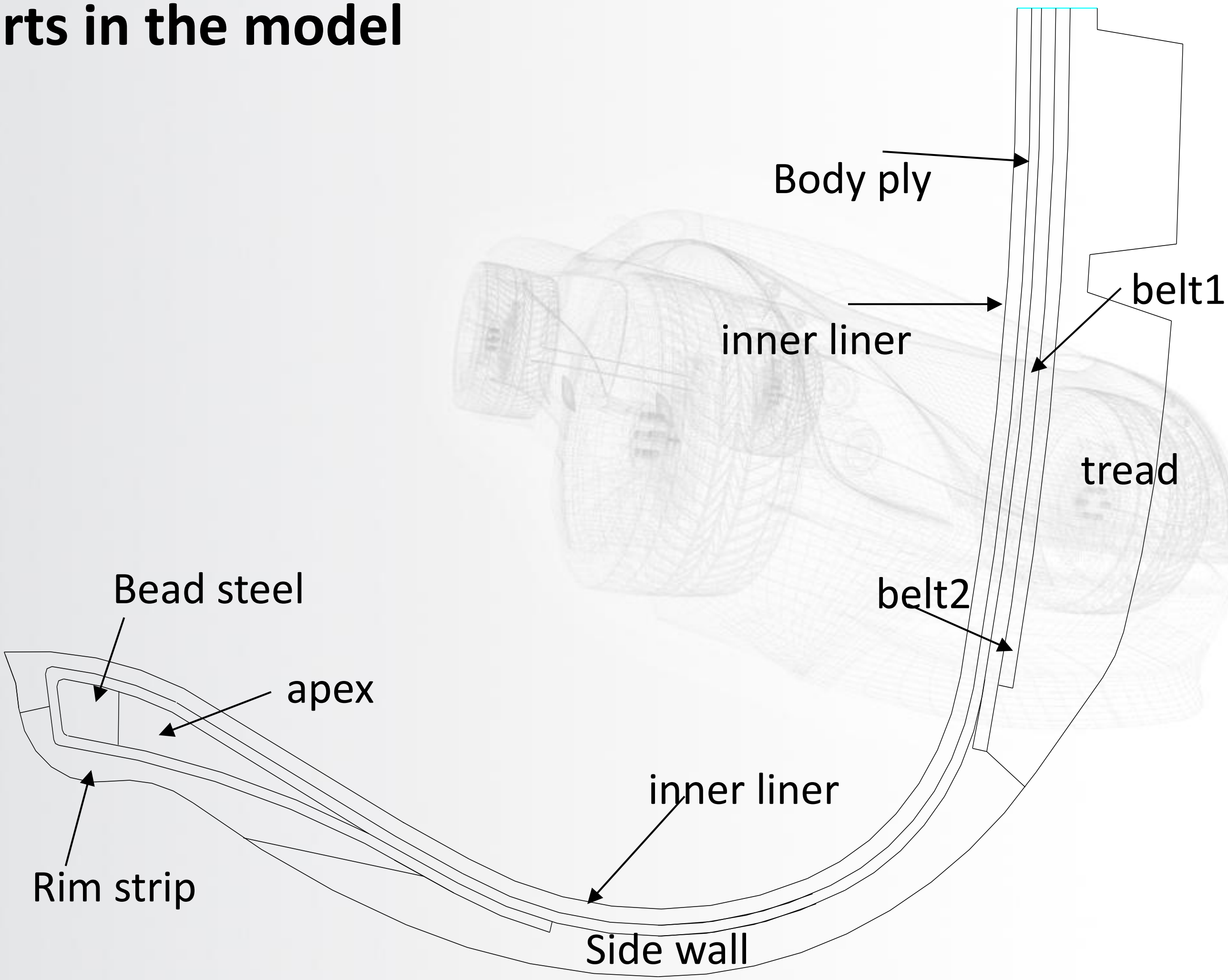
- Tires are surprisingly Complex – Geometry, Materials & Service conditions
- New tire development is a highly complex process consisting of many engineering activities such as
  - Tire pattern design,
  - Material selection,
  - Tire mold manufacture, and mass production
  - Tribological analysis,
  - Prototyping,



Typical Tire Cross-Section [Line Diagram]

There are total 9 parts in the model

1. Tread
2. Side Wall
3. Inner Liner
4. Body Ply
5. Belt1
6. Belt2
7. Bead Steel
8. Apex
9. Rim Strip



Tire Manufacturing & Design

Raw Materials
1. Rubber Bales
2. Textile
3. Steel
4. Chemicals
5. Etc …

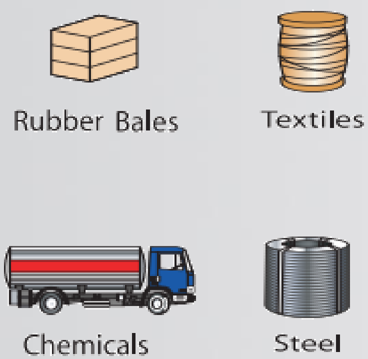
1. Rubber Compound Mixing
2. Tread & Side Wall Extrusion
3. Steel Belt / Fabric Cord Calendaring
4. Assembly Tire components
5. Tire Curing

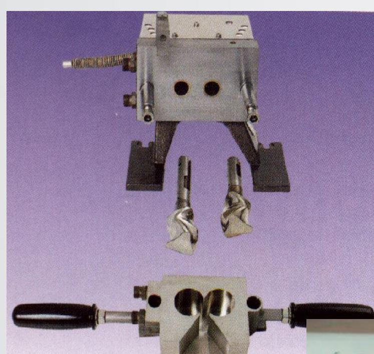
1. Performance Verification
2. Inflation, footprint, rolling analysis
3. Aquaplaning, water splashing
4. NVH Performance
5. Etc …

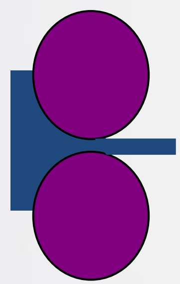
Rubber → Manufacturing → Road

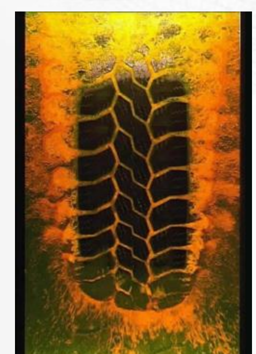
TIRE Manufacturers

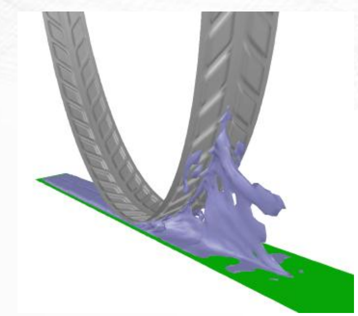
Automotive / Off Highway OEMs











Simulation of Tire Manufacturing Processes

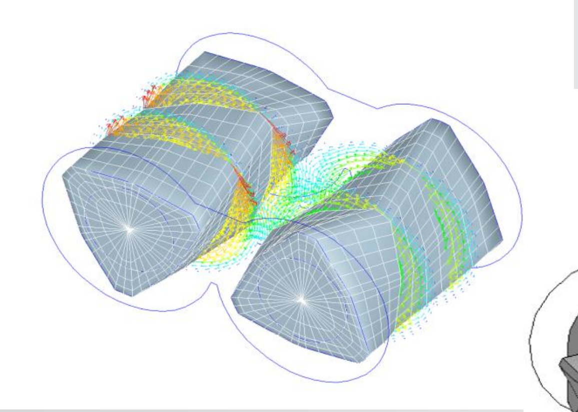
1. Mixing of Rubber Compound
2. Tire Tread Shaping & Extrusion
3. Tire Curing

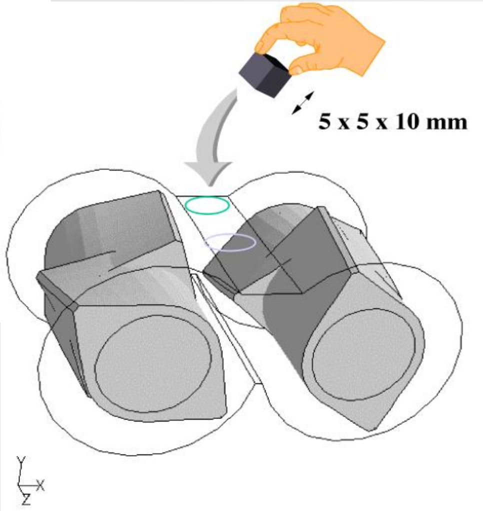
1. Mixing of Rubber Compound

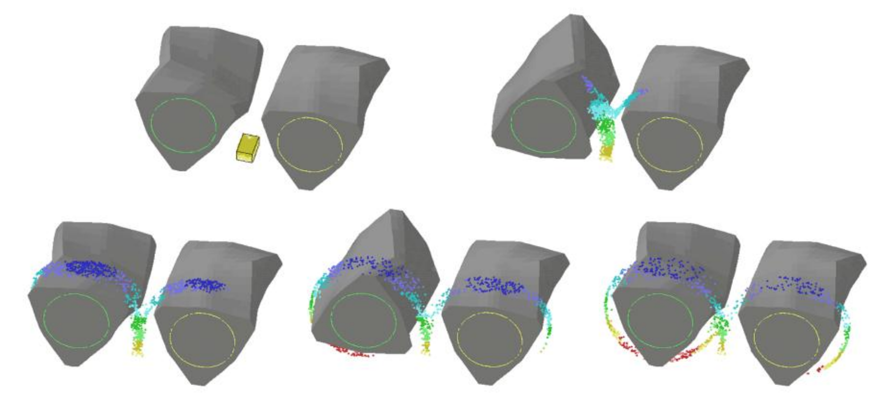
- Efficient Mixing is very important for processing rubber compounds
- Quality of Mixing is ensured by
  - Uniformity of mixture
  - Homogeneous properties of the resulting compound
- Most mixing devices generate a complex, truly 3D and transient flow pattern
  - Difficult to study with classical numerical technique
  - Various degrees of simplification are usually necessary
- ANSYS Polyflow Solution: Mesh Superposition Technique
  - Complemented by statistical analysis of the computation results.
  - Very powerful technique to simulate flow with moving and intermeshing parts, such as batch mixers and Twin Screw Extruders

ANSYS Polyflow : Batch Mixer Simulation

- **Case study: Batch mixing of rubber compounds**
- **Analysis of the effect of the rotor shape on the distributive mixing of an internal mixer by comparing configurations with 2, 3 and 4 wings.**
  - **Carrying fluid : white compound, SBR solution 60 *phr* silica/10 *phr* TiO²**
  - **Tracer (SBR solution 80 *phr* carbon black), negligible mass**







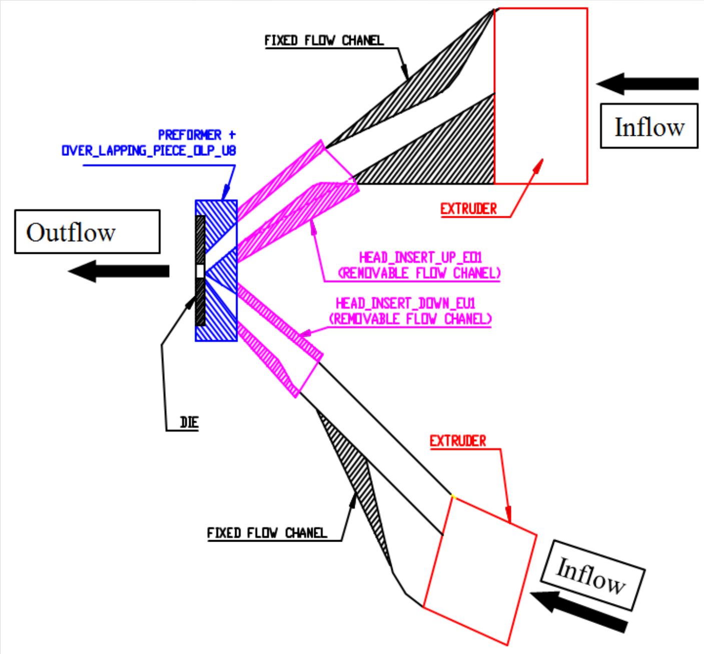
2. Tire Tread Shape & Extrusion

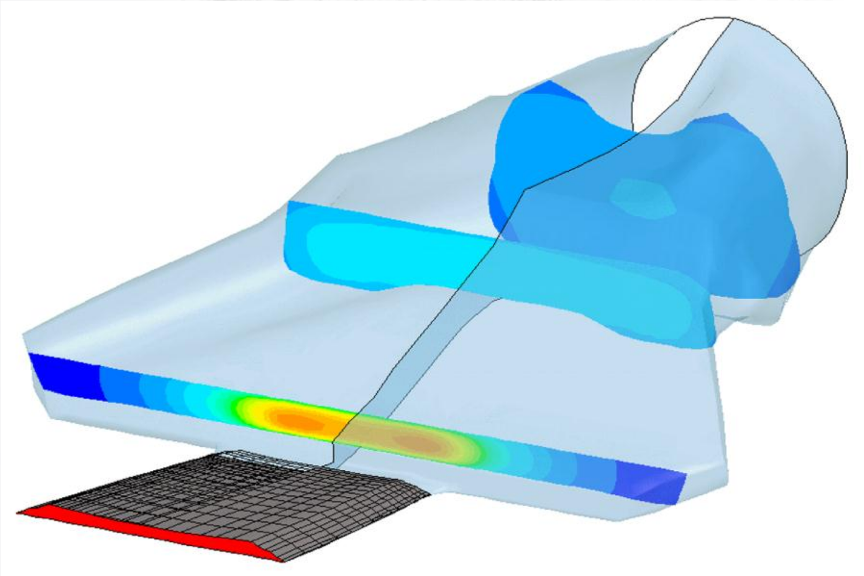
- **Tire treads are produced by continuous extrusion**
  - **It is very important to control this process in order to obtain the prescribed shapes and properties at reasonable expense**
- **Numerical Simulations Can help**
  - **Improve geometrical die data**
  - **Improve processing conditions**
- **ANSYS POLYFLOW Solution**
  - **Automatic die design functionality.**
  - **Reduce number of experiments on production line to obtain the right product**

ANSYS Polyflow : Die Design for Tire Tread Extrusion

Simulation Condition

- Temperatures measured about 95~105 °C, The first approach : isothermal model
- Take-away conveyor speed Vout=8.7 m/min
- Flow rate Q = 1.817x10-4 m3/sec
- Slip along walls evaluated and considered





Flow Modelling for the Tread Extrusion Simulation with several cutting planes

3. Tire Curing Process

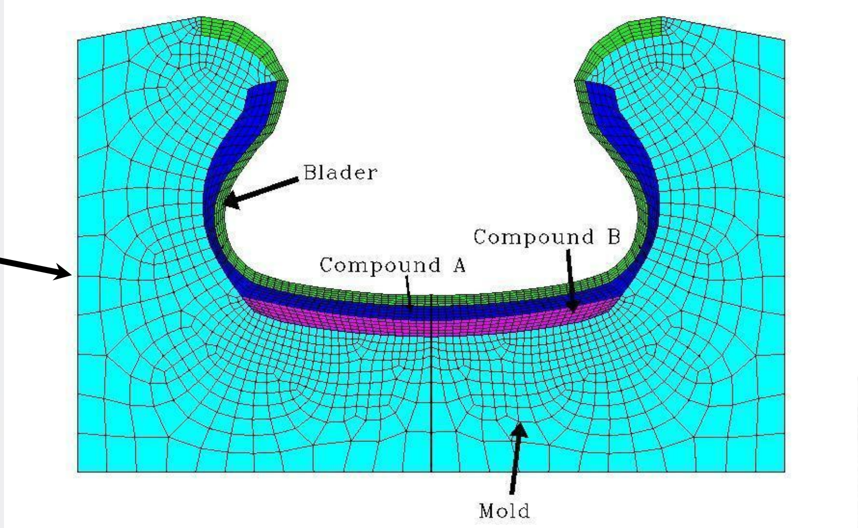
- **After the tire is formed to the desired pattern in a press, the compound is converted to a strong elastic material to meet tire performance needs by vulcanization**
- **The Curing Process is Energy-consuming and has a Strong Effect on Product Quality.**
- **The Cure Cycle should be Optimized, Minimizing Capital and Energy Expenditures.**
- **Numerical Modelling can be used to give a Valuable Insights into the Process Prior to Manufacturing.**

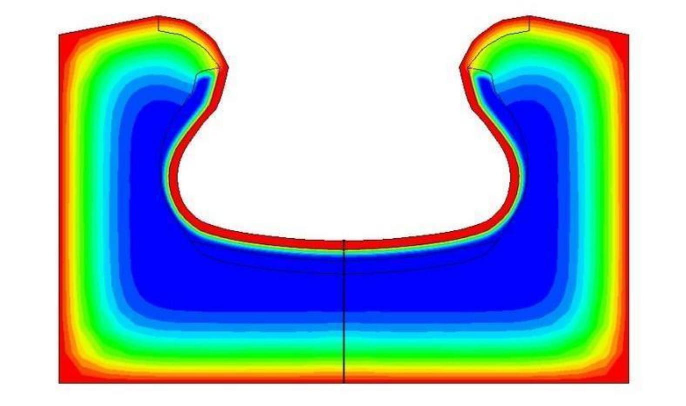
Pressing the pattern sculpture before curing (Photo: TTN Management Group)

ANSYS Polyflow : Tire Curing Process Modeling

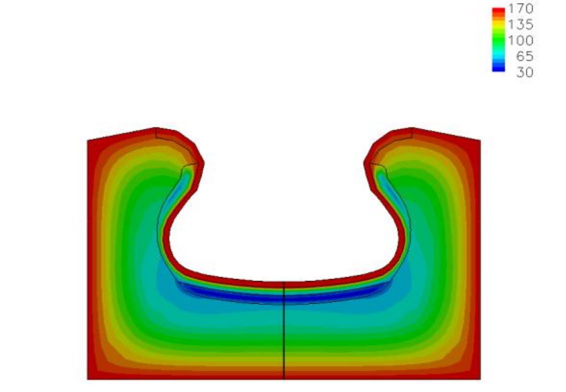
Schematic cross-section of the model tire and cure press

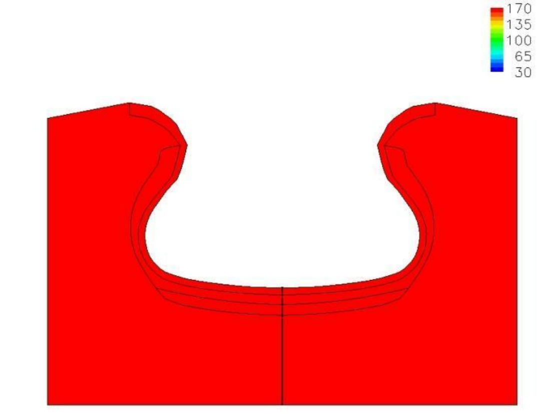
Model set-up





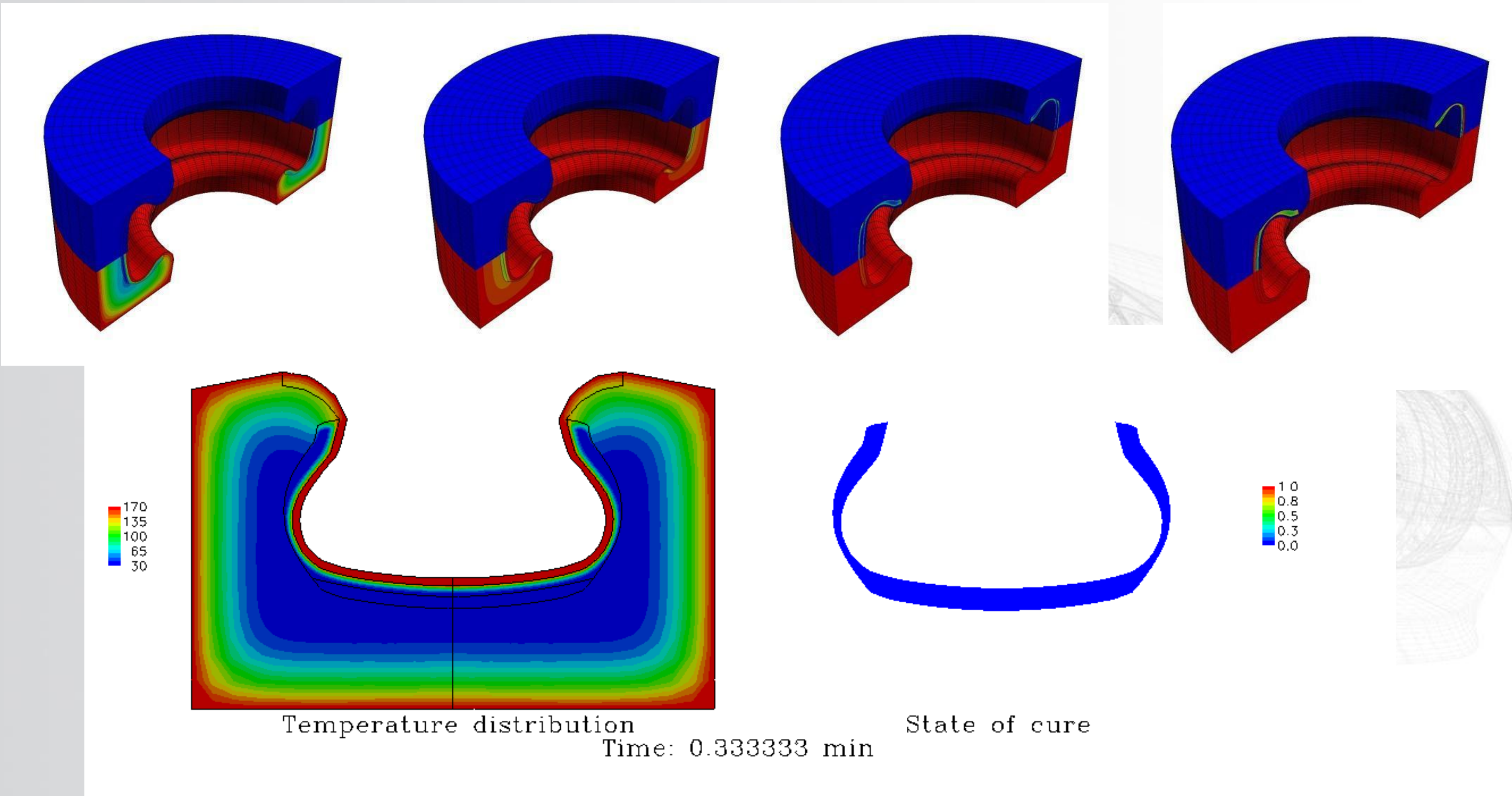
Initial temperature





Temperature after 6 min

ANSYS Polyflow : Tire Curing Process Modeling



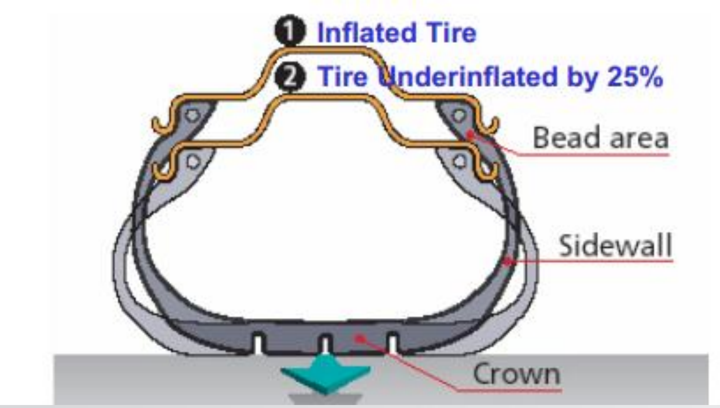
Comparison between the evolution of the temperature and the state of cure

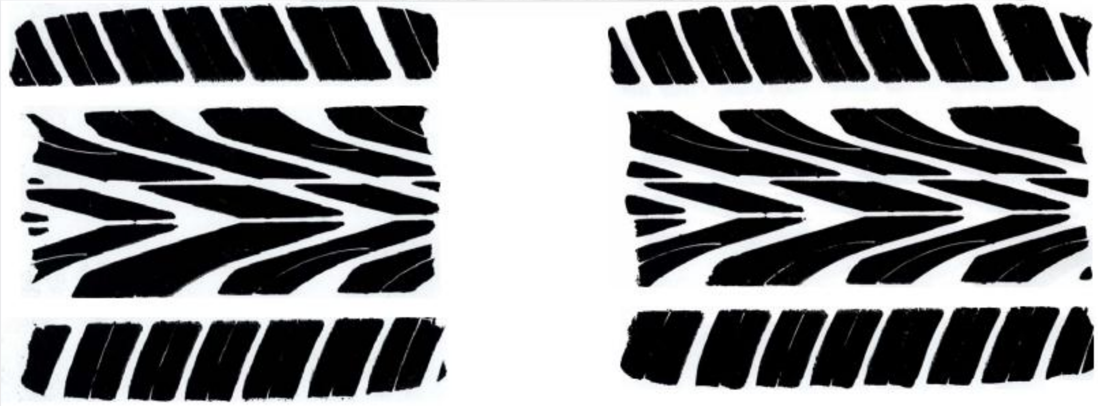
Simulation of Tire Design Performance

1. Tire Inflation, Foot-print & Rolling
2. Water Splash By Tire
3. Tire Subjected to Blast Wave

Tire Inflation, Foot-Print & Rolling Analysis using ANSYS Help understand Tire performance

- These are important tests to understand the tire Tread Design performance
- These can affect the vehicle fuel economy, tire wear, durability & vehicle handling etc.



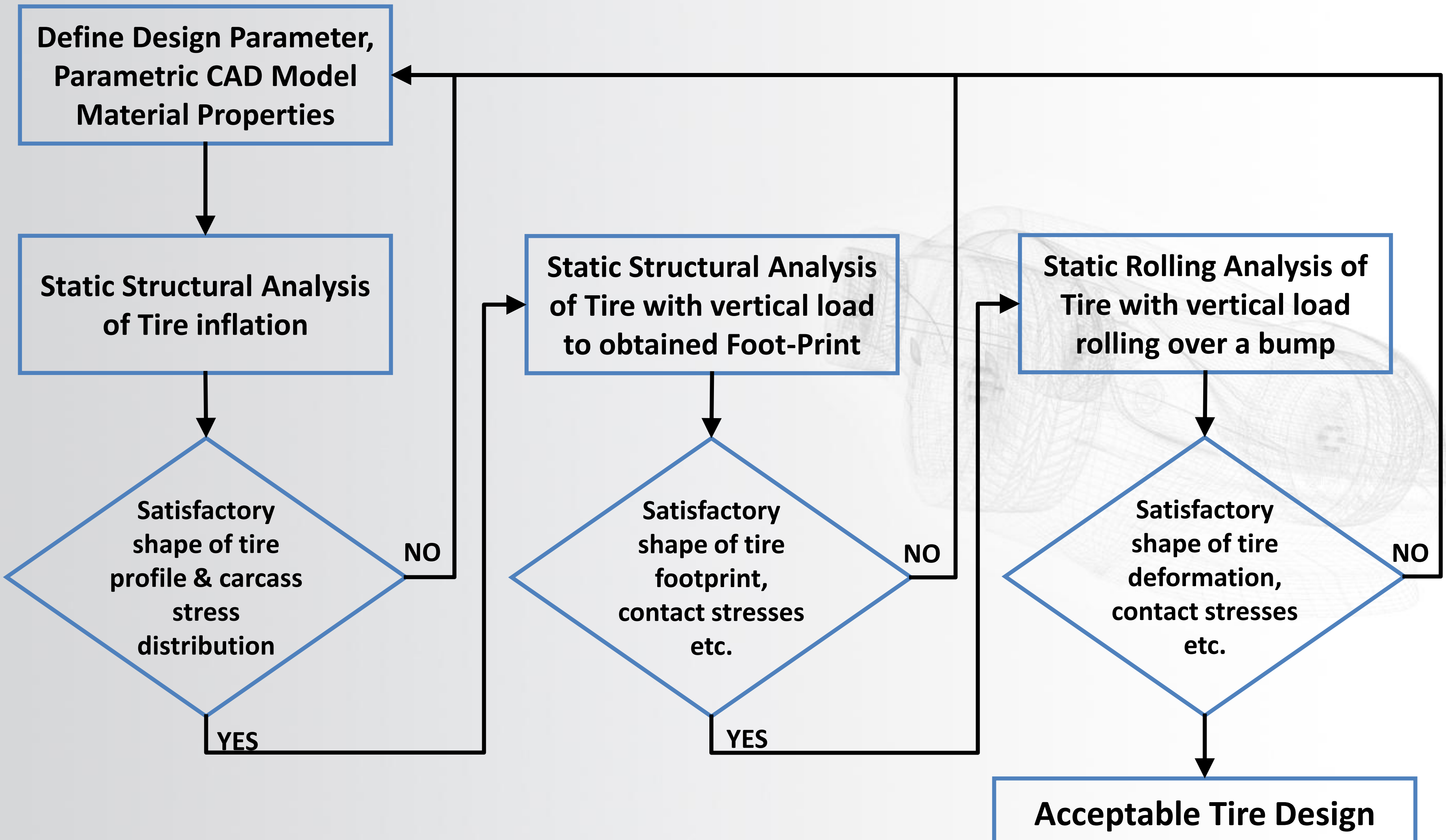


32 psi, Area = 36.5 in^2 24 psi, Area = 43.7 in^2

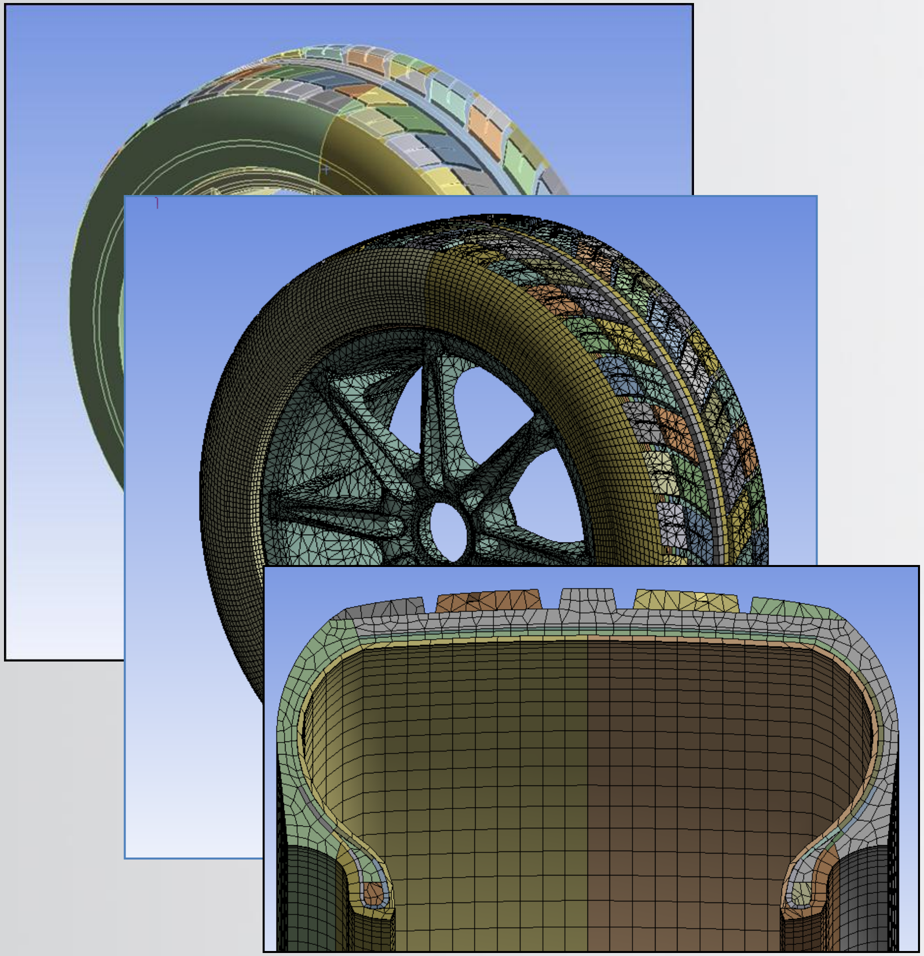
25% Pressure Loss Increases Footprint by 20% [1]

[1] http://www.arb.ca.gov/cc/tire-pressure/meetings/060408/060408exxonpresentation.pdf

Inflation, Foot-Print & Rolling Simulation Flow chart



Geometry/Meshing & Material Setup



Mesh Count :
Nodes = 157035 , Elements = 219921

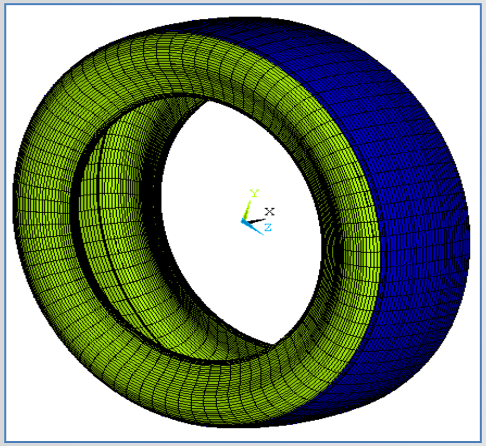
Rubber Components : Mooney Rivlin			
	C10	C01	D1
Tread Cap	0.406962	0.03468	0.0145
Side wall	0.02372	0.29765	0.0804
Belt	1.01025	0.07532	0.009712
Rimstrip	2.637214	0.0500535	0.0014804
Apex	2.637214	0.0500535	0.0014804
Body-ply	0.2652	0.1397	0.03349
Inner Liner	0.14458	0.14281	0.04861

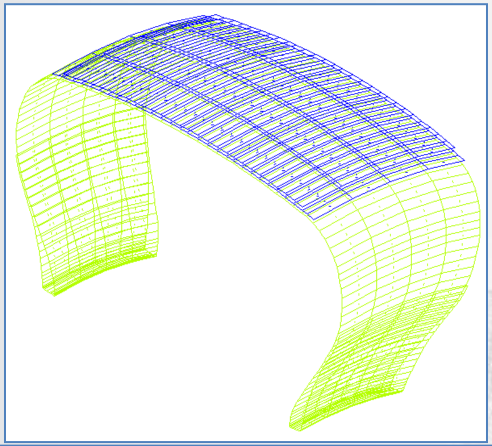
Material Properties for "Bead Steel"
E = 200 GPa, Poisson's Ratio = 0.3

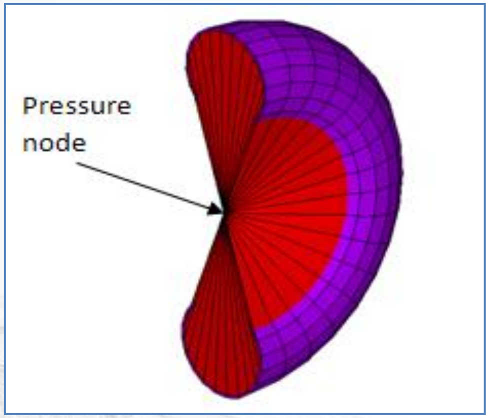
Material Properties for Rebar Elements		
Body Ply Rebar	Young's Modulus	60 GPa
	Possion's Ratio	0.3
Belts Rebar	Young's Modulus	200 GPa
	Possion's Ratio	0.3

	Cross- Section Area	Spacing
Body Ply Rebar	0.25	1.0
Belts Rebar	0.25	1.0

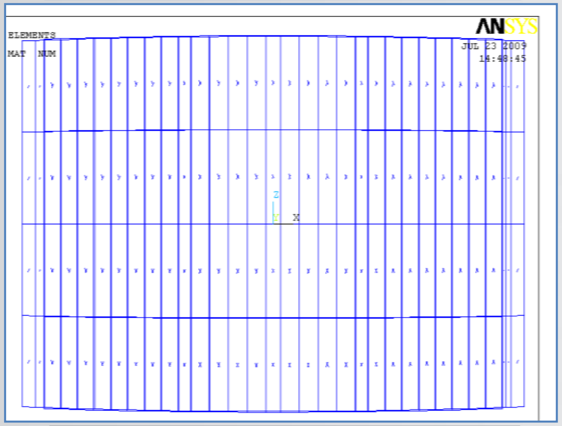
Reinforcement & Hydrostatic Element Setup



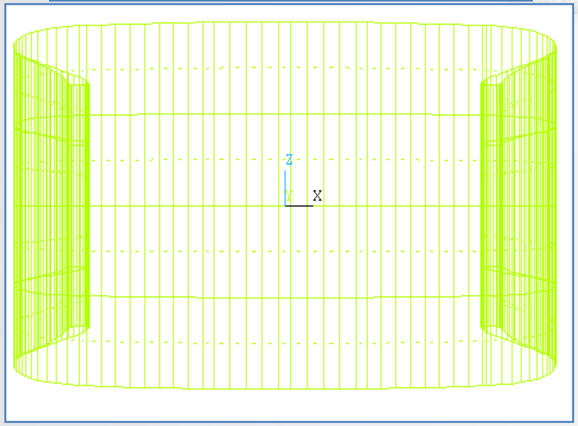




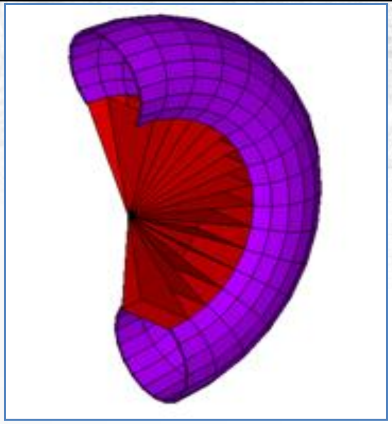
Hydrostatic Fluid Element with Positive Volume



+/- 70 degree rebars in belts

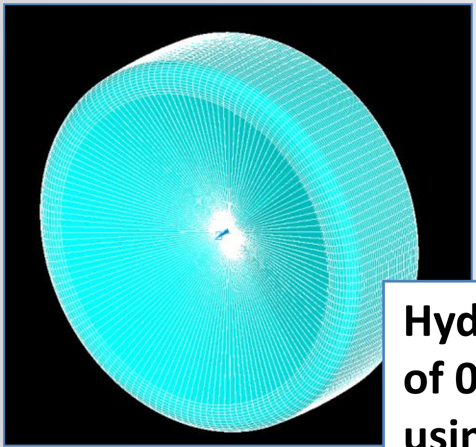


0 degree rebars in body-ply

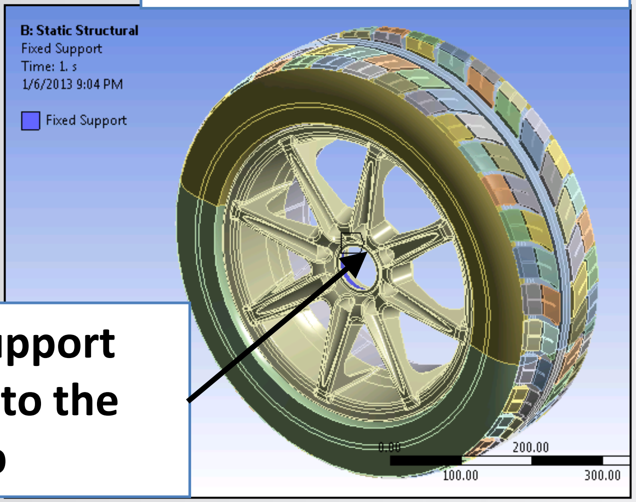


Hydrostatic Fluid Element with Negative Volume

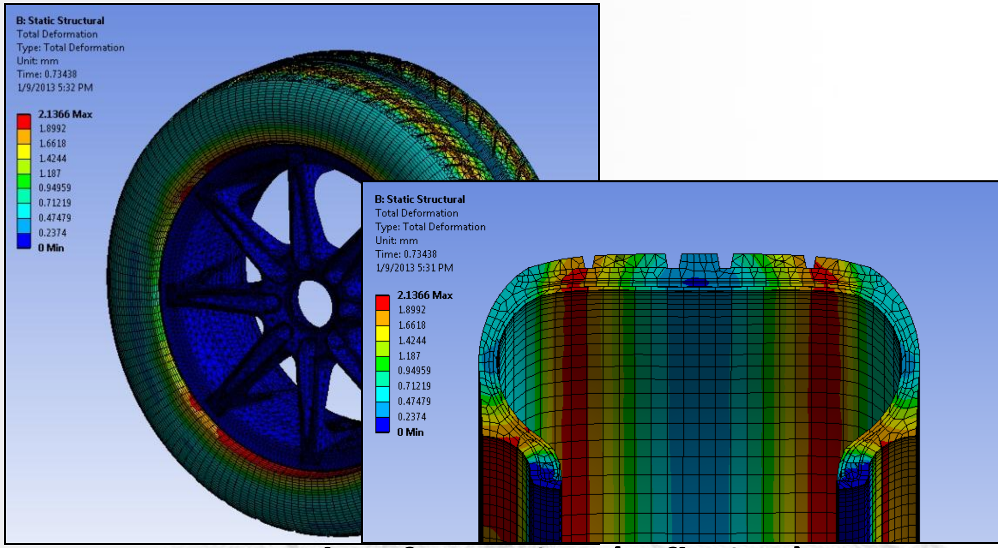
Inflation Analysis Loading & Results



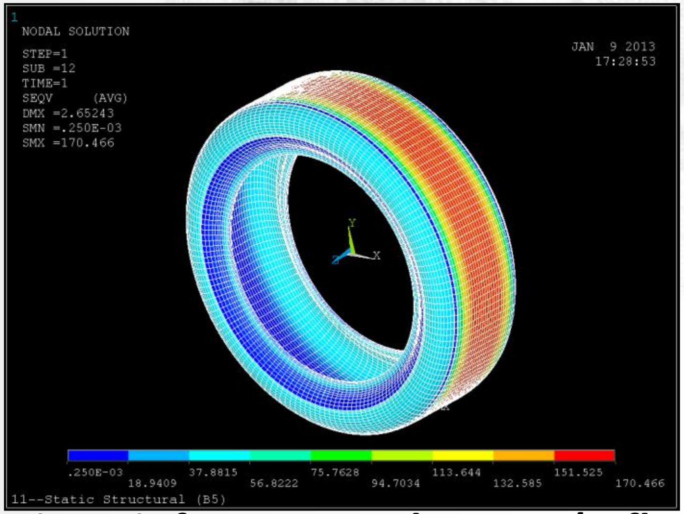
Hydrostatic Pressure of 0.24 MPa is applied using Hydrostatic Elements (HSFLD242)



Fixed Support applied to the Rim hub



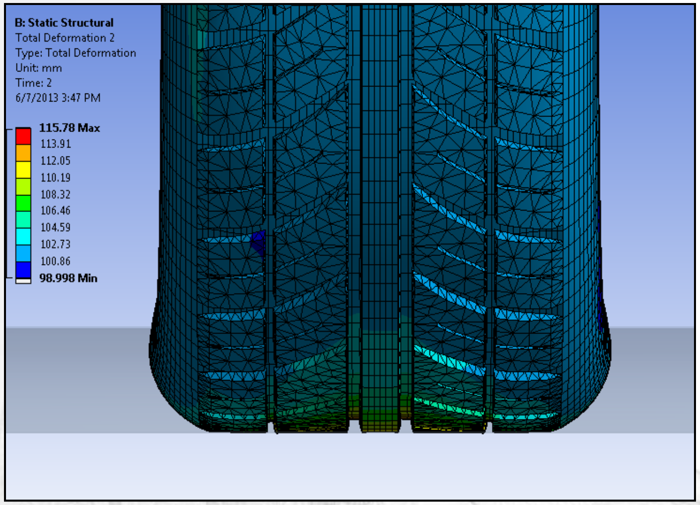
Total Deformation (Inflation)

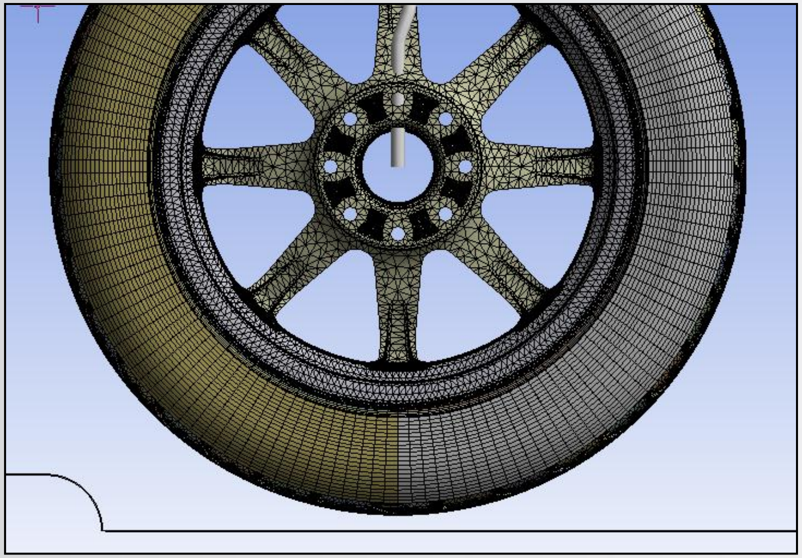


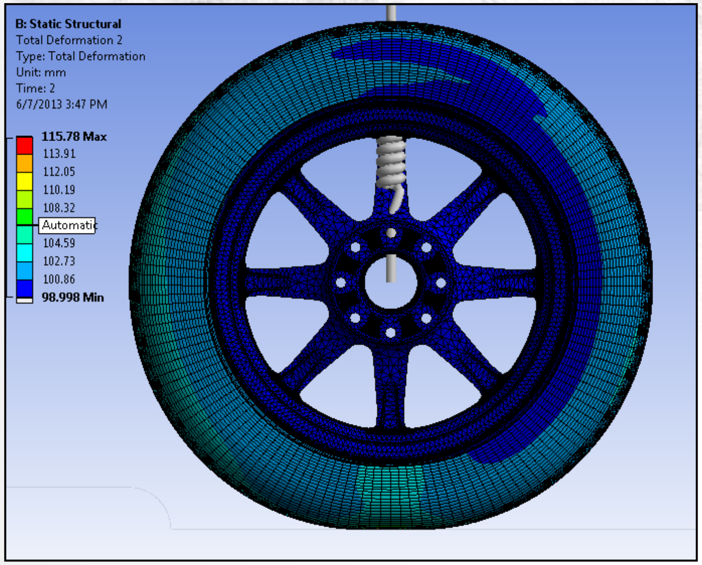
Stress in Reinforcement Elements(Inflation)

Foot-print Analysis Setup & Results

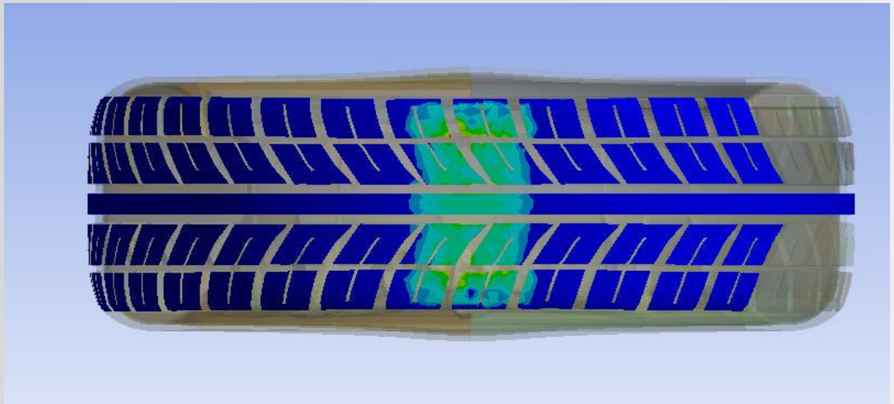
1. The tire is inflated to internal pressure of 0.24 MPa (34.8 psi)
2. Then displacement is applied to the hub of the tire to close the gap between the road & the tire and To create a force of 3000 N in the Spring
3. Assuming 3000 N = ¼ th Weight of the vehicle



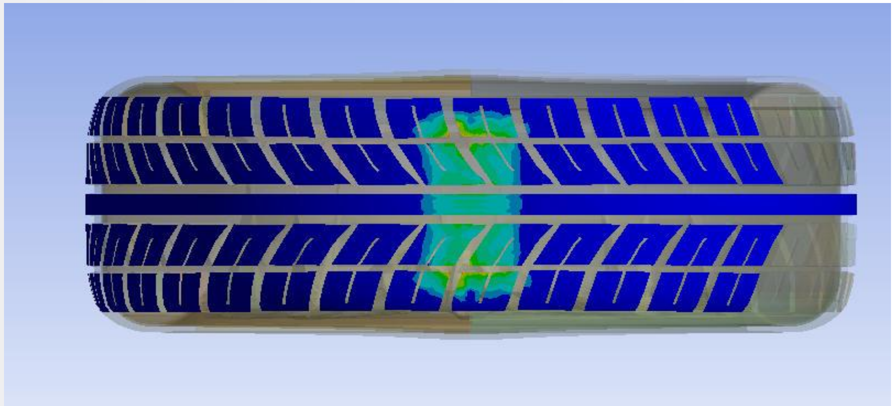




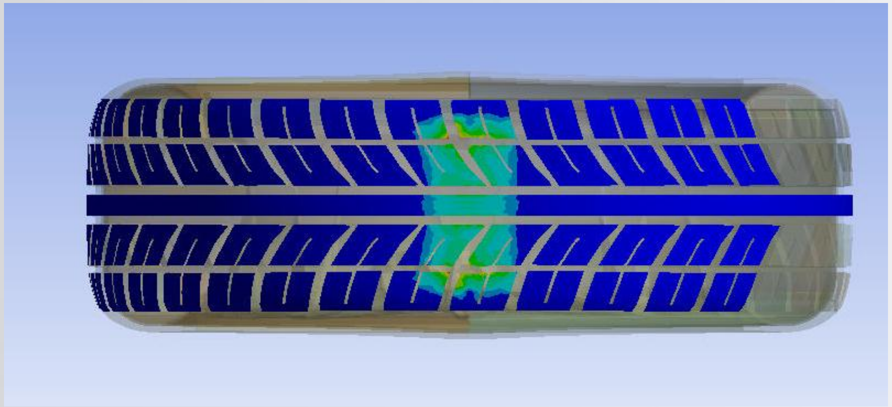
Footprint analysis – Contact Pressure



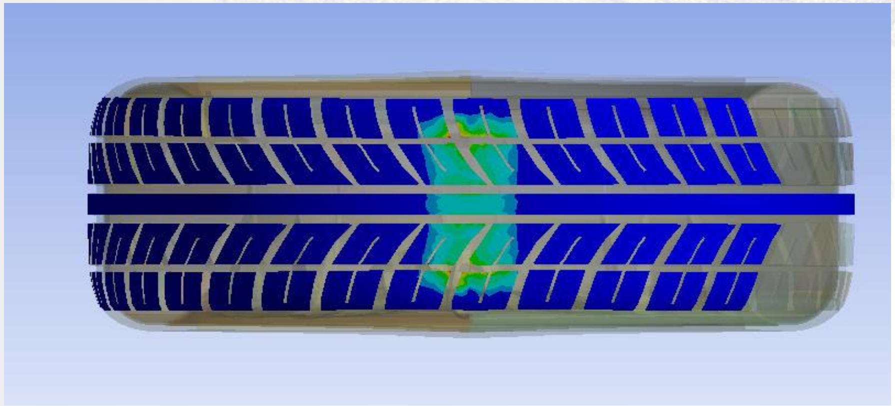
Tire internal pressure = 24 psi



Tire internal pressure = 34.8 psi



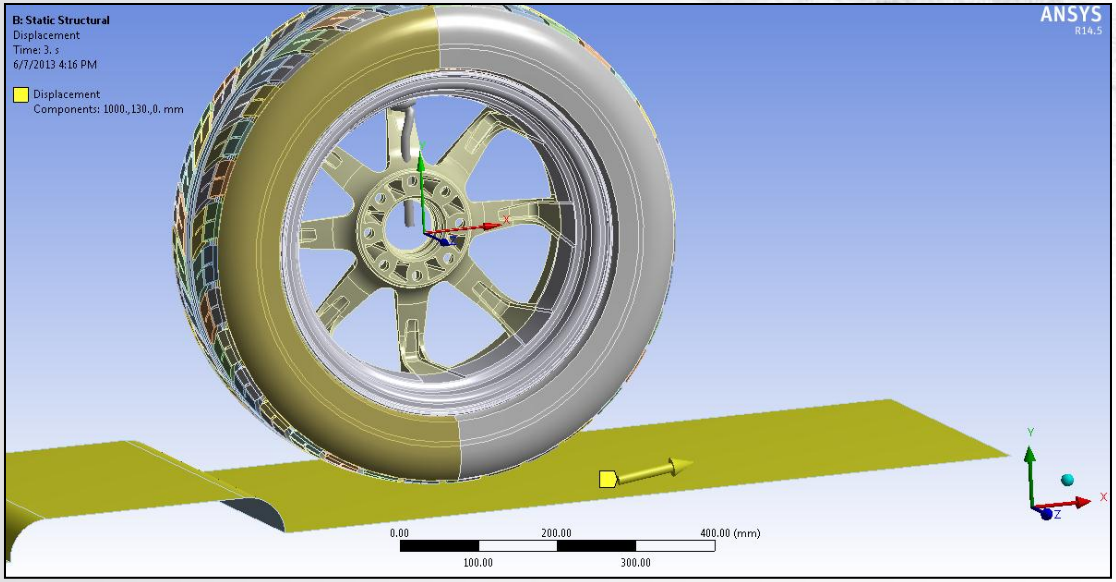
Tire internal pressure = 37 psi



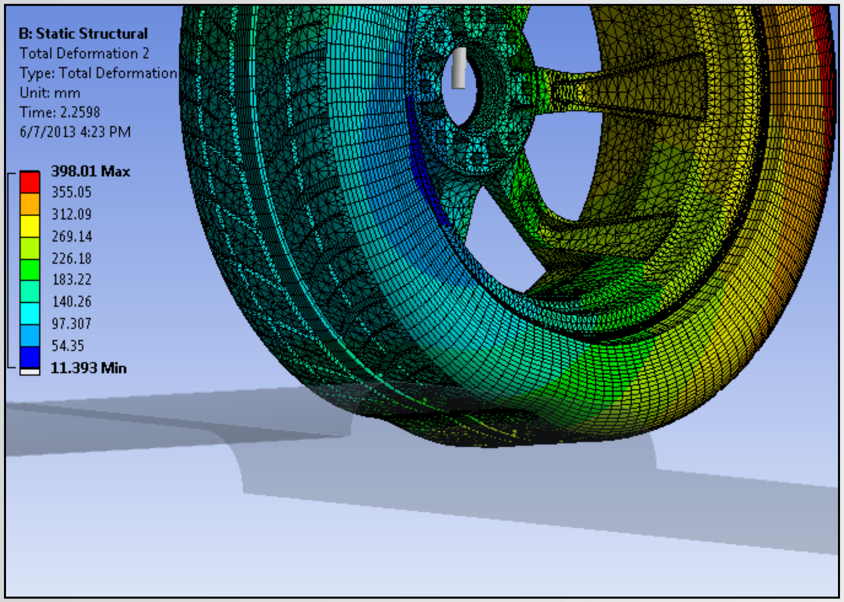
Tire internal pressure = 40 psi

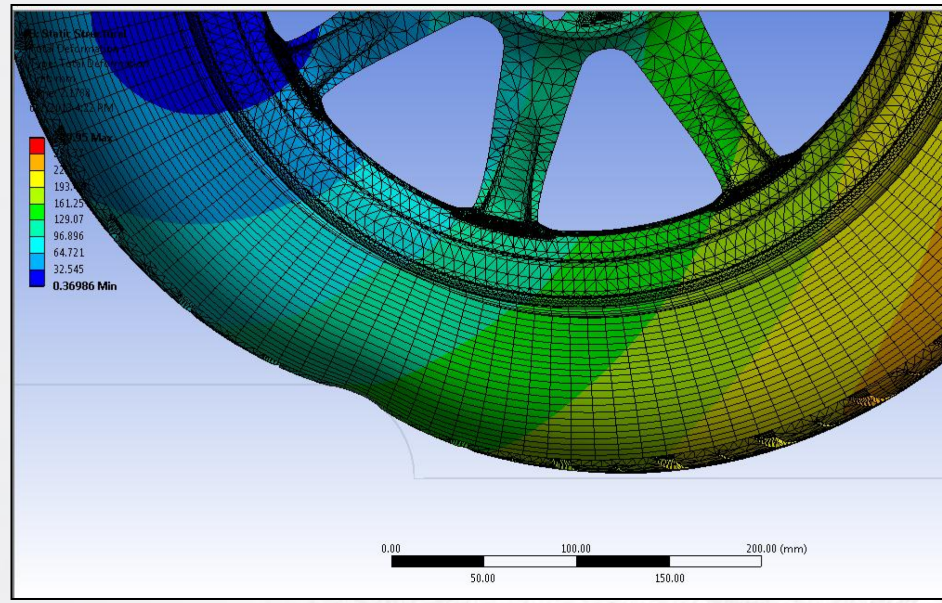
Rolling Analysis Setup

- Steady State Rolling Simulation
- The tire is inflated in the first step to an internal pressure of 0.24 MPa
- Displacement is applied to the hub of the tire to close the gap between the road and the tire that creates a force of 3000 N in the Spring
- 3000 N is ¼ th weight of the vehicle & the road surface is moved in the positive X direction so that the tire rolls over the bump



Rolling Analysis Results





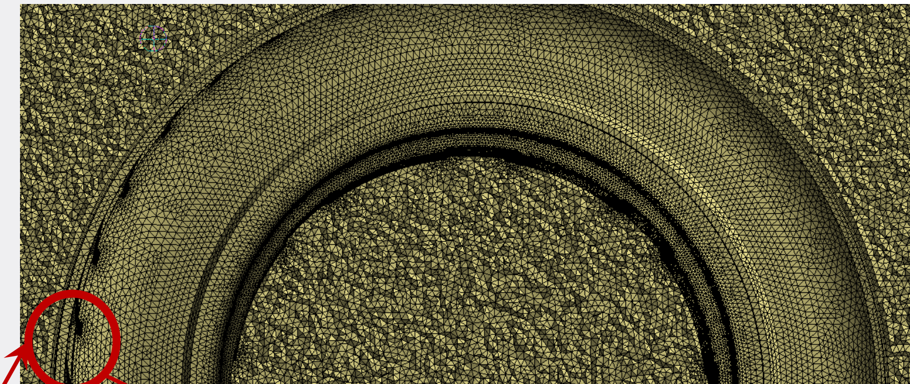
Total Deformation

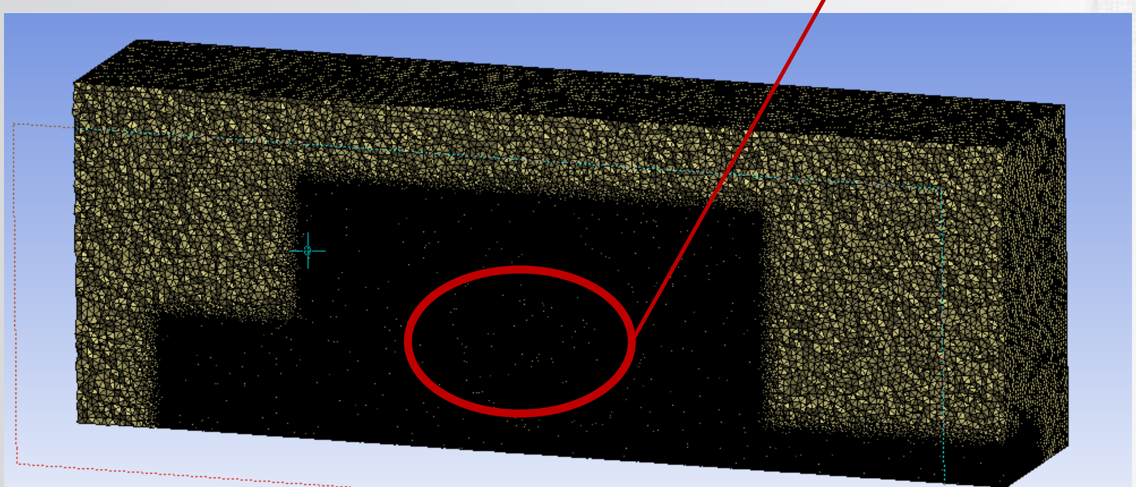
2. Water Splash by Tire

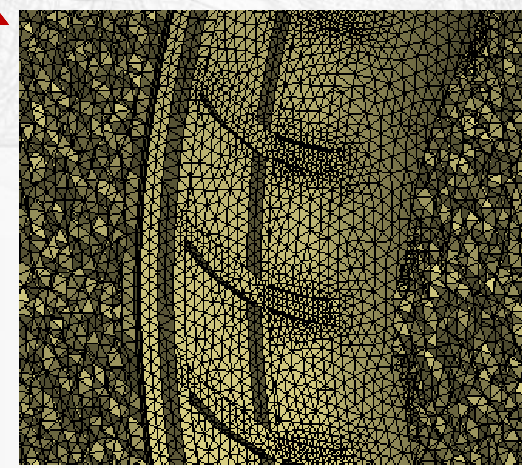
- Hydroplaning and Water splash are important parameters to be considered during the tire design
- Other than road resurfacing or vehicle body design, proper design of tire profile can reduce the water splash
- The tire has a unique shoulder/sidewall profile (chine) which acts as a splash deflector
- It is important to minimize the water splash by tire
  - To minimize the contamination in the car's engine bay and other critical components
  - To protect other vehicles and pedestrians from water/mud

Mesh Details : Water Splash by Tire Simulation

- **Tire Radius : 0.31 m**
- Tunnel Size : 2.6 m x 1.0 m x 1.0 m
- **Mesh Type : Tetrahedral**
- **Mesh Count : 34 Million**
- **Mesh Size : 5mm near the tire, 20mm in the domain**



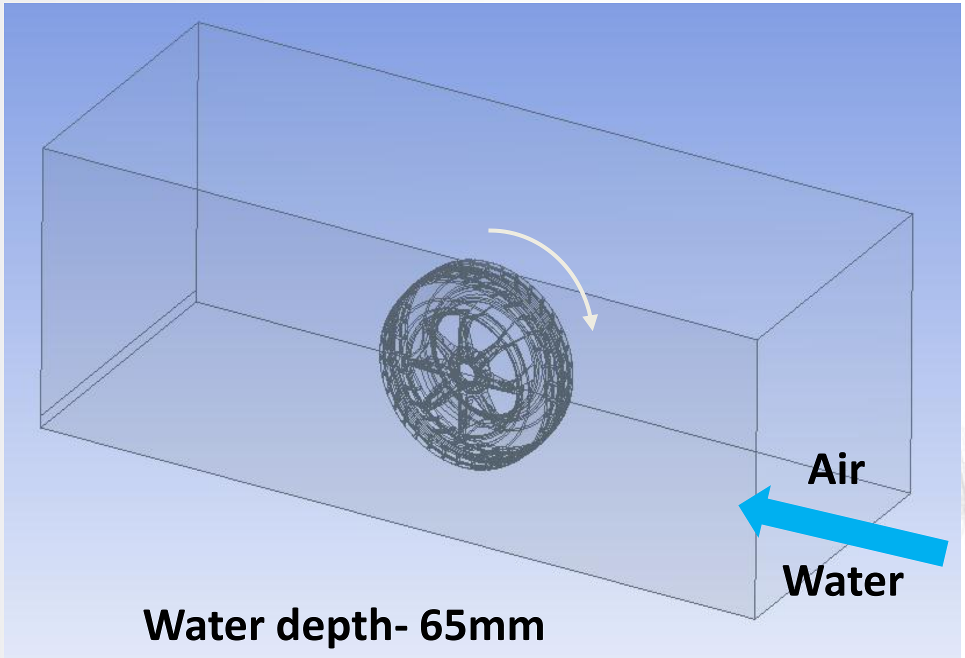




Problem Setup : Water Splash by Tire Simulation

- Multiphase Volume of Fluid (VOF) model to track the air-water interface
- SST K-Omega Turbulence Model
- Air-Water surface tension and wall adhesion are included in the model
- Tire rotation is modeled by moving wall where rpm is computed from the car velocity and the tire radius
- Computational Time taken : 20 hours for running the complete simulation (0.15s) in 96 CPUs

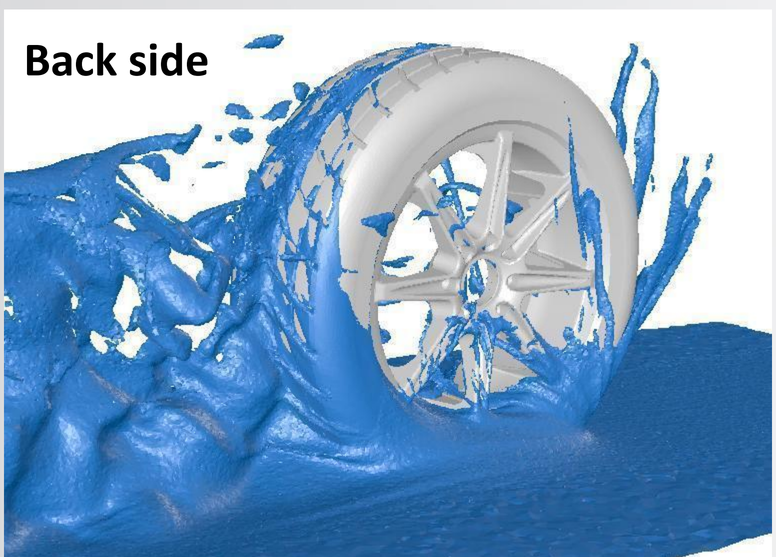
Vehicle Velocity- 60 kmph

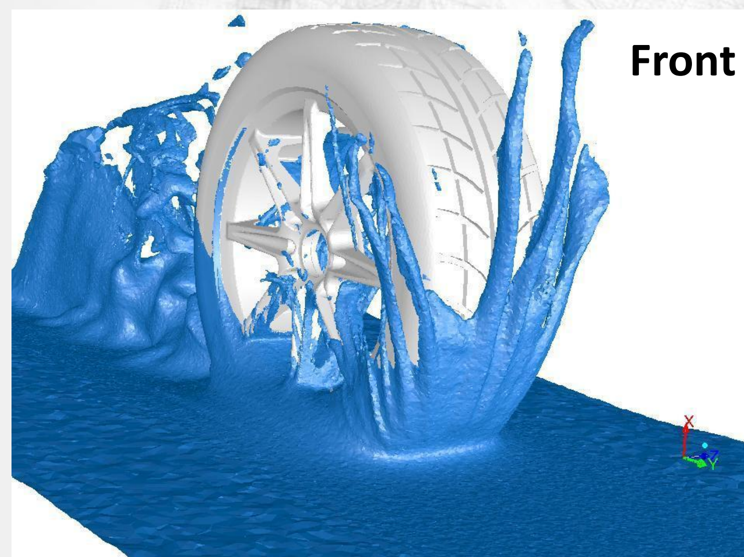


Results : Water Splash by Tire Simulation

Results : Water Splash by Tire Simulation

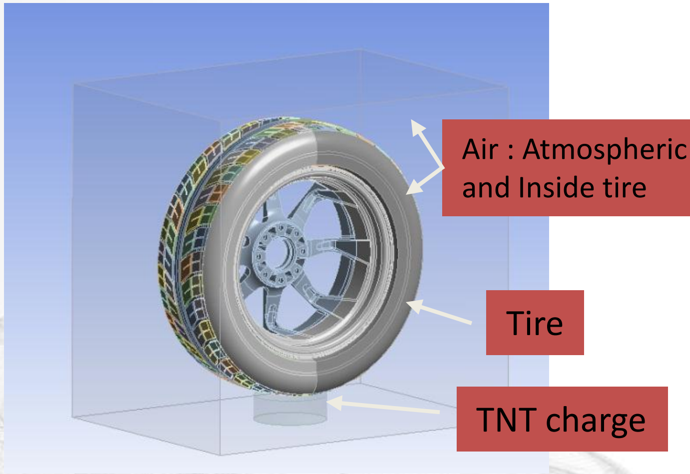
1. **This Methodology Captures the Water Splash at the Front and the Back of the tire**
2. It provides very useful insights required for tire profile design to minimize water splash
3. **All the vehicle parts close to the tire and a large portion behind the back tire are wetted**
4. **Side splashing is not captured as it would need a transient moving mesh** m**ethodology which is** computationally expensive

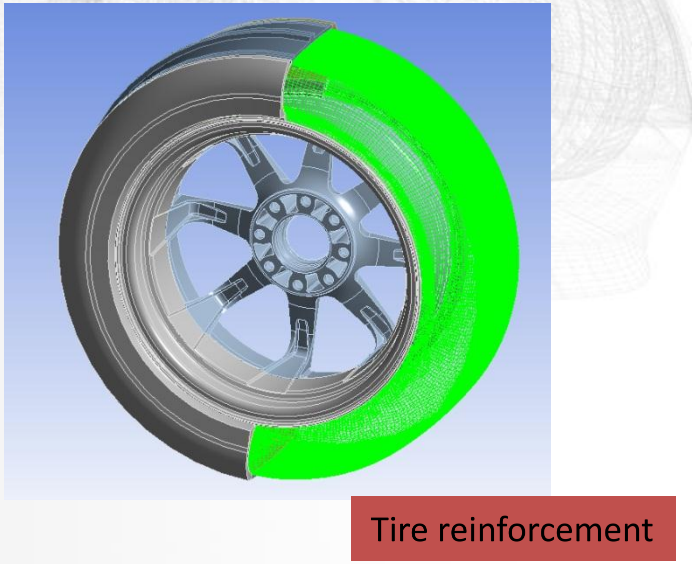




3. Tire subjected to Blast Wave

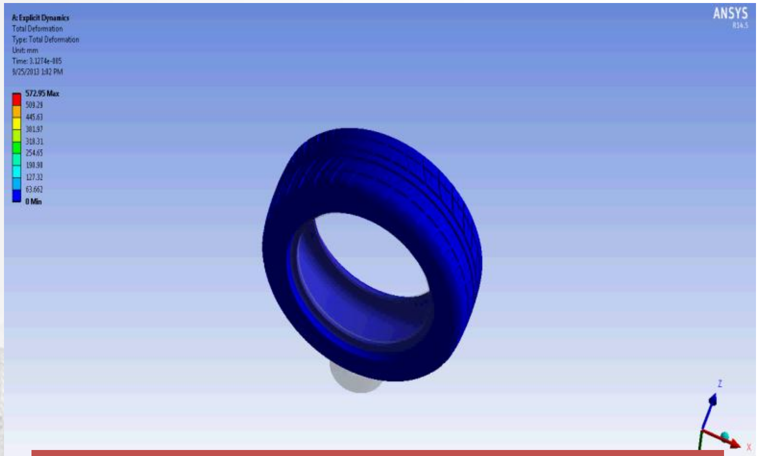
- Simulating Tire damage when it is subjected to blast wave using explicit analysis in ANSYS AUTODYN
- Complex composite sub-layers of tire made of nonlinear rubber and steel reinforcements
- Complex definition, with Euler domain of tire air, Lagrange domain of tire parts, TNT explosives and surrounding Euler domain of air
- High fidelity blast solver to solve interaction of compressed tire air with Blast wave of TNT and Tire bodies
- Accurate erosion model to predict the tire damage



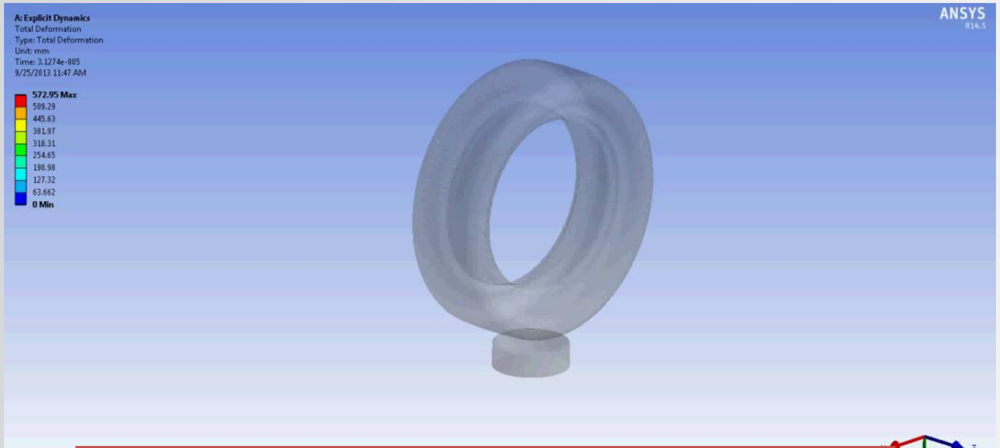


3. Tire subjected to Blast Wave

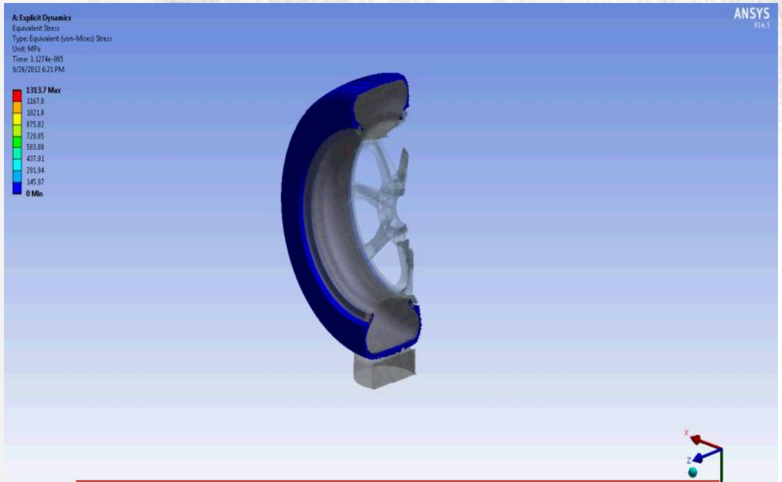
- **TNT explosion damage Tire considerably by eroding the rubber at the road interface.**
- **Tire damage leads to interaction of blast wave with Air inside Tire, which try to compress it as well as push it out to engage with Atmospheric air.**



Tire damage due to explosion of TNT



Interaction of blast wave with Air inside tire



Cross section view of Tire damage

Summary

- Simulations can play a vital role in Journey of Tire from Rubber to Road
- At every stage simulation adds value by providing valuable insights
- ANSYS has breadth of solutions to gain insights of Tire manufacturing and design process
  - ANSYS Polyflow [Tire manufacturing process]
  - ANSYS Mechanical [Tire structural performance]
  - ANSYS Explicit Structural [Blast]
  - ANSYS Fluent [Water splash]