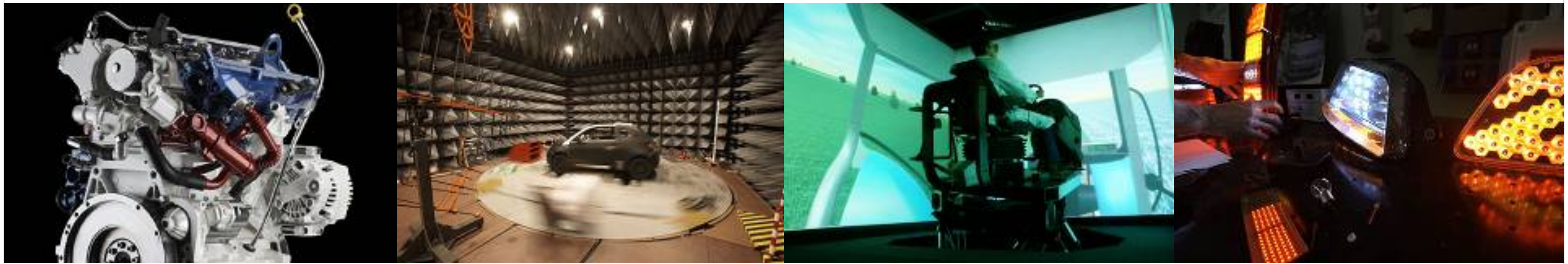

Identification of tyre lateral force characteristic from handling data and functional suspension model

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Fiat Group Automobiles
E&D – Chassis & Vehicle Dynamics

Stuttgart, June 22, 2010

About CRF

- **Centro Ricerche Fiat S.C.p.A. (C.R.F.) since 1976 is the reference centre for the activities of innovation and research of Fiat Group.**

Date of establishment: 1976

Employees: ~800

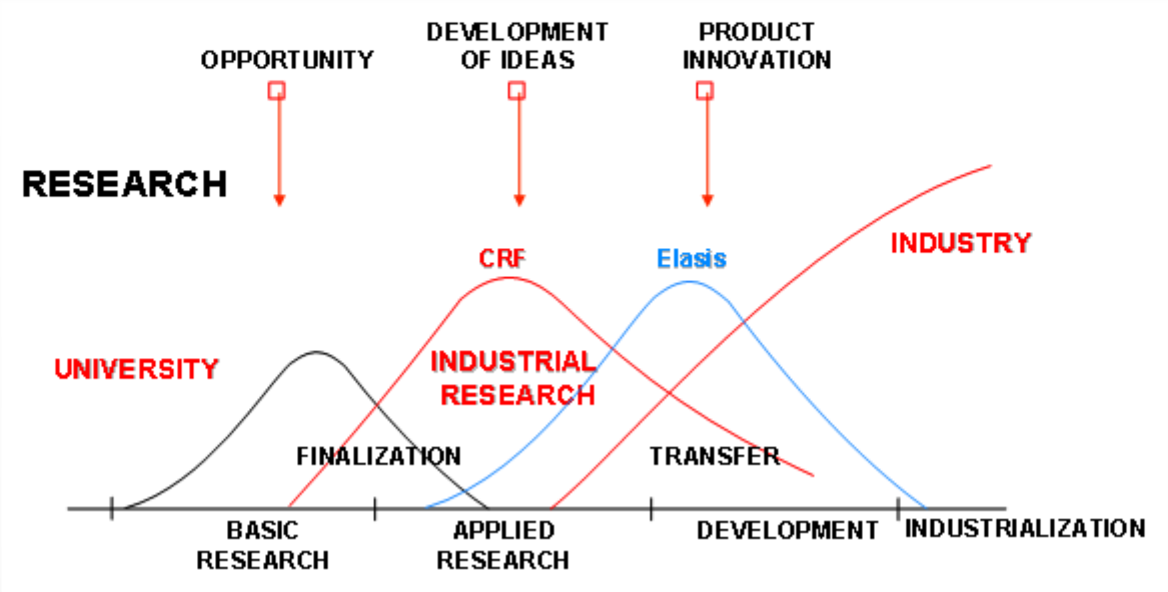
Average age: 39

Headquarters: Orbassano

Branches: Trento,

Valenzano (BA)

Foggia



Contents

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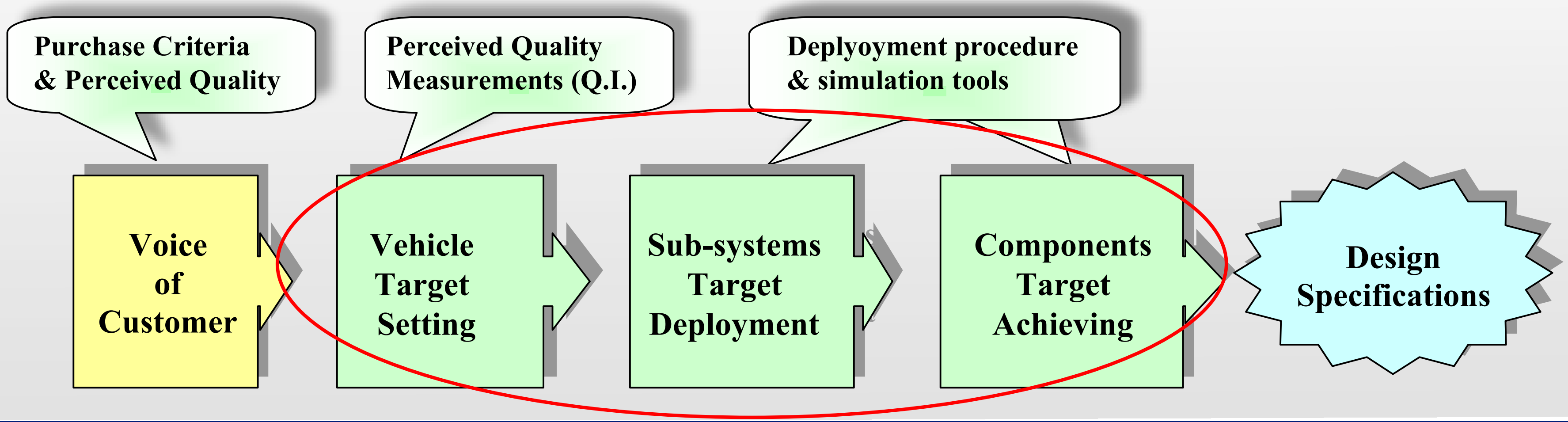
Background

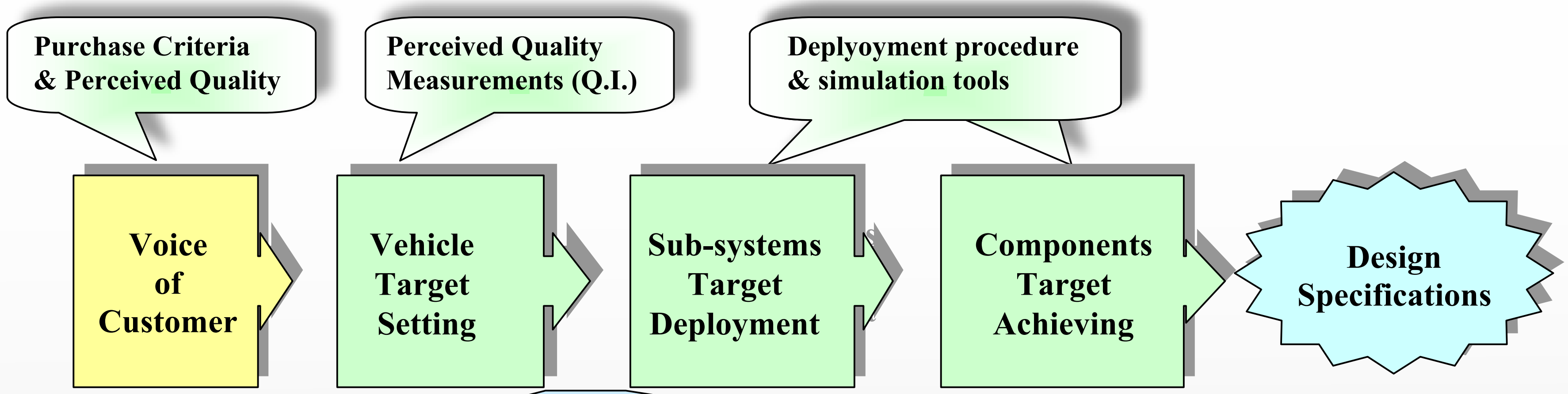
- Vehicle Dynamics & Fuel Economy Department is involved in the development of innovative methods / tools for Objective Evaluation and Virtual Analysis regarding:
  - Handling/Steering
  - Braking
  - Ride Comfort
  - Driveability
  - Fuel Consumption

  All methods cover the target setting and deployment phases in order to define and achieve customer oriented product targets.



Background

The role of synthesis models in the product development cycle



Simplified models

- ✓ Check of consistency of VTS (Vehicle Technical Specifications)
- ✓ Definition of macro target for vehicle subsystems, e.g.:
  - ❑ Front & Rear cornering stiffness
  - ❑ Roll stiffness and damping
- ✓ Capability evaluation of active systems

Goal and constraints

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GOAL

- **Identification of simple vehicle models that can be used to support target setting**
  - Target consistency check (which means realistic target)
  - first level target deployment
  - evaluation of the potential impact of active systems
- **Development of automated tools that support the vehicle dynamics engineer:**
  - identification of simple vehicle models
  - simulation of handling tests for sensitivity analysis of VTS to variation of the main design parameters

CONSTRAINTS

- **No additional time and costs with respect to the standard test protocol used for handling objective evaluation:**
  - No increase of complexity of the standard sensor setup used for vehicle dynamics objective evaluation
  - No increase of number of tests

Goal and constraints

- **Basic sensor setup required for simple models identification**

Transducer	Measured variables
Optical sensor	Vehicle speed Side slip angle
Measurements steering wheel	Steering wheel angle (Steering wheel torque)
Inertial Measurement Unit	Lateral acceleration Longitudinal acceleration Yaw rate Roll rate Pitch Rate

- **Objective tests**

Driving condition	Objective test
Linear transient behaviour	Frequency sweep sine
Steady state cornering	Constant radius cornering / Slow ramp steer input / track laps

Evolution of synthesis model for vehicle dynamics analysis

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- **Road map of implementation in custom software for vehicle dynamics objective evaluation and linked tools: W-HandsPlus©CRF**

Detail (model complexity)

Single track linear model

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio

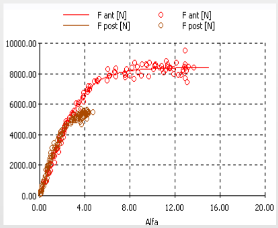
Output
- F & R Cornering stiffness
- Relaxation lengths
- Yaw inertia (if unknown)

Late '90s

Single track non linear model

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio
- Yaw inertia

Output
- F & R force characteristics (MF)

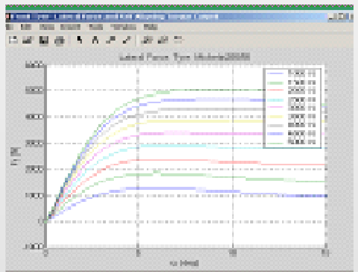


Beg. 2000

Tyre "reduced" model

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio
- Basic suspension params

Output
- "Reduced" set of MF coefficients: shape, stiffness(*Fz*), peak(*Fz*)



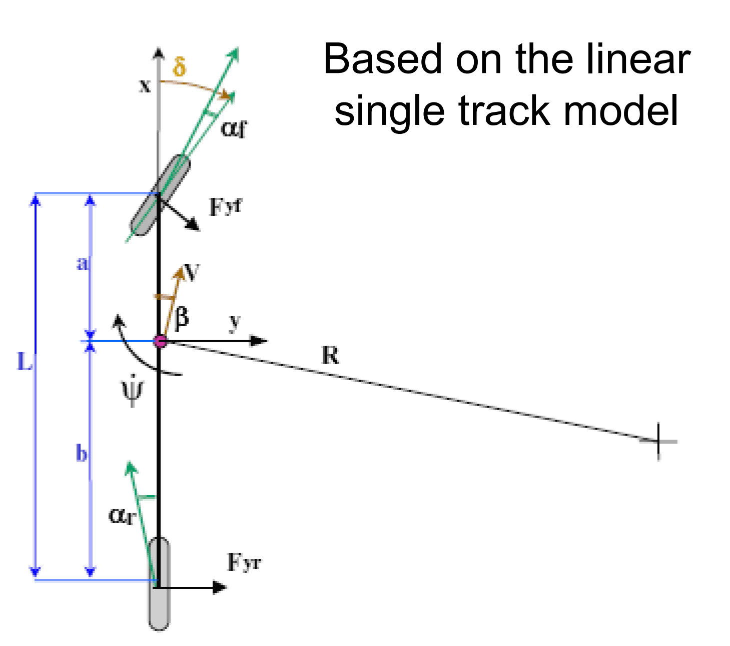
nowadays

Time

Evolution of synthesis model for vehicle dynamics analysis

The linear single track model

- **Basic theory**



Based on the linear single track model

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio

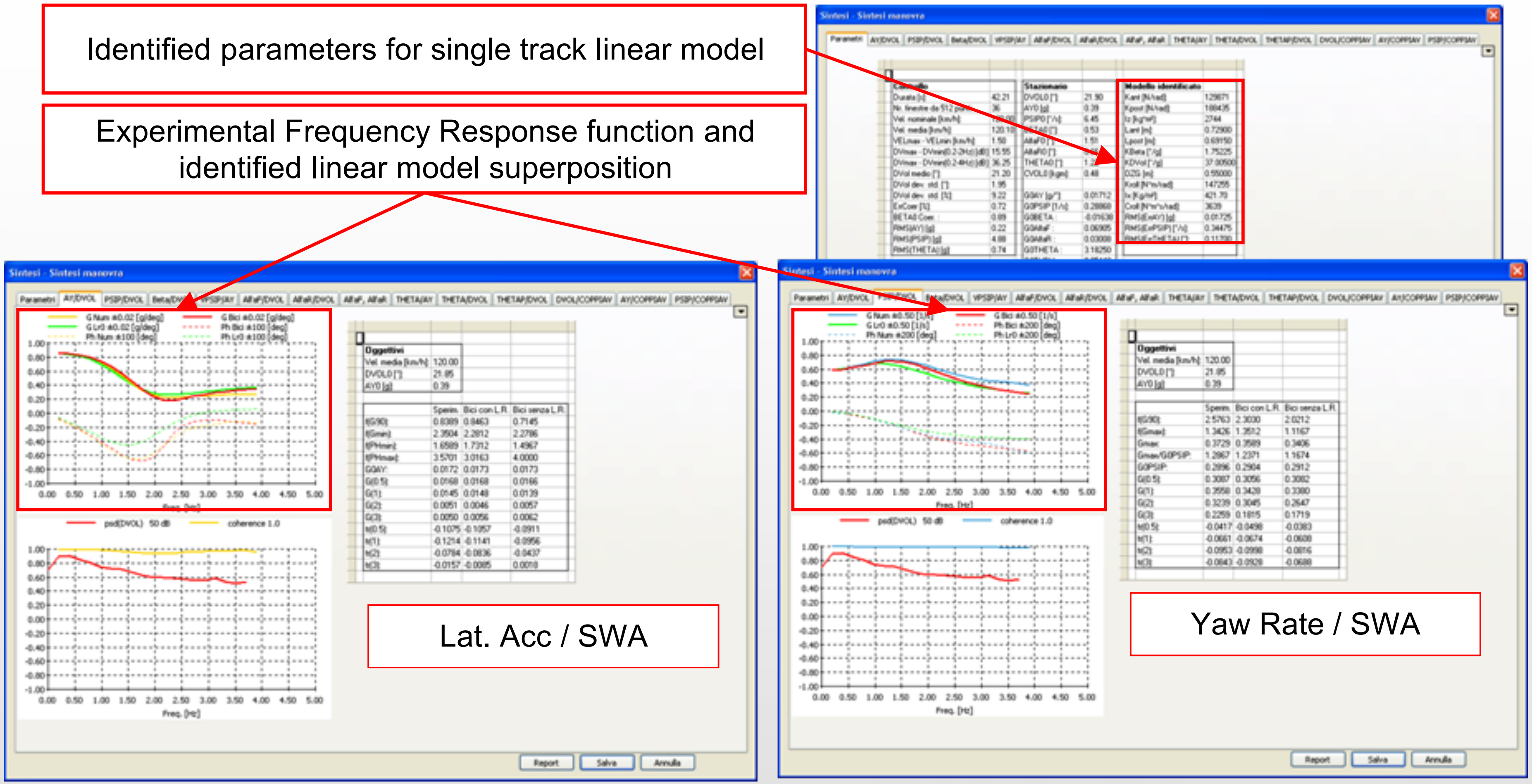
Output
- F & R Cornering stiffness
- Relaxation lengths
- Yaw inertia (if unknown)

- **Reference tests for parameters identification**
  - **Frequency sweep sine at constant speed**
- **Identification approach**
  - **Minimum error between measured and calculated motion variables (yaw rate, lateral acceleration)**

Evolution of synthesis model for vehicle dynamics analysis

The linear single track model

- **Example of results: automatic identification of linear single track model integrated in W-HandsPlus**



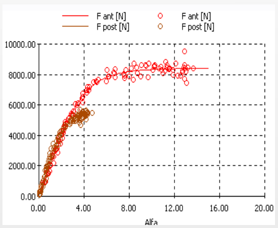
The non linear single track model

- **Basic theory**
  - **The motion equations provide estimation of the lateral force and slip angle of the front and rear axle, based on inertial vehicle data and measured motion variables.**
  - **The axles' force vs. slip angle characteristics are fitted by the Magic Formula, identifying coefficients "B_y", "C_y", "D_y", "E_y"**

$$F_{y0} = D_y \sin[C_y \arctan\{B_y \alpha_y - E_y(B_y \alpha_y - \arctan(B_y \alpha_y))\}]$$

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio
- Yaw inertia

Output
- F & R force characteristics (MF)

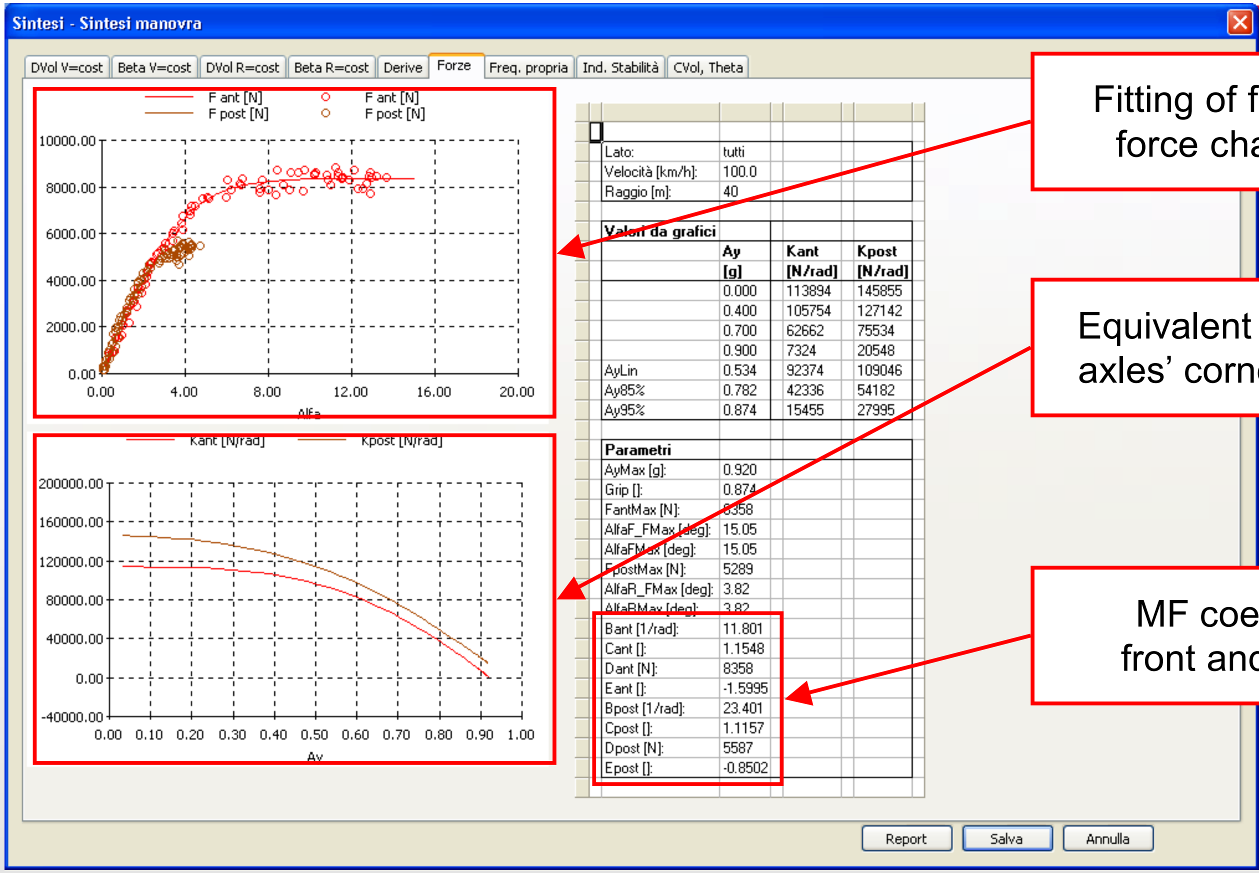


- **Reference tests for parameters identification**
  - **Steady state or near-steady state test: constant radius cornering, slow ramp steer input (spiral), track laps**
- **Identification approach**
  - **Minimum error between experimental and calculated force vs. slip angle characteristics**

Evolution of synthesis model for vehicle dynamics analysis

The non linear single track model

- **Example of results: automatic identification of non linear single track model integrated in W-HandsPlus**



Fitting of front and rear force characteristics

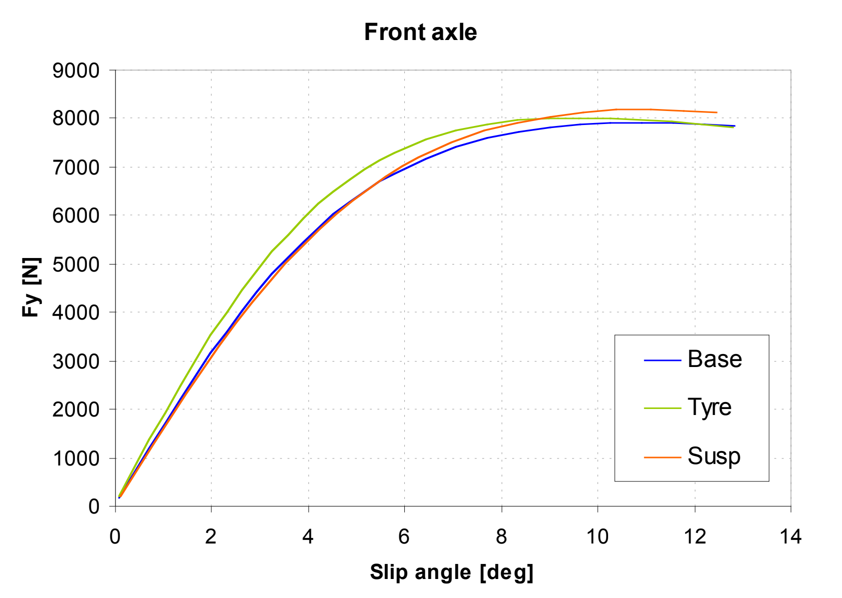
Equivalent front and rear axles' cornering stiffness

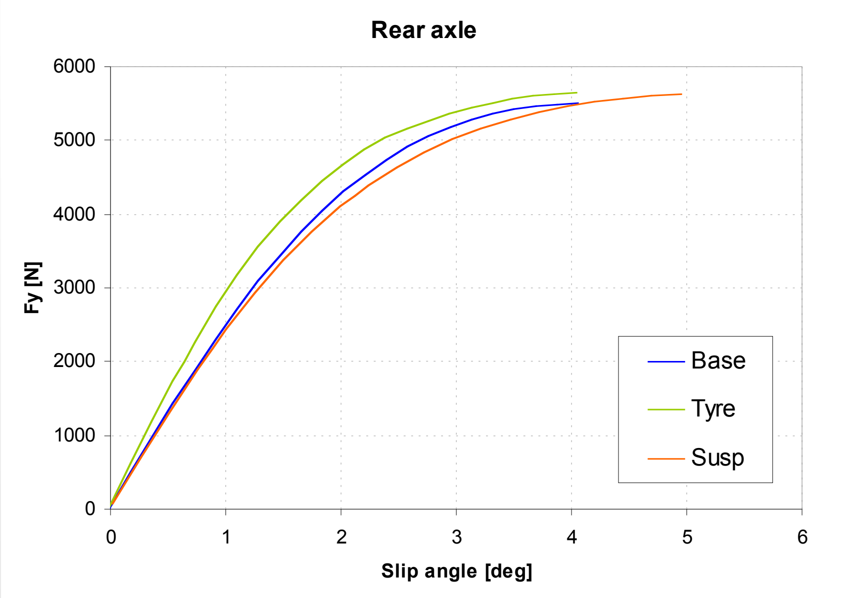
MF coefficients of front and rear axles

- **Example of results**

  Same car in a baseline configuration, equipped with different tyre and with a different suspension setup.

  Proven correlation between the driver's subjective perception of the vehicle and the different cornering force characteristics.





The method is effective in order to evaluate changes related to tyre or suspension…

…but does not allow to split the contribution of tyre and suspension

Evolution of synthesis model for vehicle dynamics analysis

From axle properties to tyre properties identification

- **Basic theory**
  - **Based on a synthesis four corner model**

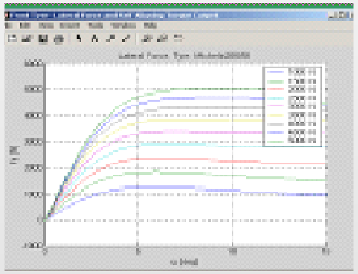
  Main assumptions
  - **Fixed front and rear roll center**
  - **Linear toe K&C**
  - **Linear camber K&C**

  Tyre model
  - **"Reduced" MF for identification. Camber effect not included yet at current stage**
  - **"Full" MF possible for simulation**

- **Reference tests for parameters identification**
  - **Steady state or near-steady state test: constant radius cornering, slow ramp steer (spiral), handling track laps**
- **Identification approach in two steps**
  - **First step based on the non linear single track model**
  - **Second step based on additional suspension data that must be known a priori or measured by other tests**

Input
- Front & Rear Mass
- Wheelbase
- Steering ratio
- Basic suspension params

Output
- "Reduced" set of MF coefficients: shape, stiffness(*Fz*), peak(*Fz*)



Evolution of synthesis model for vehicle dynamics analysis

From axle properties to tyre properties identification

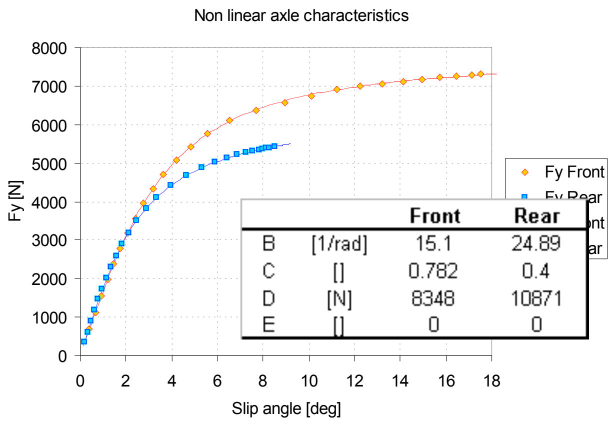
- **Identification flow chart**

Steady state Fy vs. slip angle data

Fitting →

$$F_{y0} = D_y \sin[C_y \arctan\{B_y \alpha_y - E_y(B_y \alpha_y - \arctan(B_y \alpha_y))\}]$$

Fy vs. slip characteristic (MF)



		Front	Rear
B	[1/rad]	15.1	24.89
C	[]	0.782	0.4
D	[N]	8348	10871
E	[]	0	0

Evaluation of suspension effects

Lateral load transfer

Linear toe variation

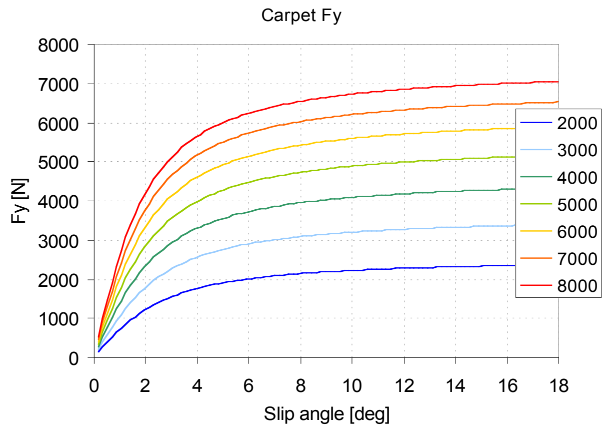
Intermediate Fy vs. slip angle data

Fitting →

“Reduced” Magic Formula

pKy1
pKy2
pCy1
pDy1
pDy2

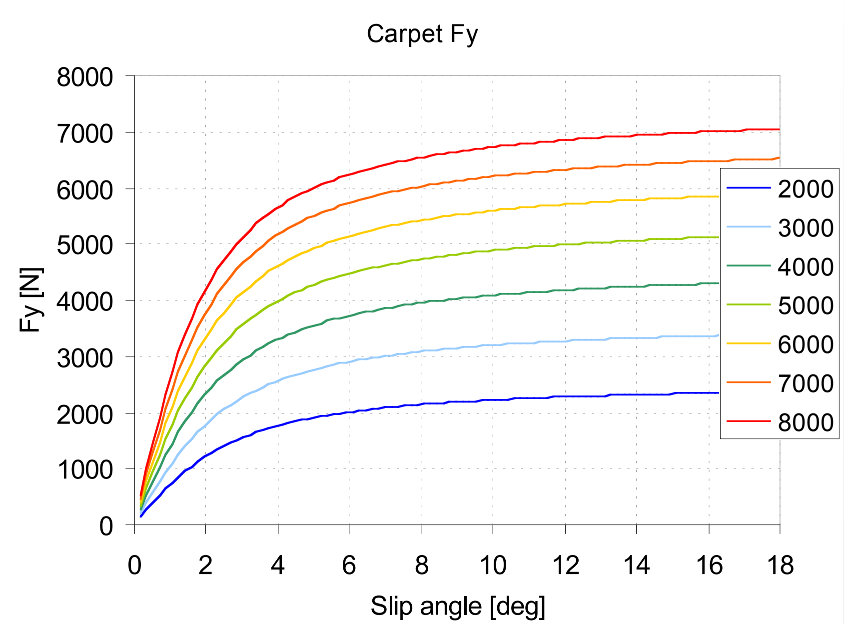
Approx. Fy carpet with Fz effect

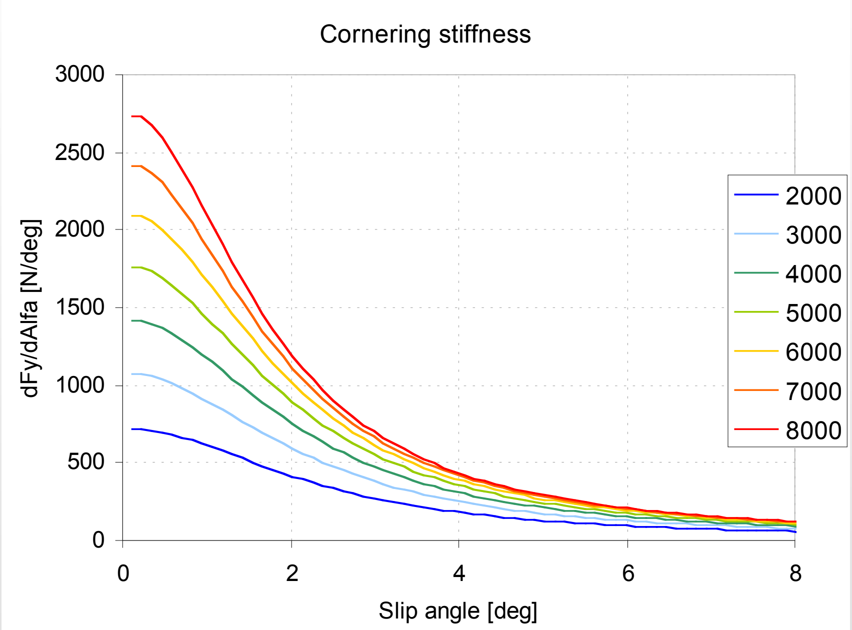


Evolution of synthesis model for vehicle dynamics analysis

From axle properties to tyre properties identification

- **Advantages**
  - **This approach allows a first level split of tyre and suspension effect on the overall cornering properties of a vehicle**
  - **The "reduced" tyre model, identified on a known vehicle, can be used to have a quick prediction of the effect of the main vehicle parameters, e.g.**
    - ☐ **Effect of vehicle mass and mass repartition front / rear**
    - ☐ **Effect of roll stiffness balance front / rear**
    - ☐ **Effect of toe variation under lateral load or suspension travel**

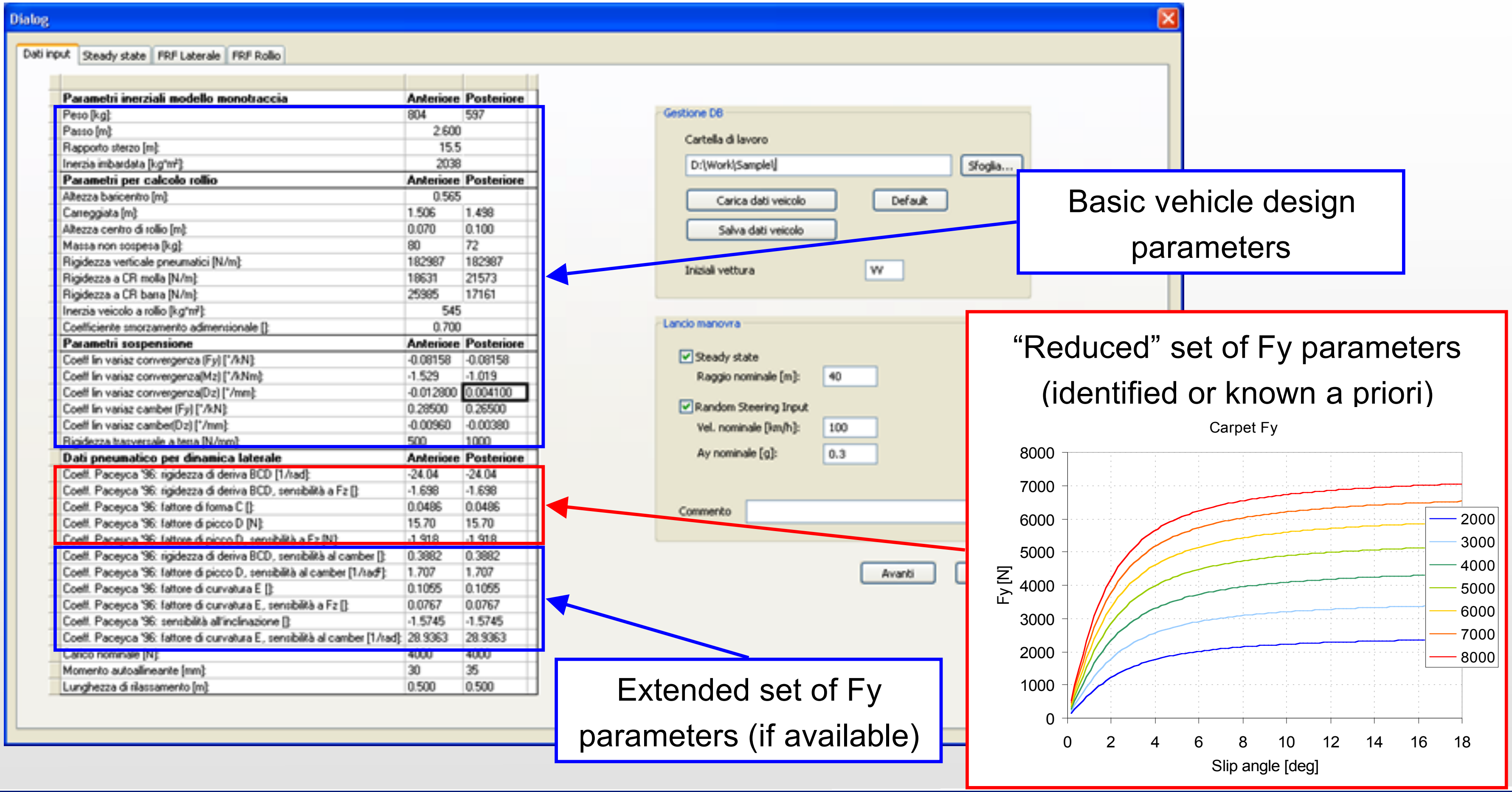




Results and applications

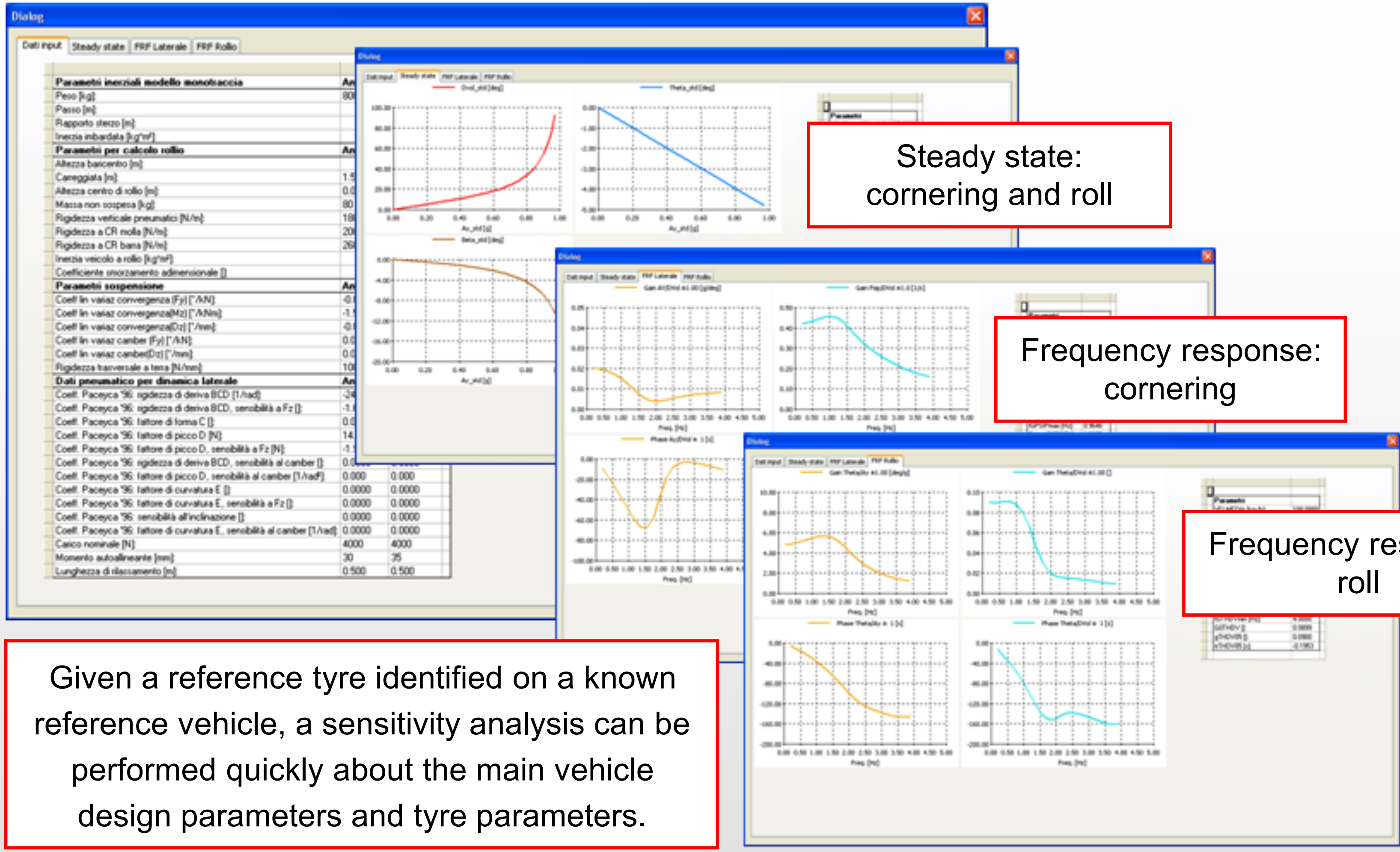
- **Use of the identified tyre data in a simplified four corner vehicle model**

Simulation tool integrated in W-HandsPlus©CRF



Results and applications

- **Use of the identified tyre data in a simplified four corner vehicle model**



Given a reference tyre identified on a known reference vehicle, a sensitivity analysis can be performed quickly about the main vehicle design parameters and tyre parameters.

Conclusions and next steps

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Achievements

- Procedures for identification of simplified handling models based on
  - standard handling experimental setup and objective evaluation tests
  - as limited as possible set of vehicle and suspension data
- Easy to use automated tools for simple model identification and simulation integrated in a custom software already used for handling data analysis and objective evaluation

Related topics

- Cross-link between testing domain and virtual analysis domain
- Tuning/Identification of tyre parameters using functional and Multi Body models
- Diagnostic/Reverse engineering

Next steps

- Development of procedures for identification of more parameters, e.g.
  - Steering system and self aligning moment
  - Camber sensitivity
  - Longitudinal force vs. slip

Thank you

Questions?