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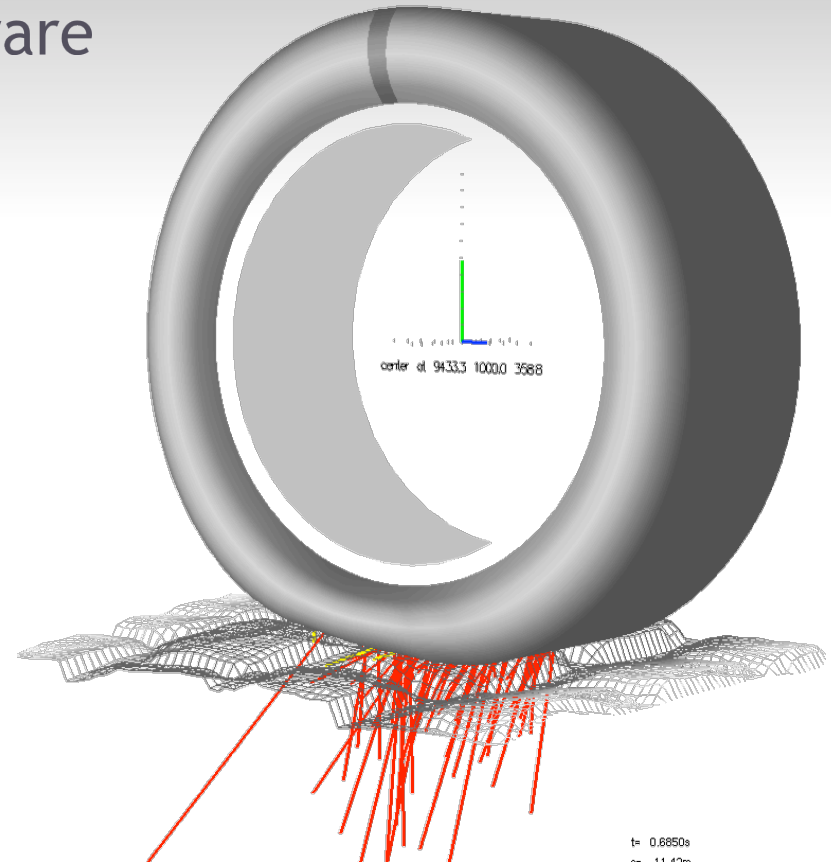

FTire: a Physically Based Tire Model for Handling, Ride, and Durability

Part 7: Tools

Michael Gipser
Esslingen University of Applied Sciences
& cosin scientific software

FTire/calc Workbench (built Sept. 5, 2008)

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q s a v d

calculate data file

FETire FTire

precision:

low med high as is

create movie

validate data after computation

FTire/sim

FTire/tools

load-case data:

1st pressure	2.0
2nd pressure	1.5
1st radial defl.	10
2nd radial defl.	20
3rd radial defl.	30
longitudinal displ.	10
lateral displ.	10
torsion angle	3
1st camber angle	3
2nd camber angle	6
cleat width	100

calculate single load-case..

animate single mode..

tire parameters:

reload save

width	215
asp_ratio	65
rim_diam	15
rim_width	7
load_index	89
infl_press	2.5
mass	10.0
dist_belt	21
filler	60.0
ang_belt	24.0
E_carc	1300
E_band	1300
dia_belt	0.5
dia_carc	0.5
pre_strain	40.0

input data files:

passenger_car.tdd

enter path:

templates

select:

passenger_car.tdd

output data files:

sample.fet

enter path:

C:/ftire

select:

sample.fet
last.tir
sample.tir

asp_ratio: tire aspect ratio [%]

choose eigenfrequency to ani...

41.18 Hz, op-tr
52.28 Hz, ip-ro
53.39 Hz, op-ro
80.02 Hz, ip-tr
99.68 Hz, op-b1
106.26 Hz, ip-b1
131.79 Hz, 3
144.90 Hz, 3
158.78 Hz, 4
176.12 Hz, 4
186.15 Hz, 5
202.18 Hz, 5
213.86 Hz, 6
227.21 Hz, 6
242.62 Hz, 7
249.88 Hz, 0
252.54 Hz, 7
254.59 Hz, 0
259.70 Hz, 1
261.18 Hz, 0

? quit

choose predefined load case:

#1 p= 2.0, 10.0mm defl. at mu=0
#5 p= 2.0, 10.0mm defl. at mu=0 on transv. cleat
#6 p= 2.0, 10.0mm defl. at mu=0 on long. cleat
#7 p= 2.0, 10.0mm defl. at gamma= 6.0deg and mu=0 on trans. cleat
#11 p= 2.0, 10.0mm defl. at gamma= 3.0deg and mu=0
#21 p= 2.0, 10.0mm defl. at gamma= 6.0deg and mu=0
#31 p= 2.0, 20.0mm defl. at mu=0
#32 p= 2.0, 10.0mm long. displ. at mu=1
#33 p= 2.0, 10.0mm lateral displ. at mu=1
#34 p= 2.0, 3.0deg torsion at mu=1
#35 p= 2.0, 20.0mm defl. at mu=0 on transv. cleat
#36 p= 2.0, 20.0mm defl. at mu=0 on long. cleat
#37 p= 2.0, 20.0mm defl. at gamma= 6.0deg and mu=0 on trans. cleat
#41 p= 2.0, 20.0mm defl. at gamma= 3.0deg and mu=0
#51 p= 2.0, 20.0mm defl. at gamma= 6.0deg and mu=0
#61 p= 2.0, 30.0mm defl. at mu=0
#65 p= 2.0, 30.0mm defl. at mu=0 on transv. cleat
#66 p= 2.0, 30.0mm defl. at gamma= 3.0deg and mu=0 on transv. cleat
#71 p= 2.0, 30.0mm defl. at gamma= 3.0deg and mu=0
#81 p= 2.0, 30.0mm defl. at gamma= 6.0deg and mu=0
#101 p= 1.5, 10.0mm defl. at mu=0
#105 p= 1.5, 10.0mm defl. at mu=0 on transv. cleat
#106 p= 1.5, 10.0mm defl. at mu=0 on long. cleat
#107 p= 1.5, 10.0mm defl. at gamma= 6.0deg and mu=0 on trans. cleat
#111 p= 1.5, 10.0mm defl. at gamma= 3.0deg and mu=0
#121 p= 1.5, 10.0mm defl. at gamma= 6.0deg and mu=0
#131 p= 1.5, 20.0mm defl. at mu=0
#132 p= 1.5, 10.0mm long. displ. at mu=1
#133 p= 1.5, 10.0mm lateral displ. at mu=1
#134 p= 1.5, 3.0deg torsion at mu=1
#135 p= 1.5, 20.0mm defl. at mu=0 on transv. cleat
#136 p= 1.5, 20.0mm defl. at mu=0 on long. cleat
#137 p= 1.5, 20.0mm defl. at gamma= 6.0deg and mu=0 on trans. cleat
#141 p= 1.5, 20.0mm defl. at gamma= 3.0deg and mu=0
#151 p= 1.5, 20.0mm defl. at gamma= 6.0deg and mu=0
#161 p= 1.5, 30.0mm defl. at mu=0
#165 p= 1.5, 30.0mm defl. at mu=0 on transv. cleat
#166 p= 1.5, 30.0mm defl. at gamma= 3.0deg and mu=0 on transv. cleat
#171 p= 1.5, 30.0mm defl. at gamma= 3.0deg and mu=0
#181 p= 1.5, 30.0mm defl. at gamma= 6.0deg and mu=0

? quit

FTire/calc GUI

FTire/calc key features

- uses parameterized description of tire structure layers (carcass, belt, tread, etc.)
- automatically launches a series of modal analyses and computation of static load-cases as 'virtual measurements', using the downward-compatible coarse FE model *FETire*
- uses these results to generate a complete *FTire* data-file

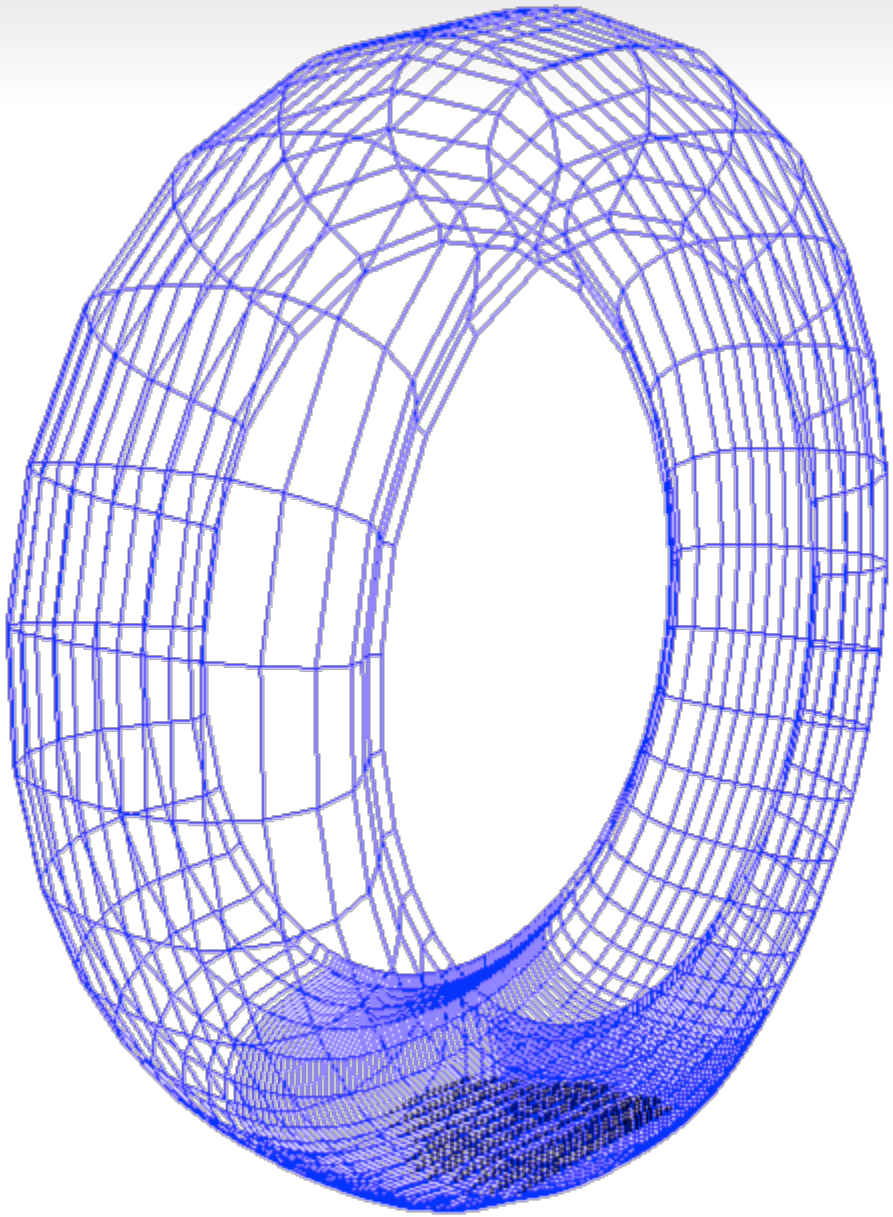
FETire grid, refined near contact patch

CPU time for single non-linear load-case:

770 nodes: 3 sec
1200 nodes: 17 sec
1710 nodes: 51 sec

total CPU time for computation of *FTire* data file:

770 nodes: 1 min 36 sec
1200 nodes: 6 min 35 sec
1710 nodes: 16 min 32 sec



Parameter section of an *FTire/calc* input file

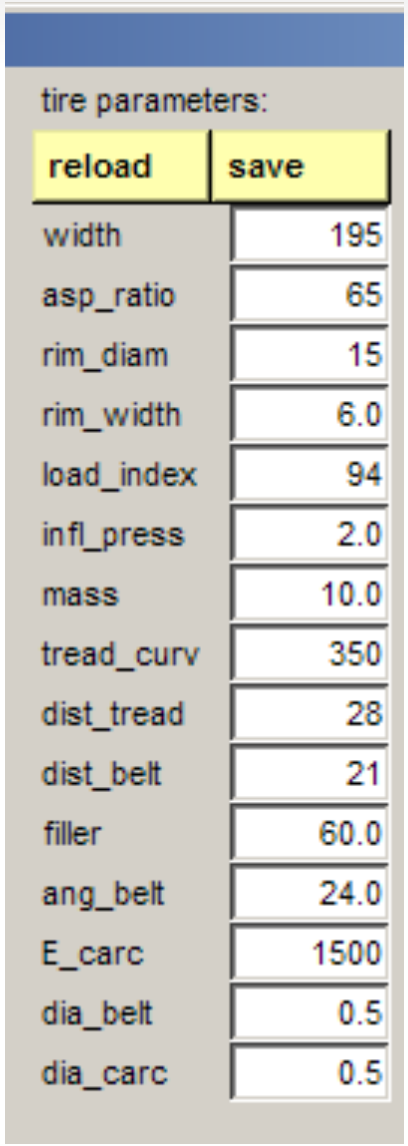
```
*********************************************************************
* FTire/calc passenger car tire tdd-template

$parameters ********************************************************
 width      195          ! tire section width [mm]
 asp_ratio  65           ! tire aspect ratio [%]
 rim_diam   15           ! rim diameter [in]
 rim_width  6.0          ! rim width [in]
 load_index 94           ! load index [-]
 infl_press 2.0          ! nominal inflation pressure [bar]
 mass       10.0         ! tire mass [kg]
 tread_curv 350          ! lateral tread curvature rel. to width [%]
 dist_tread 28           ! distance tread border to side-wall [mm]
 dist_belt  21           ! distance belt border to side-wall [mm]
 filler     60.0         ! bead filler rel. to side-wall height [%]
 ang_belt   24.0         ! cord angle in steel belt [deg]
 E_carc     1500         ! Young's modulus of carcass cord [N/mm^2]
 dia_belt   0.5          ! cross-section area of belt cord thread [mm]
 dia_carc   0.5          ! cross-section area of carcass [mm]

$more_parameters ******************************************************
 E_belt     210000       ! Young's modulus of steel cord [N/mm^2]
 E_il       2.0          ! Young's modulus of inner-liner rubber [N/mm^2]
 E_bf      15.3          ! Young's modulus of bead-filler rubber [N/mm^2]
 E_bb       8.6          ! Young's modulus of bead-base rubber [N/mm^2]
 E_cp       2.4          ! Young's modulus of carcass-ply rubber [N/mm^2]
 E_bp       9.1          ! Young's modulus of belt-ply rubber [N/mm^2]
 E_b        6.1          ! Young's modulus of bandage rubber [N/mm^2]
 E_s        2.4          ! Young's modulus of side-wall rubber [N/mm^2]
 E_tr       6.1          ! Young's modulus of tread rubber [N/mm^2]
 h_rs       4.0          ! height rim strip [mm]
 h_bf      10.0          ! height bead filler [mm]
 h_il       0.3          ! height inner liner [mm]
 h_base     2.0          ! height tread base [mm]
 h_side     2.3          ! height side-wall outer layer [mm]
 h_carc     1.0          ! height single carcass layer [mm]
 h_band     1.0          ! height single bandage layer [mm]
 h_belt     1.2          ! height single belt layer [mm]
 ang_car1   85.0         ! cord angle in 1. carcass ply [deg]
 ang_car2   95.0         ! cord angle in 2. carcass ply [deg]
```

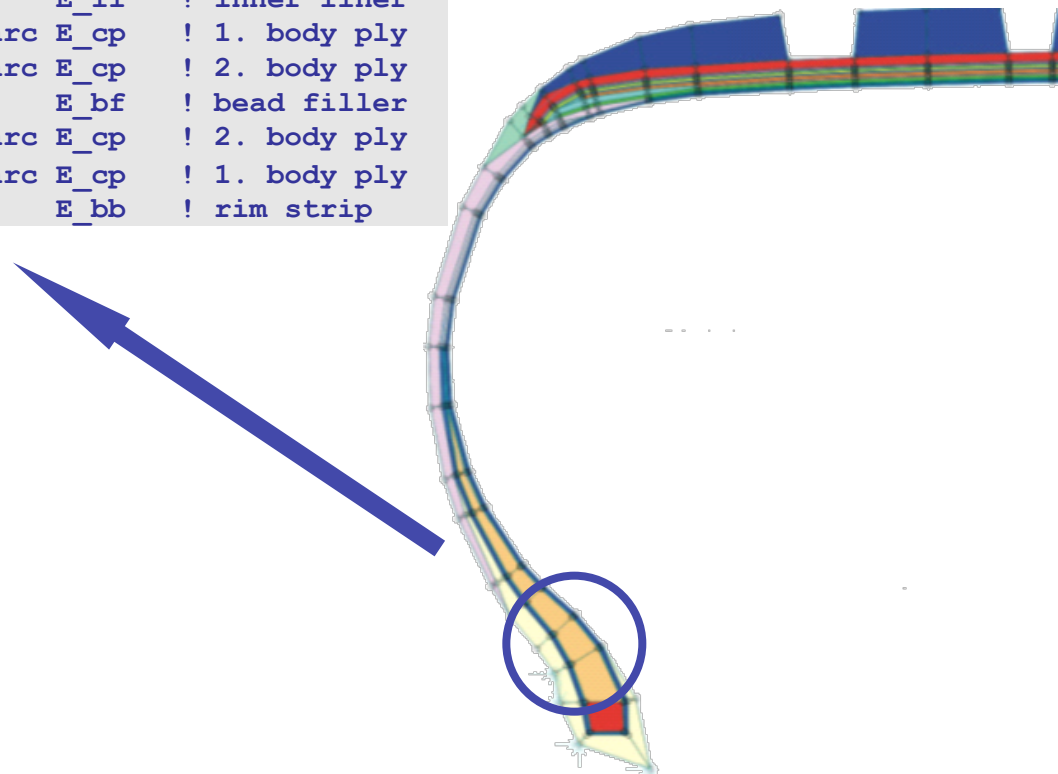
Key parameters are accessible from GUI

```
$parameters ************************************************************
 width       195          ! tire section width [mm]
 asp_ratio   65           ! tire aspect ratio [%]
 rim_diam    15           ! rim diameter [in]
 rim_width   6.0          ! rim width [in]
 load_index  94           ! load index [-]
 infl_press  2.0          ! nominal inflation pressure [bar]
 mass        10.0         ! tire mass [kg]
 tread_curv  350          ! lateral tread curvature rel. to width [%]
 dist_tread  28           ! distance tread border to side-wall [mm]
 dist_belt   21           ! distance belt border to side-wall [mm]
 filler      60.0         ! bead filler rel. to side-wall height [%]
 ang_belt    24.0         ! cord angle in steel belt [deg]
 E_carc      1500         ! Young's modulus of carcass cord [N/mm^2]
 dia_belt    0.5          ! cross-section area of belt cord thread [mm]
 dia_carc    0.5          ! cross-section area of carcass [mm]
```



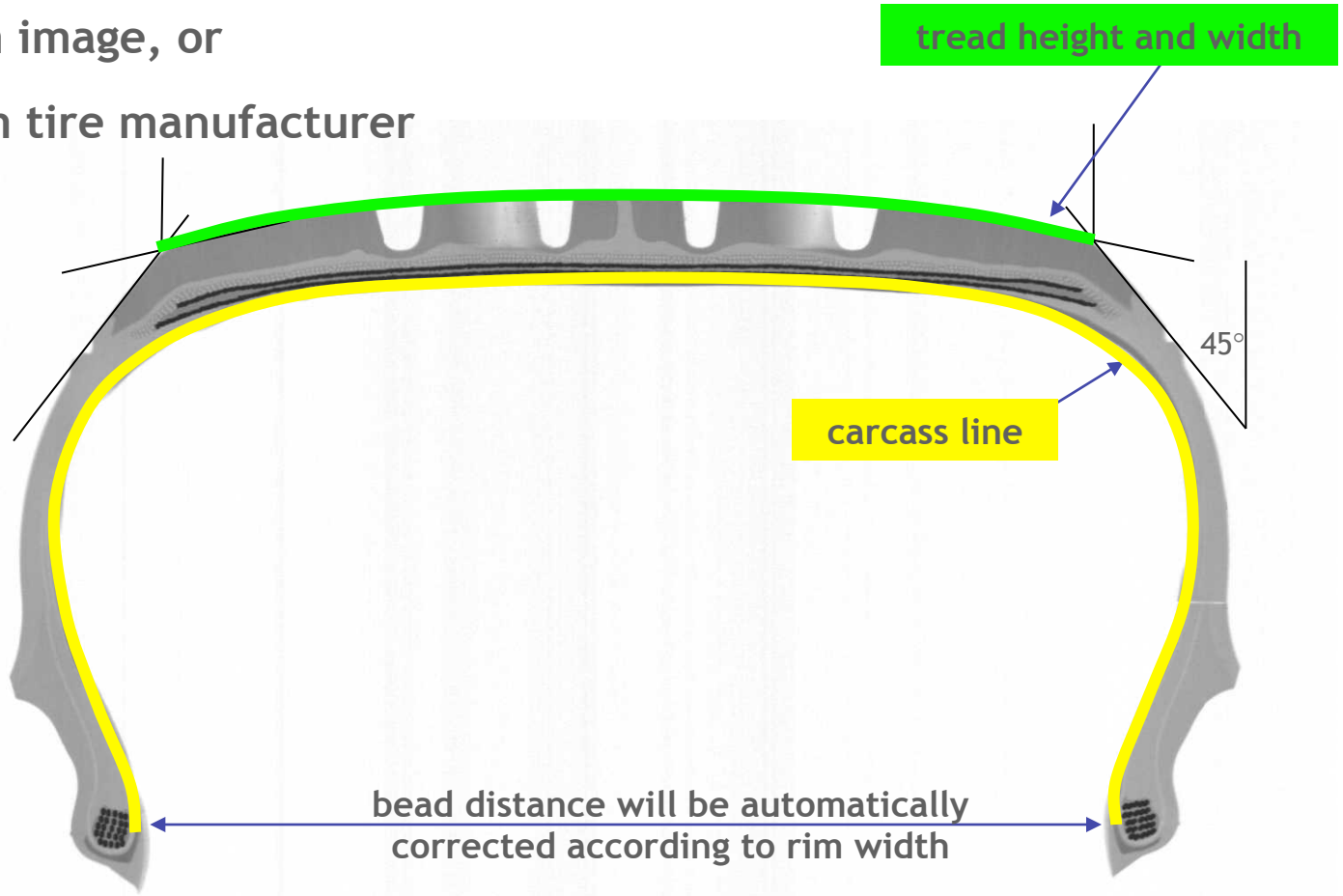
Layer structure described by template

```
*-----------------------------------------------------------------------
* cr.sect.  cord dens.  height    alpha        E cord  E matrix   type
* mm^2      thr/mm      mm        deg          N/mm^2  N/mm^2
*-----------------------------------------------------------------------
$layer_list_1 ! left bead ***********************************************
 s_left_sidewall = 0.0
  0.0       0.0         h_il      0.0          0.0     E_il    ! inner liner
  A_carc    d_carc      h_carc    ang_car1     E_carc  E_cp    ! 1. body ply
  A_carc    d_carc      h_carc    ang_car2     E_carc  E_cp    ! 2. body ply
  0.0       0.0         h_bf      0.0          0.0     E_bf    ! bead filler
  A_carc    d_carc      h_carc    ang_car2     E_carc  E_cp    ! 2. body ply
  A_carc    d_carc      h_carc    ang_car1     E_carc  E_cp    ! 1. body ply
  0.0       0.0         h_rs      0.0          0.0     E_bb    ! rim strip
```

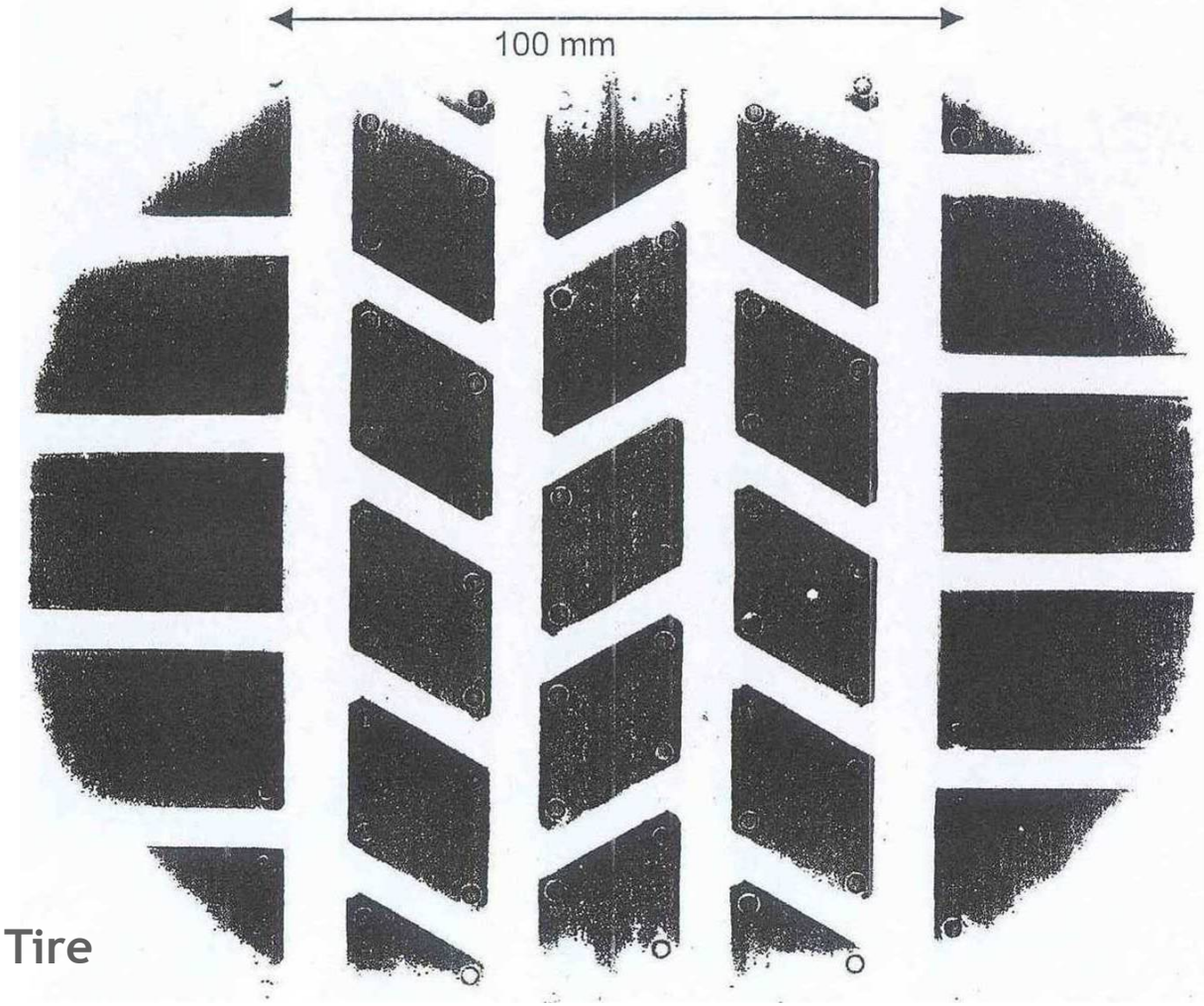


Tire cross-section geometry

- ➔ **digitized** from image, or
- ➔ **CAD data** from tire manufacturer



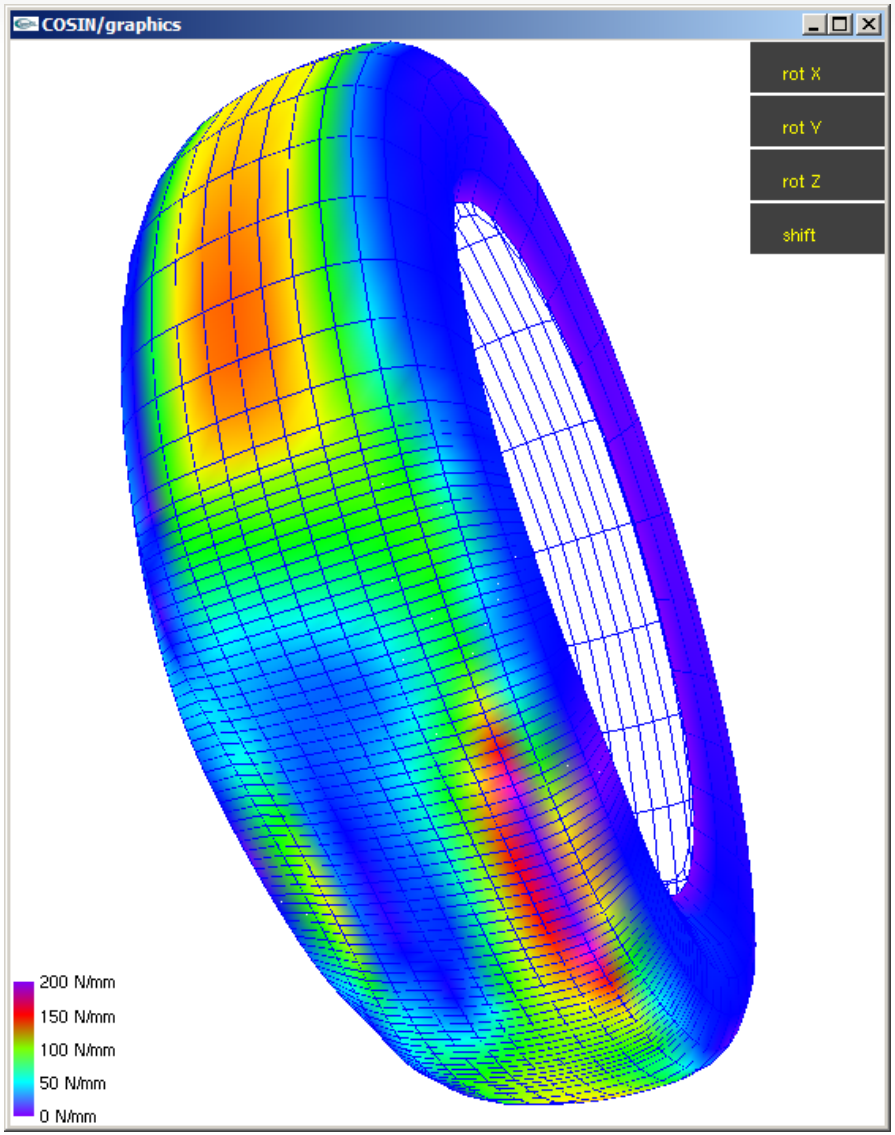
Foot-print image (bit-map file), optional



TMPT Reference Tire

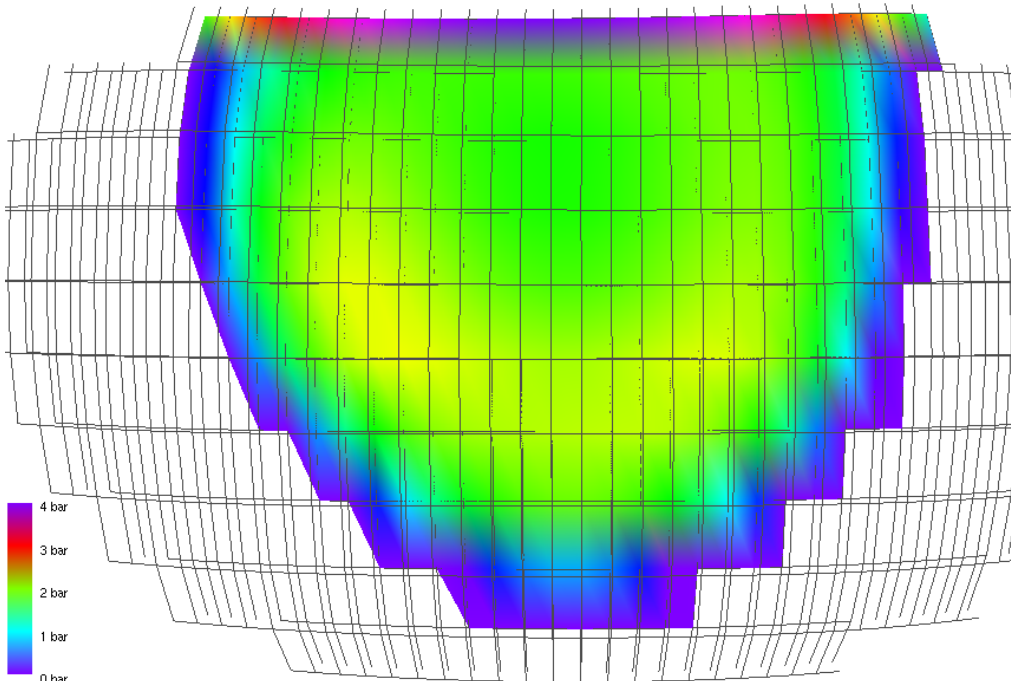
FETire Visualization in *FTire/calc*

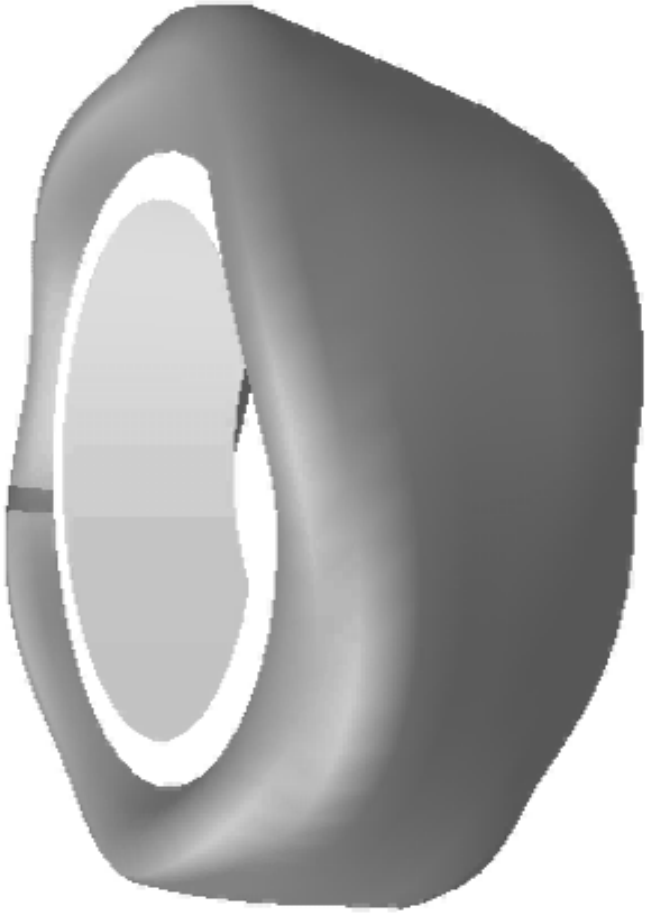
structure distortion and stress



FETire Visualization in *FTire/calc*

ground pressure distribution and mode shape animation





10. mode. 142.43 Hz, 4. order

FTire/estim GUI

FTire/estim: create FTire data file (built Sept. 5, 2008)

use following reference tire:

- car, SUV, or van tire
- truck tire
- motorcycle front tire
- motorcycle rear tire
- aircraft tire

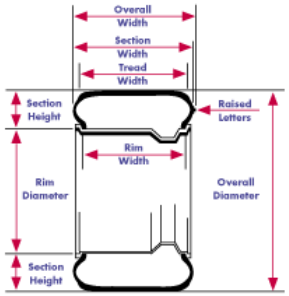
prefer following kind of data:

- same as in reference tire
- direct
- static
- handling (standard)
- handling (motorcycle)
- modal

section width		aspect ratio		rim diameter	load ind.	speed symb.
205	/	55	R	16	90	T
205		55		16	90	T
mm or in		%		in	LI	SI

tire manufacturer	?	?	
tire type	?	?	
rim width	6.5	6.5	in
nominal inflation pressure	2.5	2.50	bar
second inflation pressure	3.75	3.75	bar
tire mass	9.4	9.4	kg
deflection at max. load		25.31	mm

leave unknown fields blank; green value is value of reference tire



unit converter:

1	mm =	0.039	in
1	bar =	14.504	psi
1	N =	0.225	lbf
1	kg =	2.205	lbs
1	km/h =	0.621	mph
1	MPa =	32.278	Shore A

(dependency as assumed in FTire)

save new tire as ..
pre-process and save new tire as ..
choose reference tire ..
customize estimation formulae ..
edit reference tire templates/passenger_car.tir

show load index table
show speed symbol table

visit TireTech
visit Tyres Online

FTire/estim: customize estimation formulae

Enter estimation formula(e) to be changed. Use Matlab syntax; available parameters are:

- x reference tire's value of parameter to be estimated
- w relative tire section width
- d relative tire diameter
- h relative side-wall height
- m relative tire mass
- l relative rated max. load
- v relative rated max. speed
- k relative radial stiffness
- p relative nominal inflation pressure

tread width		w*x
lateral belt curvature radius		w*x
flat tire: distance rim flange to ground		x
rim moment of inertia		w*d^3*x
eigen-frequency in-plane rotatoric		sqrt(k/m)*x
eigen-frequency in-plane translatoric		sqrt(k/m)*x
eigen-frequency out-of-plane rotatoric		sqrt(k/m)*x
eigen-frequency in-plane bending		sqrt(k/m)*x
eigen-frequency out-of-plane bending		sqrt(k/m)*w*x
percentage of free mass		k*w
tire longitudinal stiffness		k*x
tire lateral stiffness		k*x
tire torsion stiffness		k*x
wheel load on transversal cleat		k*x
wheel load on longitudinal cleat		k*x
wheel load of cambered tire		k*x
wheel load of cambered tire on transversal cleat		k*x
belt torsional stiffness about radial axis		k*x
in-plane bending stiffness of un-inflated tire		k*x
out-of-plane bending stiffness of inflated tire		k*x
belt lateral bending stiffness of inflated tire		k*x
belt twist stiffness		k*x
belt torsion stiffness about longitudinal axis		k*x
rim flange contact stiffness		k*x

apply & quit

Independent variables provided for use in the formulae

x	reference tire's value of the parameter to be estimated
w	section width
d	tire diameter
h	side-wall height
m	mass
l	rated max. load
v	rated max. speed
k	radial stiffness
p	nominal inflation pressure

relative to reference tire

Data to be estimated by the formulae

tread width
lateral belt curvature radius
flat tire: distance rim flange to ground
rim moment of inertia
eigen-frequency in-plane rotatoric
eigen-frequency in-plane translatoric
eigen-frequency out-of-plane rotatoric
eigen-frequency in-plane bending
eigen-frequency out-of-plane bending
percentage of free mass
tire longitudinal stiffness
tire lateral stiffness
tire torsion stiffness

wheel load on transversal cleat
wheel load on longitudinal cleat
wheel load of cambered tire
wheel load of cambered tire on transv. cleat
in-plane bending stiffness of un-inflated tire
out-of-plane bending stiffness of inflated tire
belt lateral bending stiffness of inflated tire
belt twist stiffness
belt torsion stiffness
rim flange contact stiffness

Example of an estimation formula:

eigen-frequency in-plane rotatoric

= *sqrt(k/m)*x*

means:

the first natural frequency (f1)

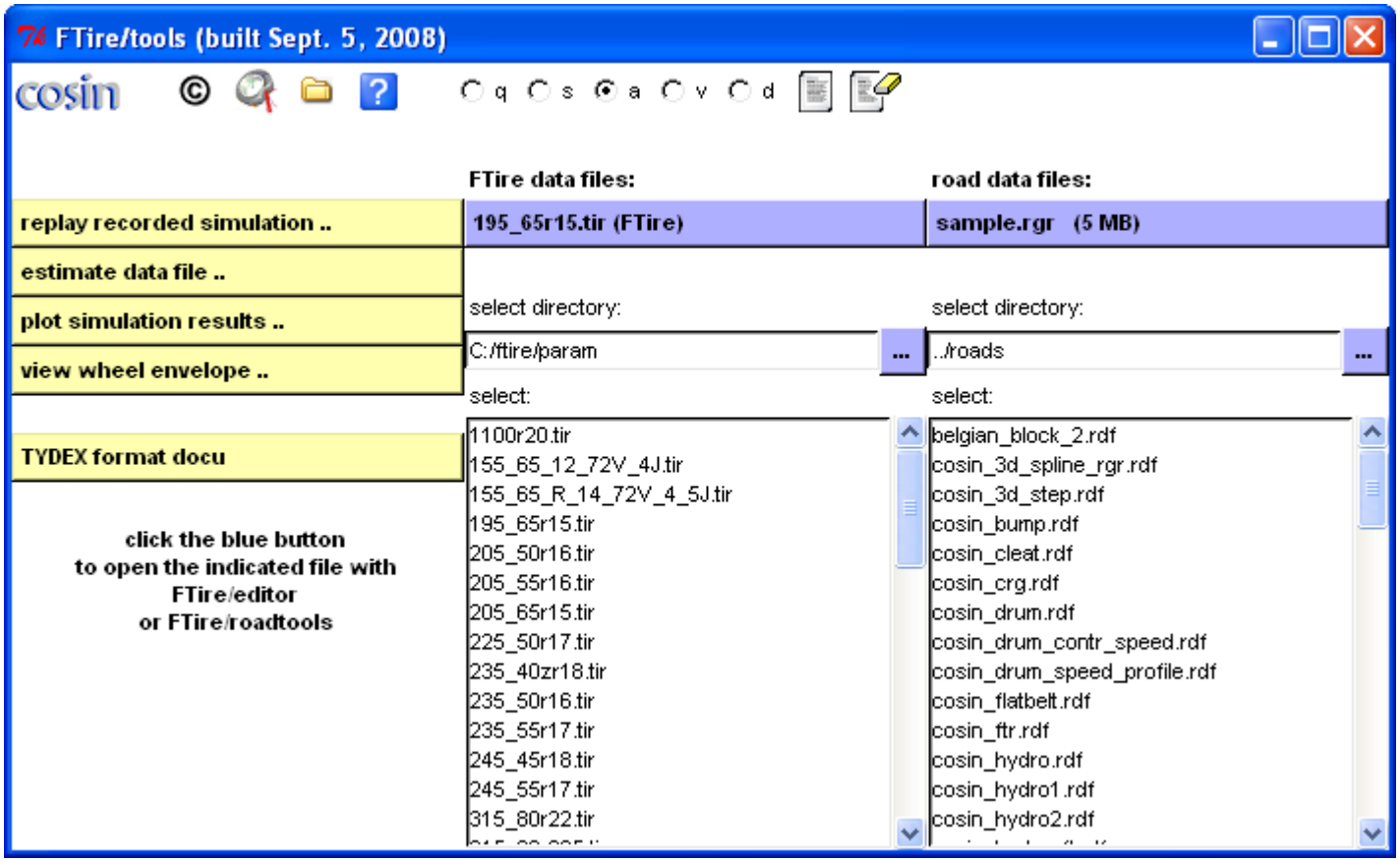
➔ grows with square-root of radial stiffness

➔ but diminishes with square-root of mass

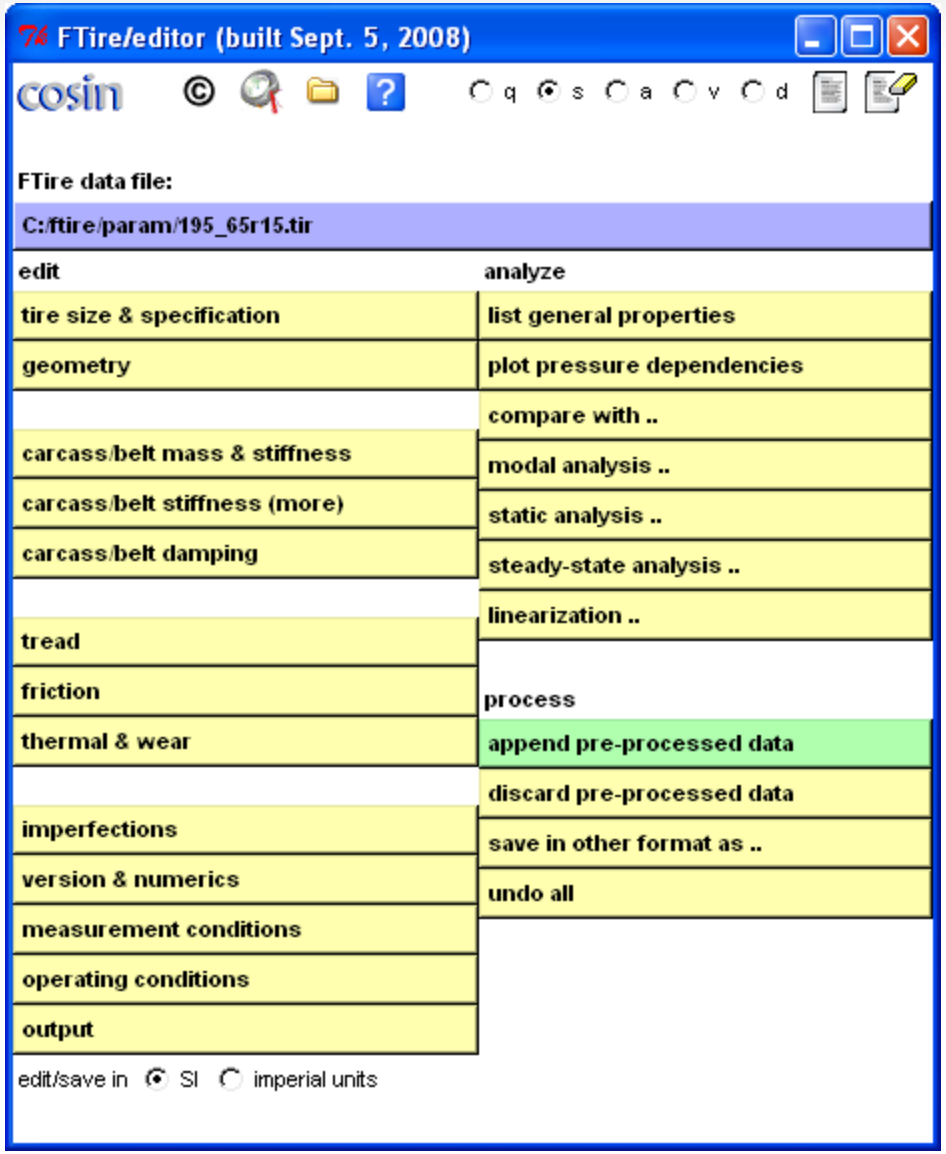
tread width		w*x
lateral belt curvature radius		w*x
flat tire: distance rim flange to ground		x
rim moment of inertia		w*d^3*x
eigen-frequency in-plane rotatoric		sqrt(k/m)*x
eigen-frequency in-plane translatoric		sqrt(k/m)*x
eigen-frequency out-of-plane rotatoric		sqrt(k/m)*x
eigen-frequency in-plane bending		sqrt(k/m)*x
eigen-frequency out-of-plane bending		sqrt(k/m)*w*x
percentage of free mass		k*w
tire longitudinal stiffness		k*x
tire lateral		

FTire/tools

collection of *FTire* analysis routines

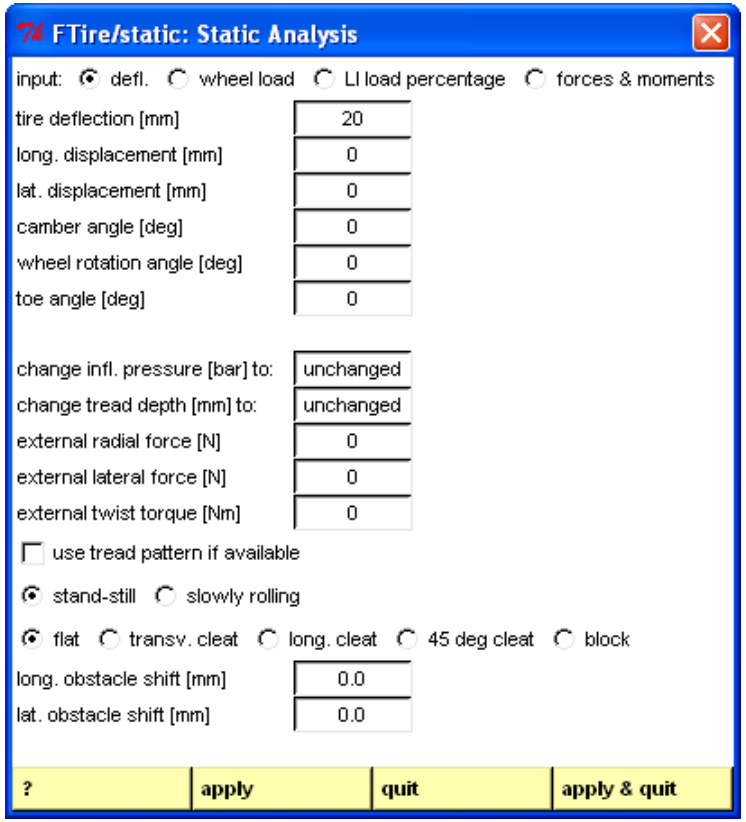


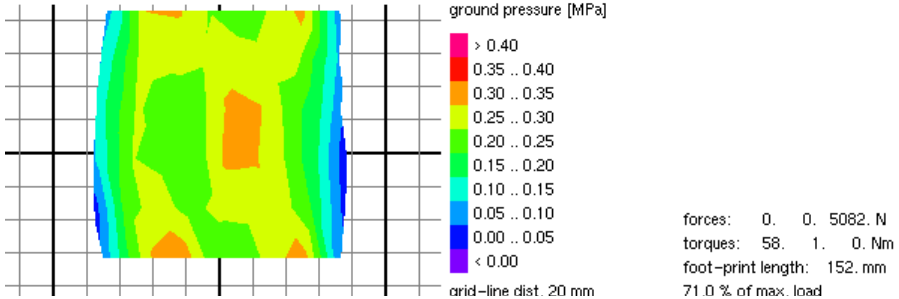
FTire/editor

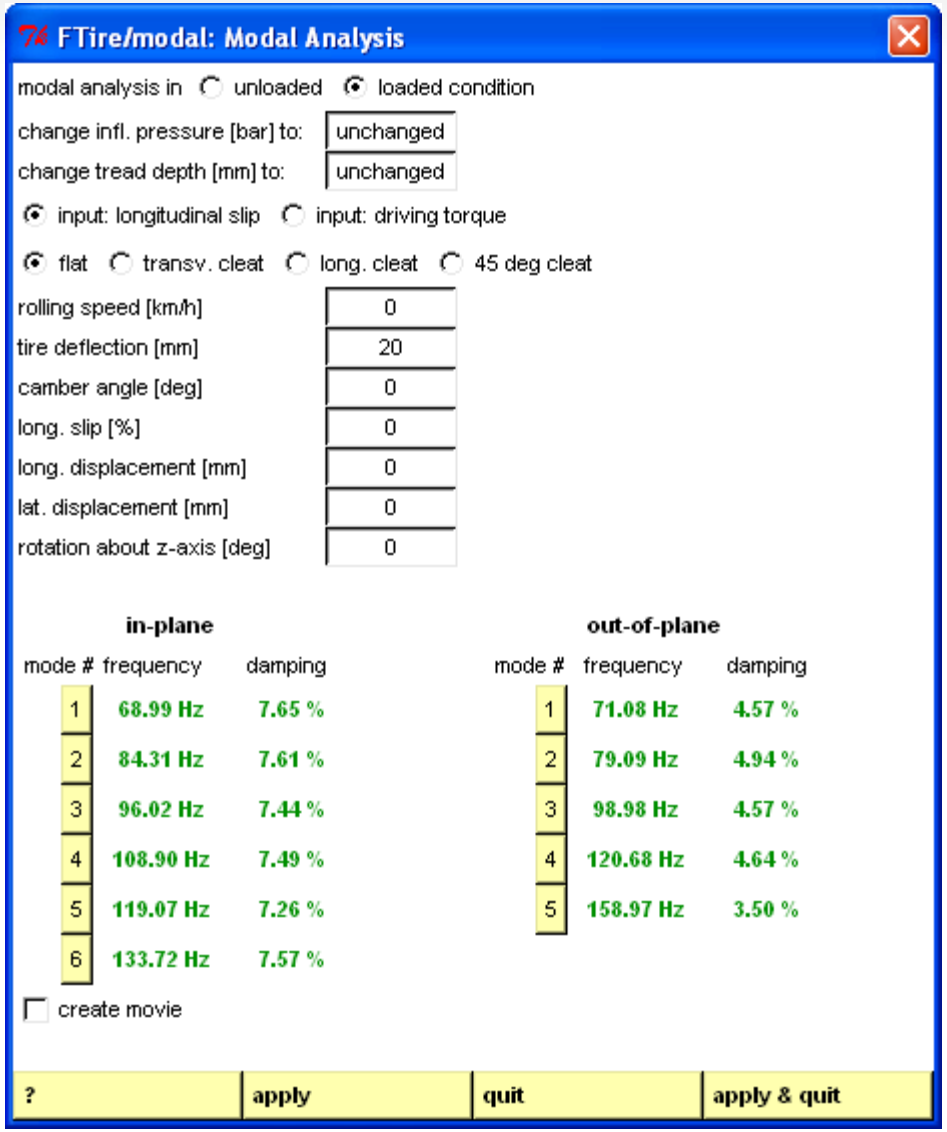


Static Analysis

computes and displays steady-state forces and moments of a standing tire with different loading conditions and surface geometries, including user-interactive, mouse-driven deflection and camber control



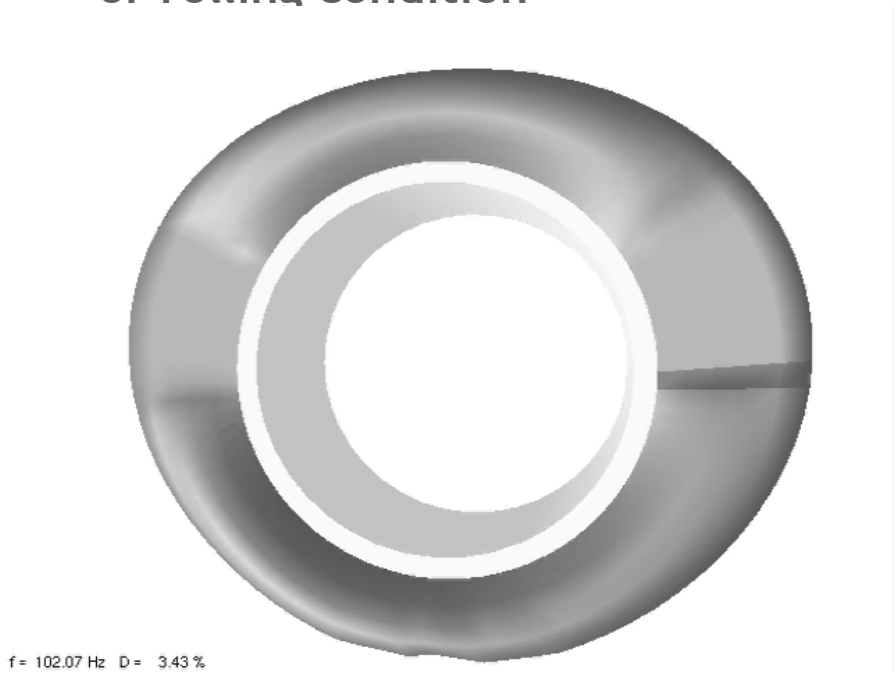




Modal Analysis

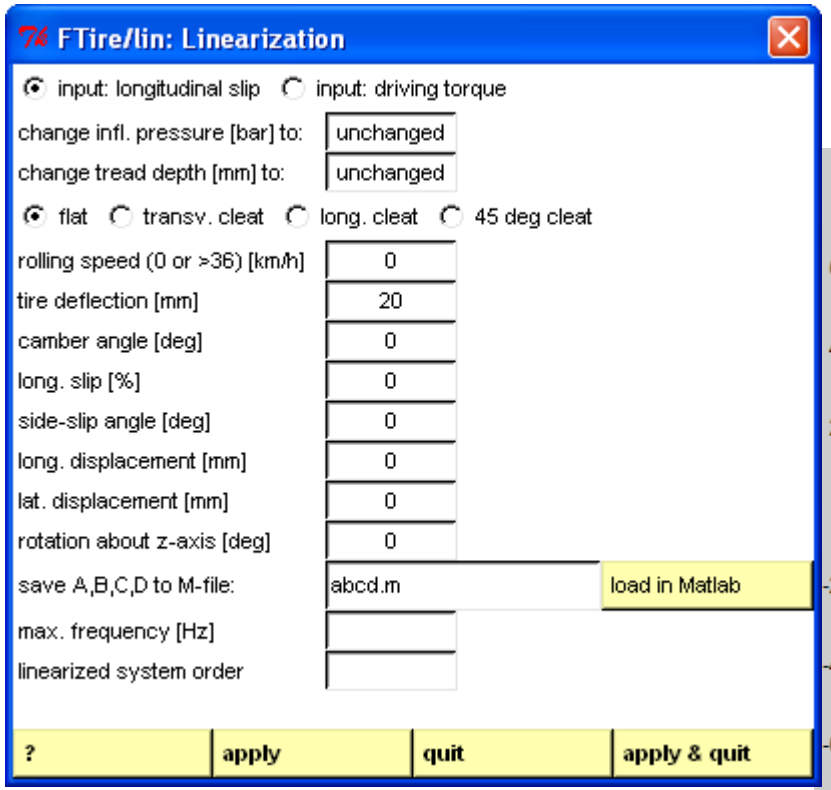
computes and animates **frequencies** and **mode shapes** for

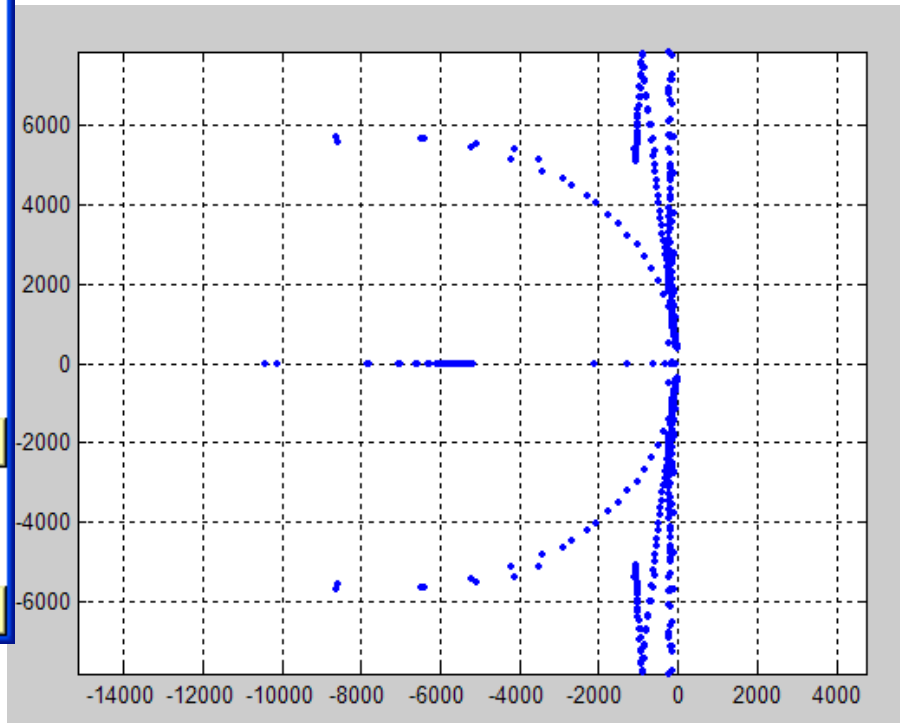
- ➔ **unloaded** (axisymmetric) tire, and
- ➔ **loaded** tire on flat surface or several different obstacles, all in blocked, floating (brake released), or rolling condition



Linearization

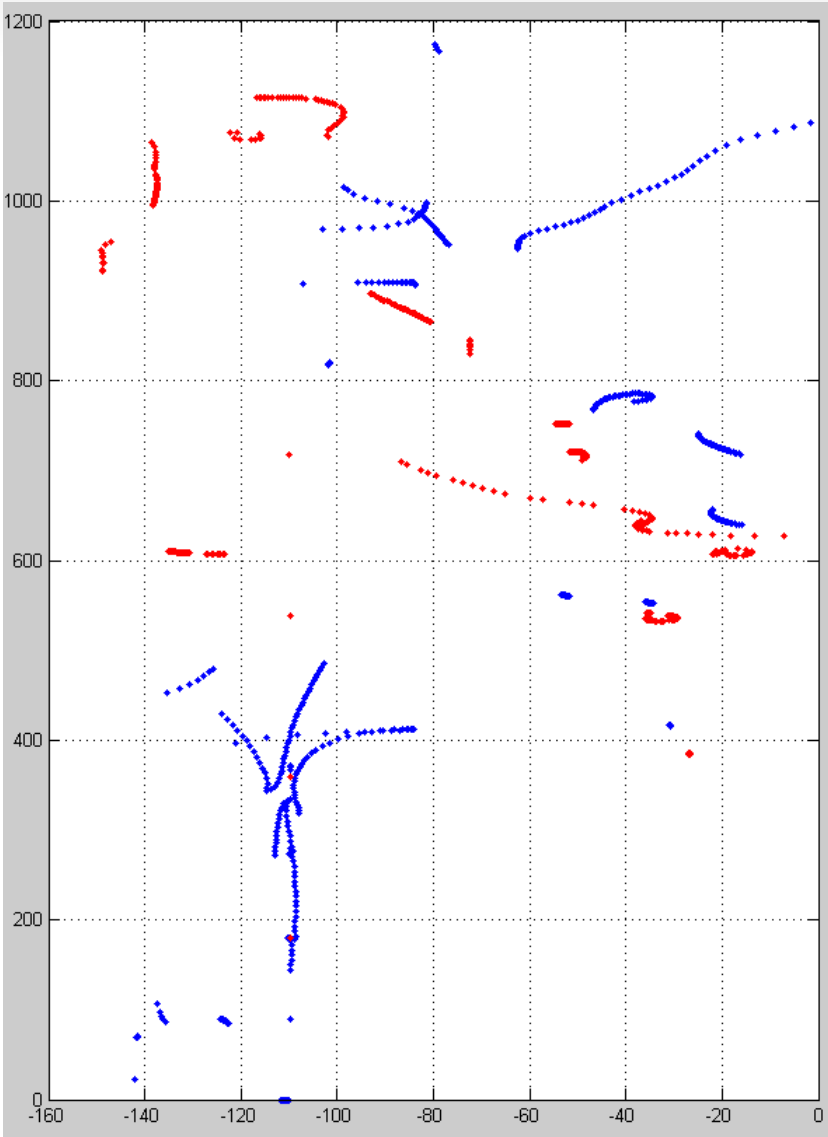
linearized **state-space matrices [A,B,C,D]**, ready-to-load into Matlab etc., with **different loading conditions** and surface geometries, **standing & rolling**





eigenvalues of the system matrix

Eigenvalue map of loaded rolling tire

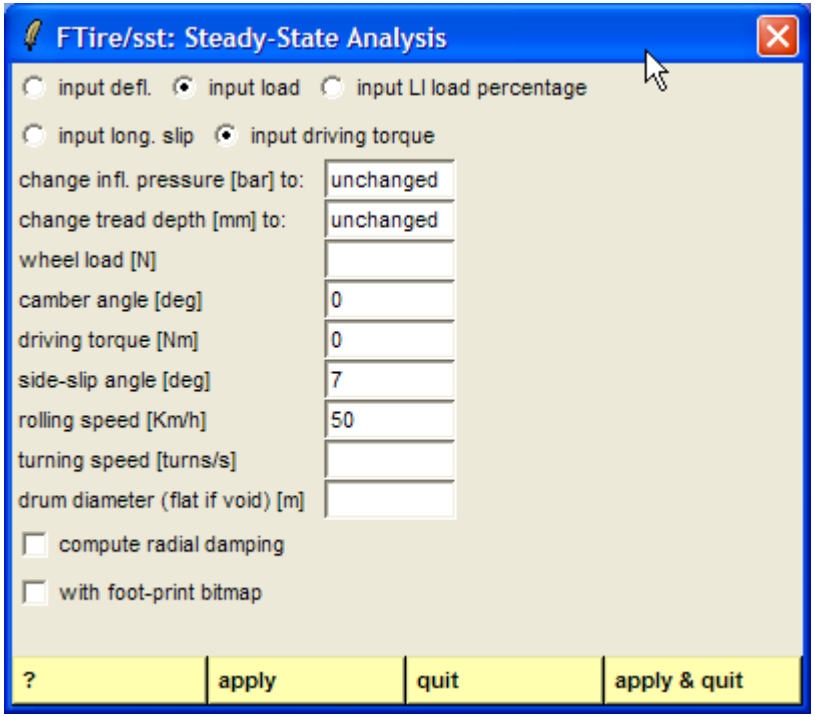


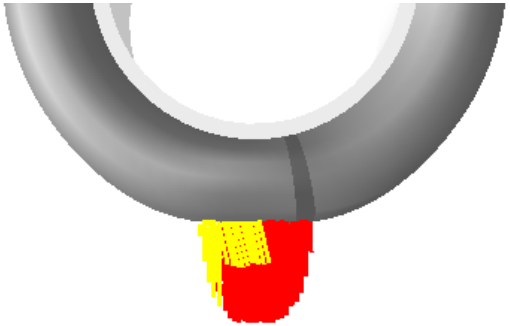
100 km/h ➔ 105 km/h

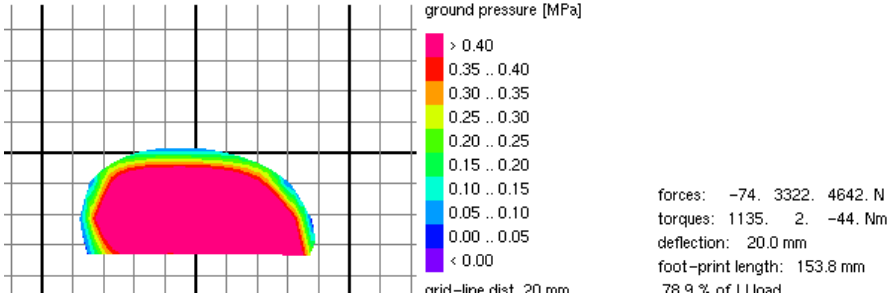
200 km/h ➔ 205 km/h

Steady-State Analysis

computes forces and moments of a tire rolling in steady-state conditions, at given slip, camber, deflection, pressure, and tread depth conditions







Tire Data Completion ('show additional tire info')

Computes and displays a predefined, comprehensive **list of static, steady-state, and modal tire properties**, like

- tread stiffness
- radial stiffness for different deflection values and camber angles
- radial stiffness on non-flat surface
- longitudinal, lateral, and torsional stiffness
- radial stiffness at different rolling speeds
- cornering stiffness, traction stiffness, pneumatic trail
- speed-dependent rolling resistance coefficients
- higher mode frequencies and damping values

FTire/sim

stand-alone *FTire* simulations, optionally with quarter-car

FTire/sim Workbench (built Sept. 5, 2008)

cosin

q s a v d

use road data file
include quarter-car model
start with previously saved state
create plot file
no movie Cinepak Indeo5
multiple exposure
continuously save contact forces
continuously save belt/carcass geometry
continuously save belt states
continuously save tread depth
save final contact forces
save final belt/carcass geometry
save final belt states
save final tread depth
select aux. parameter sliders..
plot with ref./automatic
save plot file as ..
save movie as ..
save final state
FTire/tools

simulation parameters: reload save

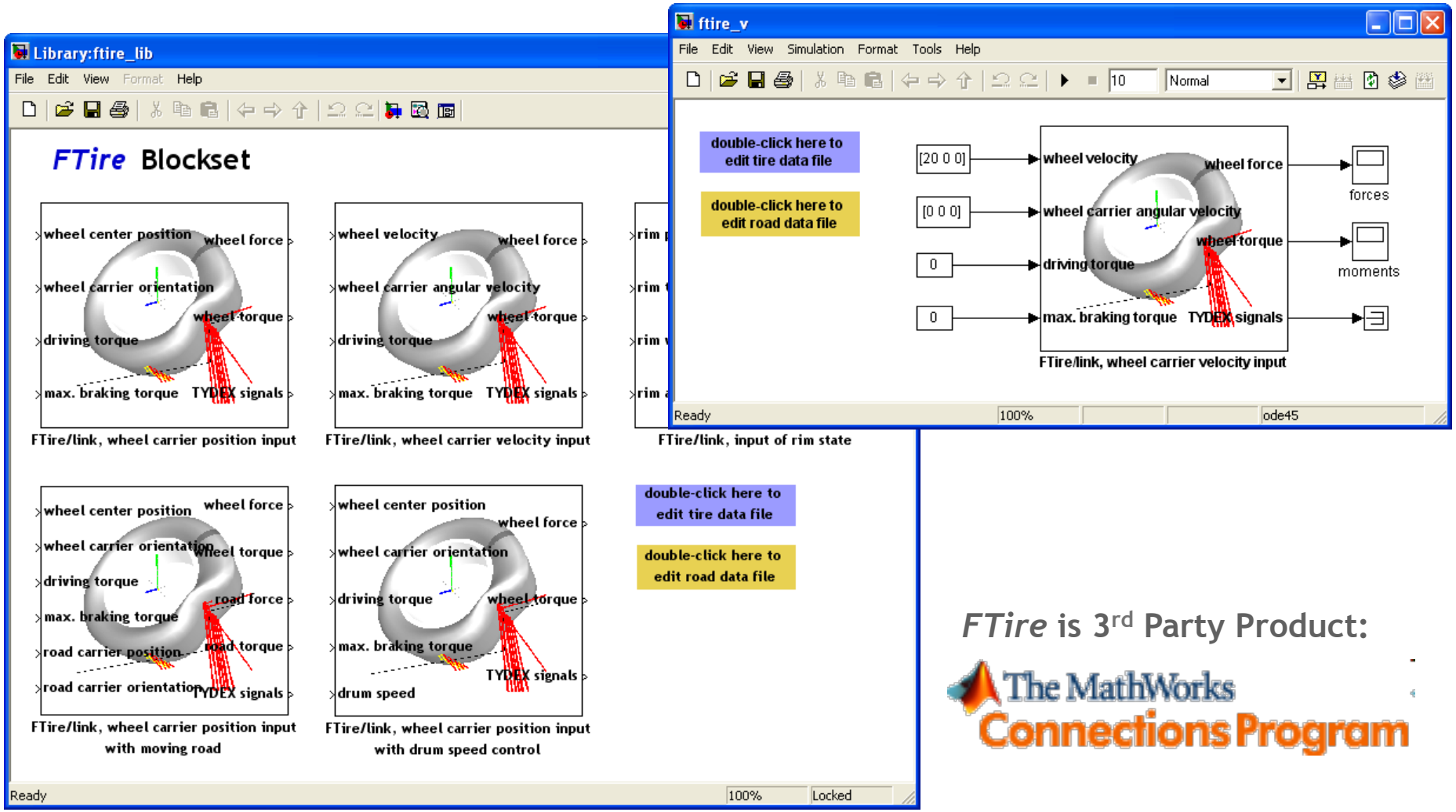
VS	20
VF	20
DEFS	40
DEFF	40
AL	-3
GA	0
P	-1
MU	1.0
H	0.001
HI	H
HA	H
TEND	1

model parameters: reload save

simulation data files:	FTire data files:	Road data files:	Quarter-car files:	reference plot files:
straight.sim	tread_pattern1.tir		sample.qc	temp.avi
enter path: C:/ftire/simul	enter path: C:/ftire/param	enter path: simul	enter path: param	enter path: C:/ftire
select:	select:	select:	select:	select:
_default.sim	1100r20.tir		sample.qc	temp.avi
abs.sim	155_65_12_72V_4J.tir		truck.qc	
actuator_testrig.sim	155_65_R_14_72V_4_5J.tir			
aircraft.sim	195_65r15.tir			
banking_angle.sim	205_50r16.tir			
brake.sim	205_55r16.tir			
camber.sim	205_65r15.tir			
camber_thrust.sim	225_50r17.tir			
camera.sim	235_40zr18.tir			
chain.sim	235_50r16.tir			
circular.sim	235_55r17.tir			
cleat.sim	245_45r18.tir			
combined_slip.sim	245_55r17.tir			
cornering.sim	315_80r22.tir			
curbstone.sim	315_80r225.tir			
drum.sim	F1_rear.tir			
envelope.sim	_default.tir			
flat.sim	aircraft.tir			
flat_run.sim	audi.tir			
flex_body.sim	bs_b390z.tir			
foreaft.sim	contour.tir			
fourwd.sim	contour2.tir			
function.sim	earth2.tir			
hockenheim.sim	earth3.tir			
hydro.sim	example.tir			
hydro_rdf.sim	grooves.tir			
hydropulse.sim	imperfect.tir			
hydropulse_2.sim	intec_front.tir			
imbalance.sim	intec_rear.tir			
inflate.sim	last.tir			
initial.sim	light_truck.tir			
iturn.sim	lt.tir			

FTire/link

Simulink block-set; full support of all *FTire* features



FTire is 3rd Party Product:

The MathWorks Connections Program

..thank you for your attention!

Q & A

FTire etc.
demo versions,
papers,
animations,
documentation,
version updates,
and more:

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