MULTI-ATTRIBUTE VEHICLE PERFORMANCE OPTIMIZATION: AMESIM AND MODEFRONTIER INTERFACE

A Joint Webinar by ESTECO and SIEMENS

June 26, 2014

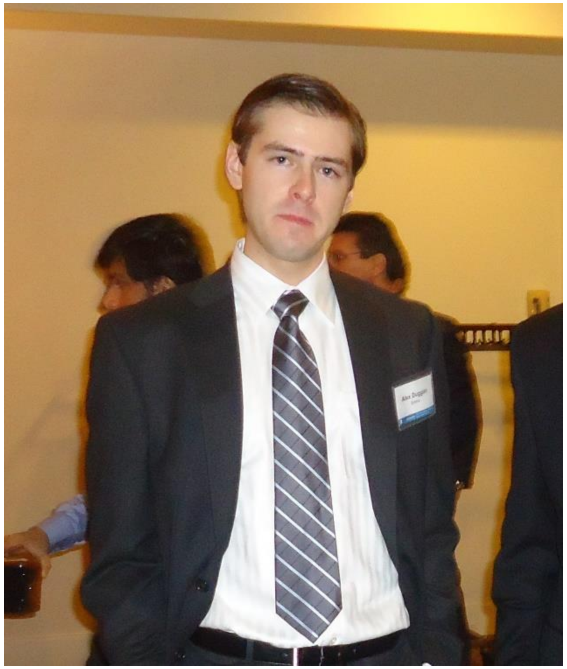
ESTECO

SIEMENS

Agenda

• Introduction	(5 min)
• Overview of modeFRONTIER	(10 min)
• Overview of Imagine.Lab AMESim	(10 min)
• Example 1: Optimization of a Check Valve	(10 min)
• Example 2: Parallel Hybrid Vehicle	(10 min)
• Conclusions	(5 min)
• Q & A	(10 min)

Team Introduction



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Siemens PLM

ESTECO

SIEMENS

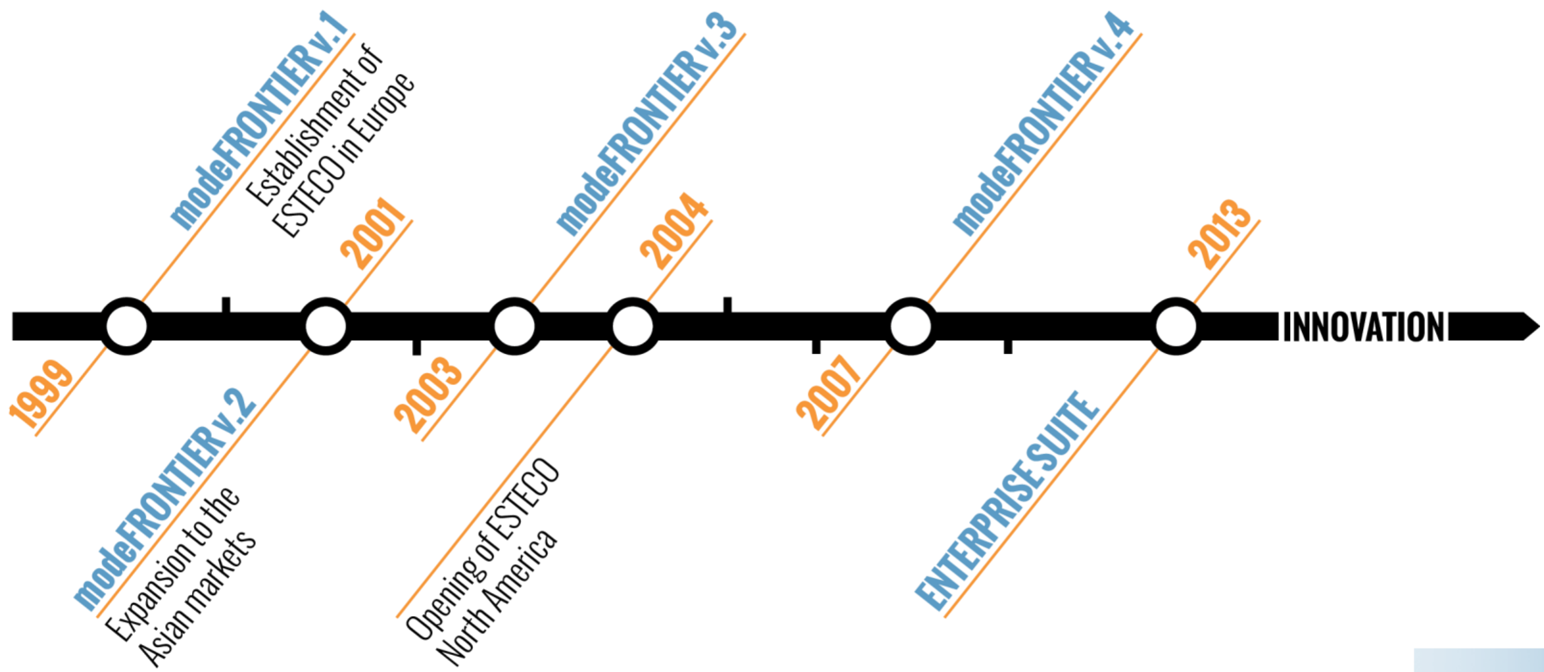
Introduction modeFRONTIER

ESTECO – about us

modeFRONTIER

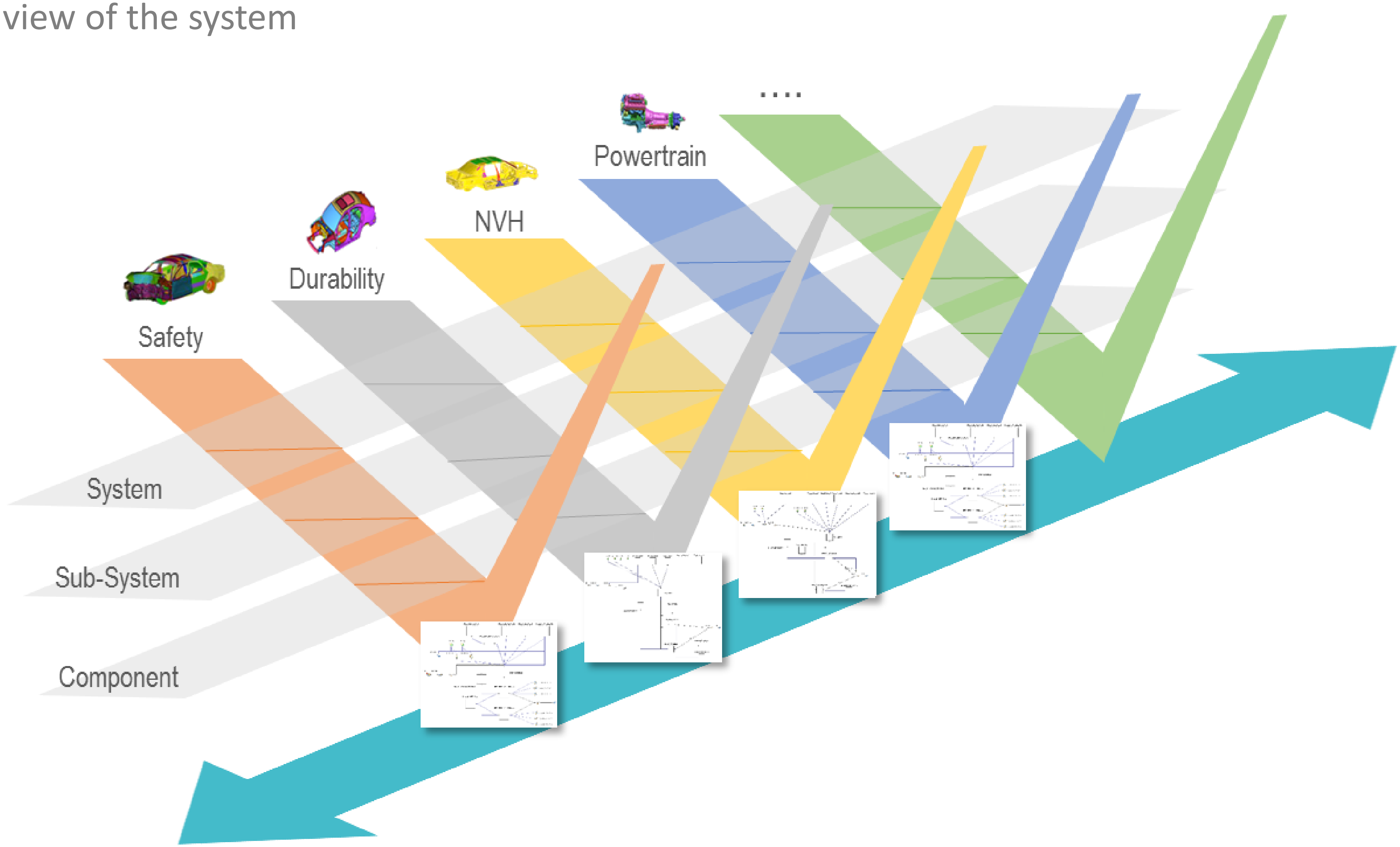
ESTECO is a pioneer in **numerical optimization** solutions

Perfecting engineering and reducing complexity in the design process is our vision

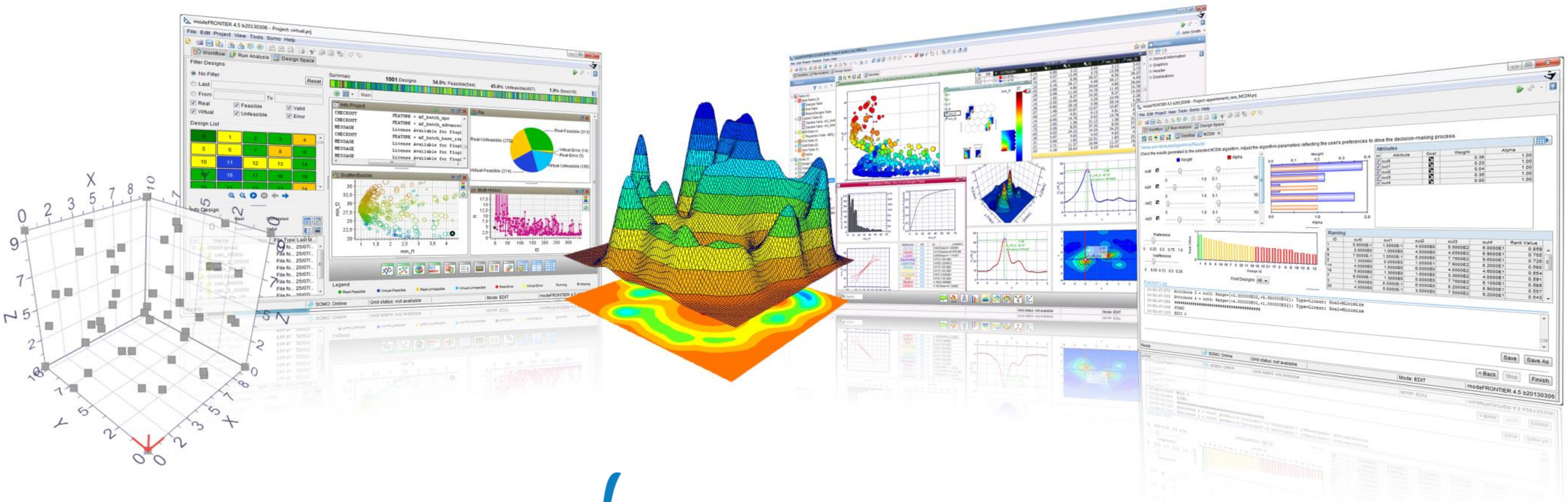


Complexity Across Domains

Different teams create more detailed and domain specific models but need to be able to verify them against a cohesive view of the system



Introducing modeFRONTIER

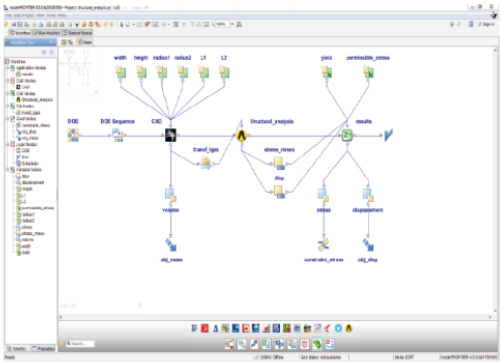


mode FRONTIER

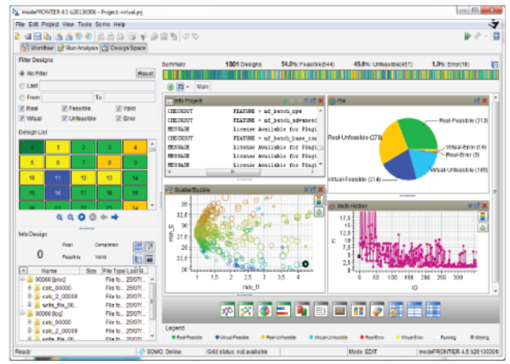
is an integration platform for **multi-objective and multi-disciplinary optimization**. It provides seamless coupling with third party engineering tools, enables the **automation** of the design simulation process, and facilitates **analytic decision making**

What can you do with modeFRONTIER?

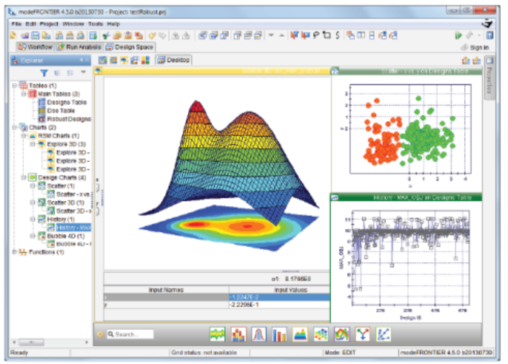
INTEGRATION AND PROCESS AUTOMATION



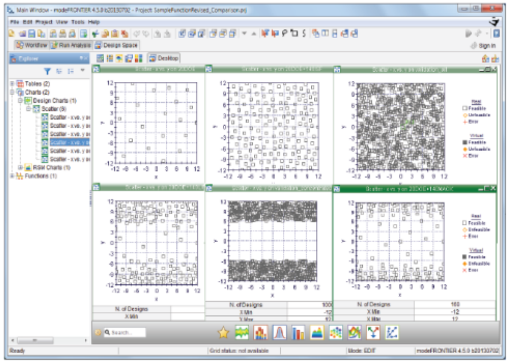
OPTIMIZATION



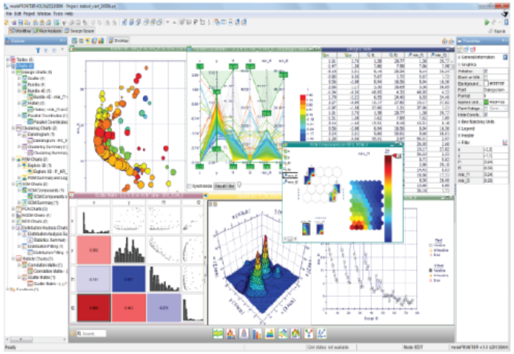
ROBUST DESIGN AND RELIABILITY



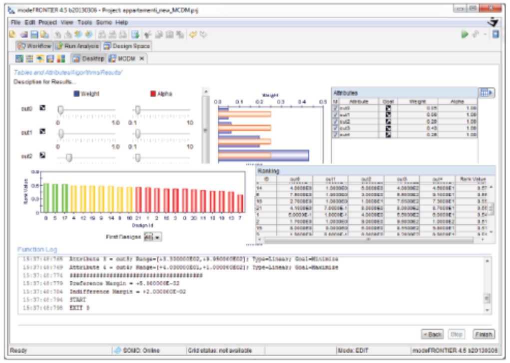
DESIGN SPACE EXPLORATION



ANALYTICS AND VISUALIZATION

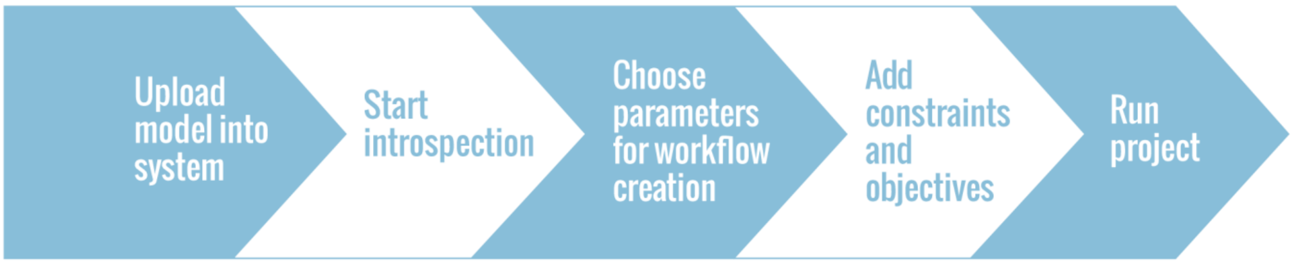


DECISION MAKING

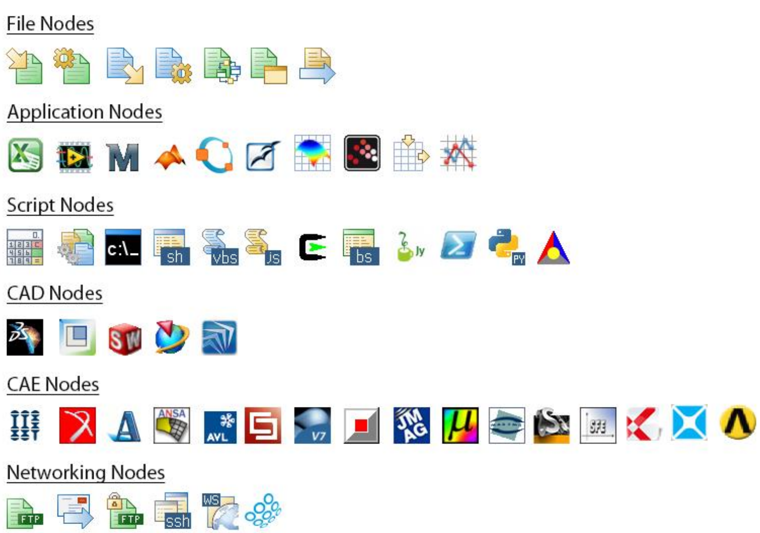


Integration and Process Automation

The modeFRONTIER workflow guarantees formalization and management of all logical steps of an engineering process. Its powerful integration capabilities allow product engineers and designers to **integrate and drive multiple Computed Aided Engineering (CAE) tools**.



Integration and automation flow with modeFRONTIER

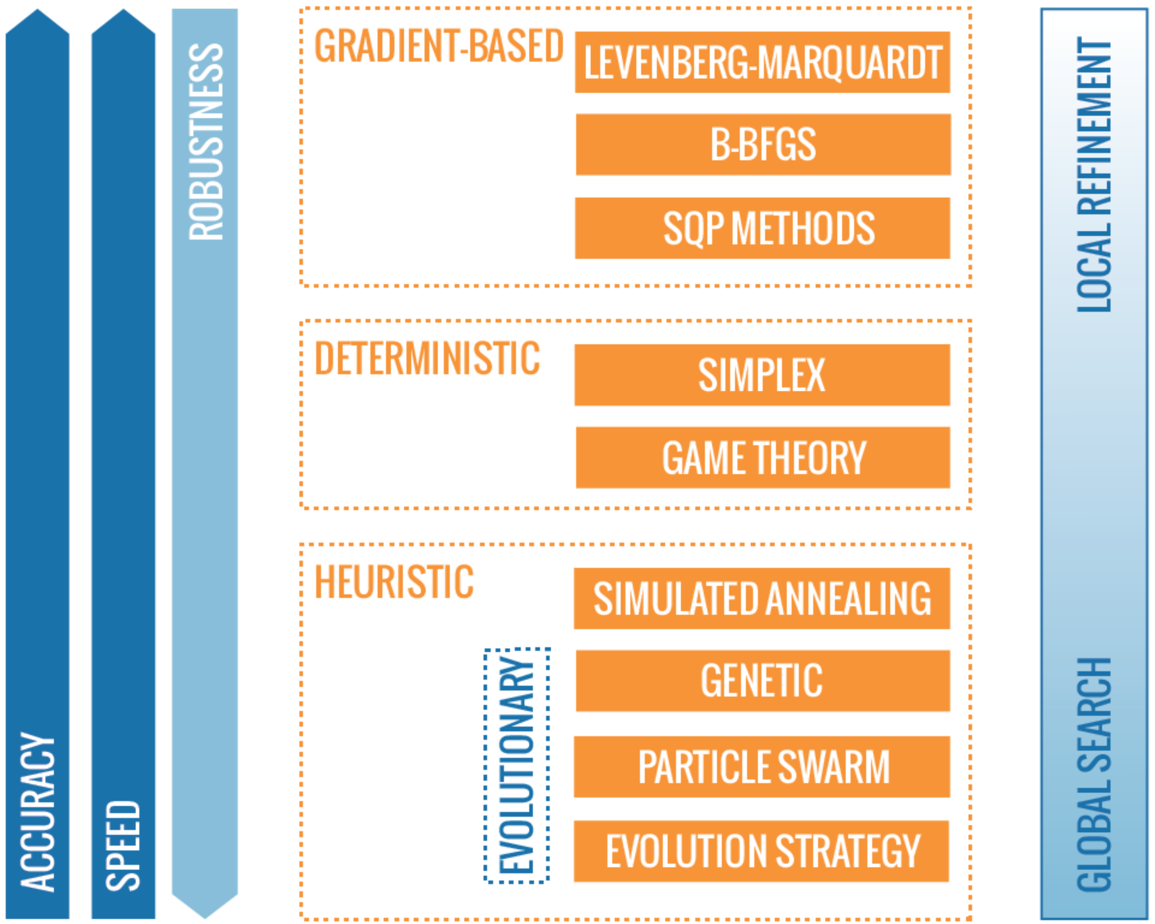


modeFRONTIER offers **over 40 direct integration nodes** to couple with the **most popular engineering solvers**, in which communication is guaranteed by APIs or automatic file exchange. Other wizard style tools are available **for building a bridge** between modeFRONTIER and any **commercial or in-house codes**.

Optimization - a set of innovative algorithms

ESTECO's expertise in numerical solutions equips designers with a **complete array** of optimization algorithms covering **deterministic**, **stochastic** and **heuristic** methods for single and multi-objective problems.

Besides the traditional methods, modeFRONTIER provides fine-tuned **hybrid** algorithms combining **the strengths of single approaches**.



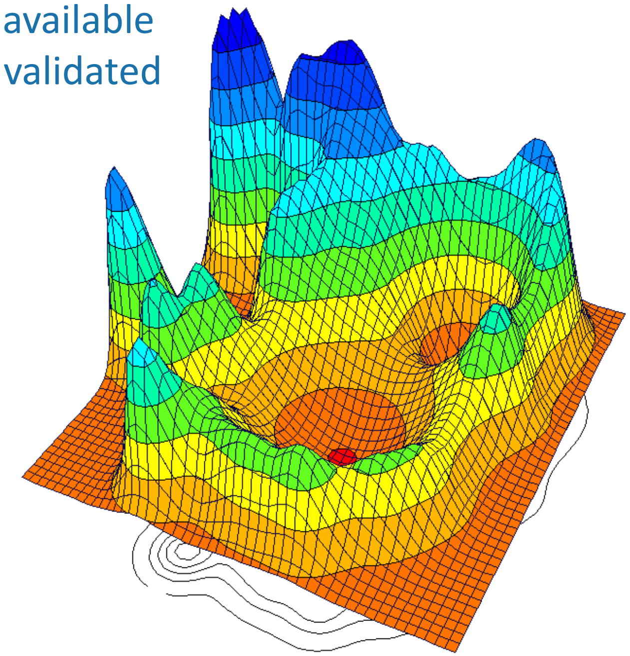
RSM-based, or virtual optimization is a valid strategy which serves as a surrogate for heavy simulation processes, allowing engineers to fast-run the classic optimization process

How does it work in modeFRONTIER?

1. RSMs are **trained** from an available database of real designs and validated one against another.

2. The best model is used to **compute** the outputs of the system; this process is called **virtual optimization**.

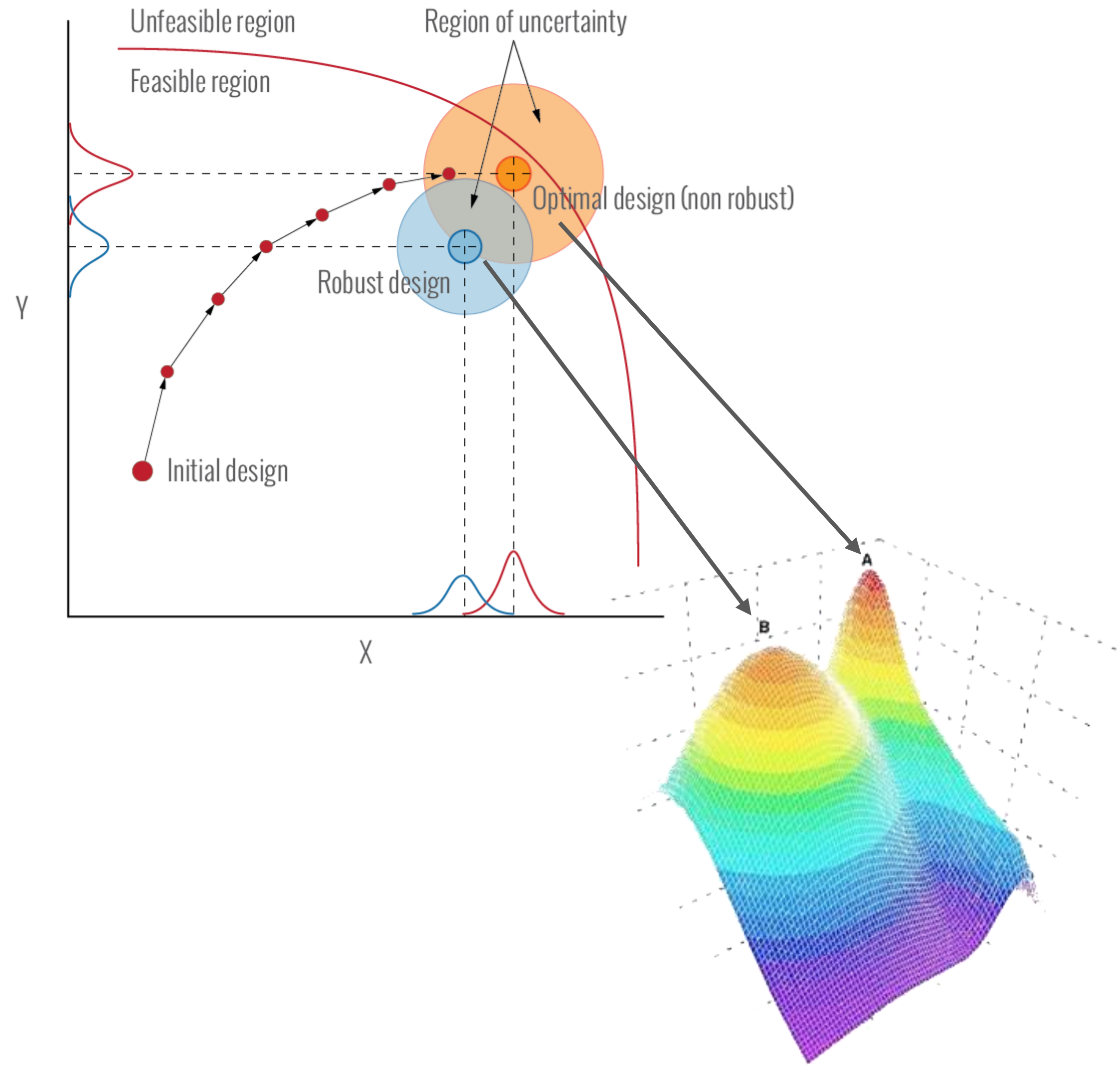
3. The best designs obtained through virtual optimization are then **evaluated by the real solver**



Main advantages

- ✓ perform thousands of design evaluations in short time
- ✓ accelerate the optimization step
- ✓ use small amounts of data efficiently
- ✓ smart exploitation of available computational resources

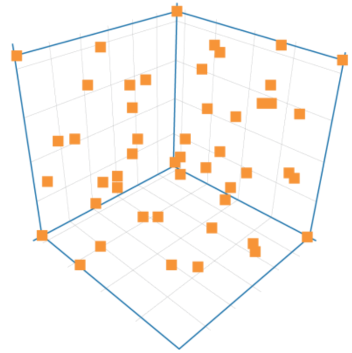
The input parameters' **uncertainty** is reflected in the outputs of the system: modeFRONTIER multi-objective robust design optimization (MORDO) algorithms generate a **scatter of samples** (noise factors) around the design, in order to verify how sensitive the design is to variations, i.e. whether the values of the outputs are still within the user-defined limits.

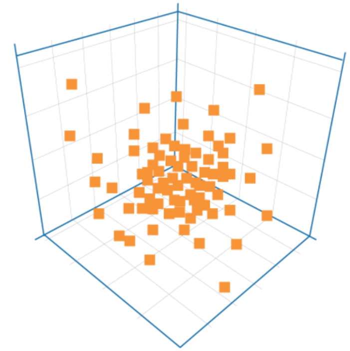


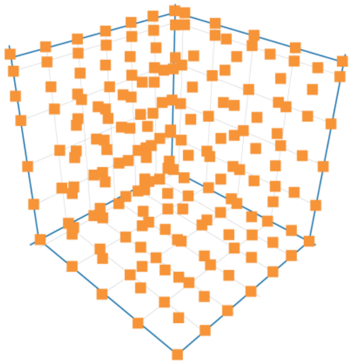
Design Space Exploration

modeFRONTIER offers a number of sophisticated and efficient DOE methods:

- ✓ **Space Filler DOEs** serve as the starting point for a subsequent optimization process or a database for response surface training;
- ✓ **Statistical DOEs** are useful for creating samplings for the sensitivity analysis thus allowing in-depth understanding of the problem by identifying the sources of variation;
- ✓ **Robustness and reliability DOEs** help create a set of stochastic points for robustness evaluation;
- ✓ **Optimal Designs DOEs** are special purpose techniques used for reducing the dataset in a suitable way.



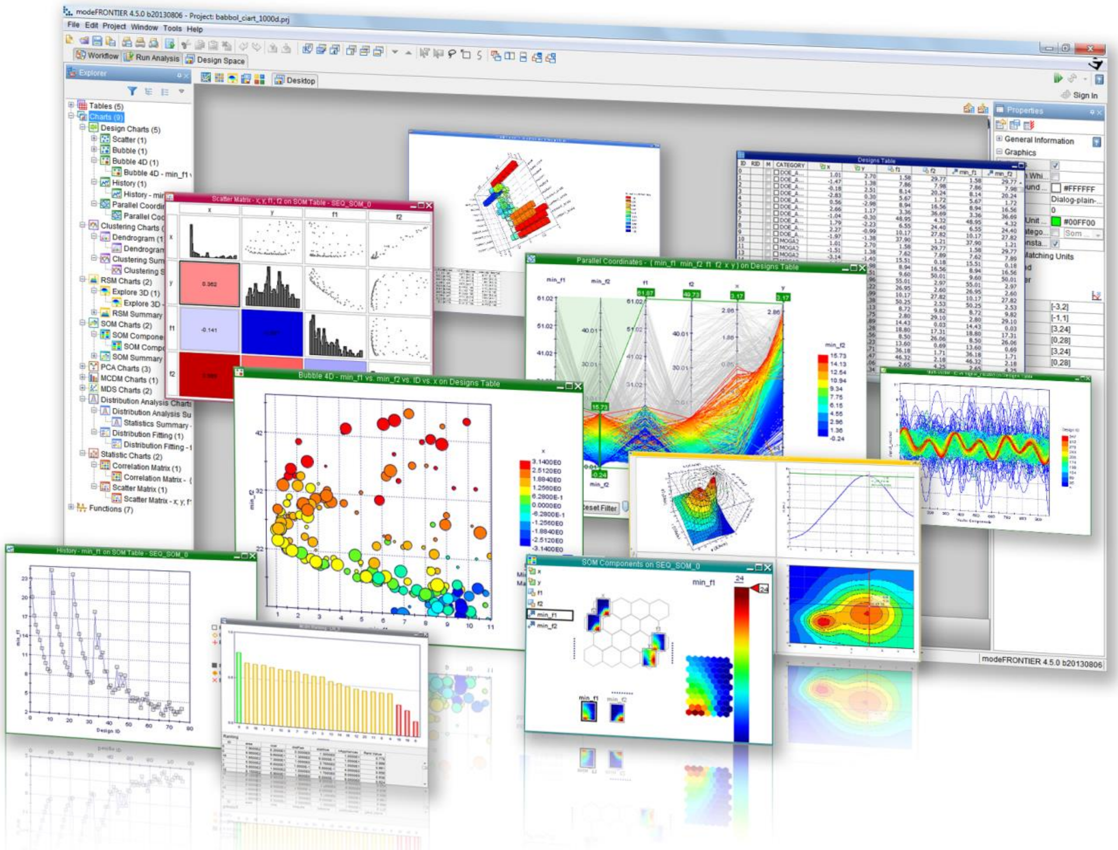




Analytics and Visualization

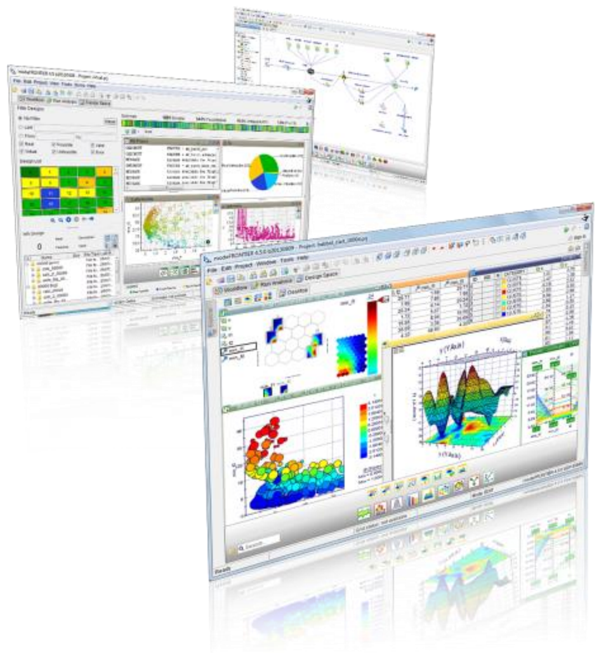
To maximize product performance, a **full and rapid understanding** of the design space is essential for extracting the most relevant information from a database of experiments.

modeFRONTIER provides a **complete and comprehensive environment for data analysis and visualization**, enabling statistical assessment of **complex datasets**. Its sophisticated **post-processing tools**, such as Sensitivity Analysis, Multi-Variate Analysis, and Visual Analysis, allow results from multiple simulations to be **visualized in a meaningful manner** and **key factors** to be identified.



ESTECO Enterprise Suite

modeFRONTIER



SOMO

ESTECO Enterprise Suite

modeFRONTIER

SOMO

Collaboration

Web-Based Access

Project Versioning

Multiple DOE & Optimization Strategies

Distributed Execution

Analysis of Results & Reporting

ESTECO ENTERPRISE SUITE

modeFRONTIER

Integration & Process Automation

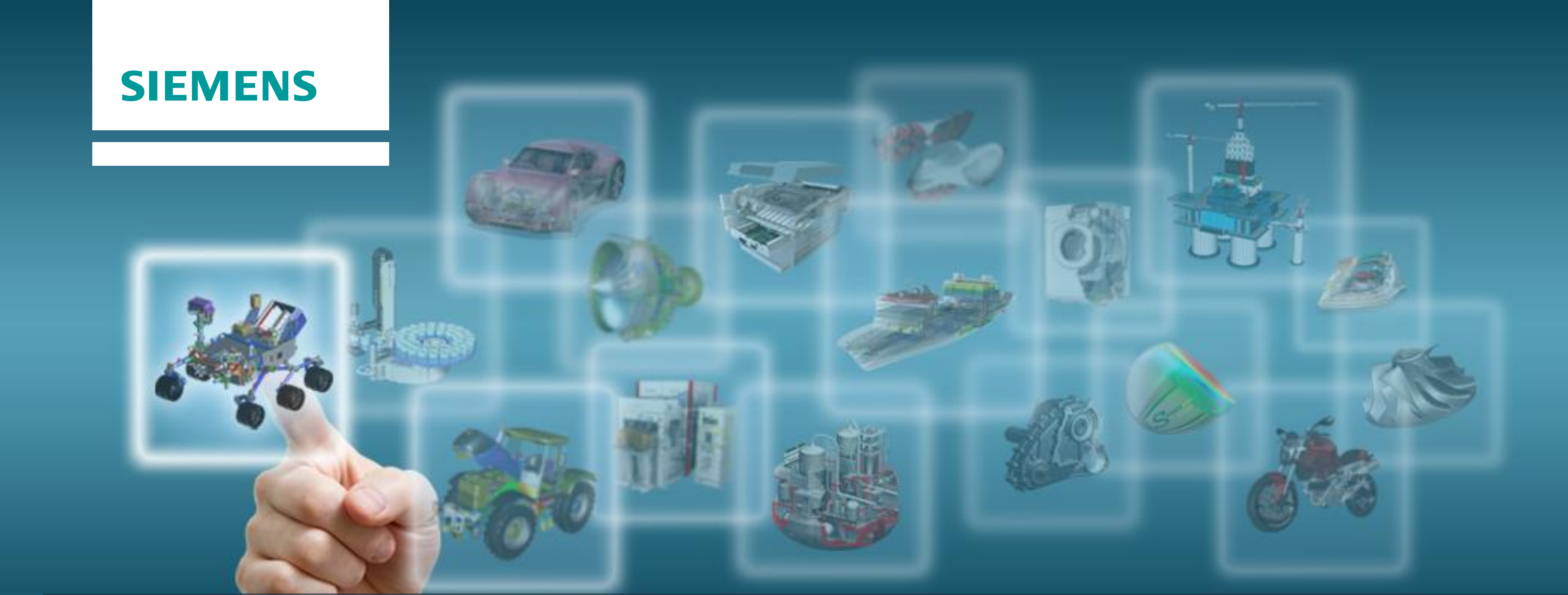
Robust Design & Reliability

Virtual Optimization Using RSMs

Advanced Analytics & Data Visualization

Decision Making

Introduction AMESim



Multi-Attribute Vehicle Performance Optimization: AMESim and modeFRONTIER interface

Siemens Introduction

June 26, 2014

The Siemens Vision:
Provide Answers to the Great Challenges of our Time

Siemens – the pioneer in

- Energy efficiency
- Industrial productivity
- Affordable and personalized healthcare
- Intelligent infrastructures

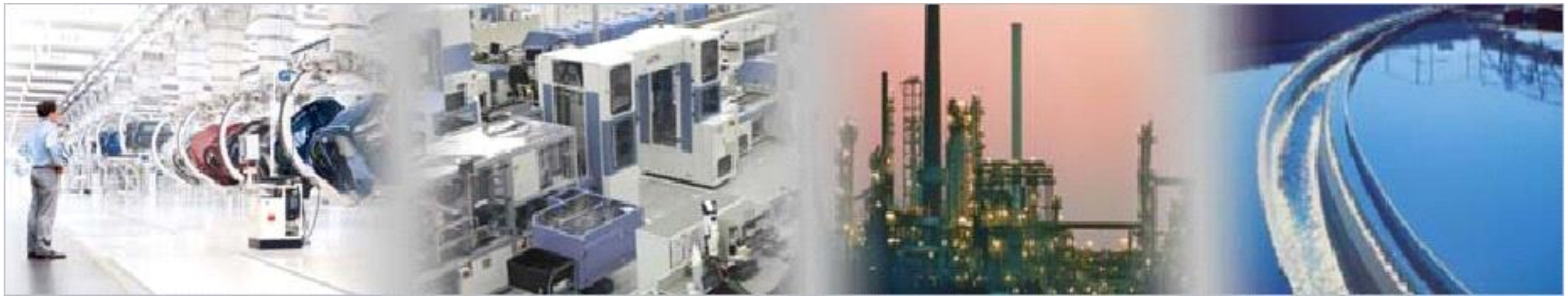
Siemens Organization:
Four Sectors Covering the Global Challenges

Industry Automation:
Boosting Industrial Productivity

SIEMENS

We help boost productivity and improve resource efficiency along the entire product development and production process to enhance the competitiveness of our customers.

Product Design and Engineering → **Production Engineering and Automation**

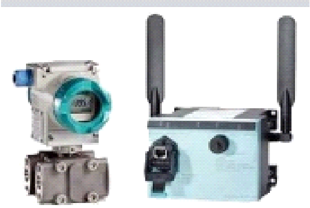


PL
PLM Software
Grindstaff (CEO)
Affuso (Chairman)

AS
Industrial
Automation Systems
Eberle (CEO)

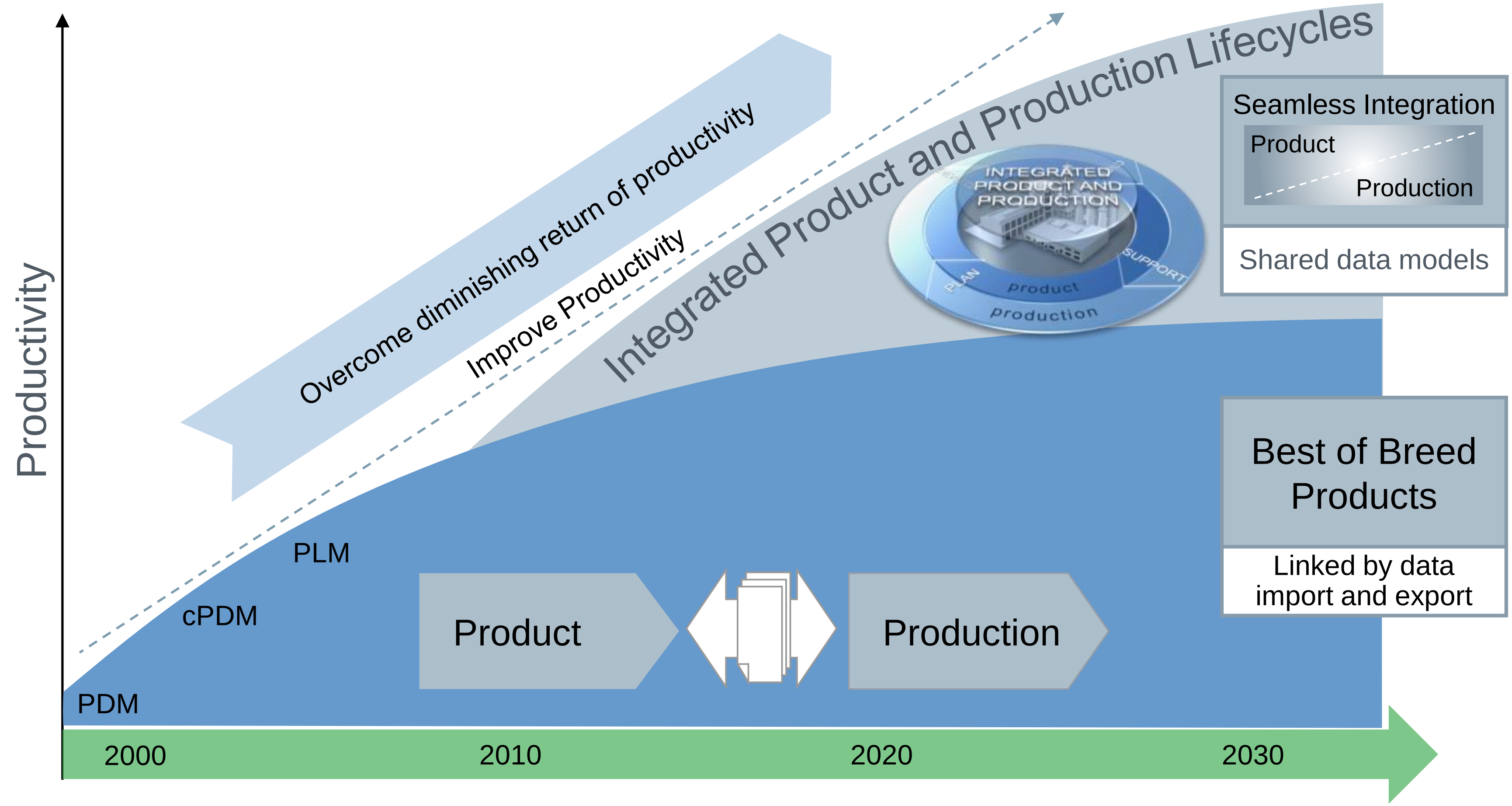
CE
Control Components and
Systems Engineering
Kaul (CEO)

SC
Sensors and
Communication
Kumpfmüller (CEO)



WT
Water
Technologies
Dr. Löffler (CEO)

The Next Level of Productivity
Integrated product and production lifecycles



Adoption of “systems Engineering”
Superior Product Innovation and Managing increasing complexity

SIEMENS

“Systems Engineering”

The “Smart Products” of the Future

“System of Systems Engineering”

The “Smart Industry Solutions” of the Future

Design → **System Validation Simulate & Test** → **Build** → **Operate**

Systems Engineering

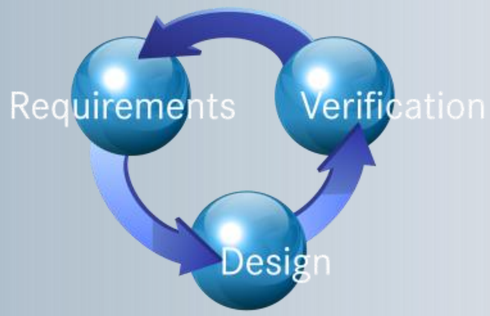
Functional Performance Engineering to Drive PLM & Superior Innovation

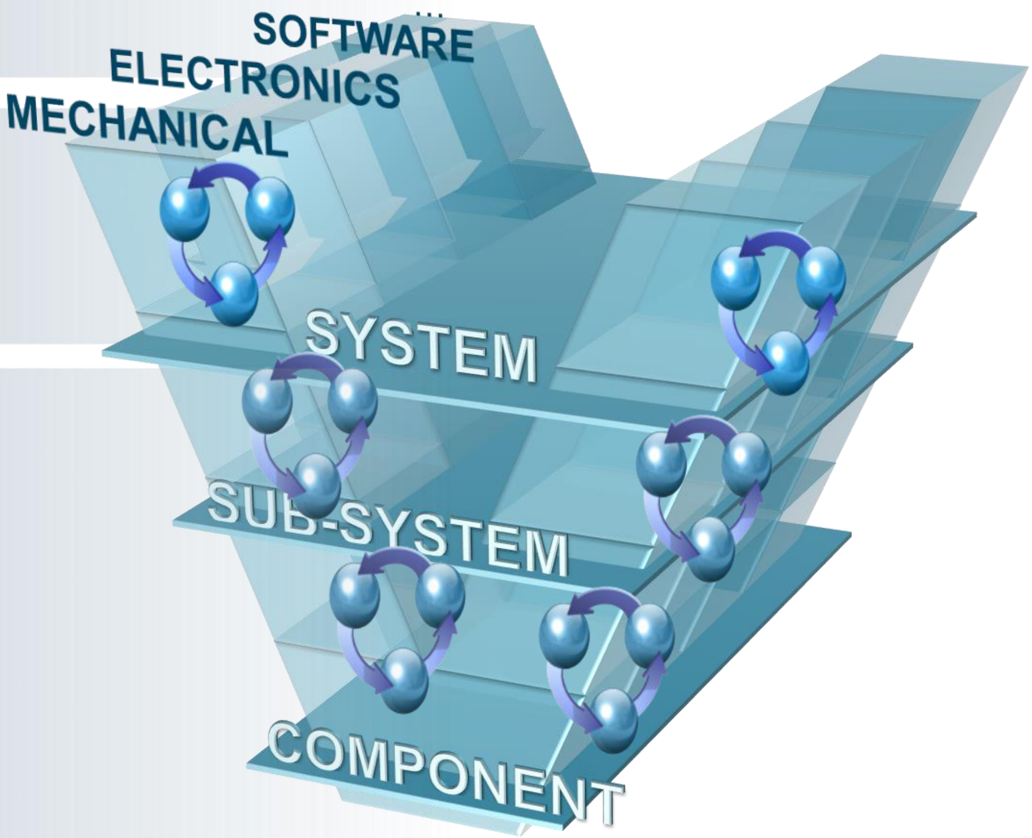
Siemens PL and LMS
Enabling "Closed-loop System Driven Product Development"

Integrating multi-disciplinary activity...

Adopting Model Based Product Development
In all Stages of Development

…enabled by **closed-loop performance verification**





LMS Imagine.Lab Solutions
From Physics Based Authoring …
… to Model Based System Engineering

SIEMENS

Automotive & Ground Vehicles

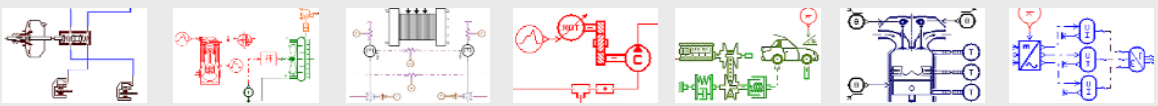
- Internal Combustion Engine
- Transmission
- Thermal Systems
- Vehicle Dynamics
- Electrical Systems

Aerospace & Defense

- Landing Gear & Flight Controls
- Engine Equipment
- Environmental Control Systems
- Fuel Systems
- Aircraft Engine
- Electrical Aircraft

Mechanical Industries

- Pumps & Compressors
- Electro-Hydraulic Valves
- Fluid Actuation Systems
- Heat Exchangers
- Heat Pumps / Refrigerators
- Electrical Systems



Fluids | Thermodynamics | Energy | Control | Mechanical | Internal Combustion Engine | Electrical

30 Libraries / 4,000 Multi-physics Models

- Validated and maintained
- Supporting multiple levels of complexity
- No need for details physics expertise

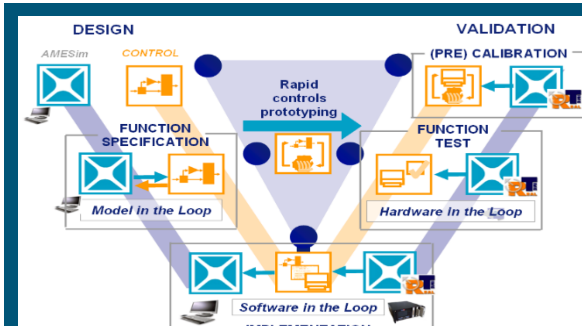
Open and Customizable

python VBA MODELICA

Scripting / Customization
MODELICA
Import / Edit / Assembly

The MathWorks
modelisar
AutoSAR

Interfacing
- To Simulink/Matlab
- To numerous 3D CAE
- *"FMI" Interface* for
- Mechatronic Co-simulation



Scalable Simulation
Connecting "Mechanical" – "Controls"

High-fidelity Plant Modeling

Model reduction for Real-time – SIL, HIL
Supporting Multiple SIL/HIL Platforms

dSPACE IPG The MathWorks RT-LAB ETAS NATIONAL INSTRUMENTS

Interlock "Mechanical" and "Controls" Engineering
Enable ISO 26262

Automotive Engineering Challenges
Balancing Emissions, Cost, and Brand Performance

Eco-Driven Powertrain Concepts

Innovative and Lightweight Design

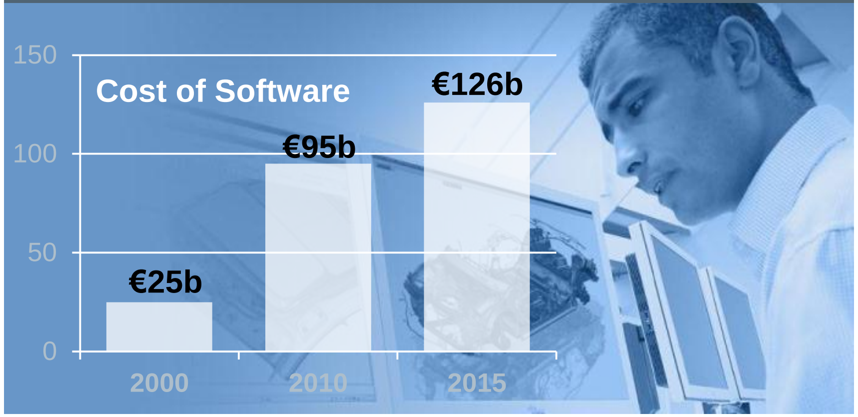
Creating Brand Value through Performance

Creating Brand Value through Systems

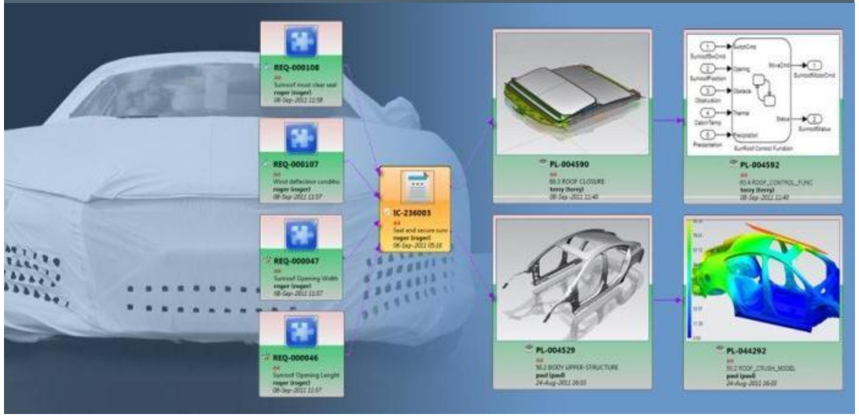
Current Engineering Practice:
Struggling to Control Complexity

SIEMENS

Dramatic Growth of Electronics Systems



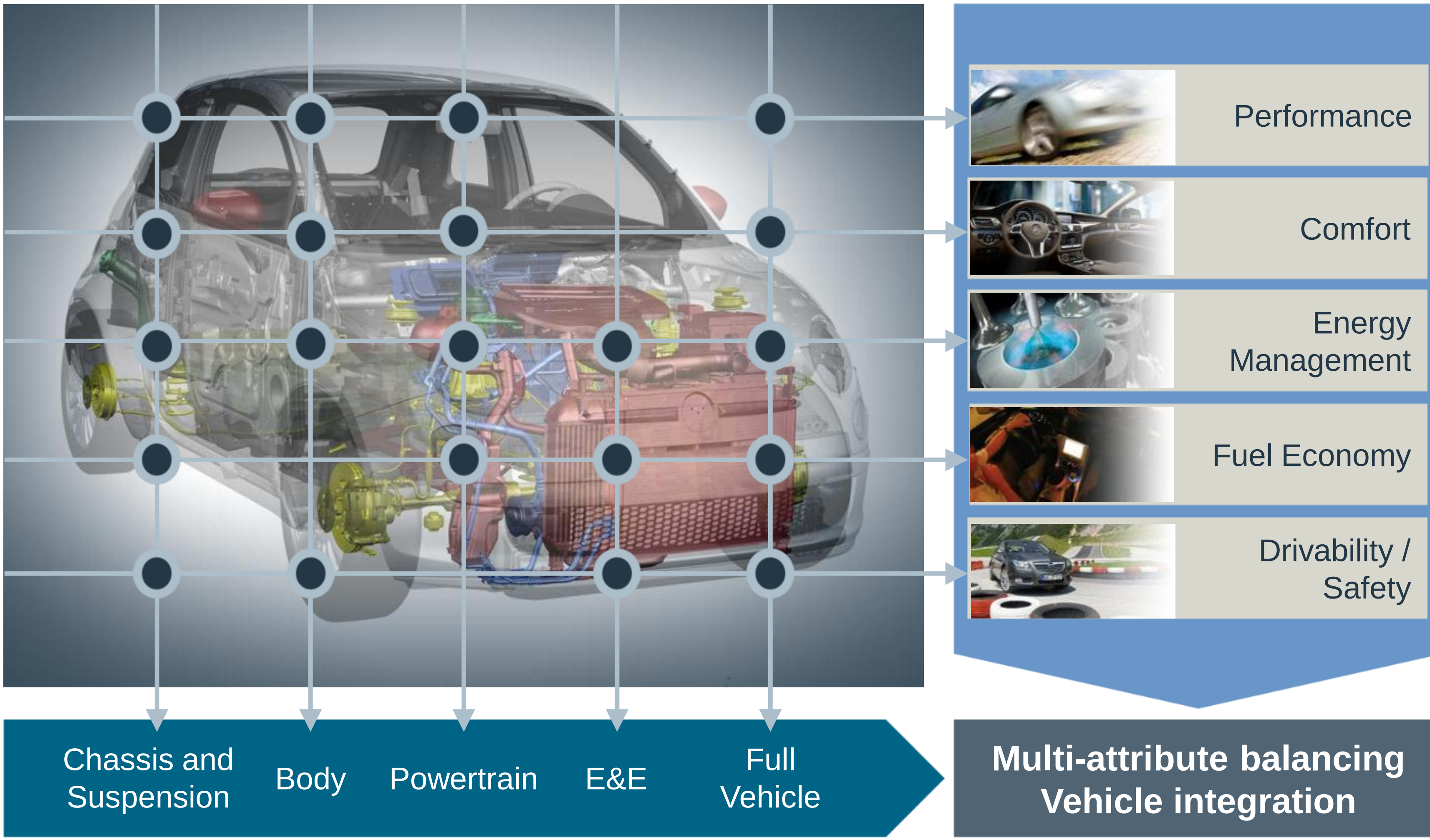
Exploding Requirements and Test Cases



Multiple Variants and System Architectures

Multiple Sites, Multiple Participants

What If You Could Optimize These Attributes Across the Organization?



The LMS Imagine.Lab Platform

The innovative Model-Based Systems Engineering approach for Mechatronic System Development

Physical Modeling

Thermal, Mechanics, Fluids,…

Controls Modeling

Electronics, Software…

LMS Imagine.Lab

LMS Imagine.Lab AMESim

Software environment for multi-physics, multi-level, mechatronic system modeling, simulation and analysis.

LMS Imagine.Lab SysDM

Solution for the organization and management of mechatronic data, from mechanical to controls engineering

LMS Imagine.Lab System Synthesis

Software tool to support configuration management, systems integration and architecture validation.

LMS Imagine.Lab AMESim (1/2)

The Open and Productive Development Environment

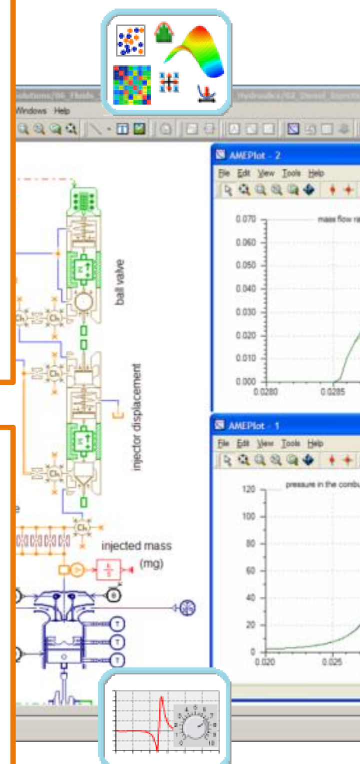
Simulate and analyze multi-physics controlled systems

INTUITIVE GRAPHICAL INTERFACE

- User-friendly modeling environment
- Seamless connection between various validated and predefined components
- Display of the system throughout the simulation process
- Several customization and scripting tools

UNRIVALLED NUMERICAL CORE

- Capability to robustly execute inhomogeneous dynamic systems
- Advanced numerical techniques (ODE, DAE)
- Dynamic selection of calculation methods
- Discrete partitioning, parallel processing and co-simulation



ADVANCED ANALYSIS TOOLS

- Fast Fourier Transform
- Plotting facilities, 2D/3D post-processing tools
- Spectral map & Order Tracking
- Linear analysis (eigenvalues, modal shapes, root locus, and transfer function representation)

OPEN-ENDED PLATFORM

- Efficient integration with 3rd party software for SiL, MiL, HiL, real-time simulation, MBS, process integration and design optimization
- Generic co-simulation interface to couple to dynamic 3D models
- Modelica-compliant platform

SIEMENS

LMS Imagine.Lab AMESim (2/2)

The Validated, Off-the-Shelves Physical Libraries

Chose after 4500 multi-domain models

FLUIDS

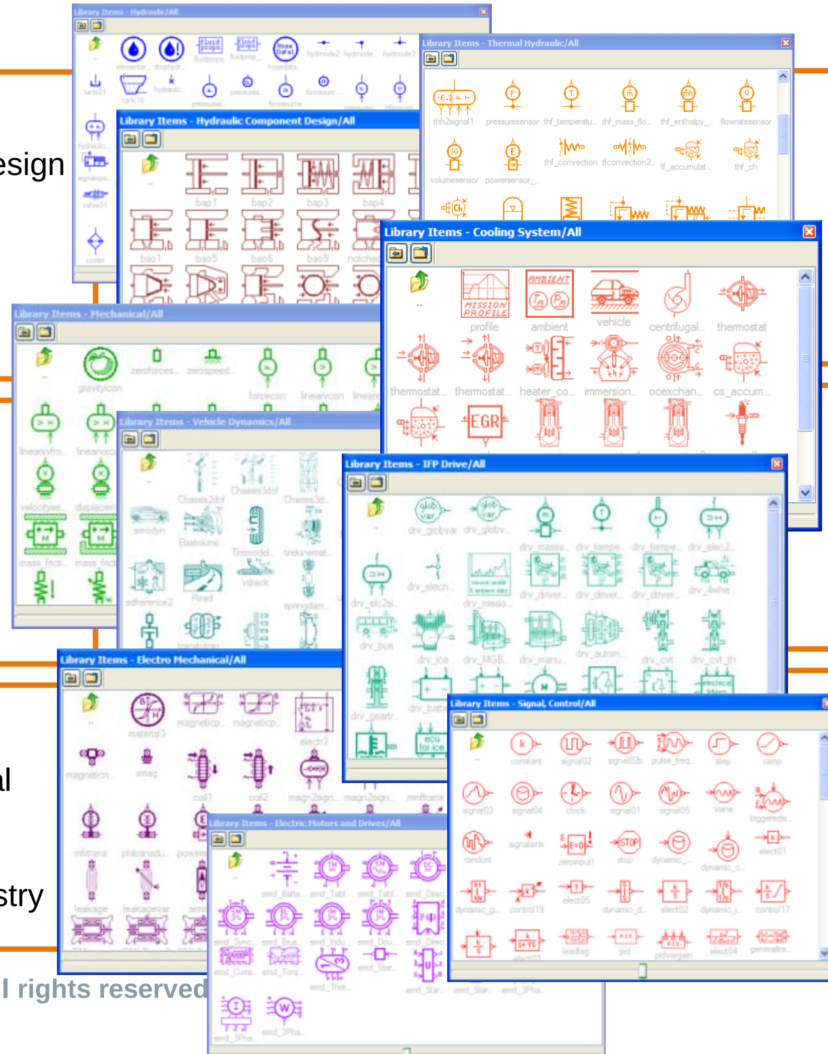
Hydraulic, Hydraulic Component Design
Hydraulic Resistance, Filling
Pneumatic, Pneumatic Component Design
Gas Mixture, Moist Air

MECHANICS

1D mechanical, Planar mechanical
Transmission, Cam & Followers
Finite-Elements Import
Vehicle Dynamics

ELECTRICS

Electrical Basics, Electromechanical
Electrical Motors & Drives
Electrical Static Conversion
Automotive Electrics, Electrochemistry



THERMODYNAMICS

Thermal, Thermal Hydraulics
Thermal-Hydraulic Component Design, Thermal Pneumatic,
Cooling, Air-Conditioning
Two-Phase Flow

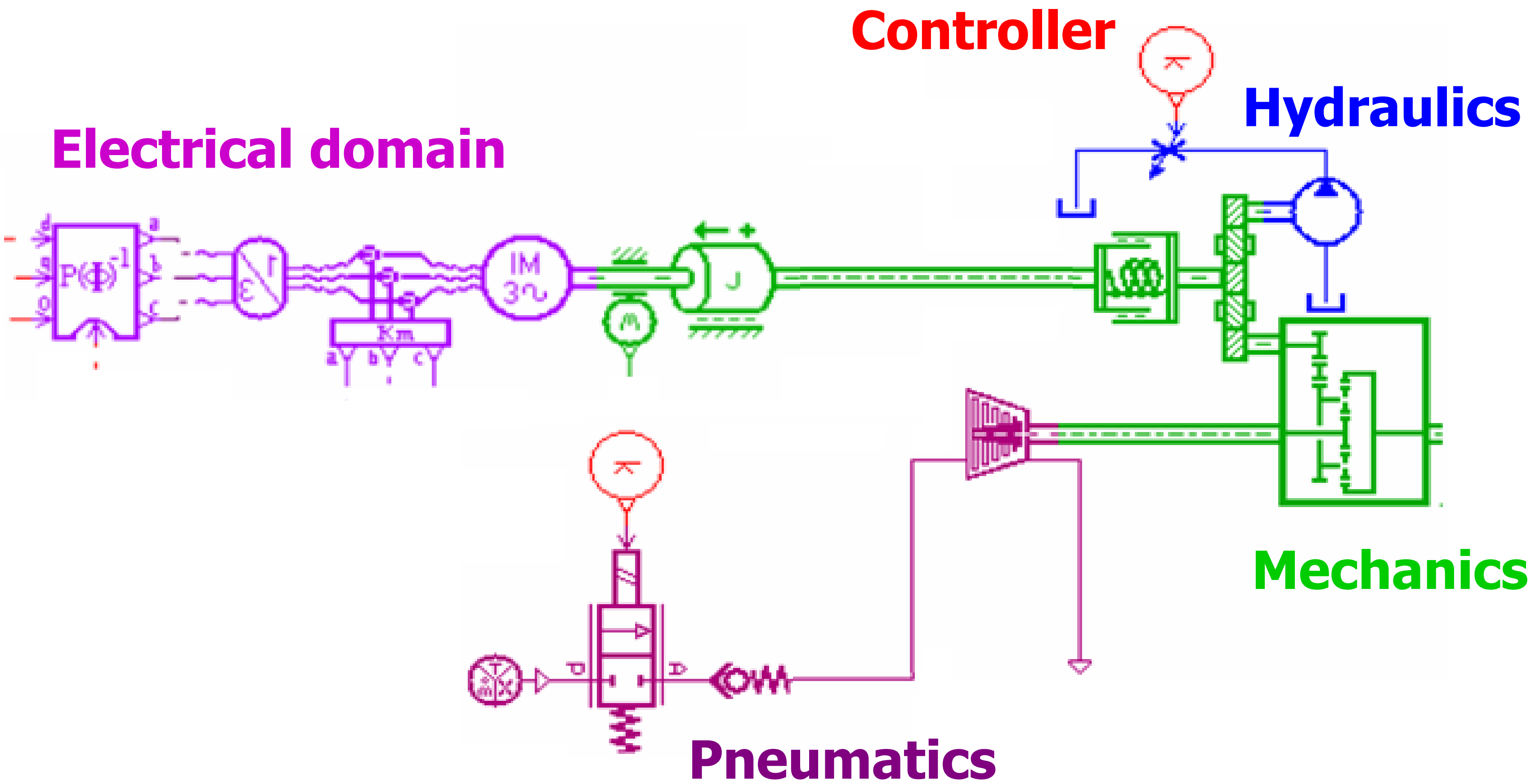
ENGINE

IFP Drive, IFP Engine
IFP Exhaust
IFP C3D, CFD-1D

CONTROLS

Signal and Control
Engine Signal Generator

Multi-Domain simulation in AMESim

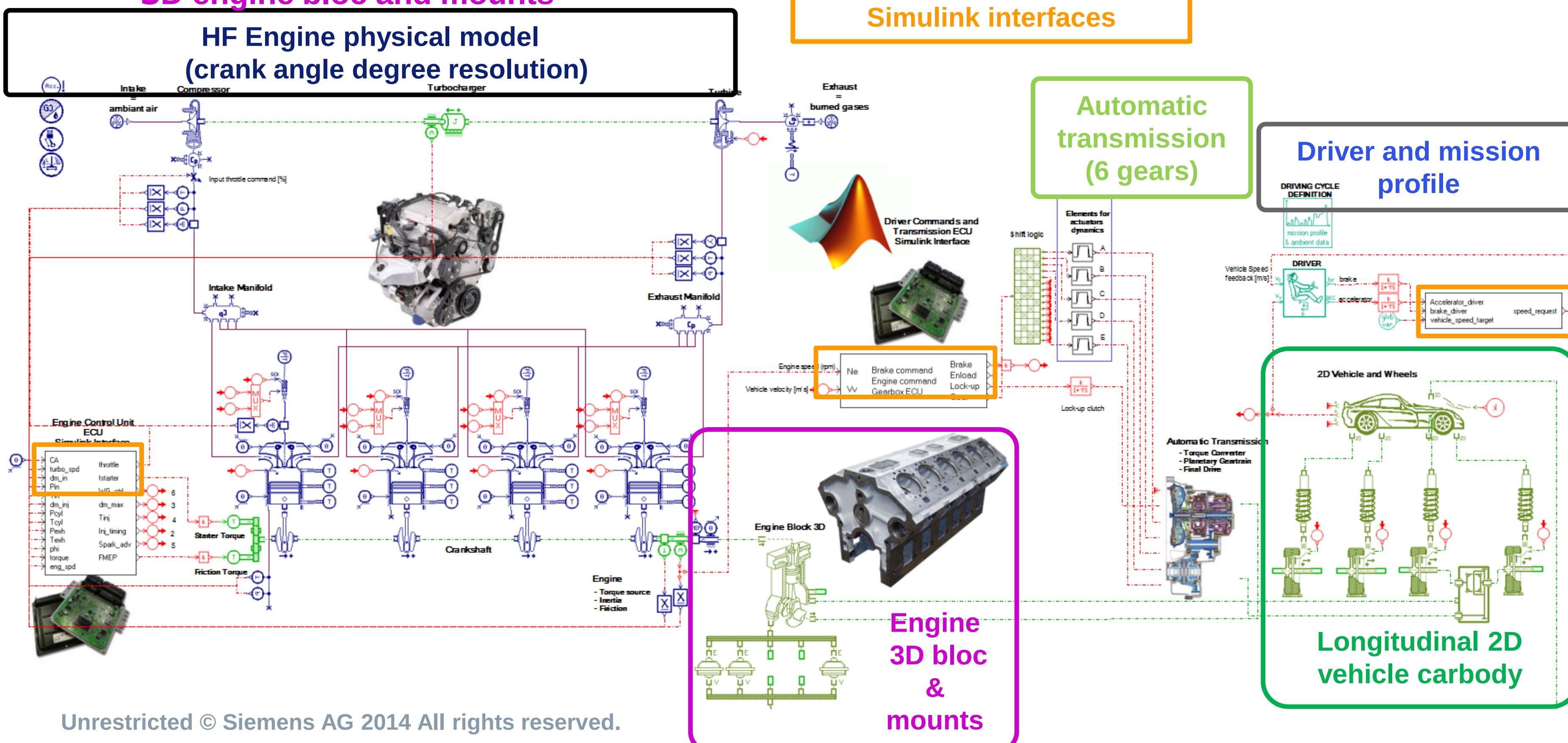


SIEMENS

Closed loop powertrain model for drivability
Overview

Powertrain model including:

- HF 4 cylinder engine model (crank angle degree resolution)
- 6 gear Automatic transmission
- 2D longitudinal vehicle + Driver and mission profile definition
- 3D engine bloc and mounts



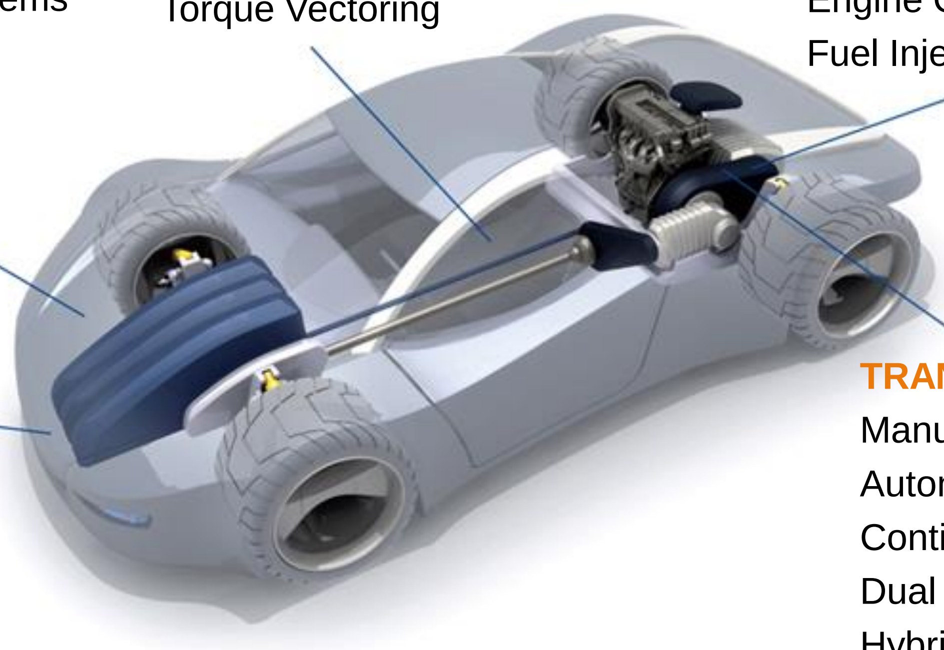
LMS Imagine.Lab AMESim – The integrated platform for multi-domain system simulation

SIEMENS

VEHICLE INTEGRATION
Conventional, EV, HEV
Exhaust
Underhood Thermal Systems
Air Conditioning
Cabin
Electrical Networks
Chassis Systems

DRIVELINE
Torsional Analysis
Dual-mass Flywheel
Torque Vectoring

INTERNAL COMBUSTION ENGINE
Engine Controls
Air Path
Combustion
Engine Cooling, Lubrication
Fuel Injection and Valvetrain



CHASSIS SUBSYSTEMS
Braking
Steering
Suspension/ Anti-rol

TRANSMISSION
Manual
Automatic
Continuously Variable
Dual Clutch
Hybrid Architectures

Example 1

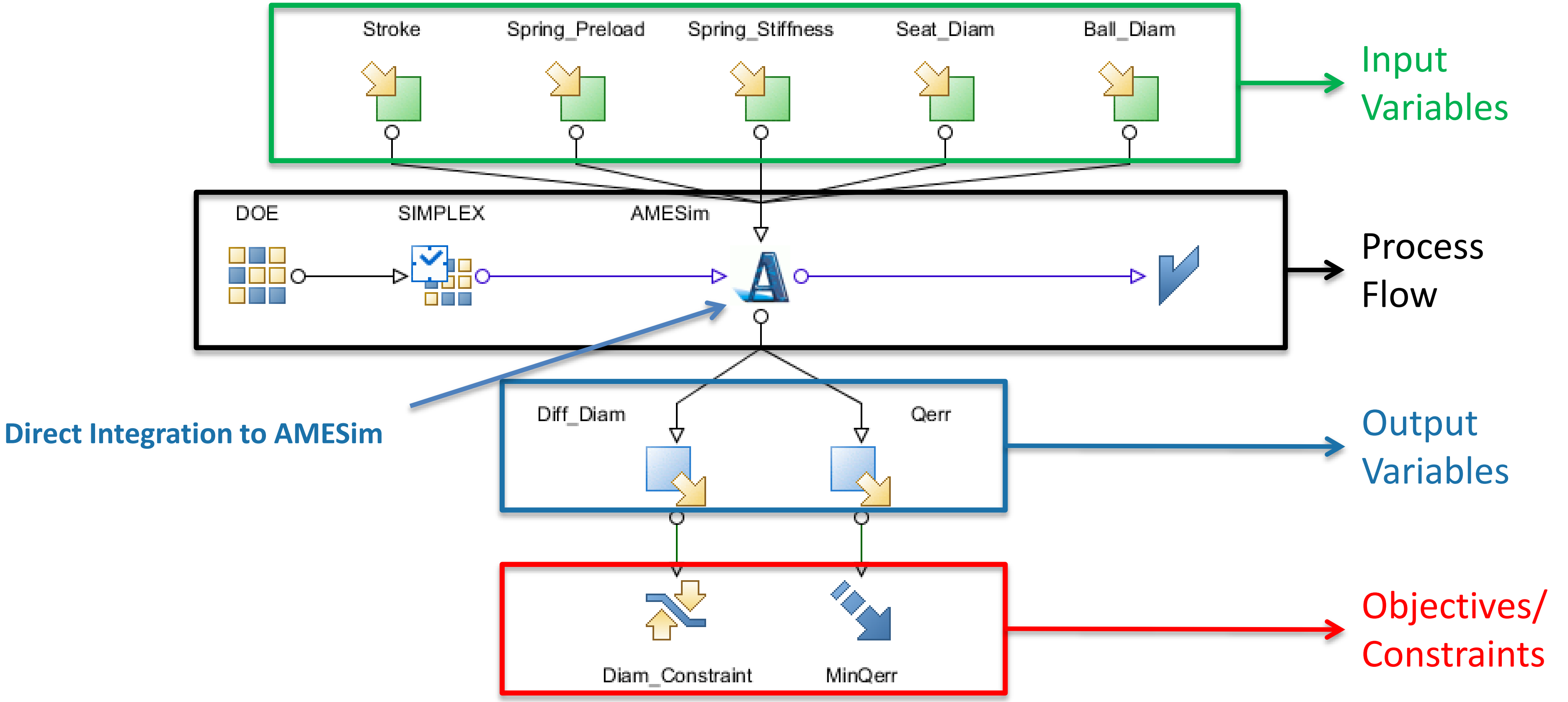
DEMO CHECK VALVE

modeFRONTIER

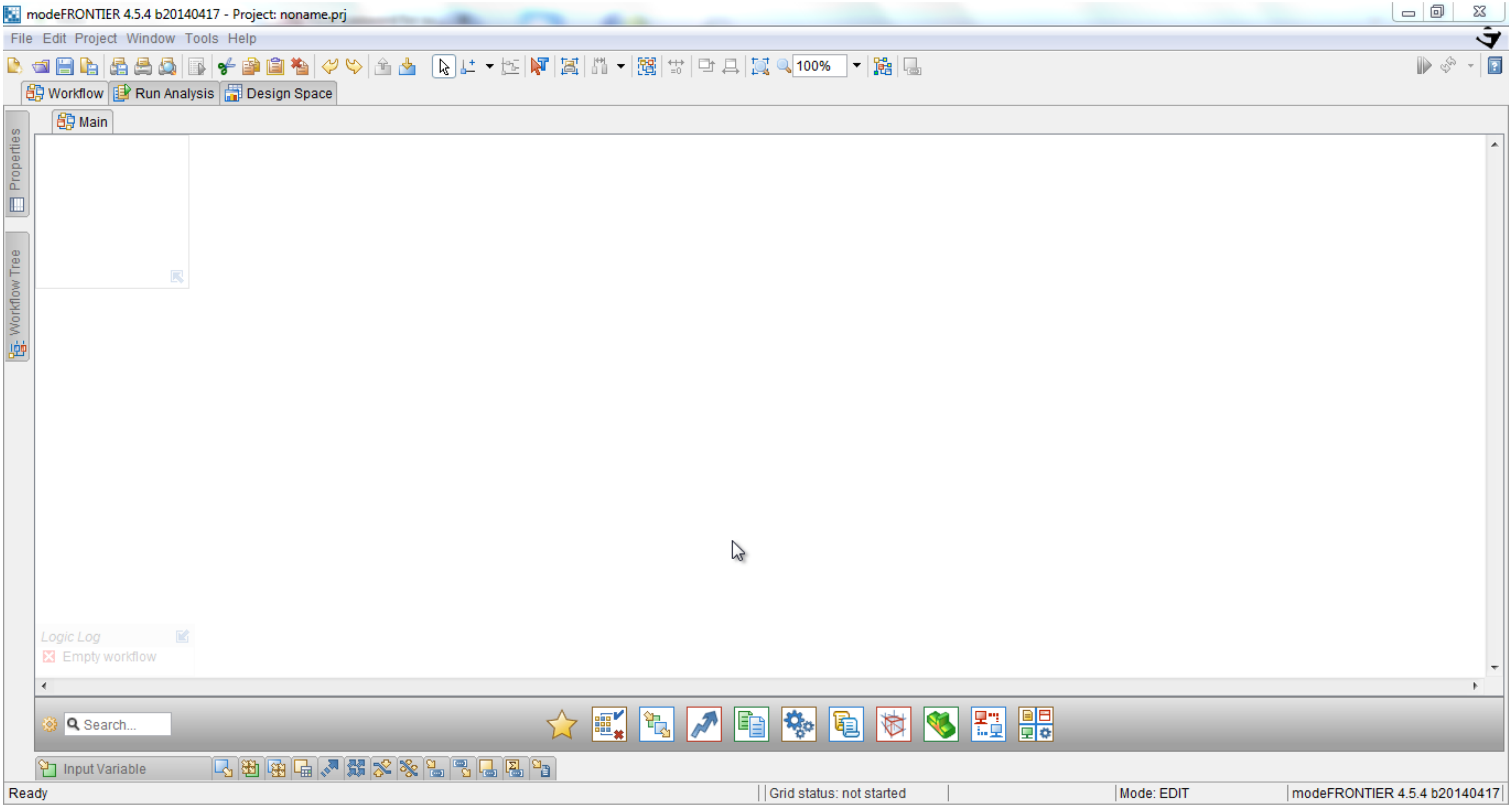
Example 1: Optimization of a Check Valve

modeFRONTIER

Workflow Components:

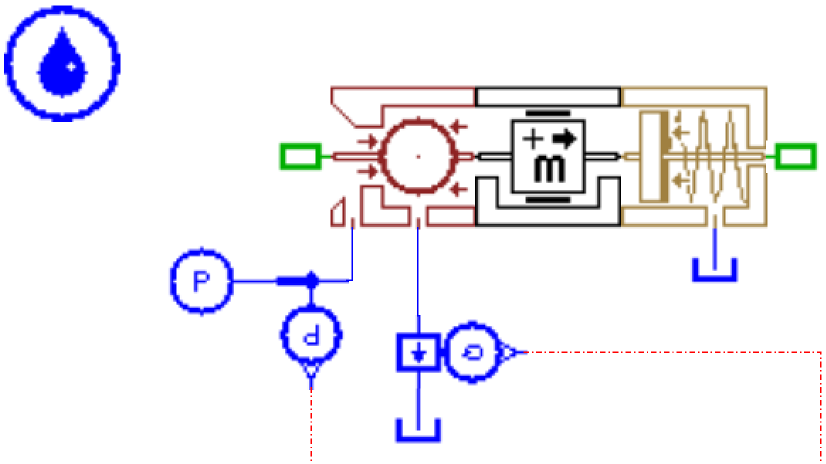


Check Valve: Workflow Building Example



5 Input Variables:

- Stroke Length ∈ [1, 10] mm
- Spring Preload ∈ [0, 100] N
- Spring Stiffness ∈ [1E-5, 100] N/mm
- Seat Diameter ∈ [1, 25] mm
- Ball Diameter ∈ [1, 30] mm

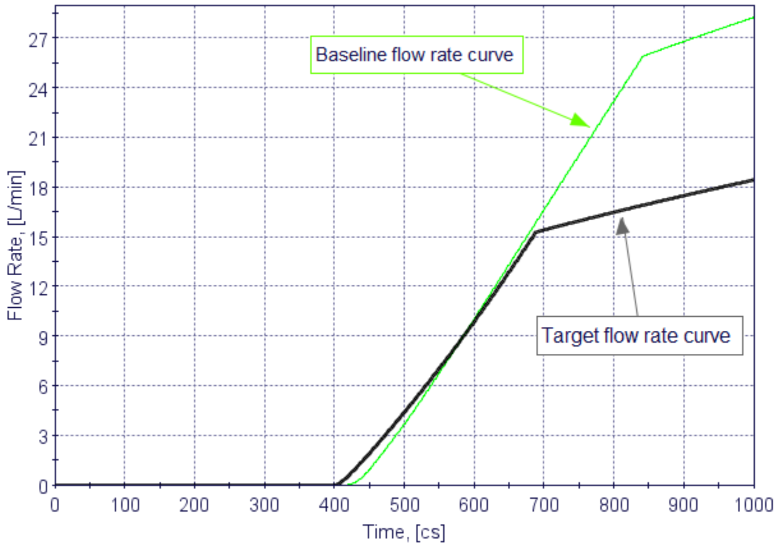


Constraint:

- Ball diameter must be greater than the seat diameter

Objective:

- Minimize the **sum of squares error (SSE)** between the target and simulation flow rate responses (model correlation/calibration study)



Check Valve: Optimization Strategy

modeFRONTIER offers over 15 optimization algorithms

2 algorithms used for this case:

- **Levenberg-Marquardt Algorithm (LMA)**
  - Gradient based method used for curve fitting problems
  - Starting point: baseline design
- FAST Strategy
    - Uses Response Surface Models (RSM) and real evaluations
    - Optimization uses RSM
    - Best designs are validated
    - RSM adapted using new validation runs
    - Optimization repeated
  - **FAST-SIMPLEX**: Mono-Objective SIMPLEX algorithm used as optimizer
    - Start population: 6 Uniform Latin Hypercube (ULH) Designs of Experiments (DOE)
    - Robust convergence

Check Valve: LMA Run Statistics

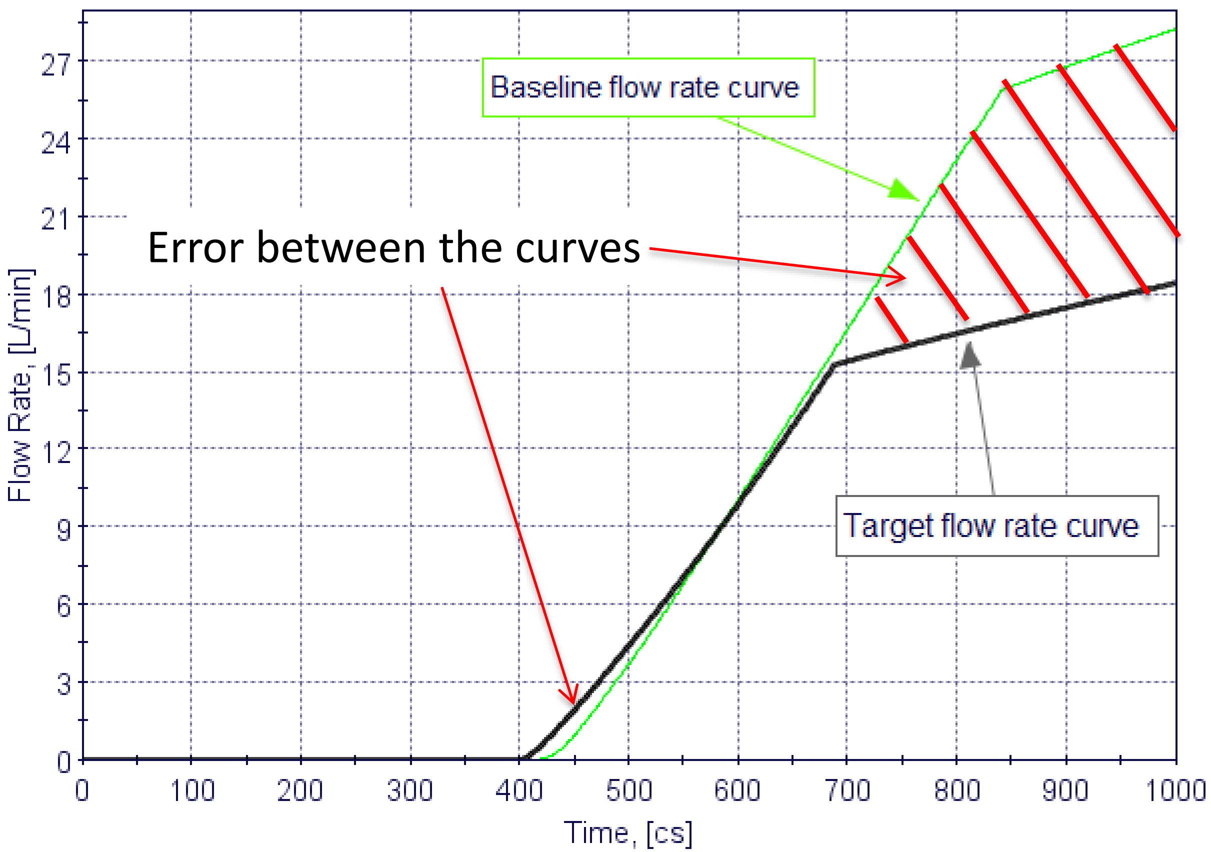
Hardware:
- Dell Latitiude w/ Intel Core i7

Software:
- modeFRONTIER v4.5.4
- AMESim v13.0

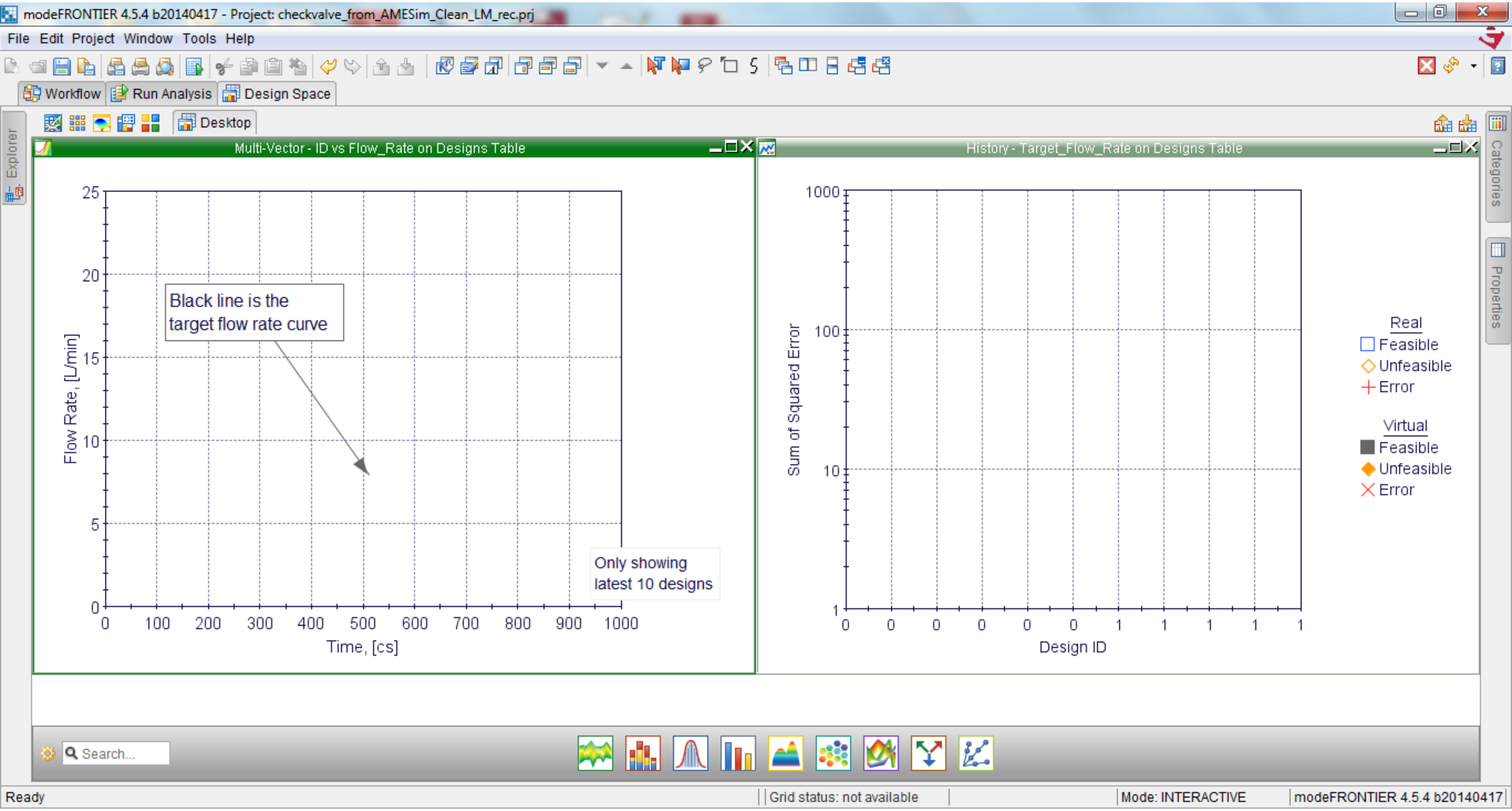
Run times:
- Number of parallel evaluation: 2
- Number of total evaluations: 36
- Average single evaluation time: 5 sec
- Total runtime: 2 min

modeFRONTIER

Levenberg-Marquardt started from baseline design:

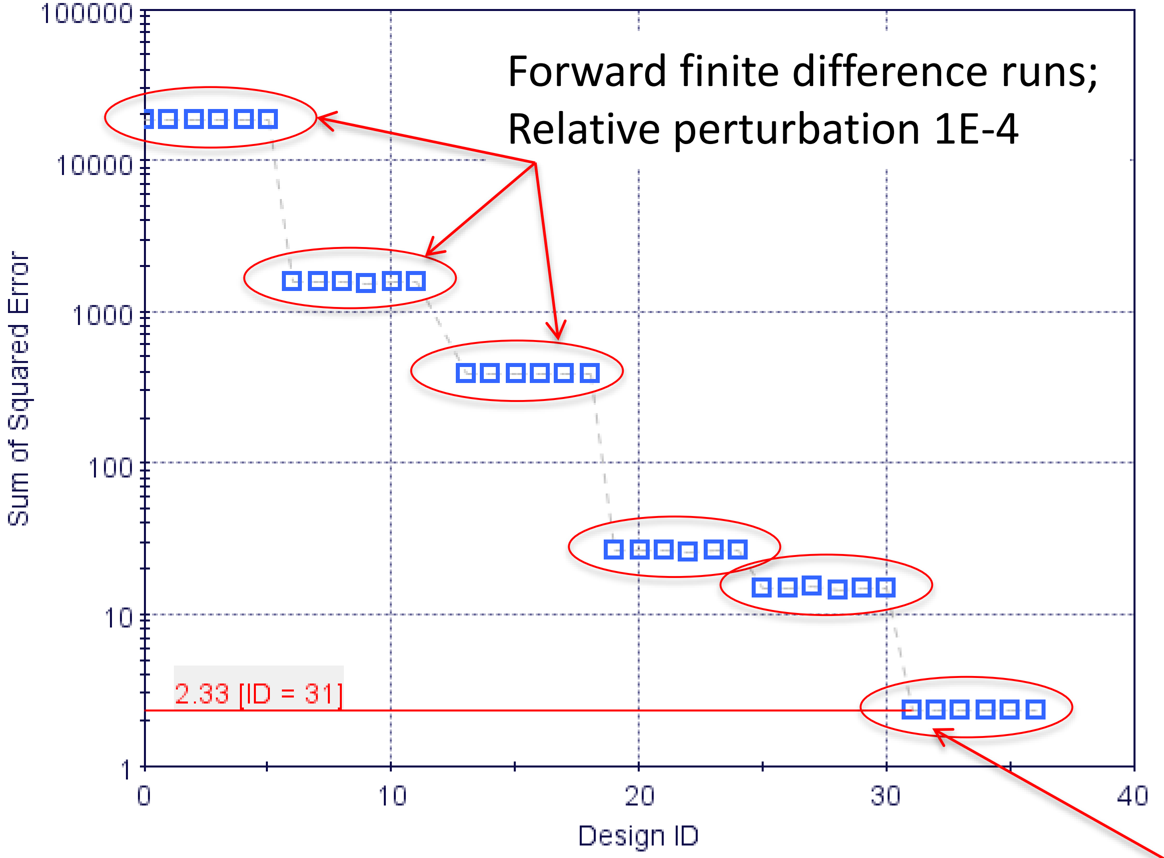


Check Valve: LMA Convergence



Check Valve: LMA Convergence

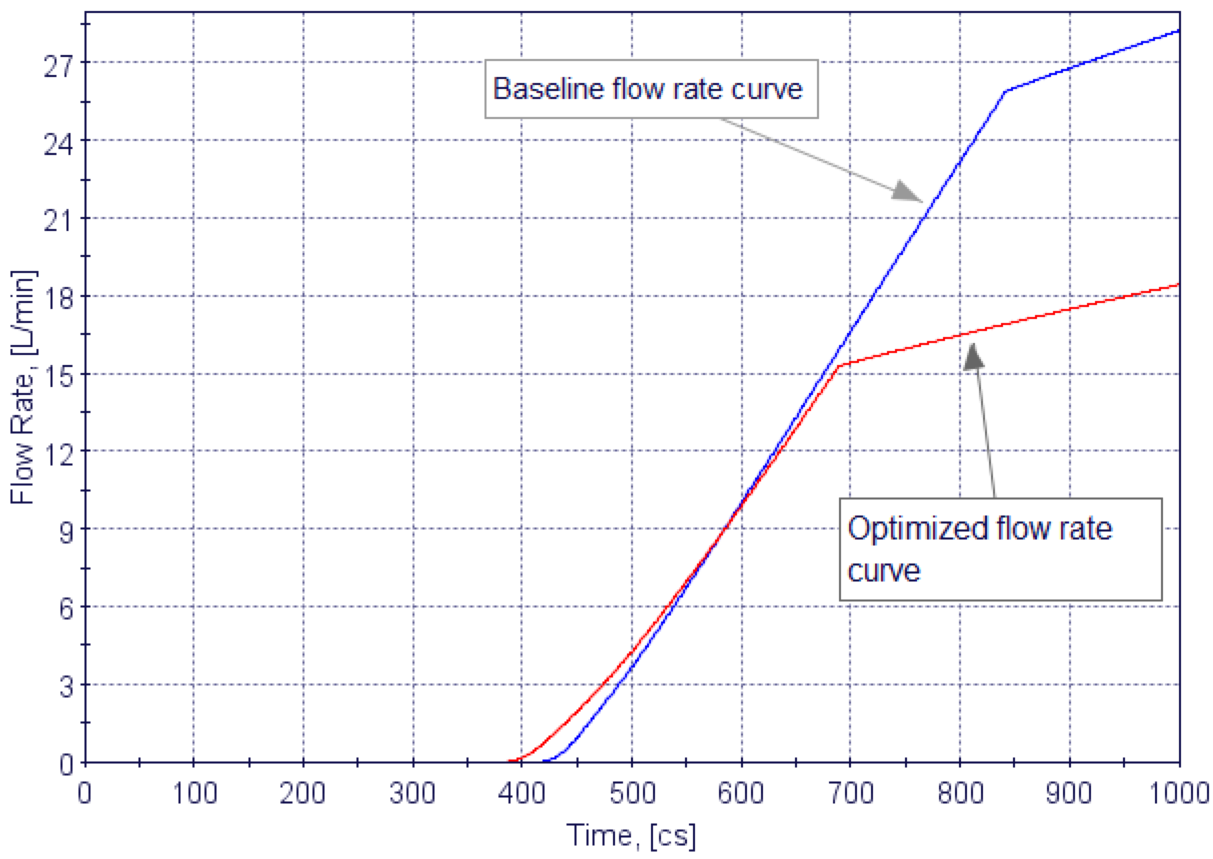
LMA optimization history:



Converged to optimum in 5 moves

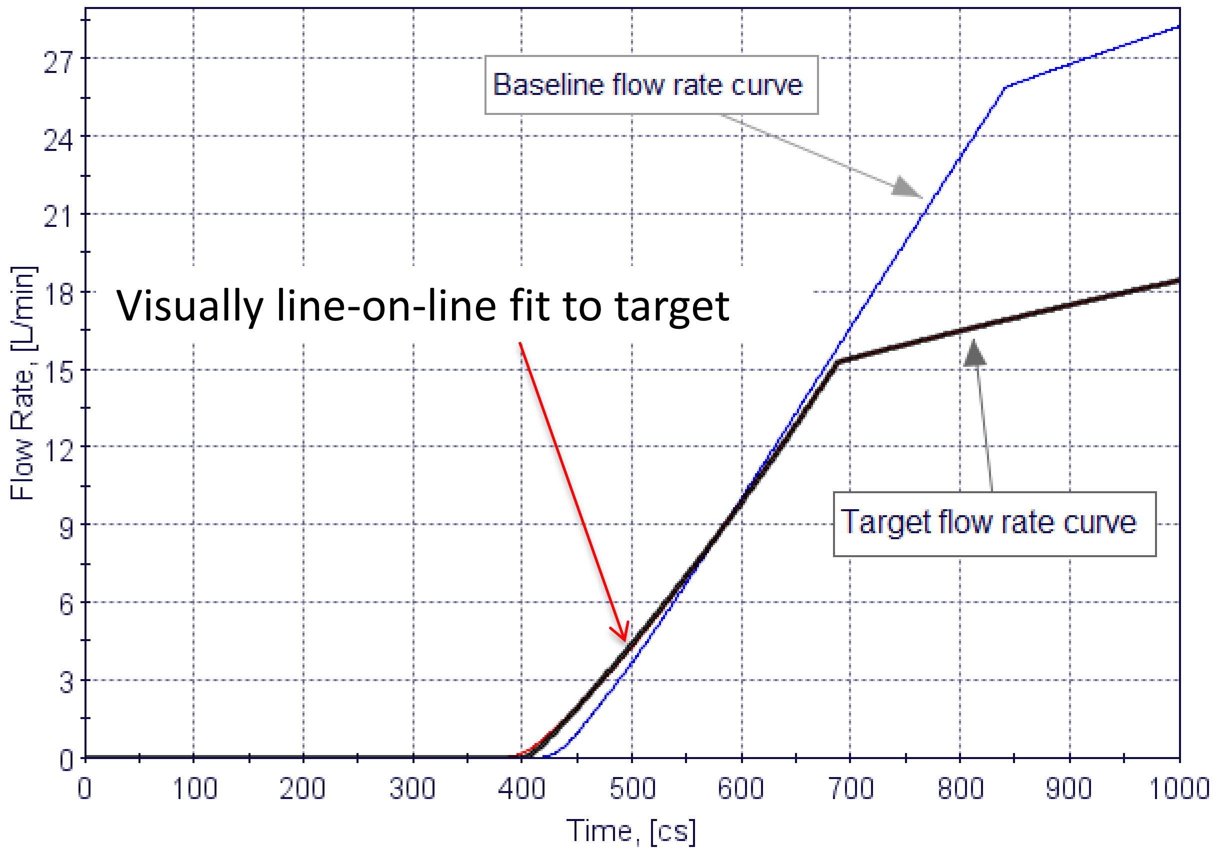
Check Valve: LMA Result

Optimized flow rate comparison:

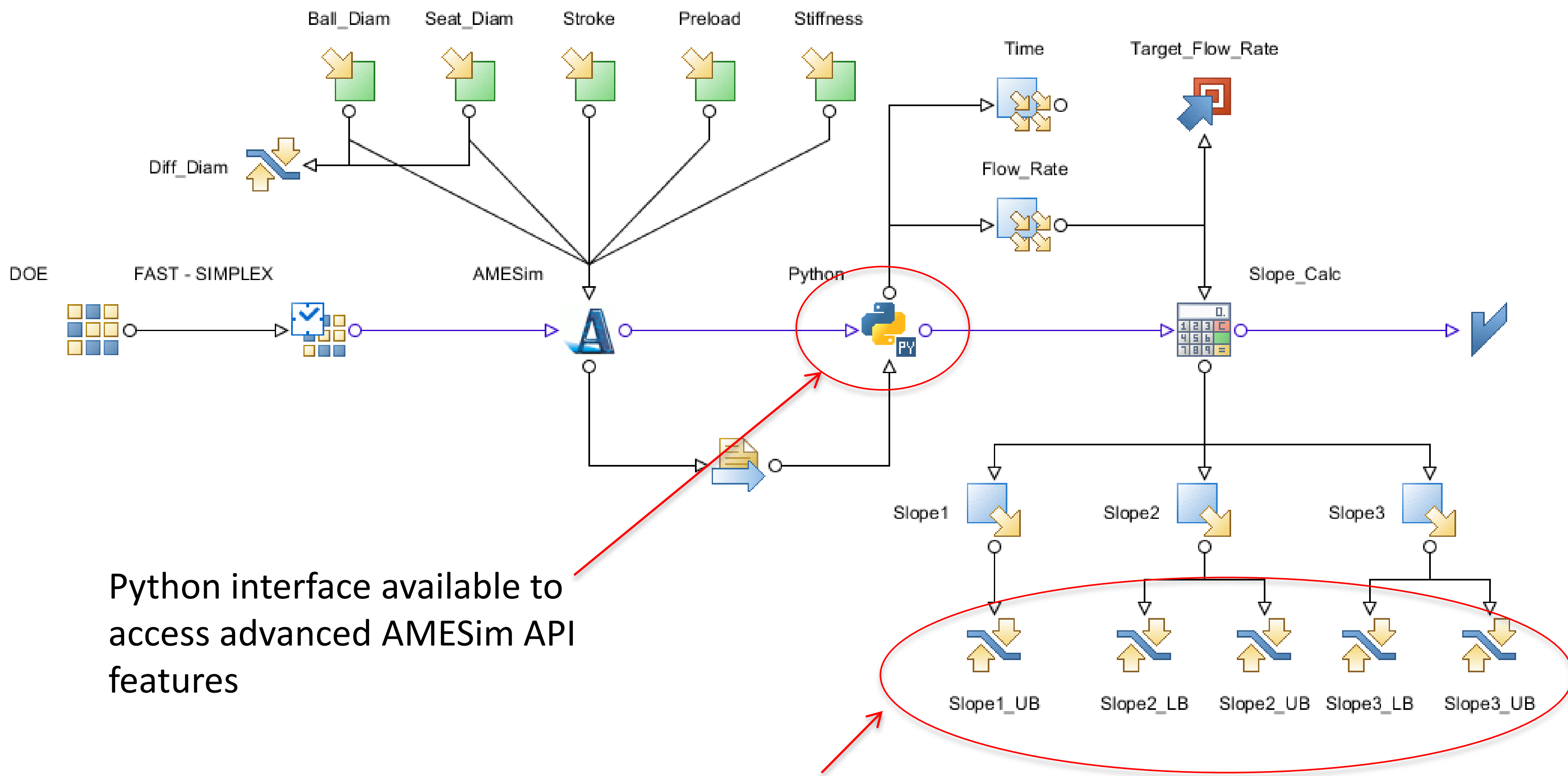


Check Valve: LMA Result

Optimized flow rate comparison:



Check Valve: Workflow for FAST-SIMPLEX

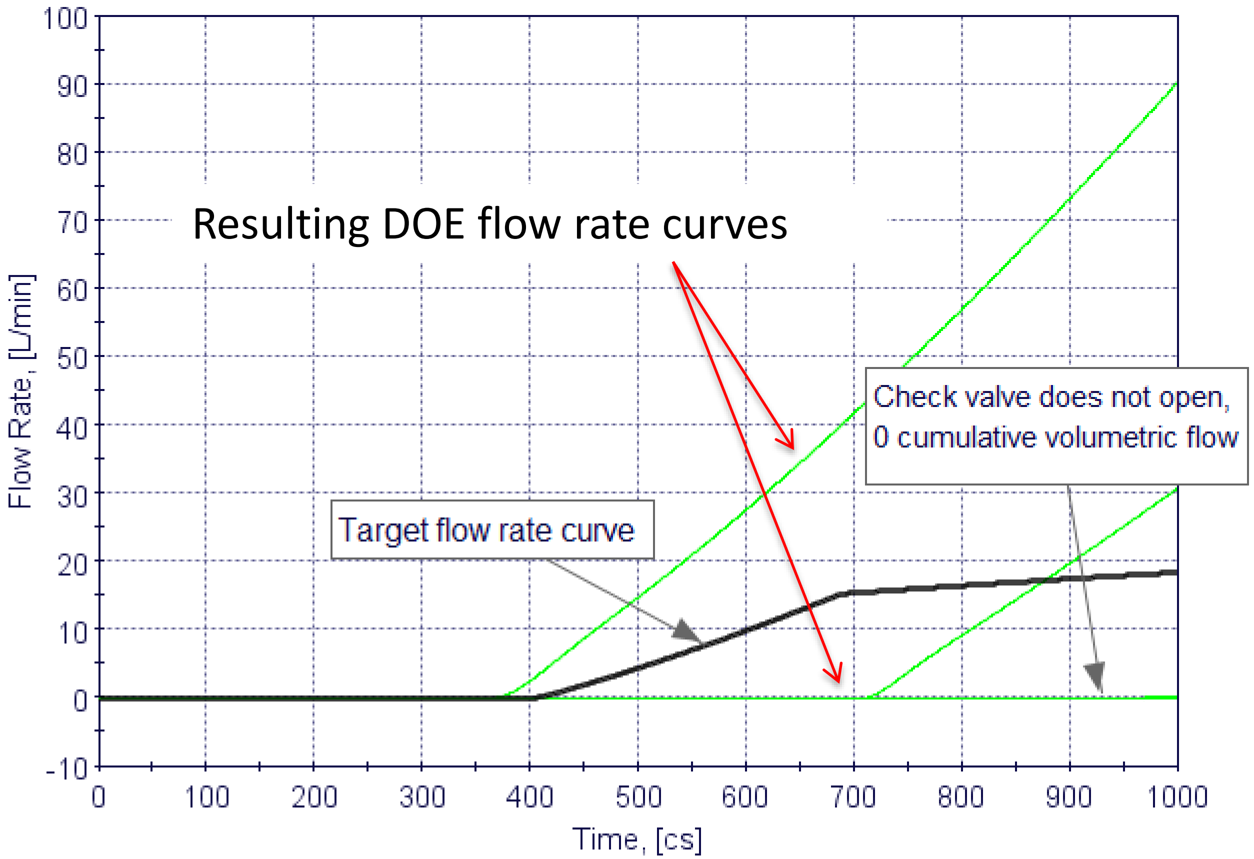


Python interface available to access advanced AMESim API features

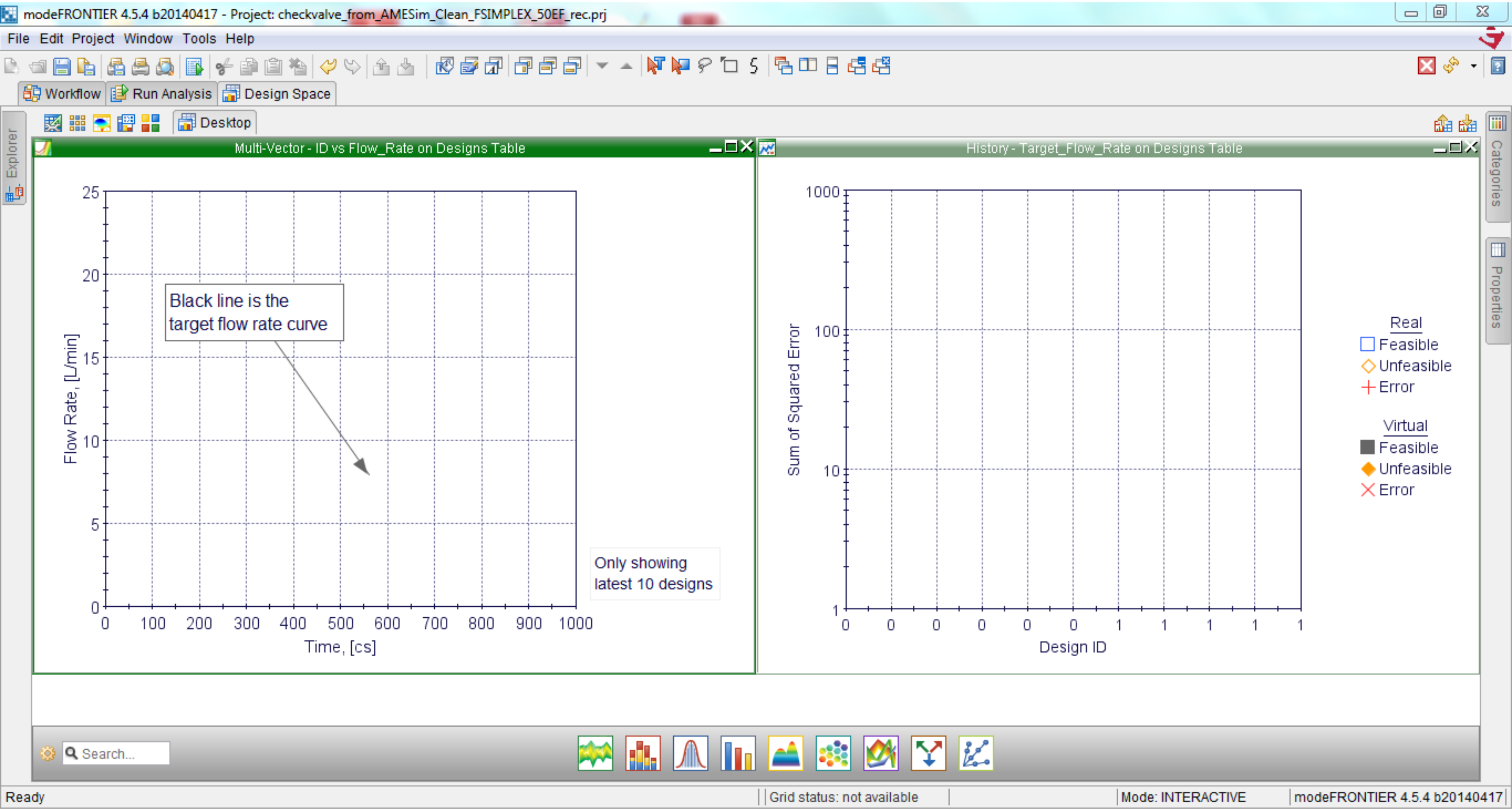
Constraints added to ensure slopes of three linear segments of the curve are within ±20% of target (speed-up convergence);

Check Valve: FAST-SIMPLEX Starting Population

FAST-SIMPLEX started from 6 Uniform Latin Hypercube (ULH) DOE points

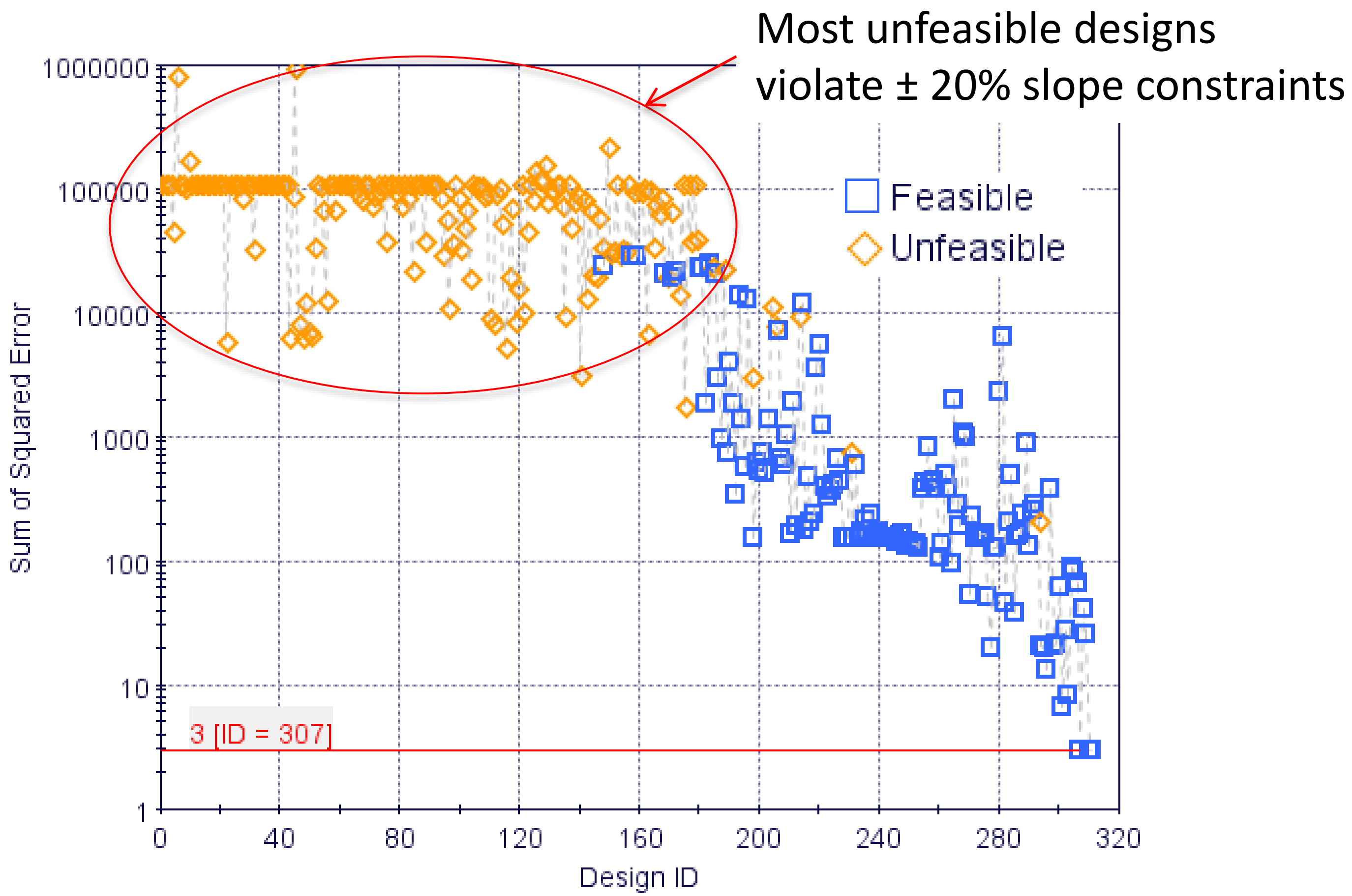


Check Valve: FAST-SIMPLEX Convergence



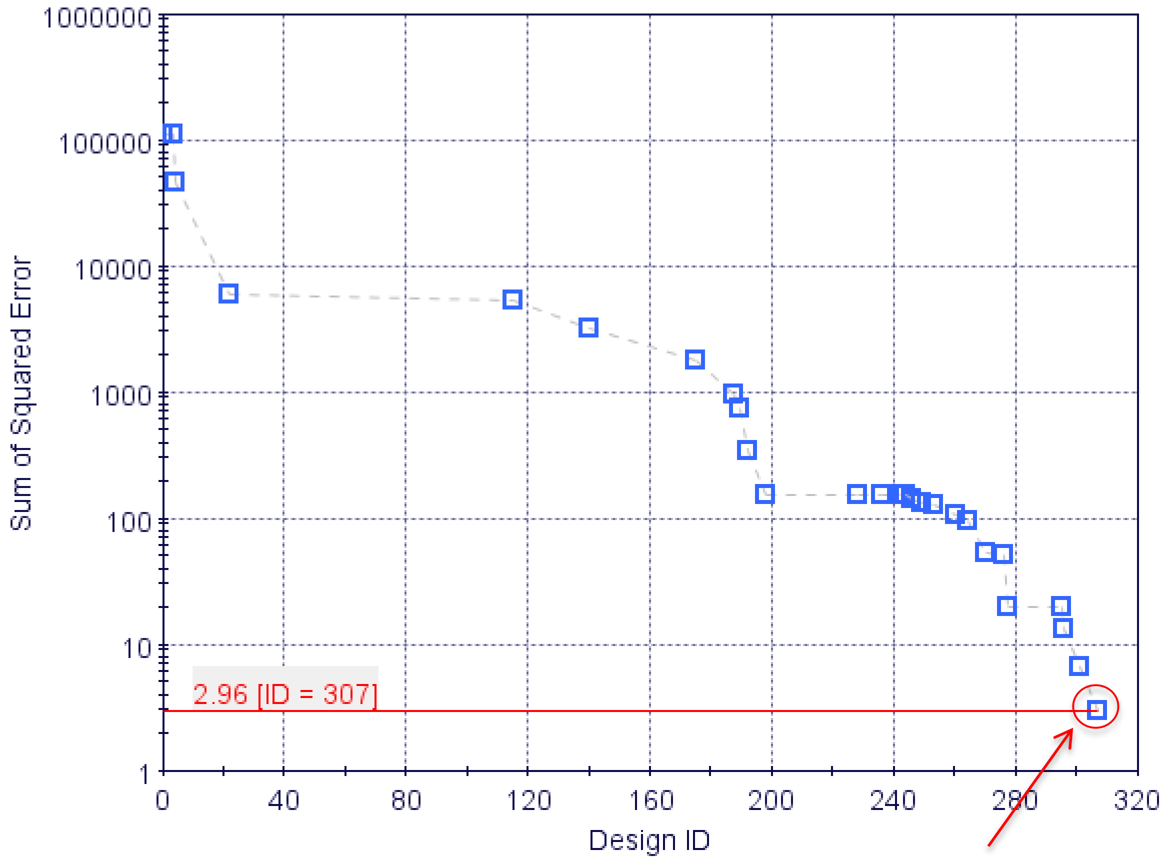
Check Valve: FAST-SIMPLEX Convergence

FAST-SIMPLEX history:



Check Valve: FAST-SIMPLEX Convergence

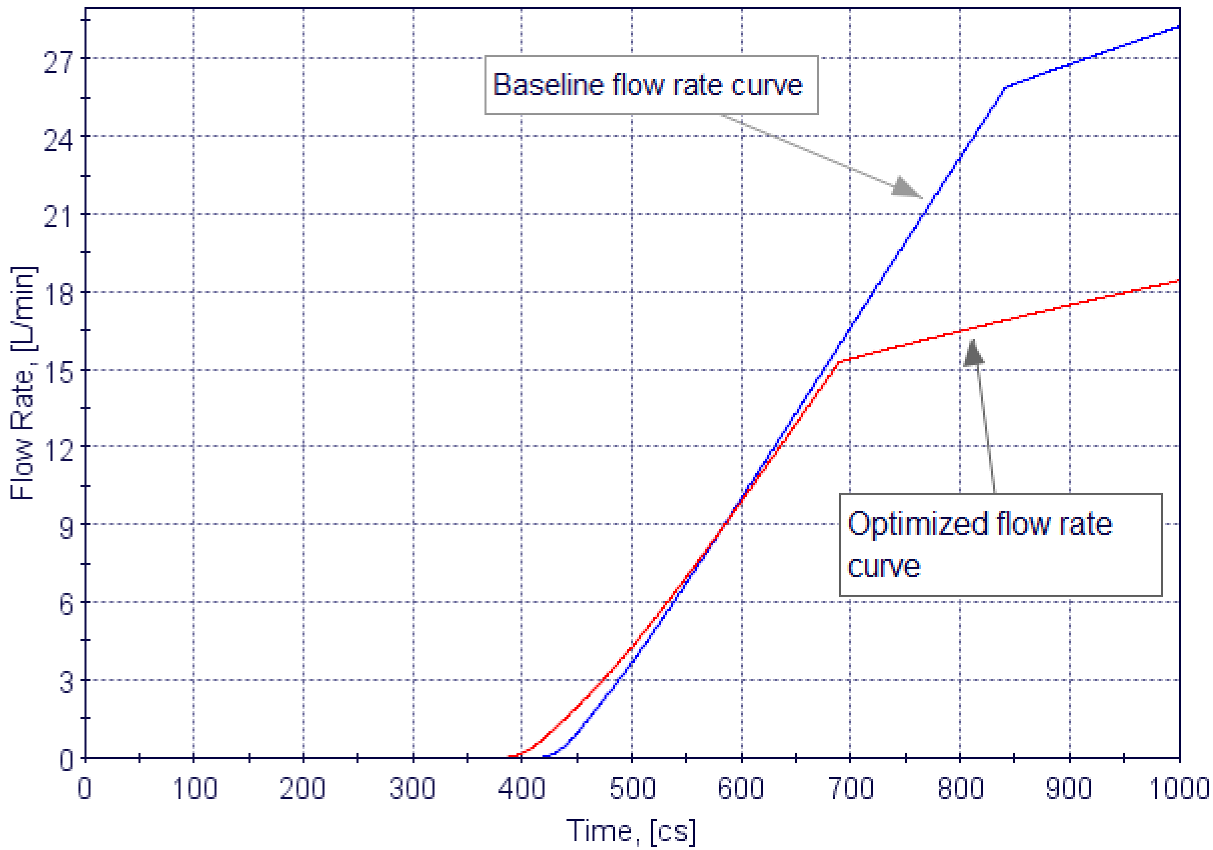
FAST-SIMPLEX history (showing improved designs):



Converged to optimum in 308 evaluations

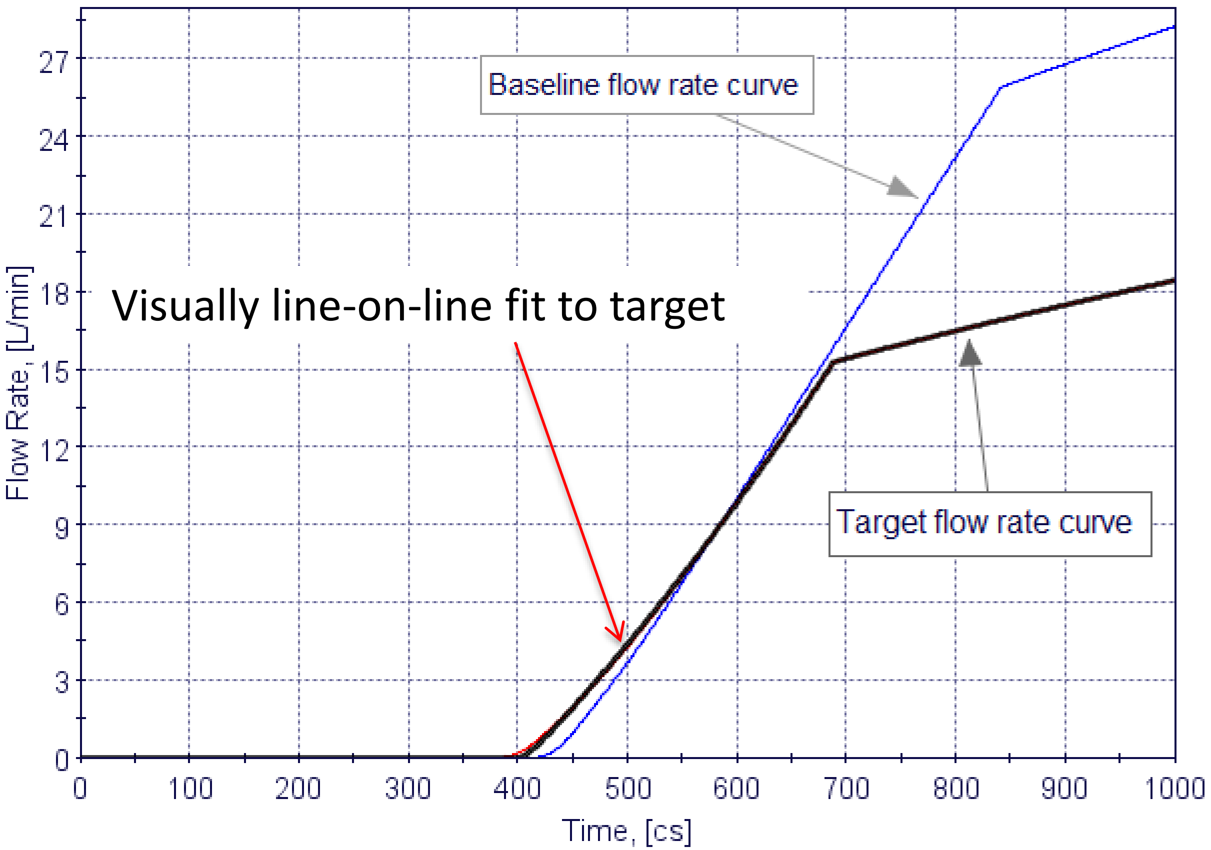
Check Valve Optimization: LMA

Optimization convergence:



Check Valve Optimization: FAST-SIMPLEX

Optimized flow rate comparison:



Check Valve: Result Comparison

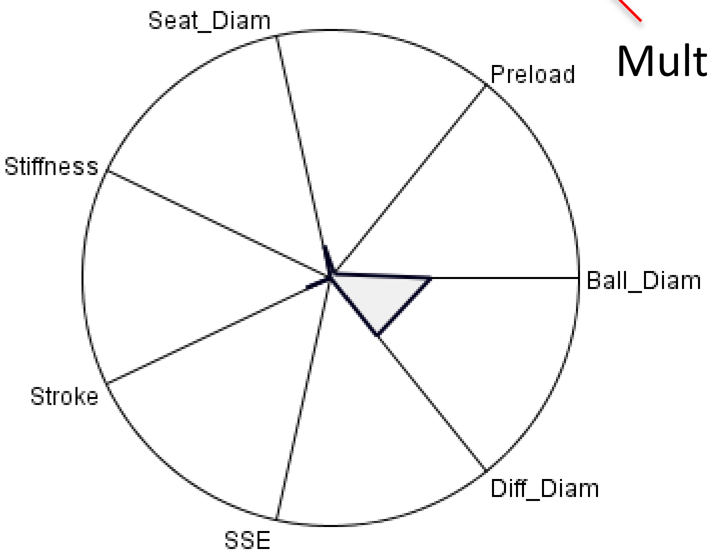
Levenberg-Marquardt

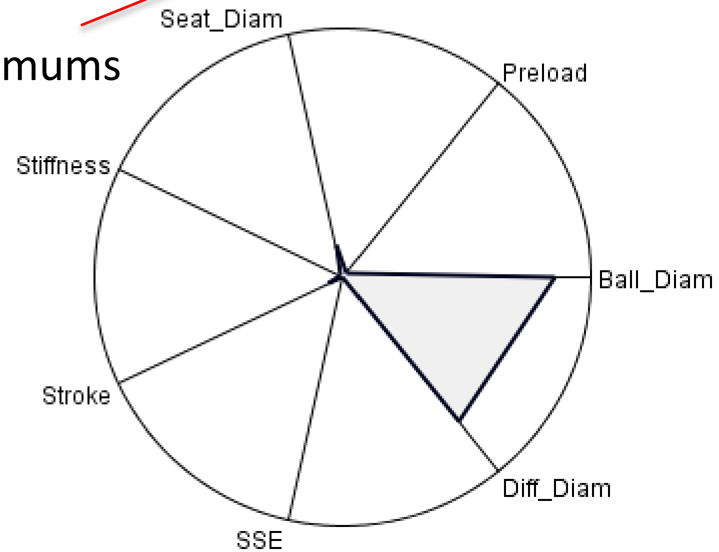
Variable	Value
Spring Preload, *N*	2.33
Spring Stiffness, *N/mm*	0.450
Stroke Length, *mm*	2.00
Ball Diameter, *mm*	12.9
Seat Diameter, *mm*	4.04
SSE	**2.34**

FAST-SIMPLEX

Variable	Value
Spring Preload, *N*	2.32
Spring Stiffness, *N/mm*	1.01
Stroke Length, *mm*	1.59
Ball Diameter, *mm*	25.8
Seat Diameter, *mm*	4.04
SSE	**2.96**

Multiple local optimums





Example 2

DEMO PARALLEL HYBRID VEHICLE

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Example 2: Parallel Hybrid Vehicle

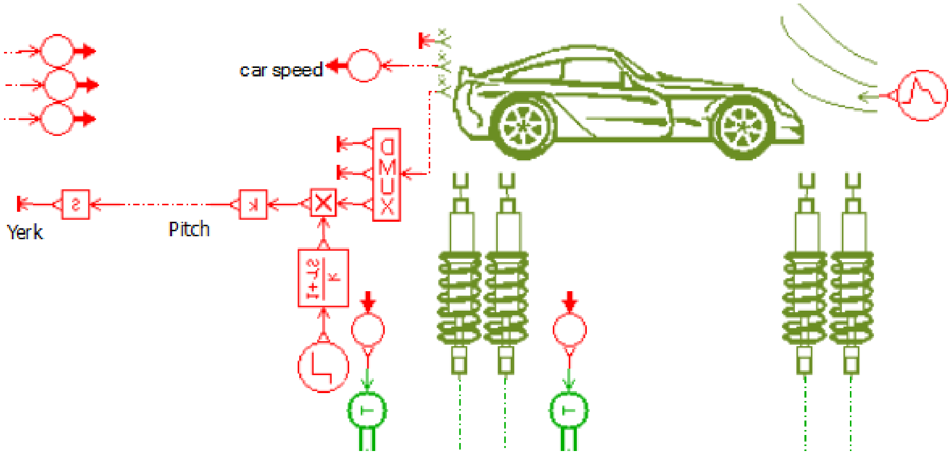
Parallel Hybrid: Problem Description

4 Input Variables:

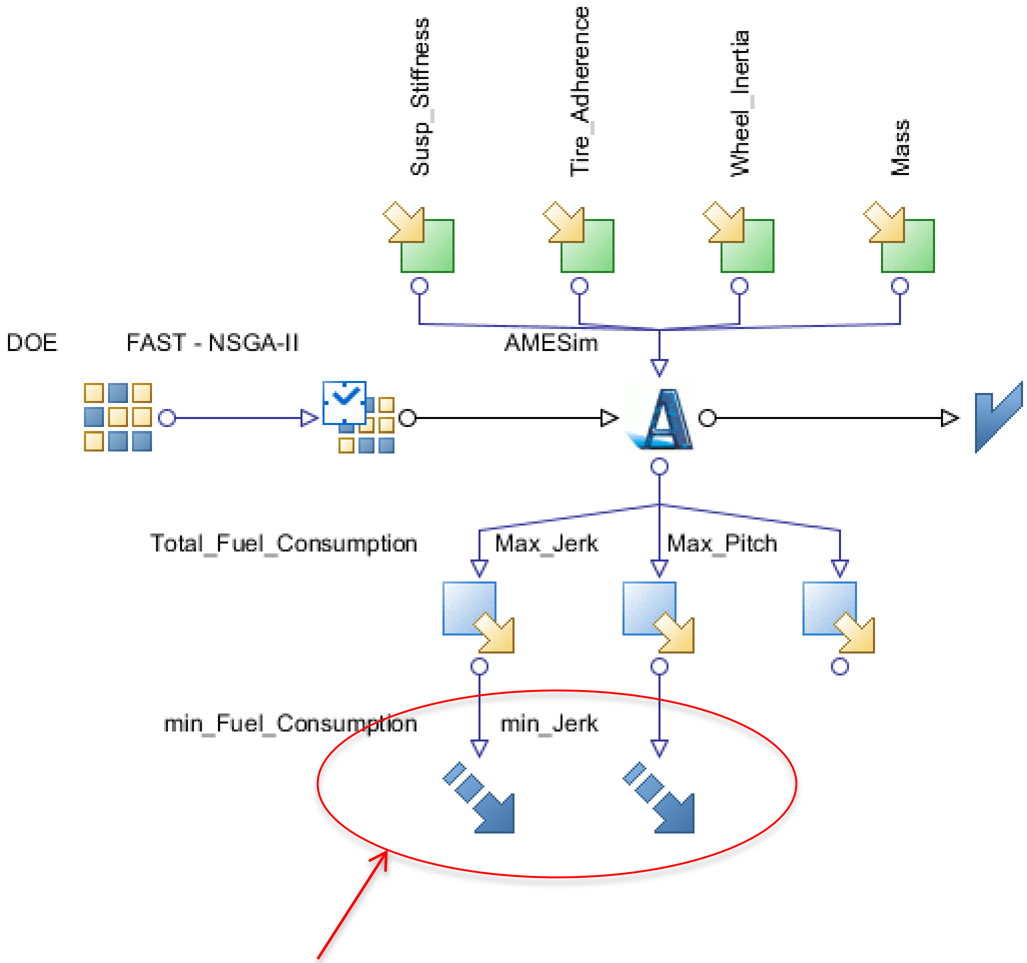
- Suspension Stiffness ∈ [5000, 15000] N/m
- Tire Adherence Coefficient ∈ [0.5, 1.5]
- Wheel Inertia ∈ [0.35, 4.0] kg·m²
- Vehicle Mass ∈ [1250, 1550] kg

Objectives:

- **Minimize** the **total fuel consumption**
- **Minimize** the maximum **jerk**



Parallel Hybrid Vehicle: Workflow



Pure multi-objective optimization defined

Parallel Hybrid Vehicle: Strategies

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2 approaches used for this case:

- **DOE + Statistical Analysis**
  - 100 ULH DOE points
  - Correlation
  - Main effect
  - Smoothing-spline ANOVA (SS-ANOVA)
    - ANOVA decomposition applied to smoothing spline fit to data
- 3 optimization algorithms used:
    - **FAST-NSGA-II**: FAST strategy using non-dominated sorting genetic algorithm (NSGA) used as optimizer
    - **HYBRID**: Combination of gradient based and genetic algorithm optimizers
    - **NSGA-II**: Regular NSGA used as optimizer
  - Starting population: 10 ULH DOE points and ran a total of 1000 evaluations

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Example 2: Parallel Hybrid Vehicle Statistical Analysis

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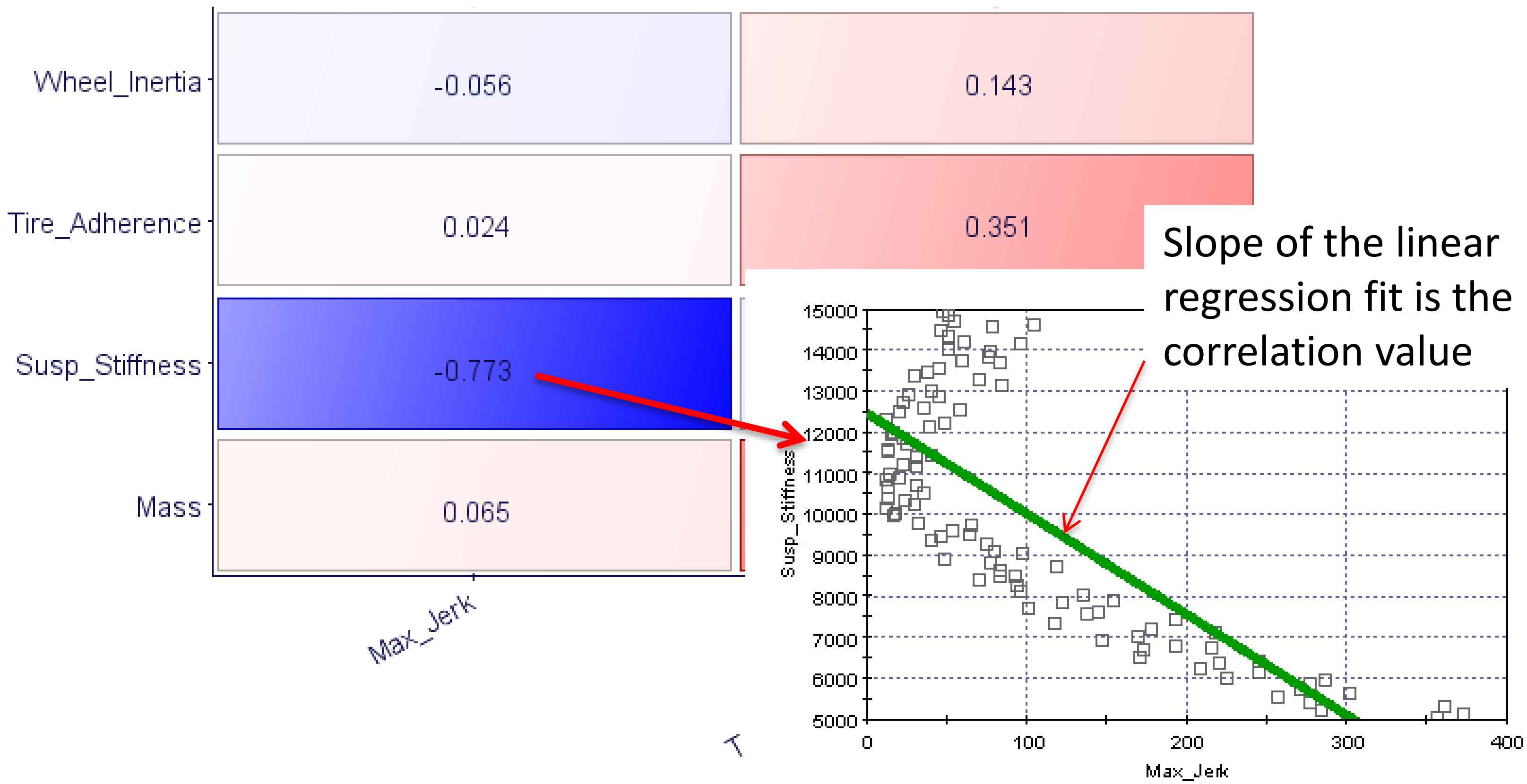
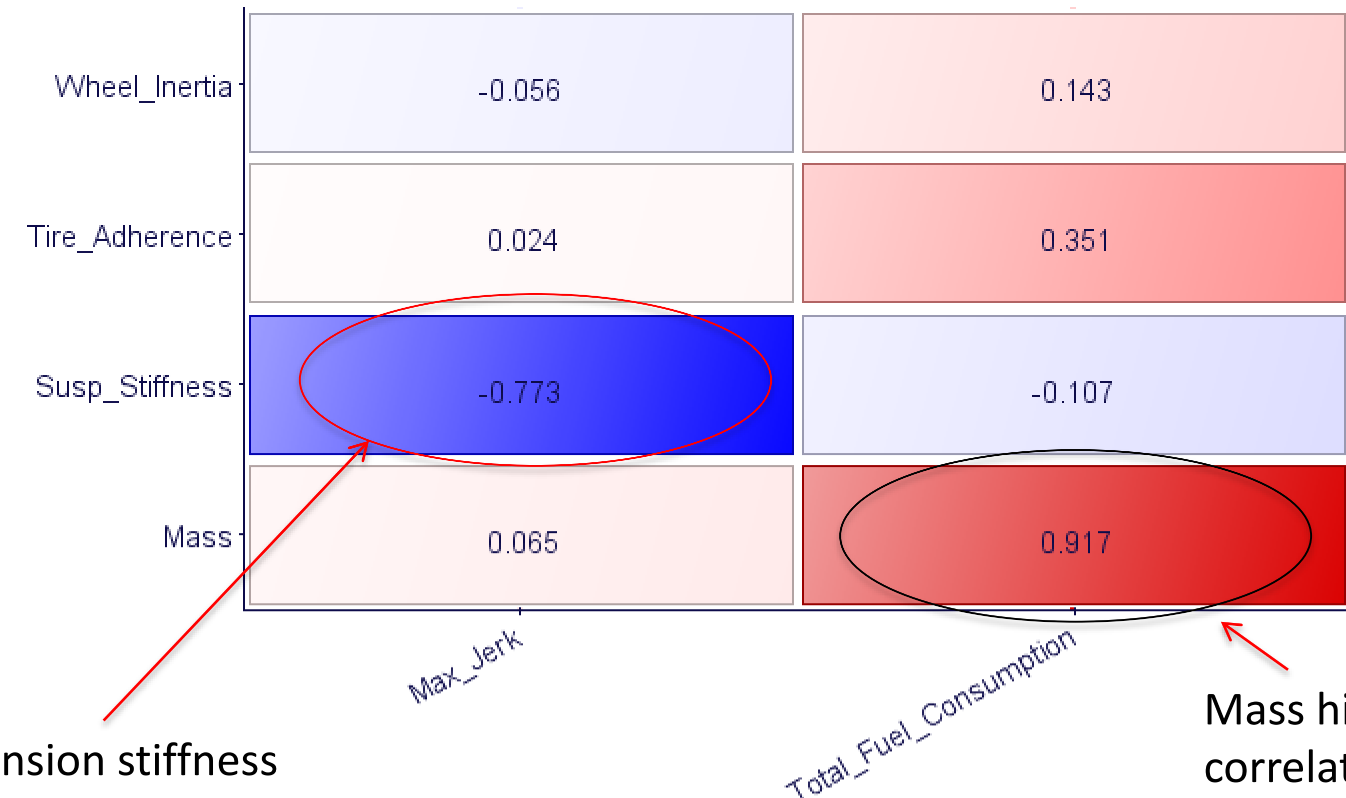
Correlation values:

- Values represent the slope of a normalized linear regression fit
- Max value 1.0, Min value -1.0



Correlation values:

- Values represent the slope of a normalized linear regression fit
- Max value 1.0, Min value -1.0



Suspension stiffness highly **inversely** correlated with jerk

Mass highly **directly** correlated with fuel consumption

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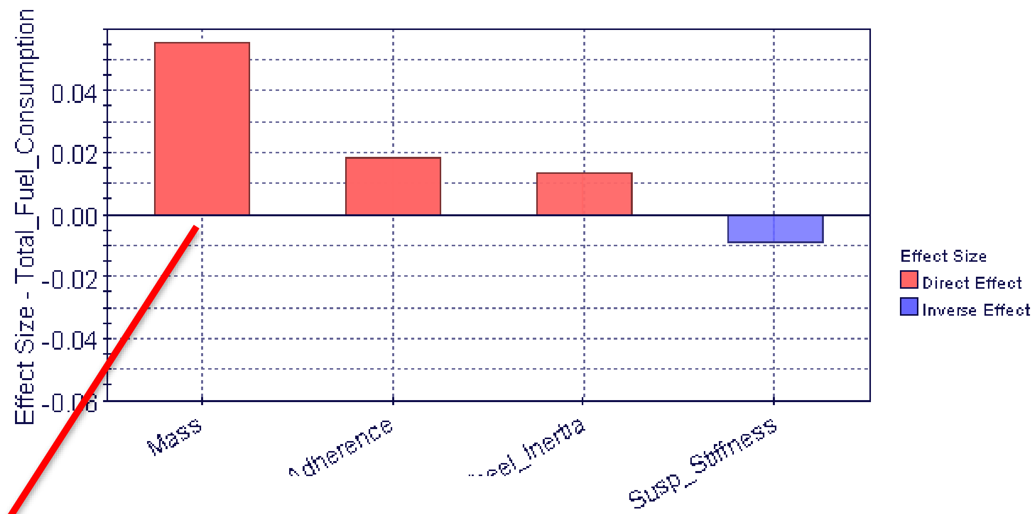
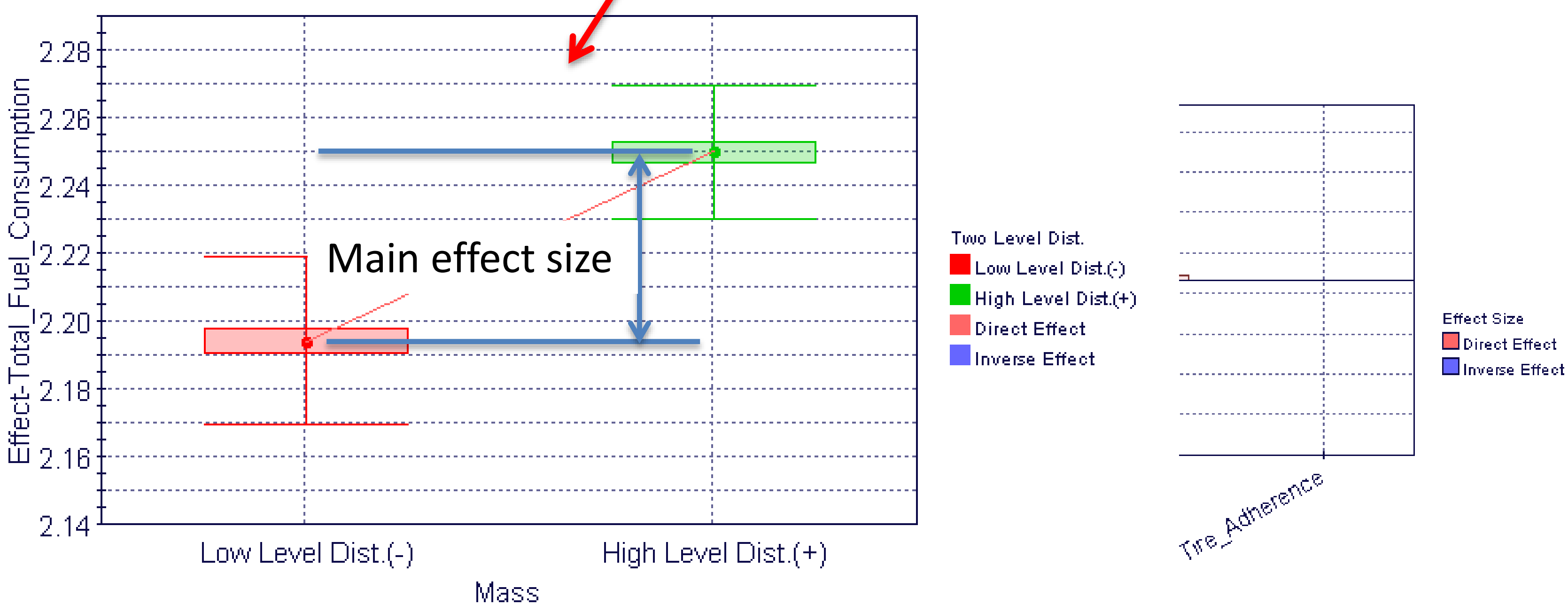
Main effect sizes:

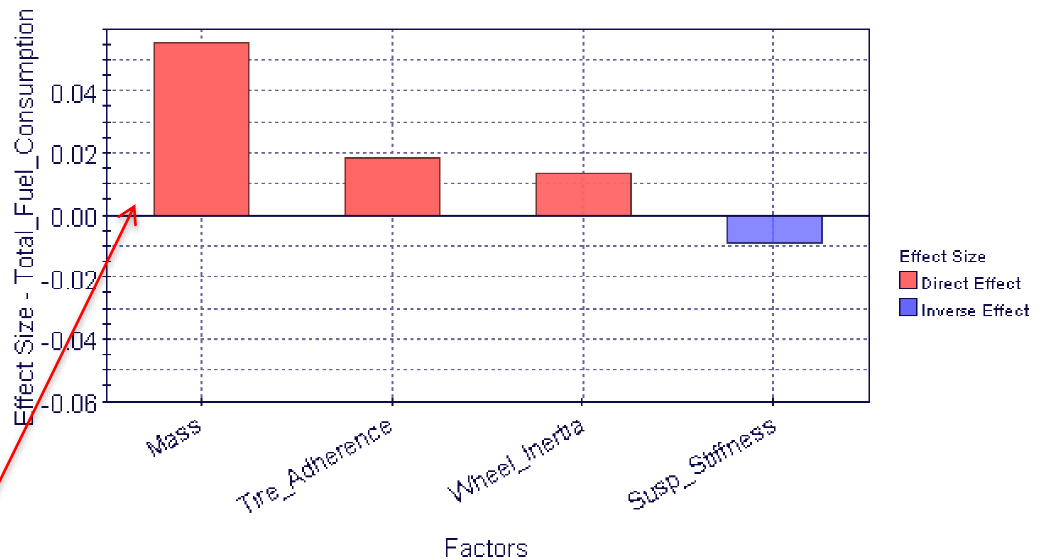
- Main effect size is the difference between the means of the lower half and higher half of the distributions



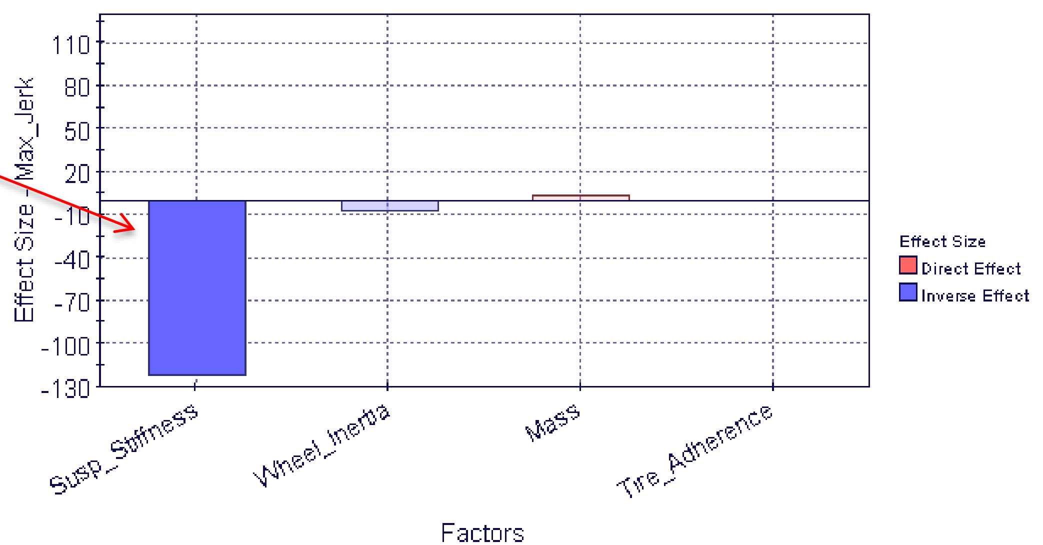


Main effect sizes:

- Main effect is the difference between the means of the lower half and higher half of the distributions



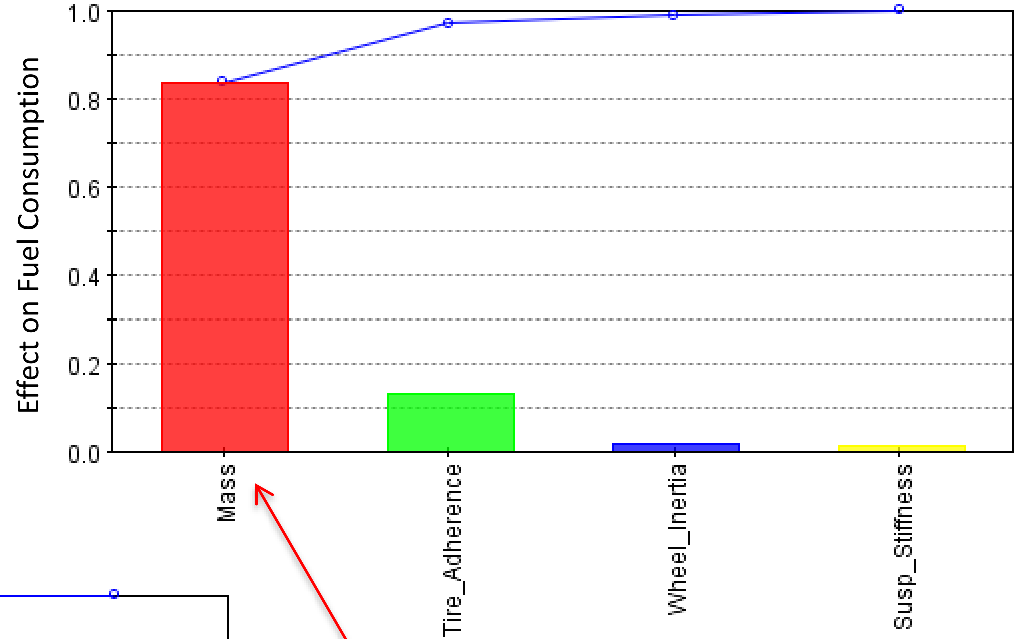
Mass and suspension stiffness factors have the most effect on fuel consumption and jerk respectively



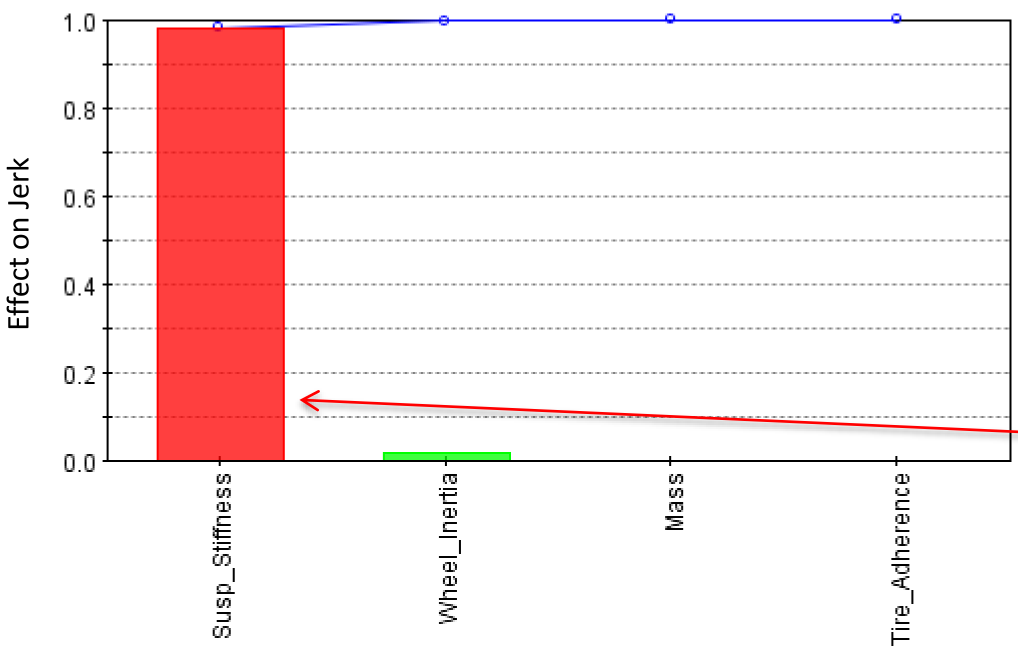
Parallel Hybrid Vehicle: Statistical Analysis

SS-ANOVA:

- ANOVA decomposition applied to smoothing spline fit
- All factor effects sum to 1



Mass contributes over **80%** of the total effect on fuel consumption



Suspension stiffness contributes over **95%** of the total effect on jerk

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Example 2: Parallel Hybrid Vehicle Optimization

Parallel Hybrid Vehicle: Optimization Run Statistics

Hardware:
- Dell Latitiude w/ Intel Core i7

Software:
- modeFRONTIER v4.5.4
- AMESim v13.0

Run times:

• Number of parallel evaluation:	1
• Number of total evaluations:	1000
• Average single evaluation time:	6-7 sec
• Total runtime:	≈3 hrs.

Parallel Hybrid Vehicle: Optimization Convergence

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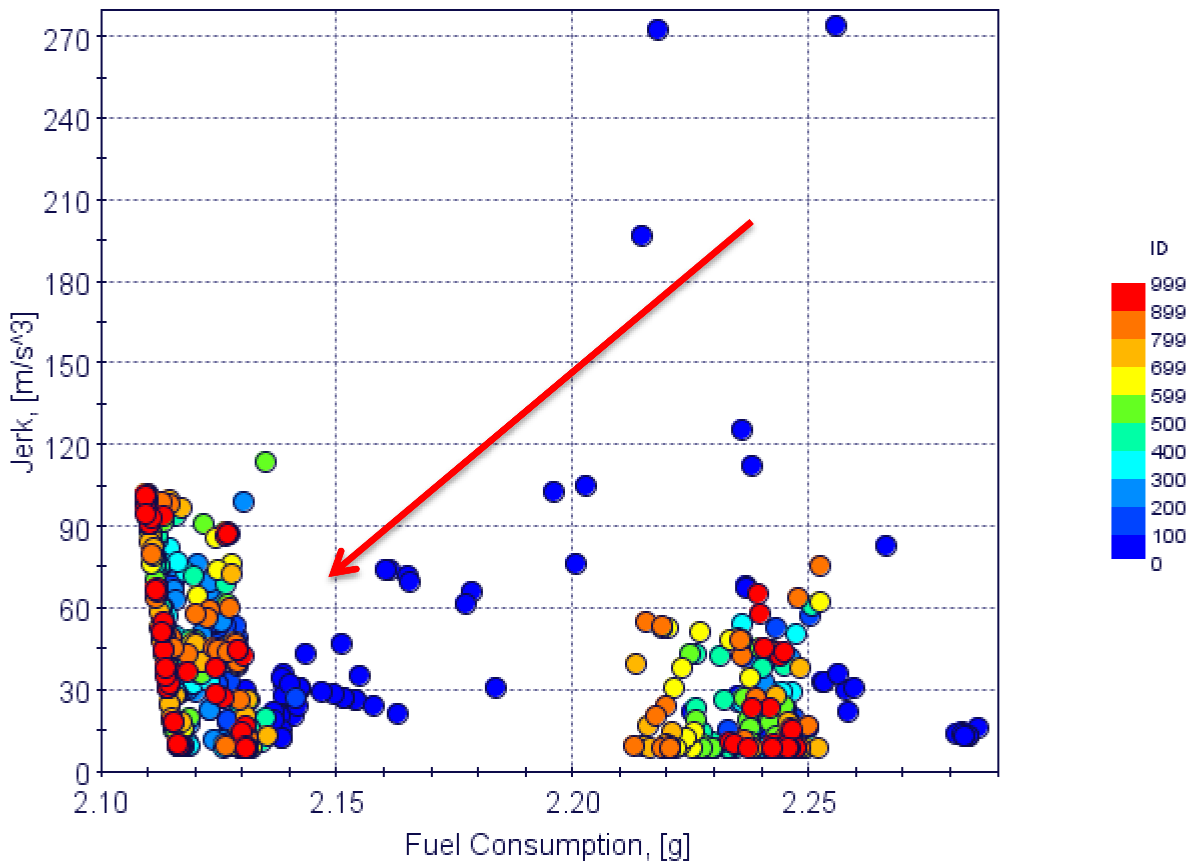
NSGA-II History:



Parallel Hybrid Vehicle: Optimization Results

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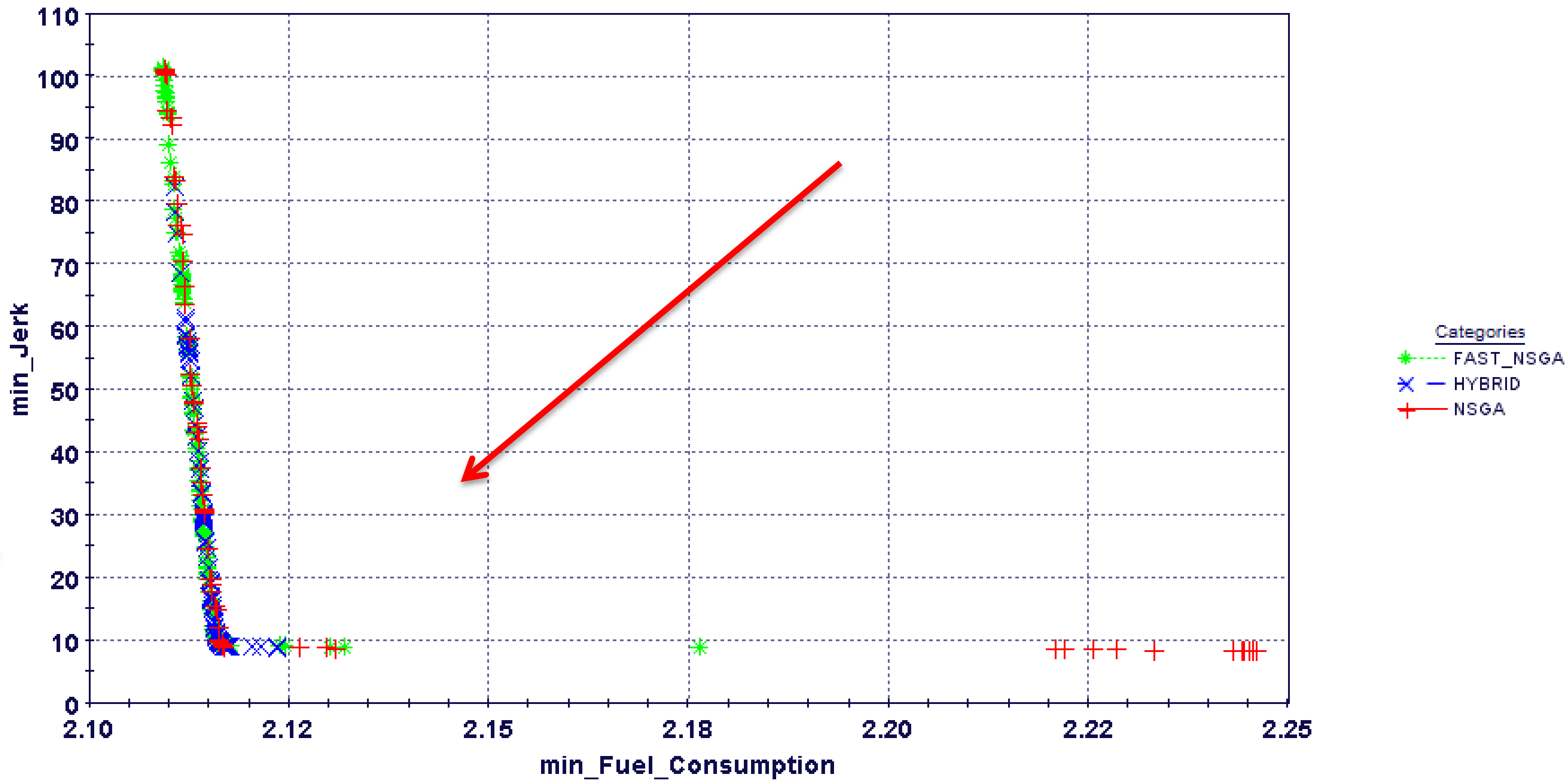
Pareto designs for the 3 optimization algorithms:



Pareto at [illegible]000 evaluations

Parallel Hybrid Vehicle: Optimization Results

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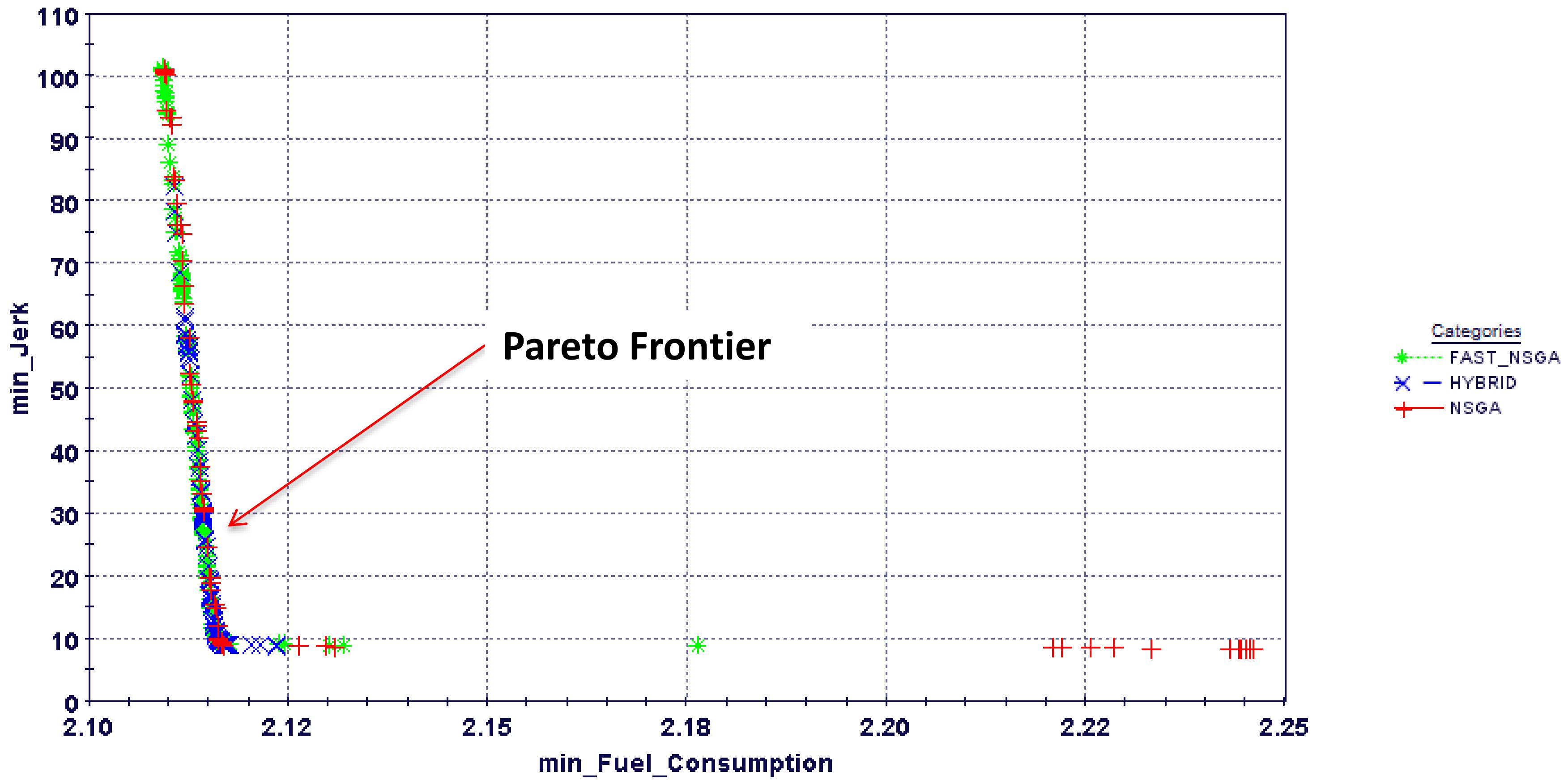
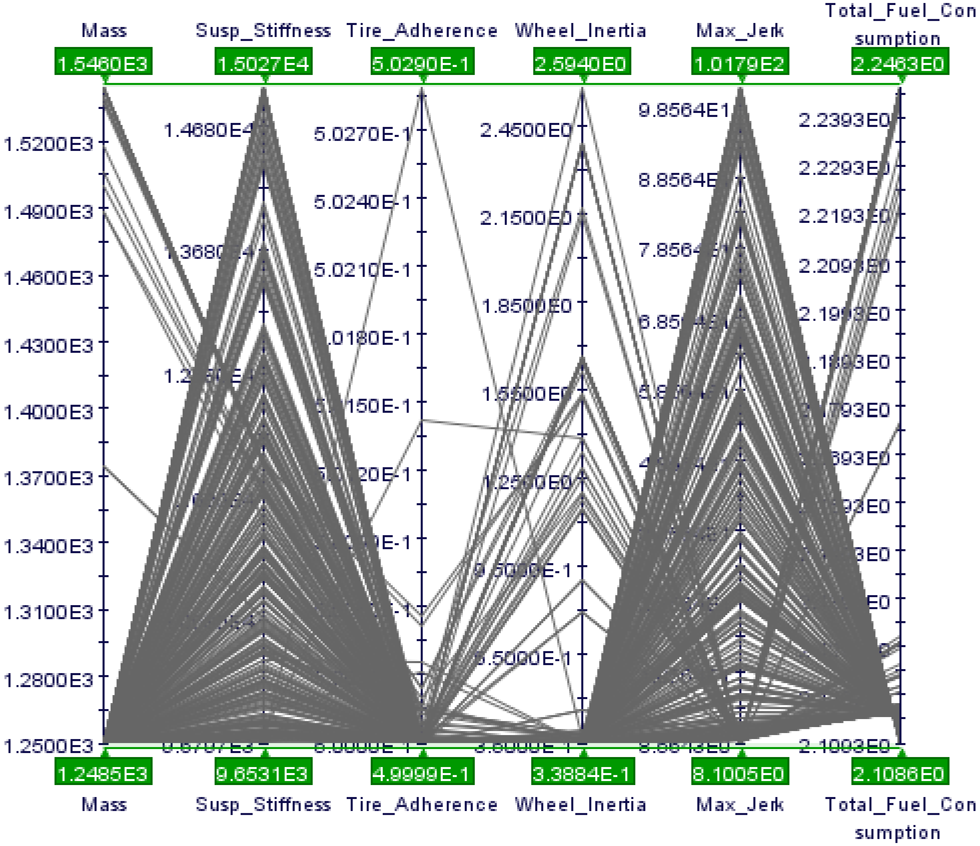
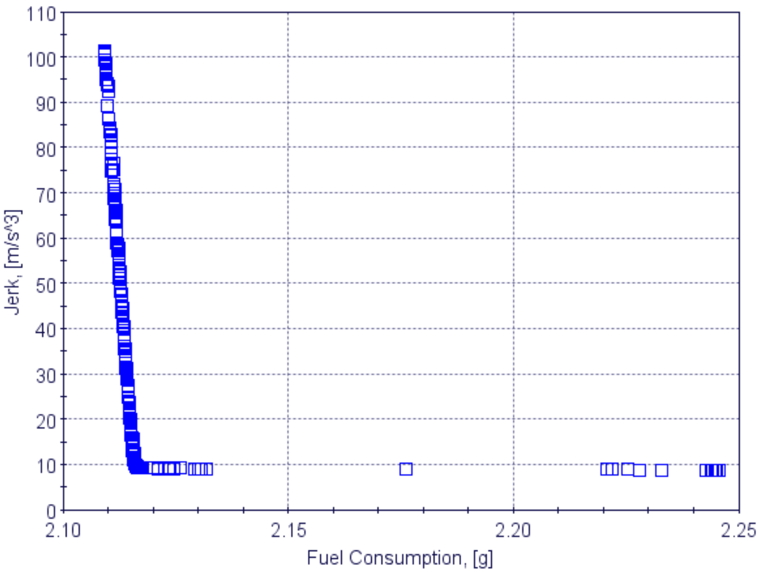
Pareto designs for the 3 optimization algorithms:



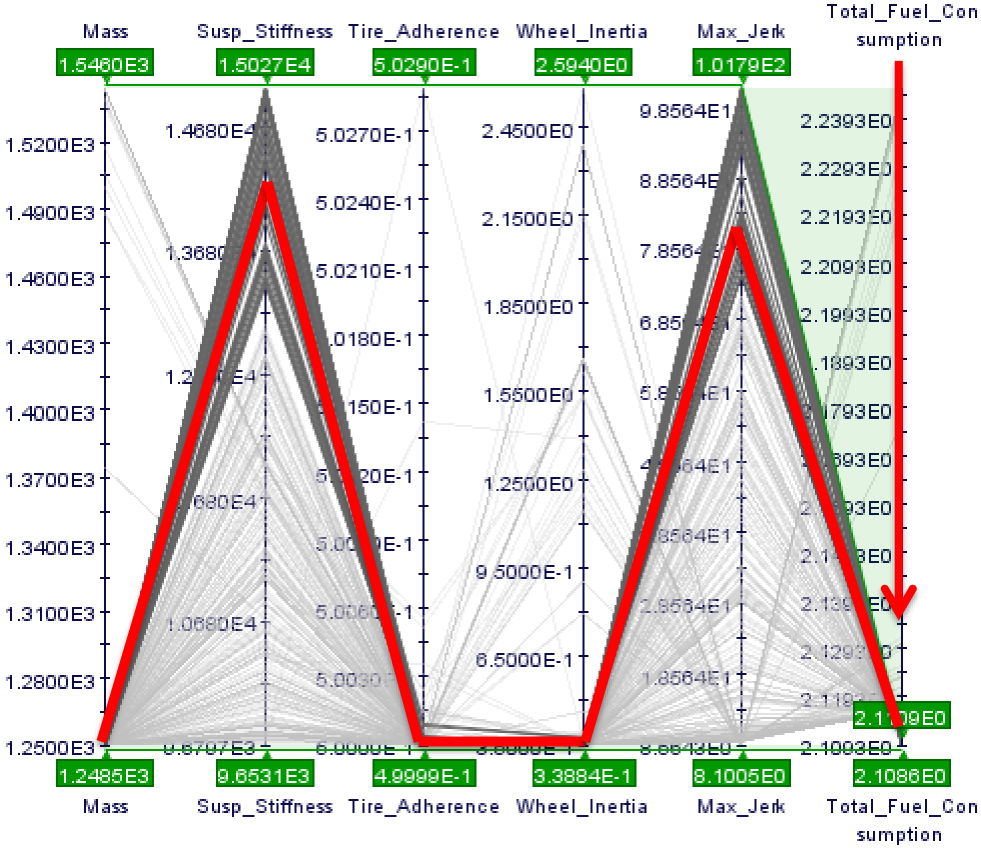
Parallel Hybrid Vehicle: Optimization Results

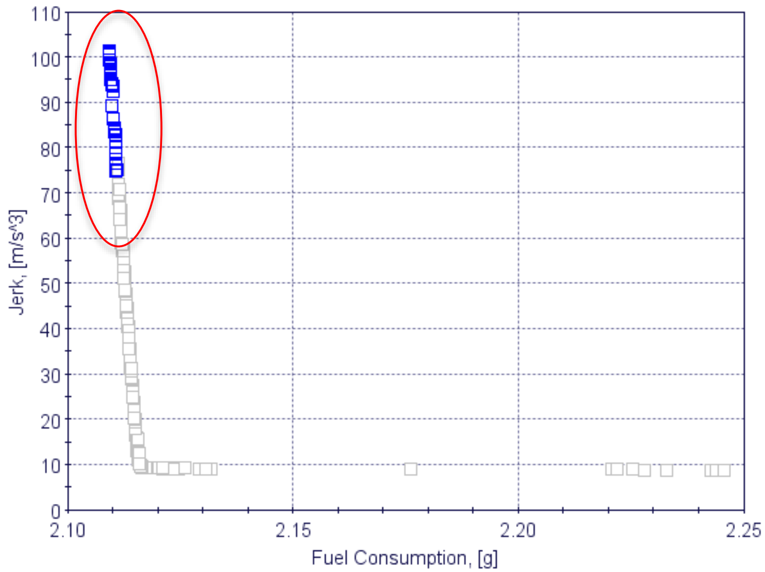
Trade-off analysis:





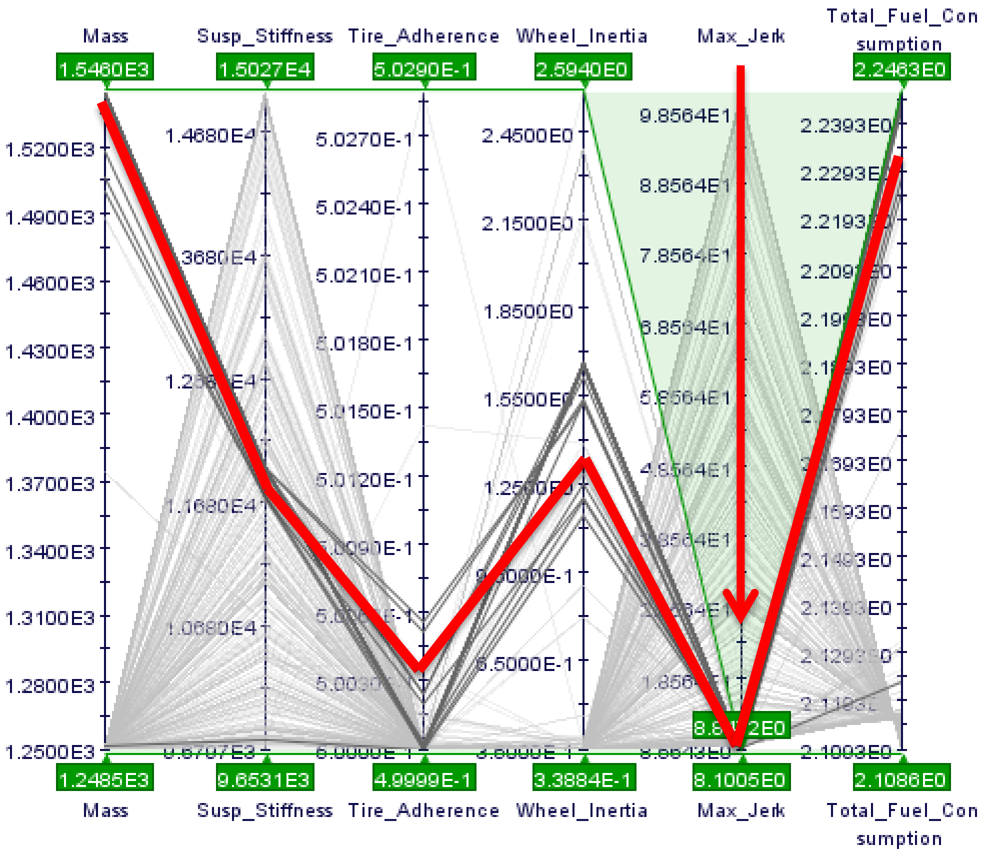
Trade-off analysis:

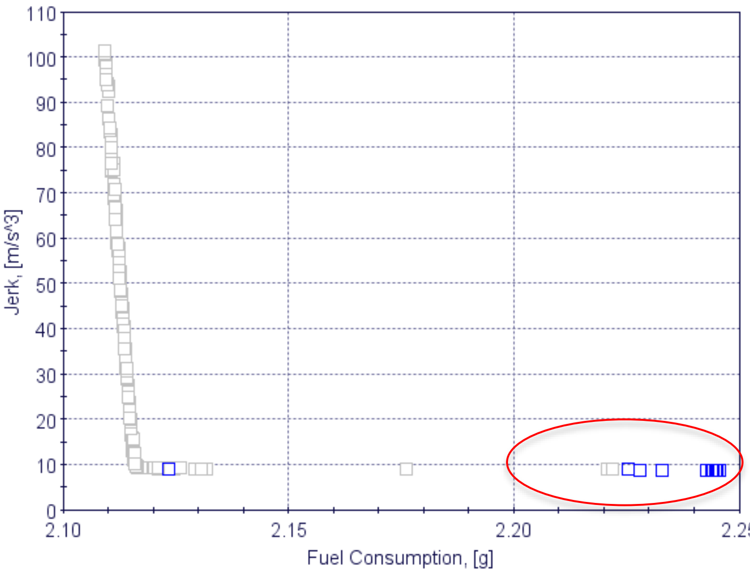




Parallel Hybrid Vehicle: Optimization Results

Trade-off analysis:





Parallel Hybrid Vehicle: Optimization Results

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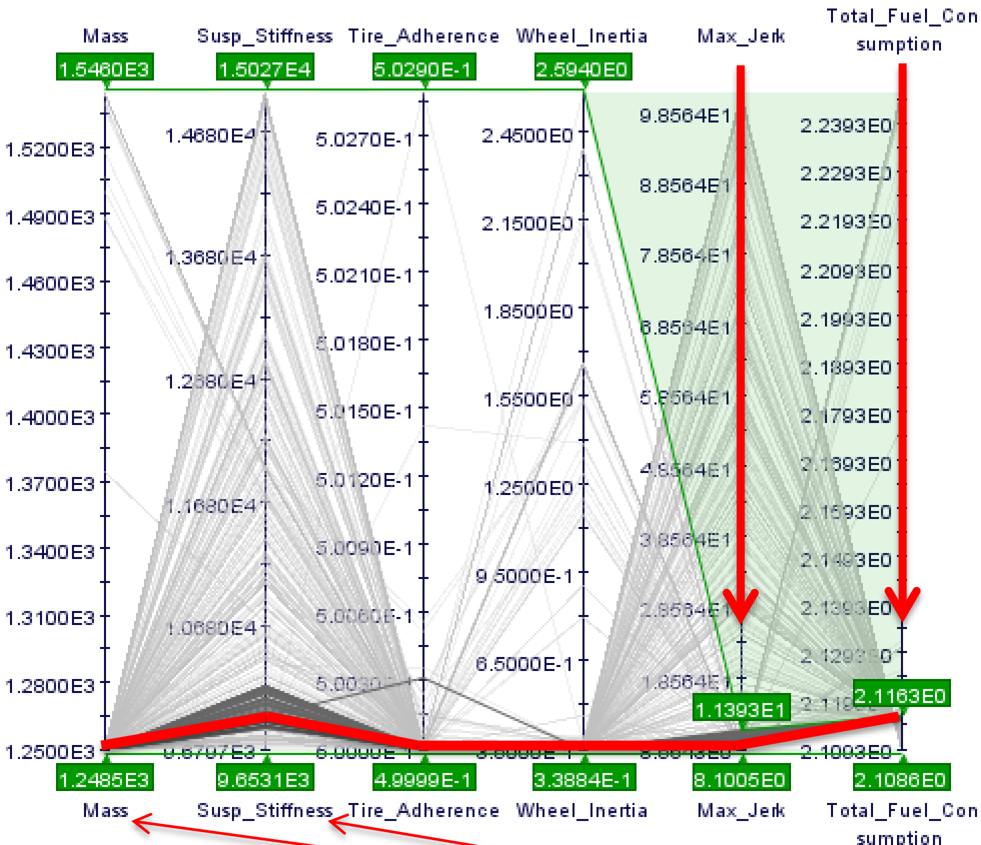
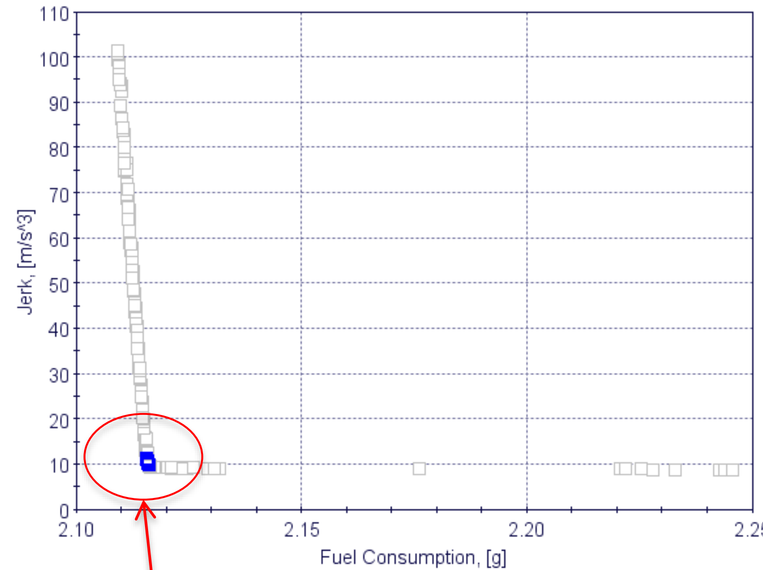
Trade-off analysis:





Designs resulting from low mass and low suspension stiffness (statistical analysis conclusion)

Conclusions

- modeFRONTIER provides an easy to use interface to integrate AMESim models for (collaborative) MDO
- Get more out of your AMESim models by exploring the full design space and visualize all options
- Automate your simulation process by integrating AMESim with other analytical tools
- Very suitable for Model Based Systems Engineering

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Q & A