Improving Technology Development Through Systems Integration and Math-based Tools

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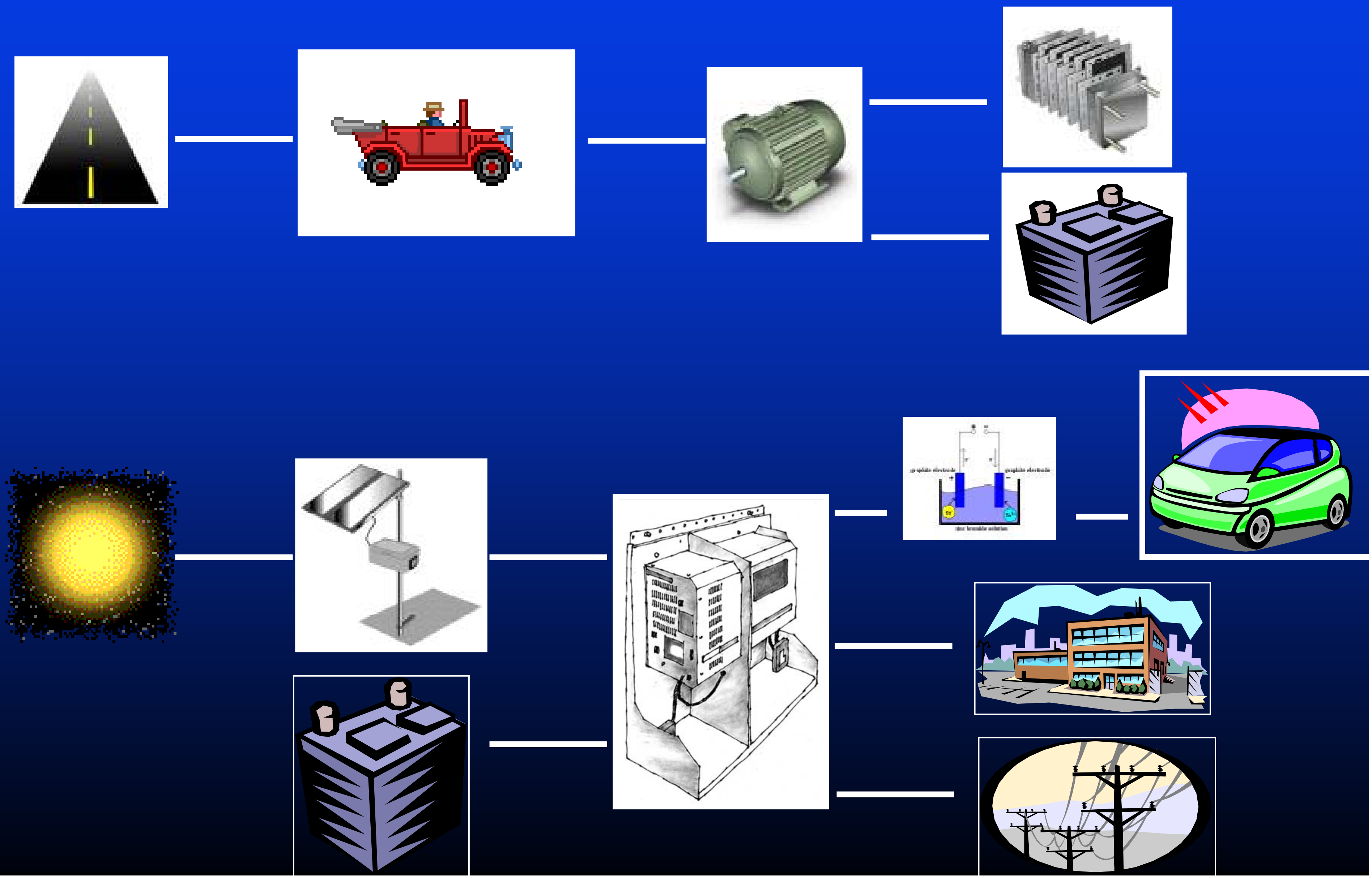
Technology Manager

National Renewable Energy Laboratory

Workshop on Systems Driven Approach for Inverter R&D

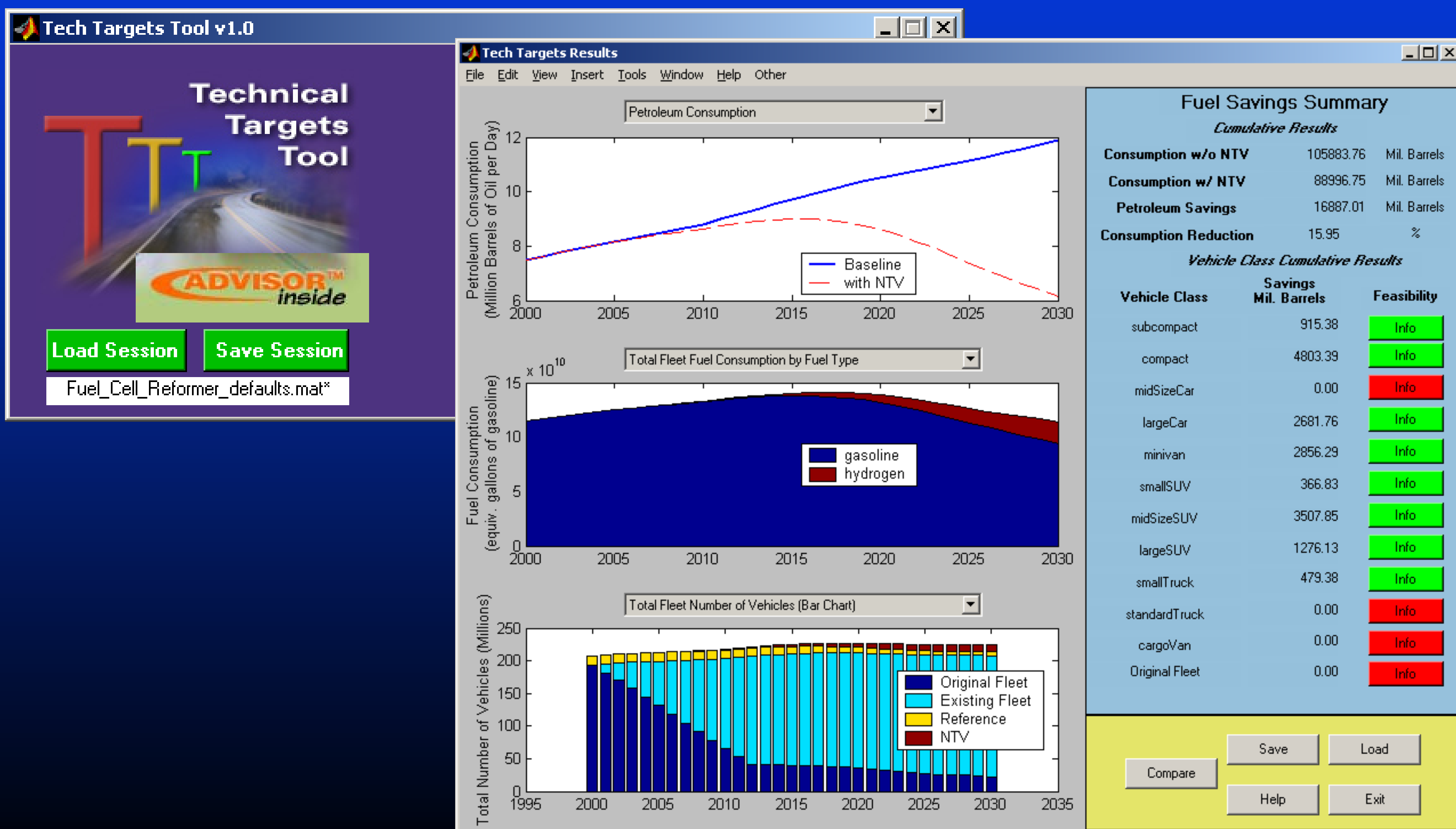
March 23, 2003

Systems Modeling Approach



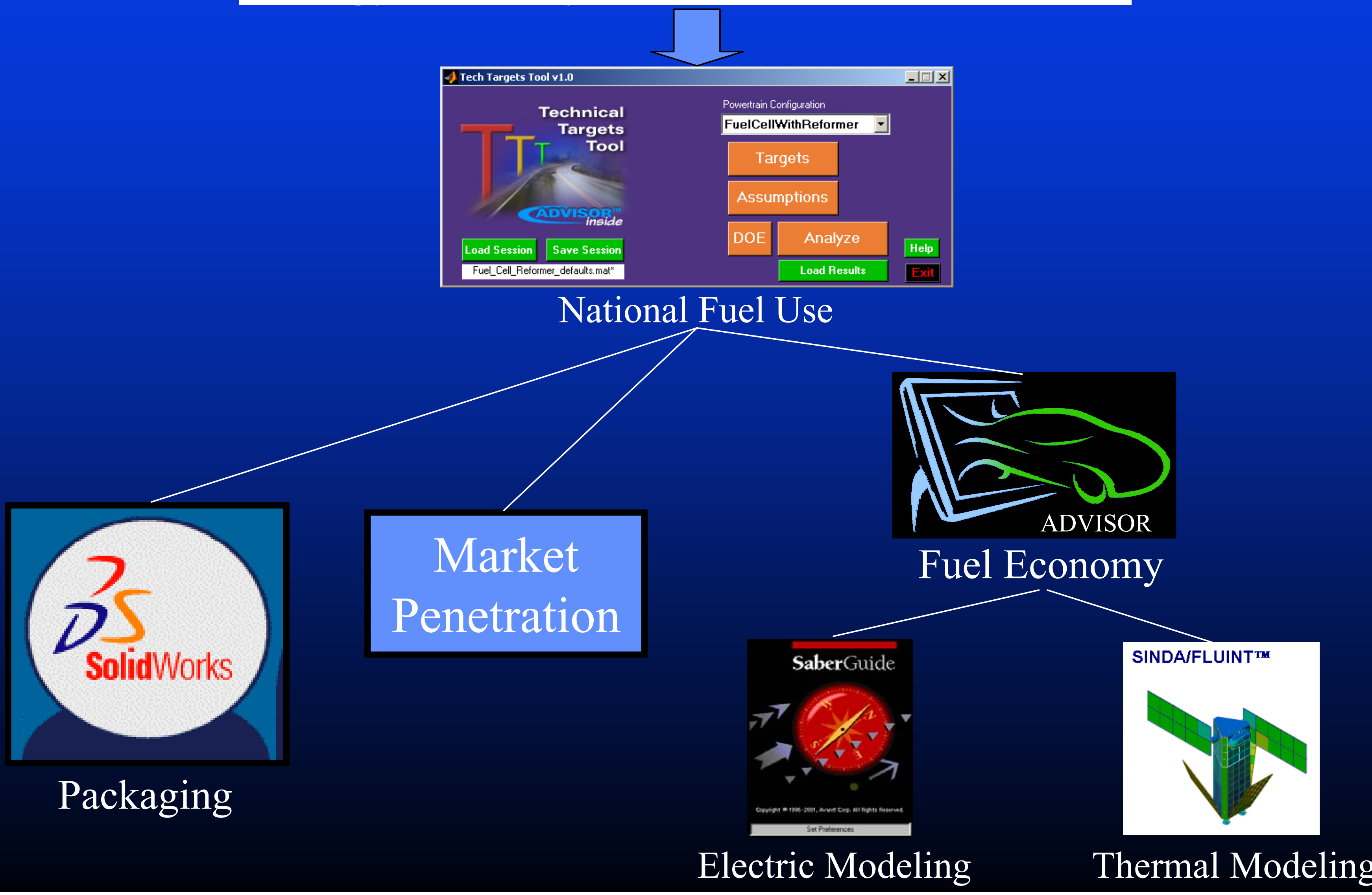
Approach to Vehicle Systems Analysis

- Map models to end goals



Vehicle Systems Analysis

Energy Security: Reduce Vehicle Oil Use



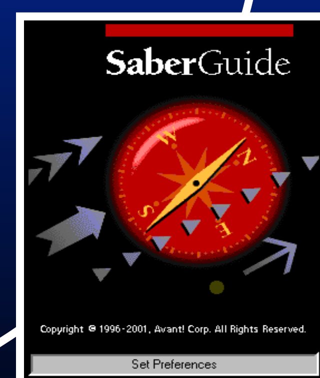
Vehicle Issues and Modeling Solutions

Issues

- Efficiency
- Cost
- Performance
- Thermal Management
- Packaging
- Safety
- Voltage regulation
- Emissions
- Configuration

ADVISOR

SolidWorks



Inverter Issues and Modeling Solutions

Electric Power Modeling

Issues

- Reliability
- Efficiency
- Cost
- Power quality
- Modularity
- Thermal management
- Packaging
- Safety
- Voltage regulation
- Equipment protection
- Islanding

Finite Element Analysis (FEA)

Continuous Fluid Dynamics (CFD)

Solid Modeling

What is a Automotive OEM company?

OEM

System Integration
- GM
- VW
- Toyota

1st Tier Supplier

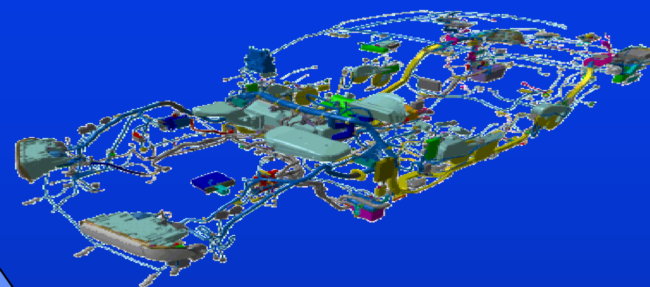
System House

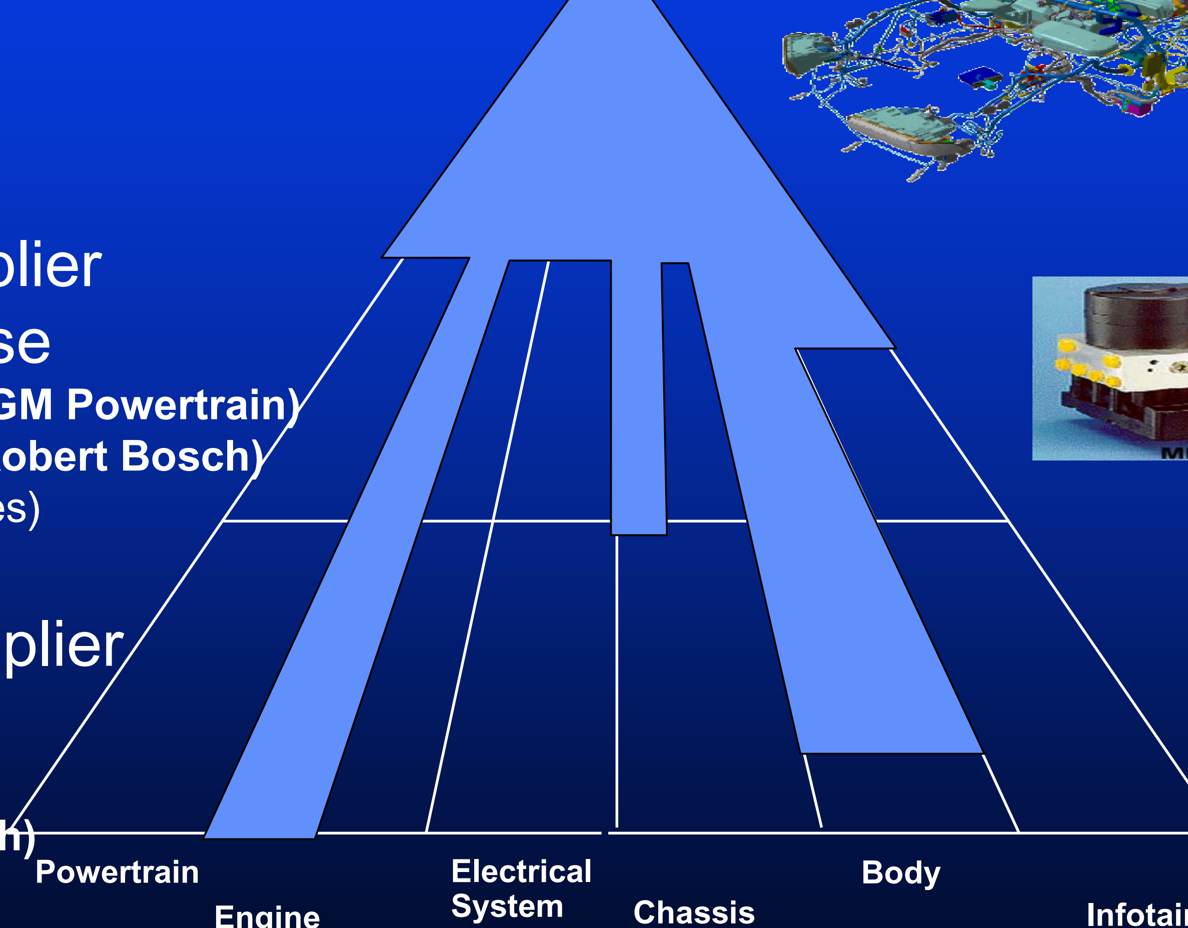
- **Powertrain (ZF, GM Powertrain)**
- **Power Supply (Robert Bosch)**
- Break (Conti Teves)

2nd Tier Supplier

Component

- **Sensor (Delphi)**
- **Generator (Bosch)**
- CAN (Infineon)



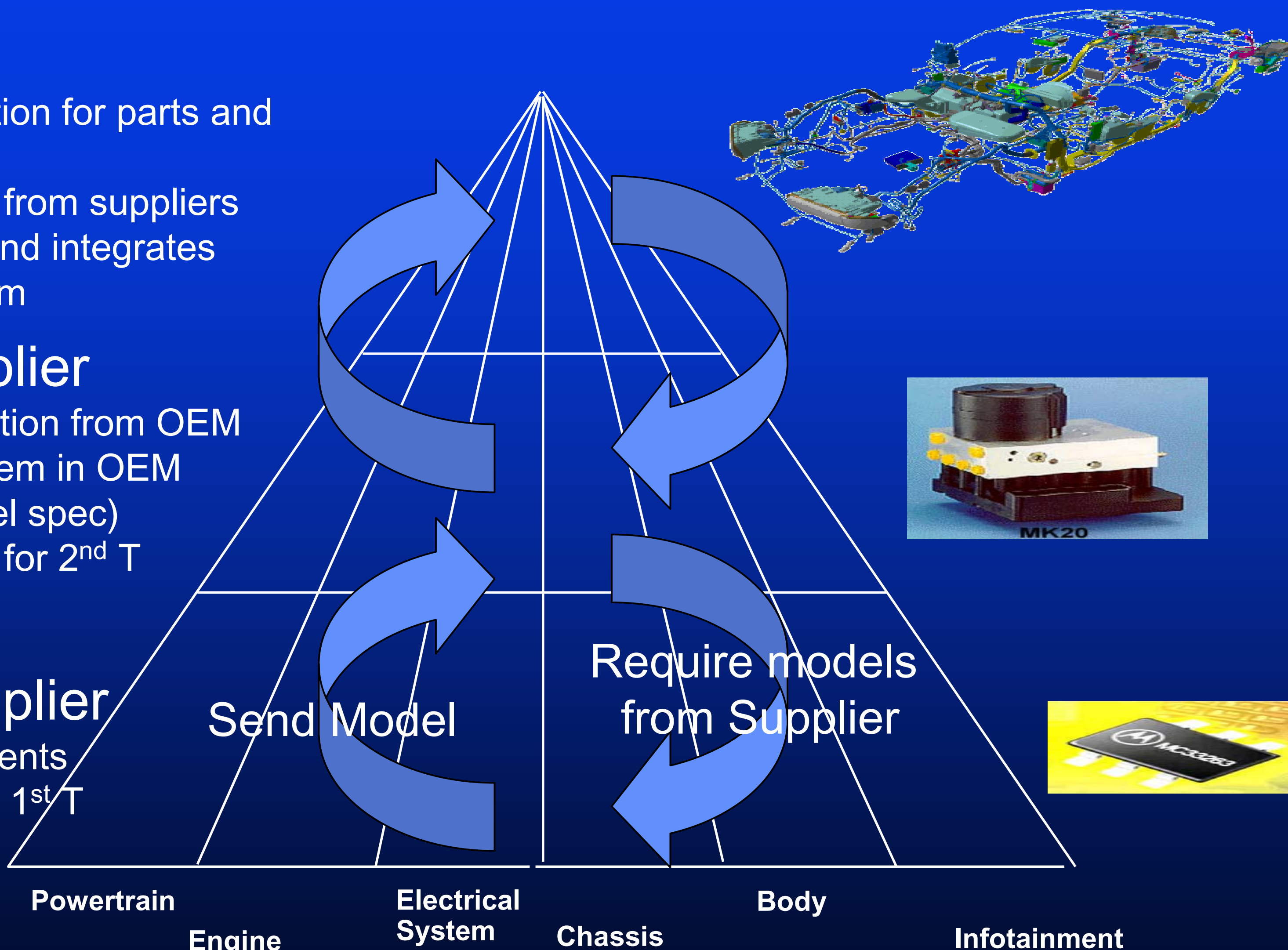


Model Exchange

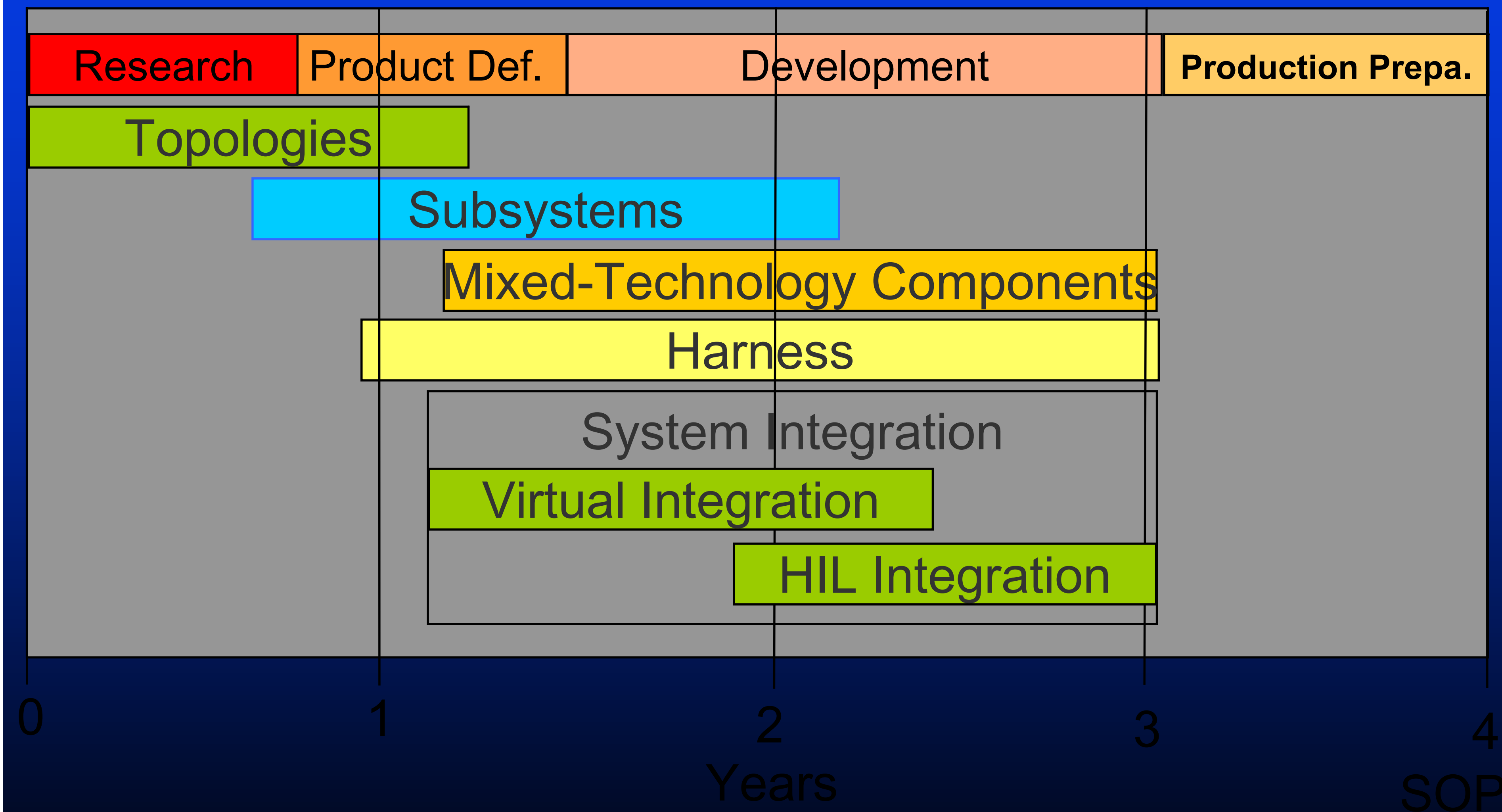
OEM
- Creates specification for parts and models
- Requests models from suppliers
- Collects models and integrates them to a subsystem

1st Tier Supplier
- receives specification from OEM
- testing of subsystem in OEM Specification (model spec)
- Requests models for 2nd T

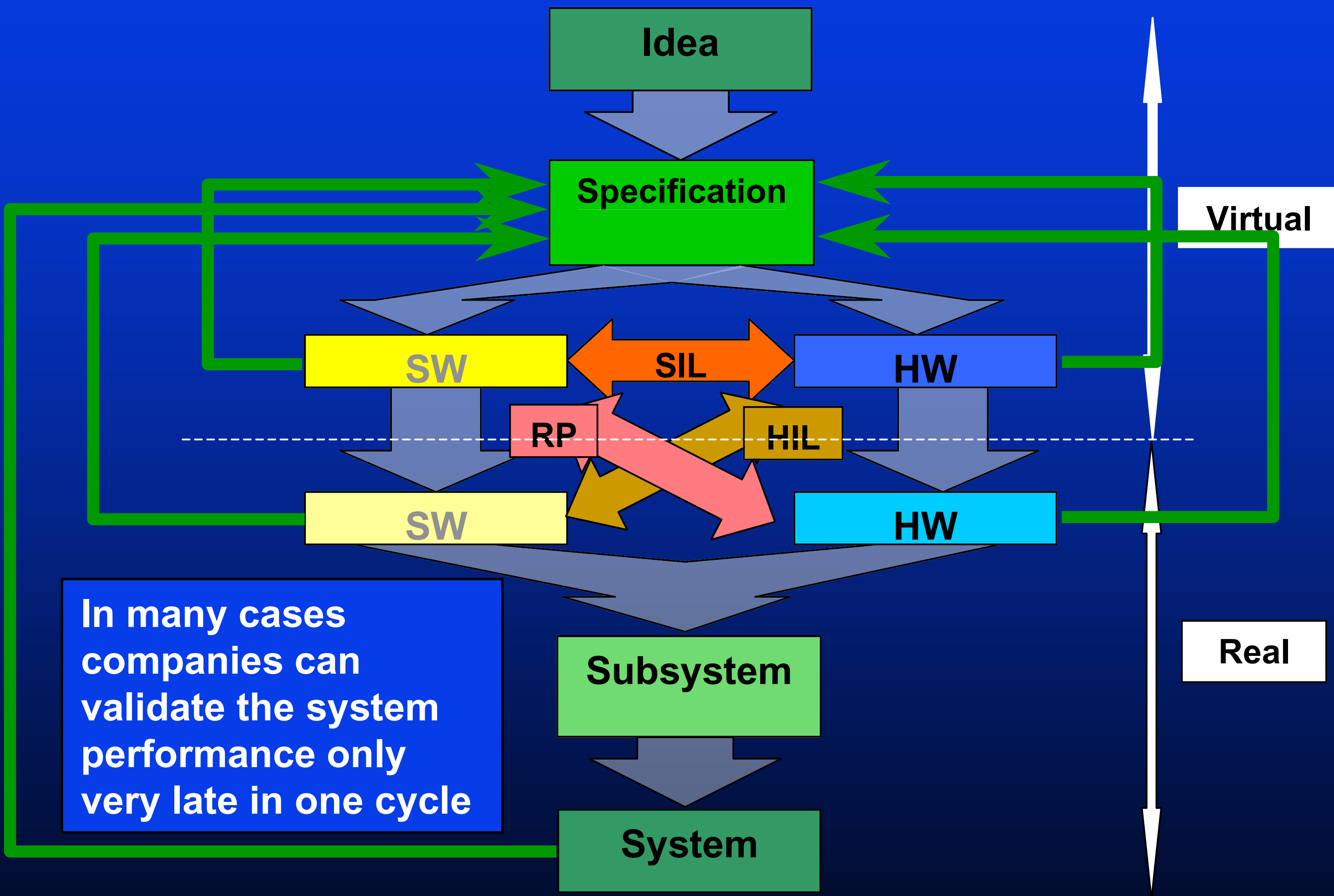
2nd Tier Supplier
- develops components and sends them to 1st T



Full Design Process Coverage

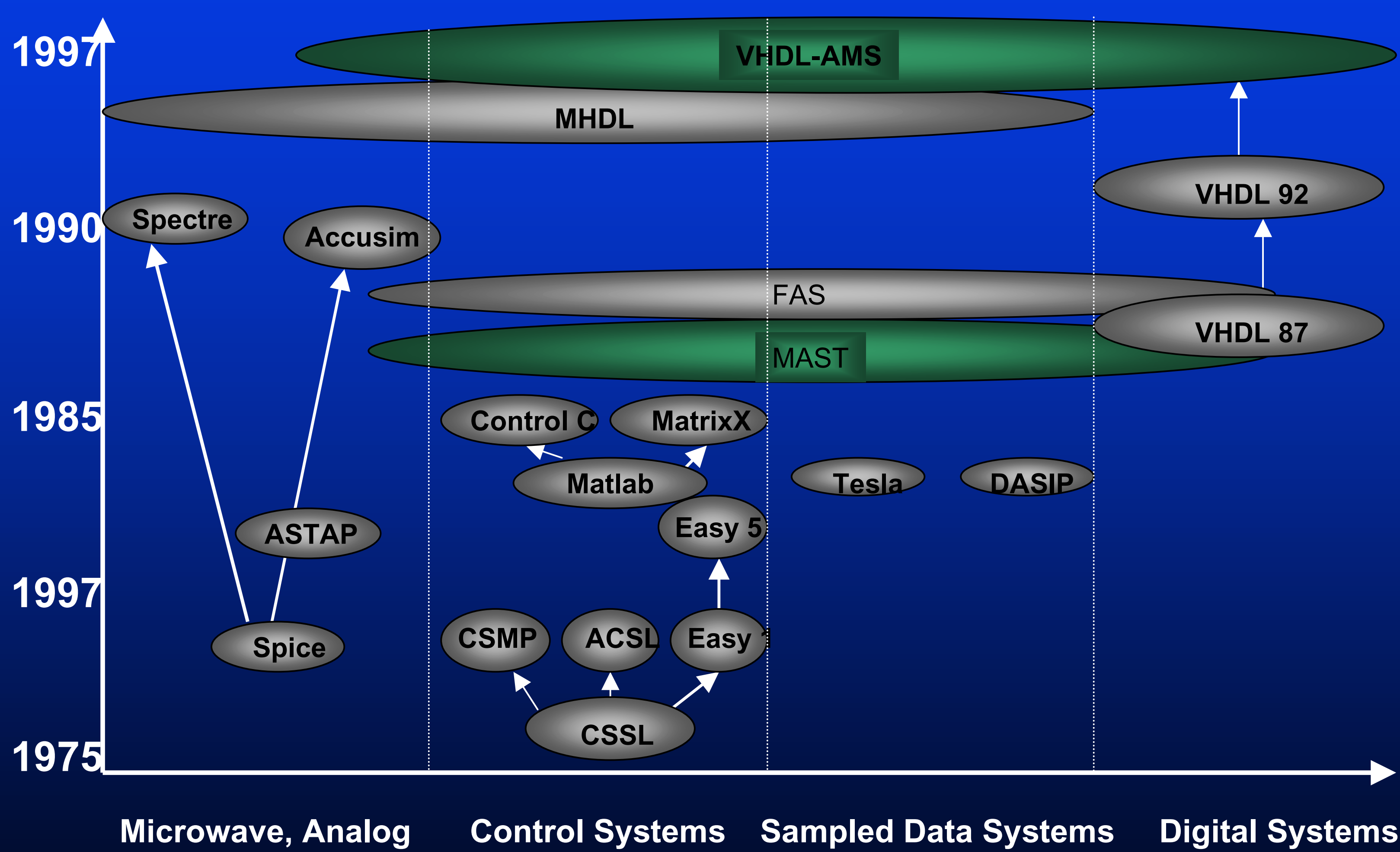


Common Design Cycle



In many cases companies can validate the system performance only very late in one cycle

Which Language to speak ?



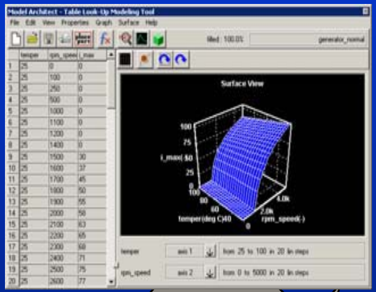
Language Independence

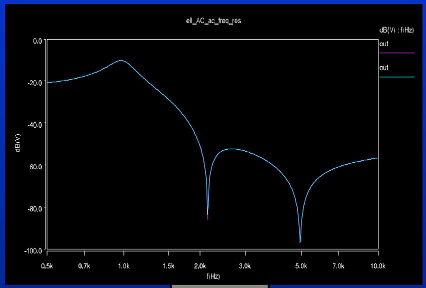
Static
Lock-up table

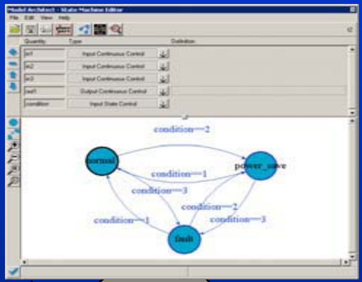
Dynamic
Frequency dependent

State
Mixed-Signal
State Charts

- Physical/mathe-matical equations
- Language neutral







ModelArchitect

- HDL
- Language dependent

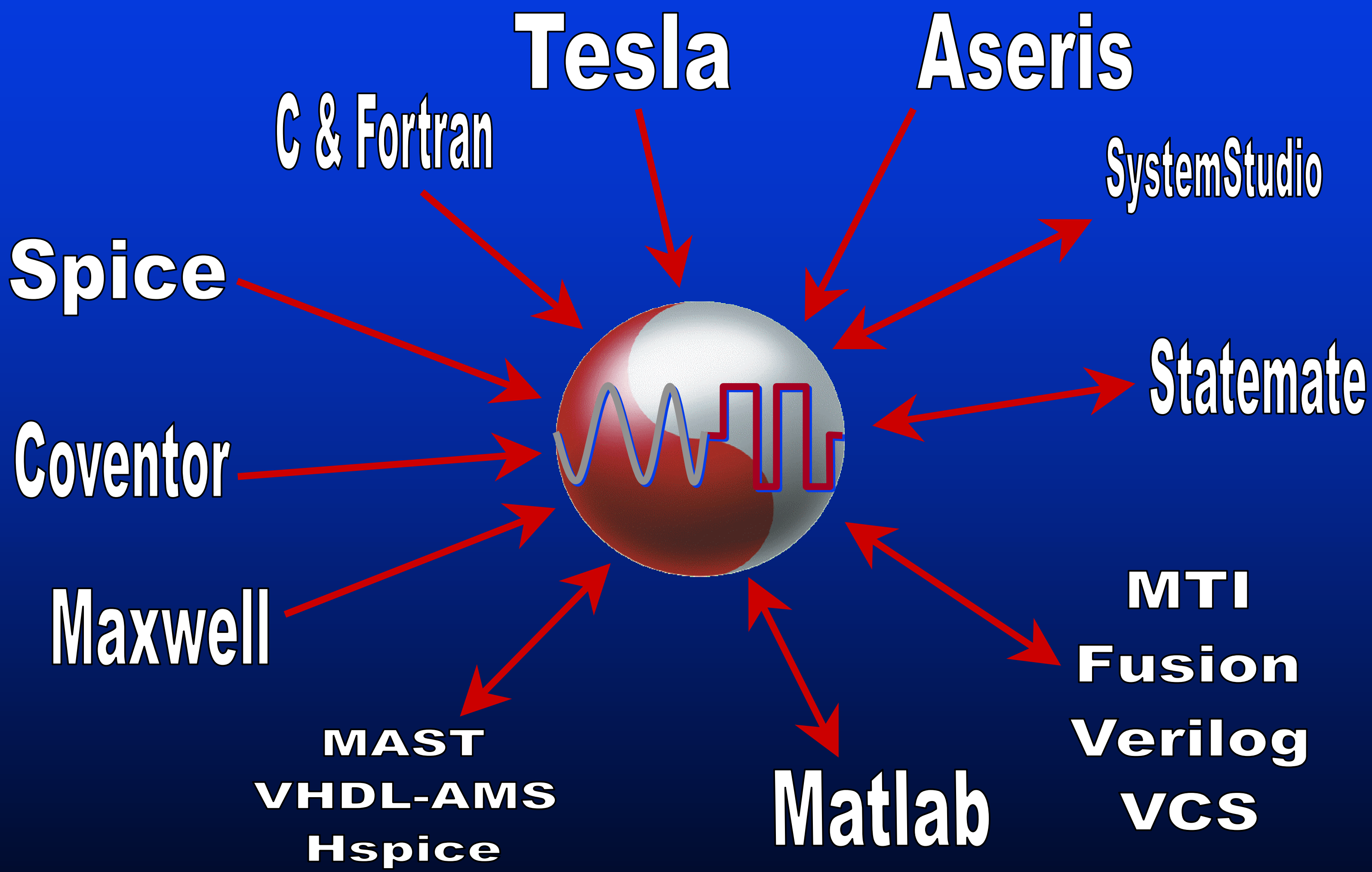
MAST

VHDL-AMS

Other HDLs

Archive

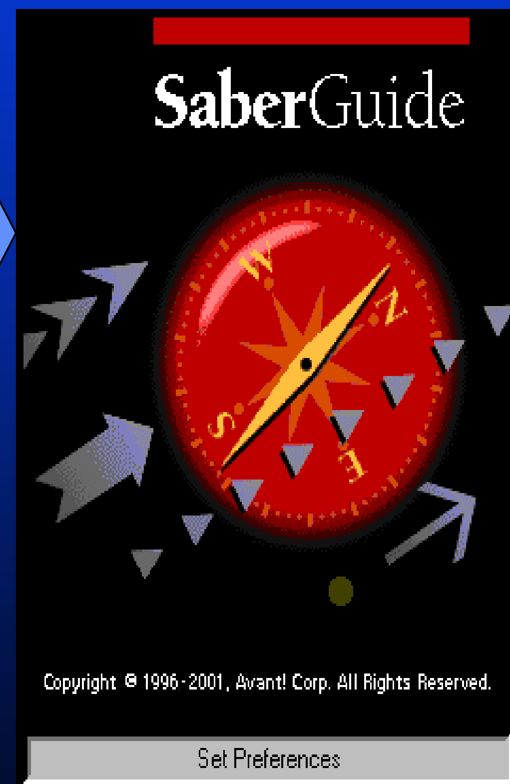
Possible Interfaces



Approach to Vehicle Systems Analysis

- Link appropriate tools

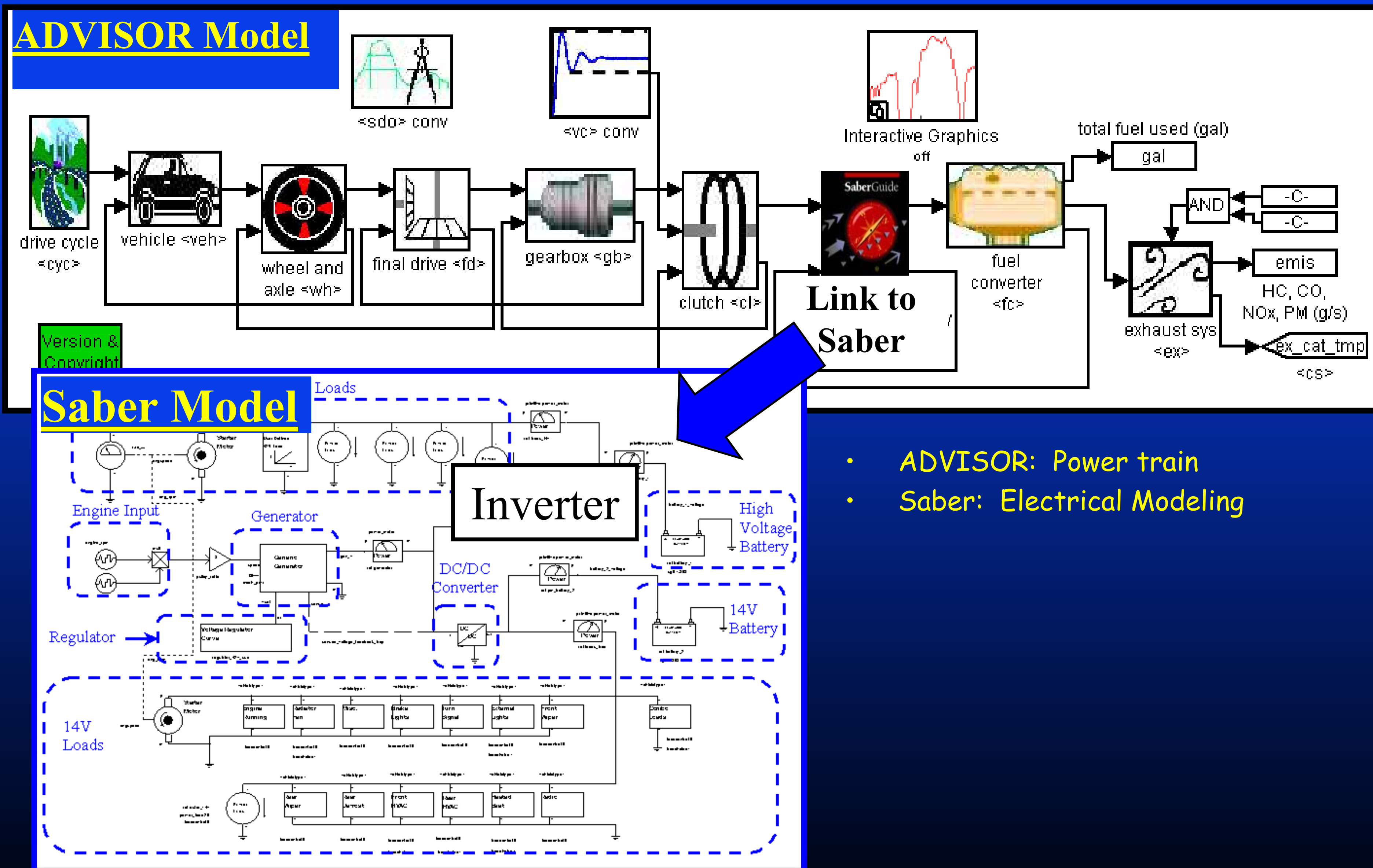
ADVISOR: Powertrain



Saber: Electrical

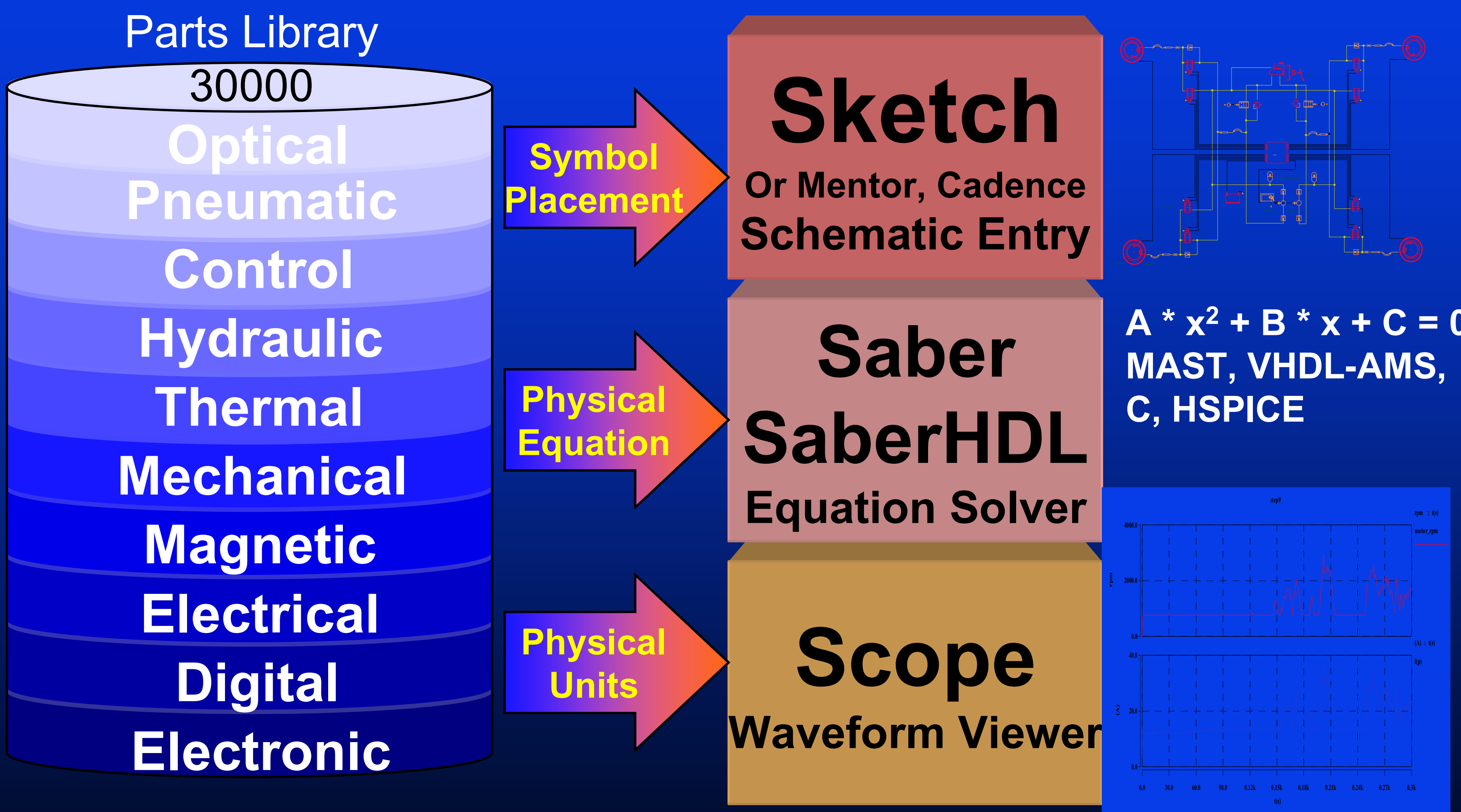
Optimize

Linking ADVISOR to Saber



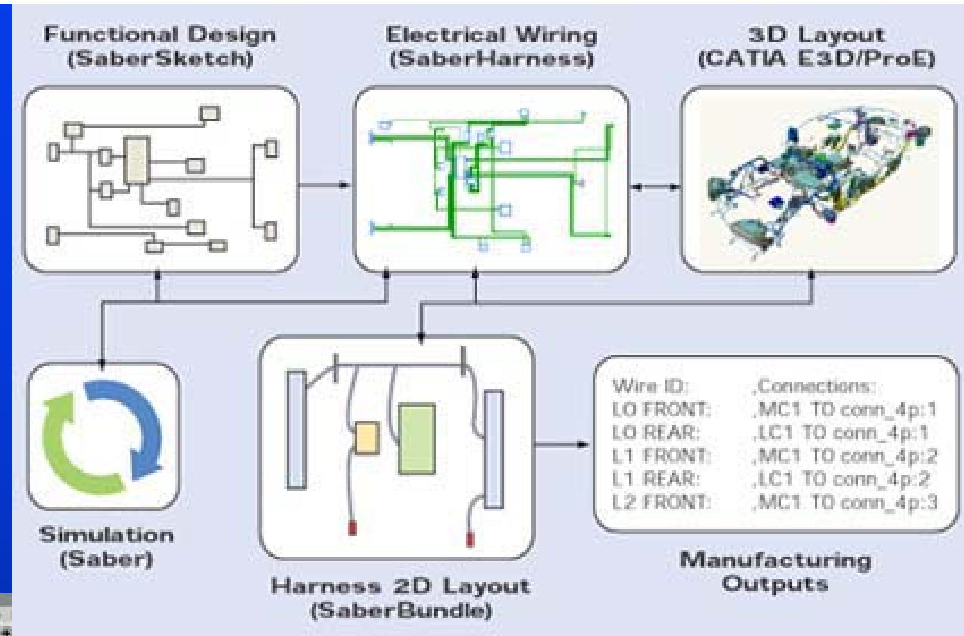
- ADVISOR: Power train
- Saber: Electrical Modeling

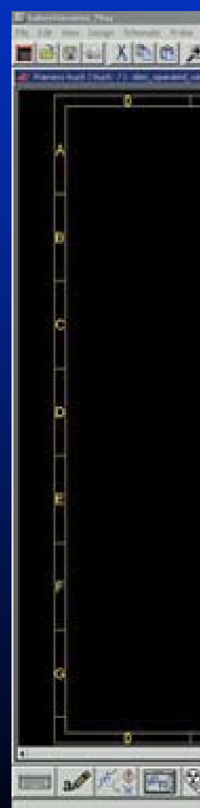
SaberDesigner



SaberHarness

- •Integrated wire harness design environment
- •Concurrent design, database integrity, design rules checks
- •Links to 3D CAD
- •Generated drawings from database
- •Standard format manufacturing outputs



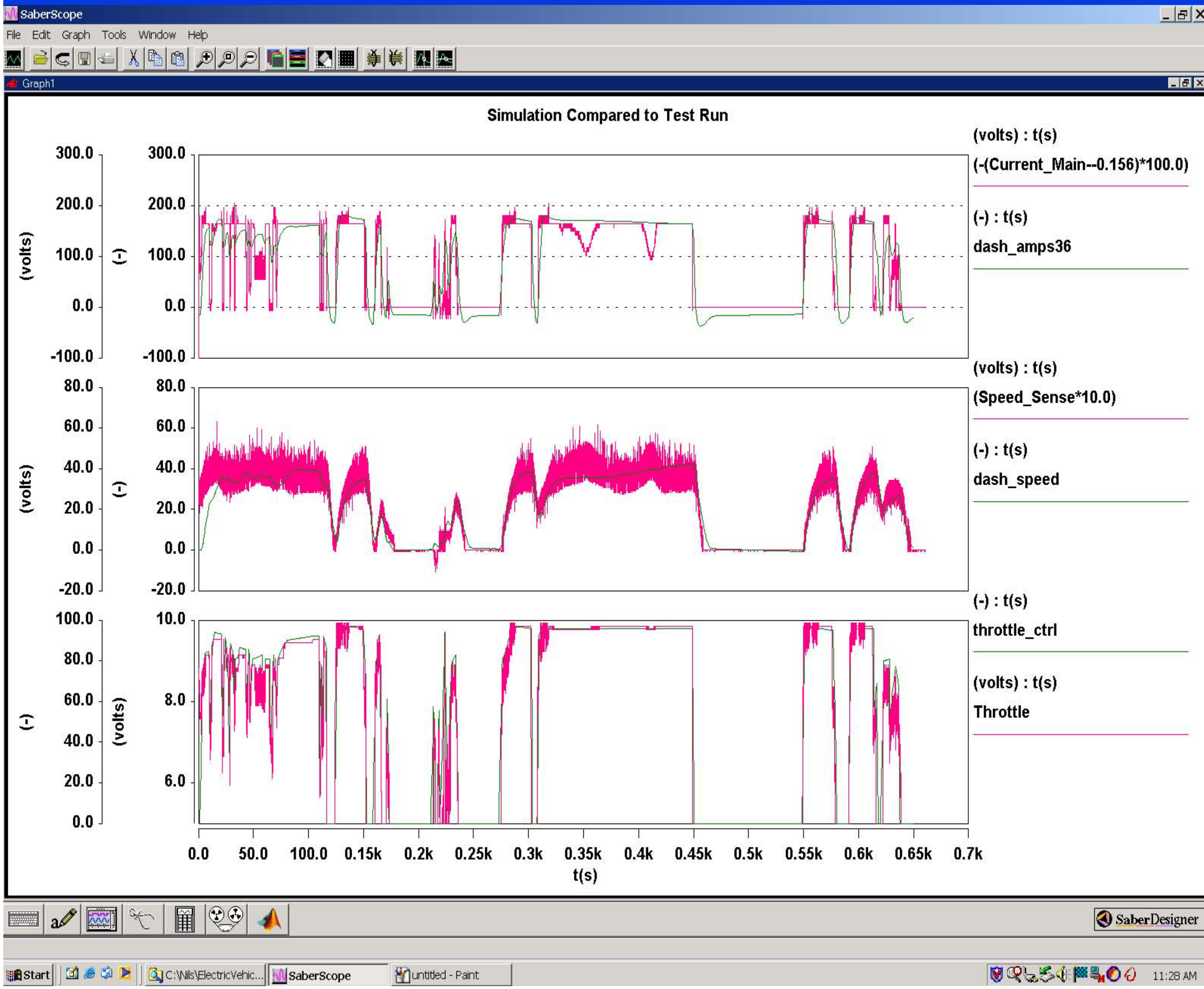


Model Abstraction Level

- Depending on task different abstraction levels necessary

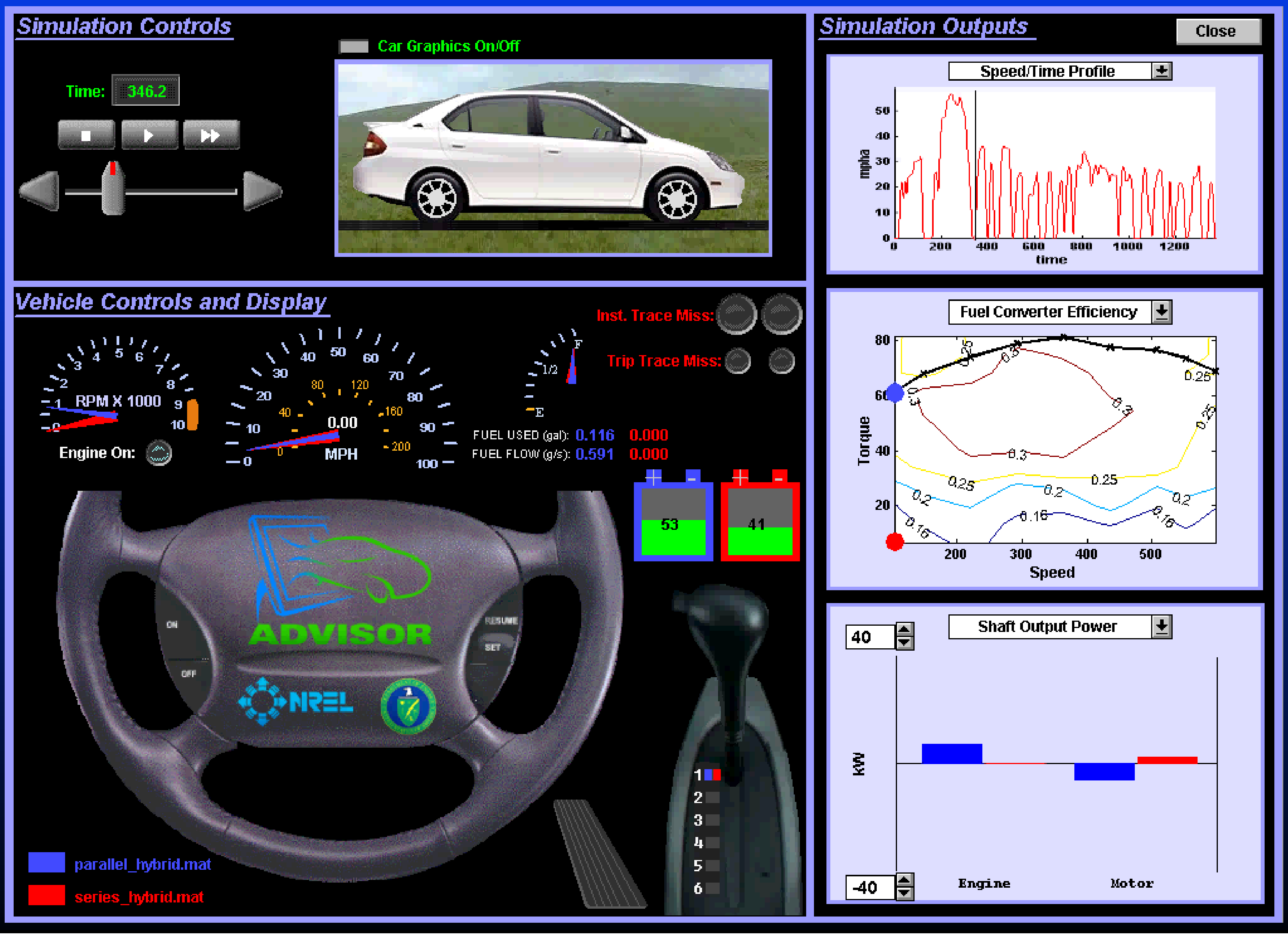
Abstraction Level	Effects	Accuracy	Simulation Speed	Modeling Effort
Behaviour (functional) Level	none	low	high	low
Physical Level	dyn. thermal, ripples, spikes,...	high	low	high

Simulation and Measured Data Compared



Measured data shown in Red and Simulation data shown in Blue

ADVISOR's Dynamic Comparison of Simulations



What do we Mean by:

Integration of Math-based Tools

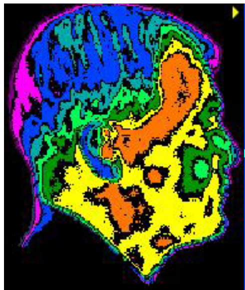
- Integration of the latest Computer Aided Engineering tools with advanced design techniques to solve key technical barriers and to accelerate the development process. We work closely with industry to identify technical challenges and provide innovative solutions.

Integration of Math-based Tools

- Sampling from the NREL Tool Kit:
  - TRIZ & Topology Optimization for conceptual design
  - Parametric Behavioral Modeling CAD *(not dimension but attribute driven design)*
  - Finite Element Modeling (implicit, explicit, VPG)
  - Multi-physics applications *(structural/thermal, fluid/thermal, electromagnetics,etc)*
  - Optimization integrated with CAD & FEA
  - Design for 6-sigma using CAE (DFSS)
  - Probabilistic Design Methods *(engineering quality into designs)*
  - Experimental Design Techniques
  - Integration with Vehicle Systems Analysis tools
  - Engineering Resources and Computational Power Available at National Labs

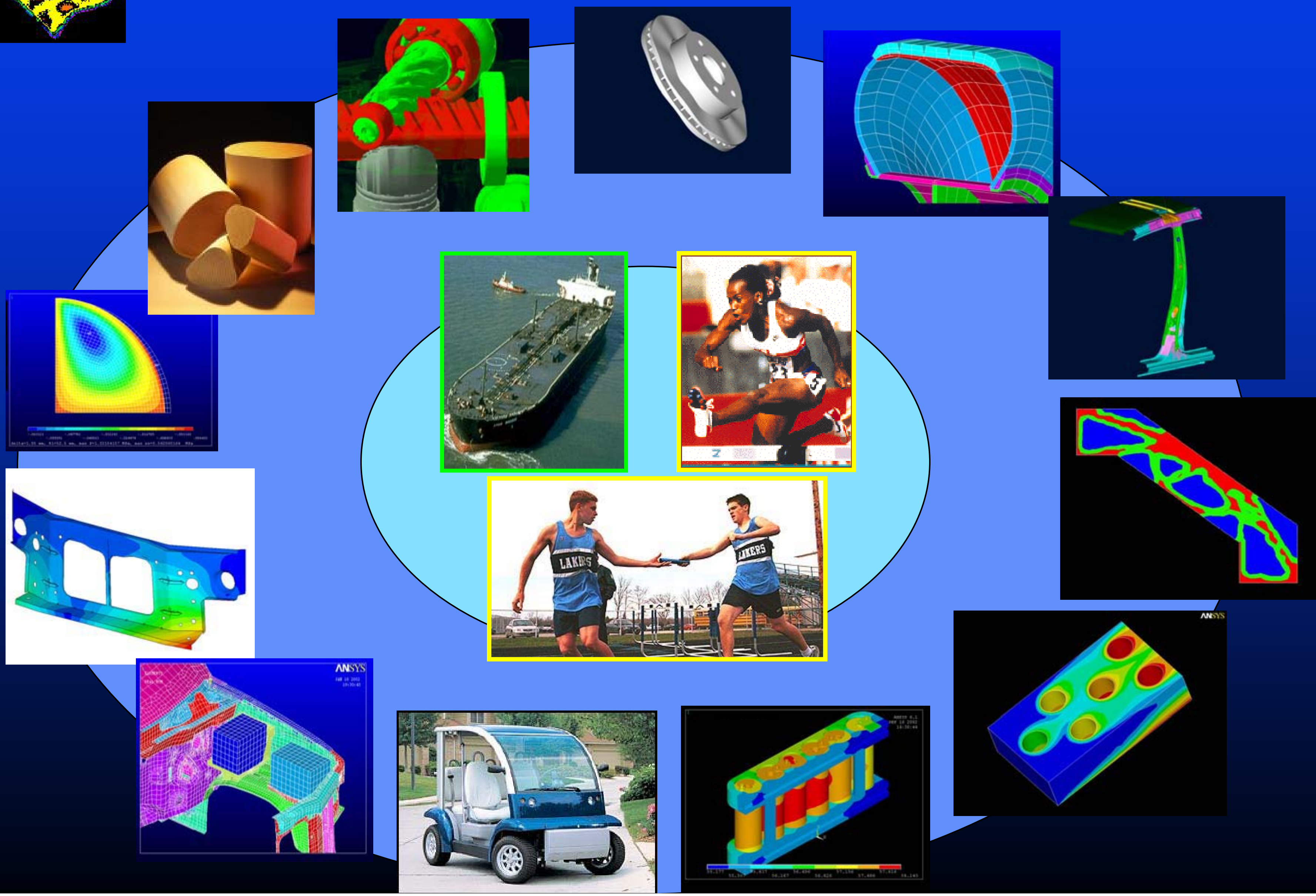
More Examples to Get You Thinking

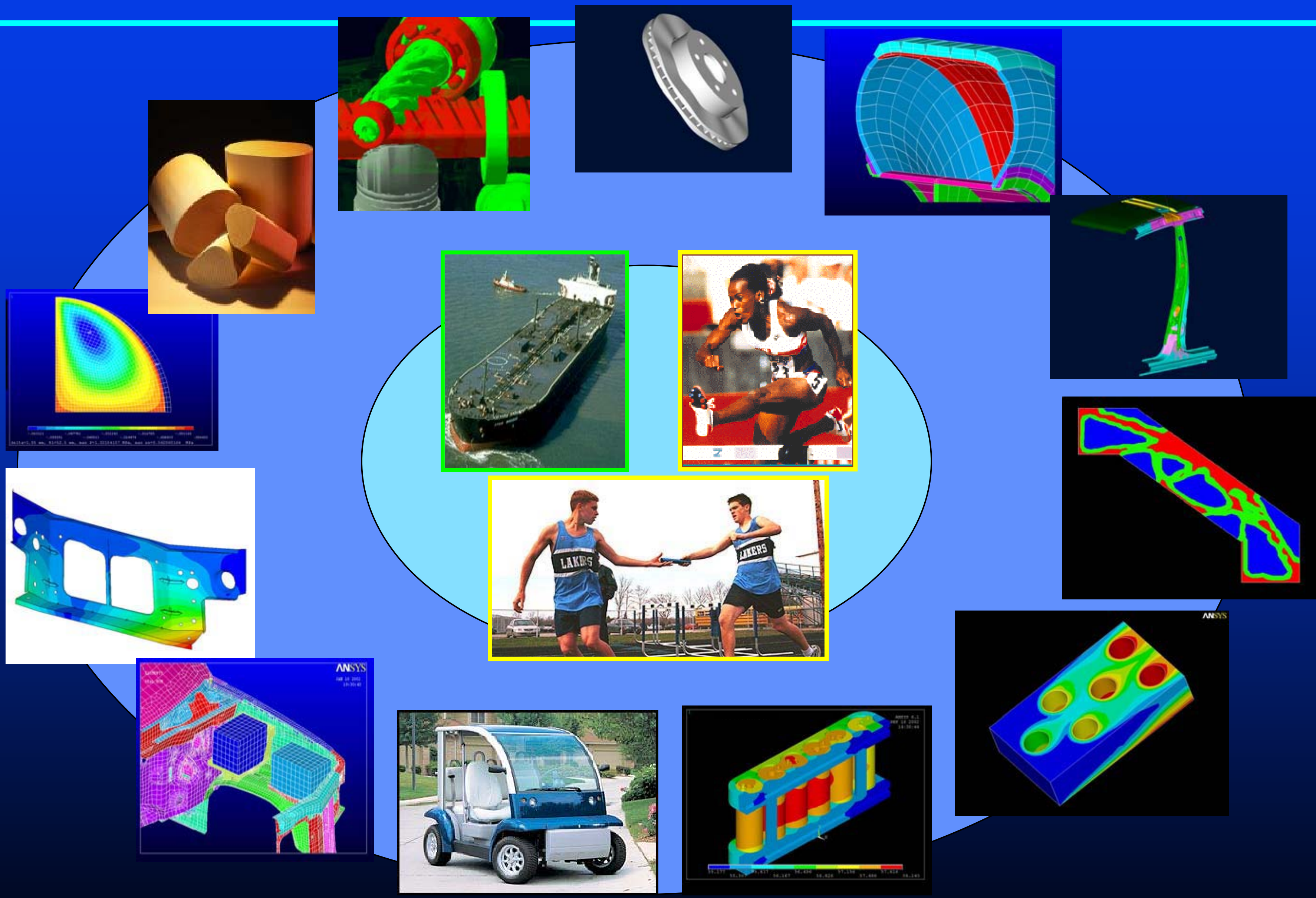
- Overall Integrated Design Process
- FORD Think Mobility Design Optimization
- Robust Design of Fuel Cell Stack
- Power Electronics Cooling with Behavioral Modeling
- Design For Six-sigma in Battery Thermal Management
- Design of Experiments Techniques for Road Load Reduction
- Catalytic Converter



Recent Applications for Integrating Math-based Tools

Petroleum Consumption, Technical Hurdles, Transfer to Industry

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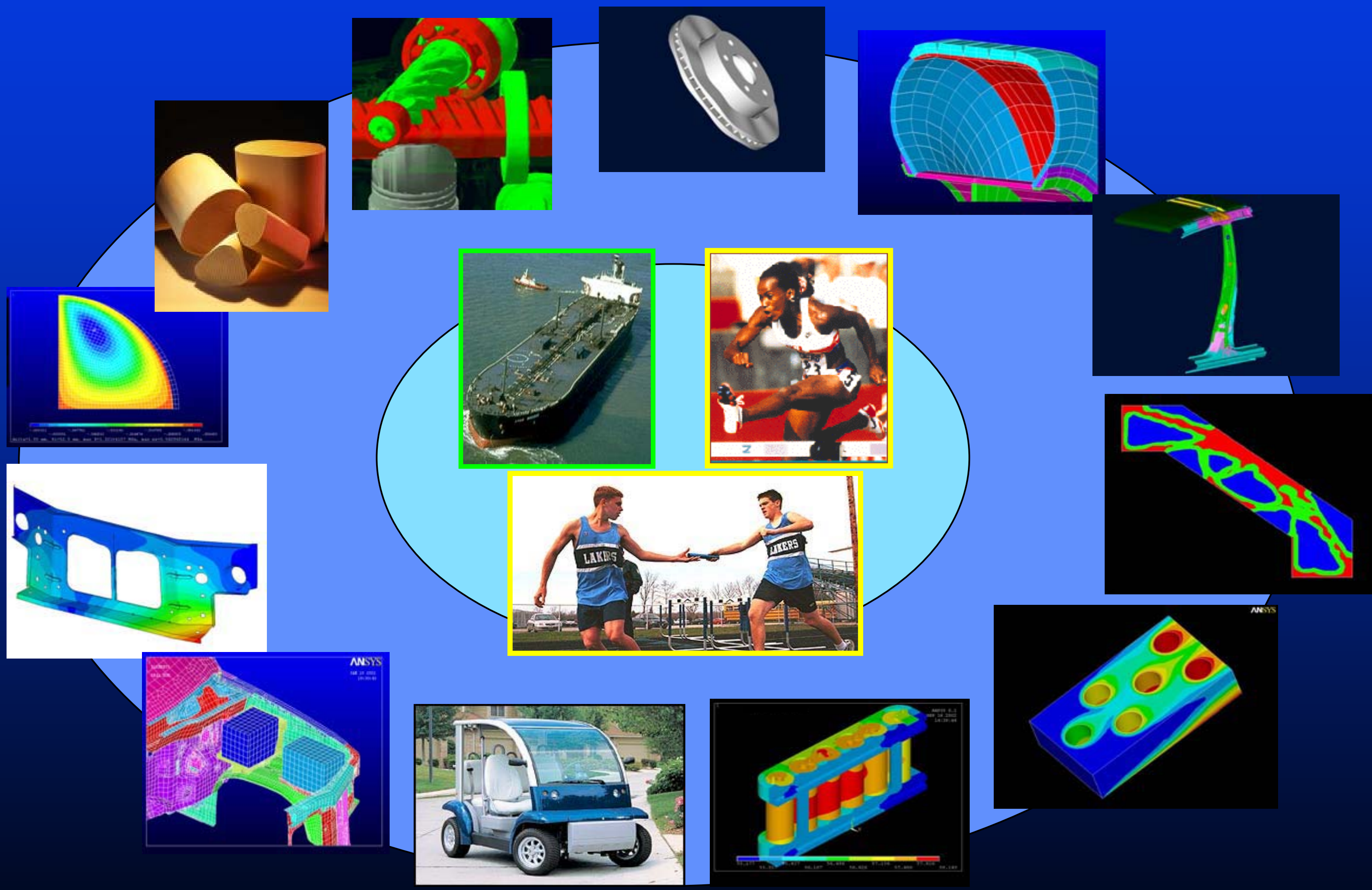

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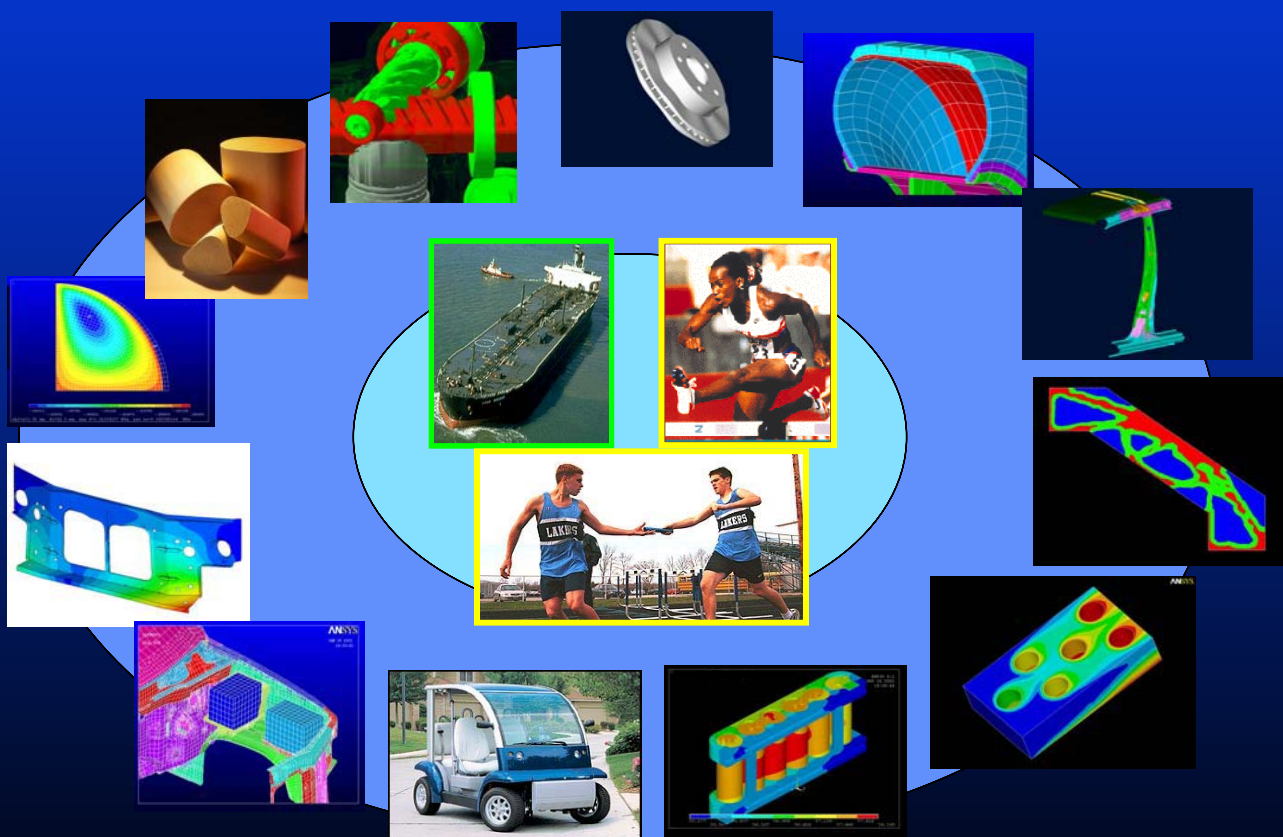
ANSYS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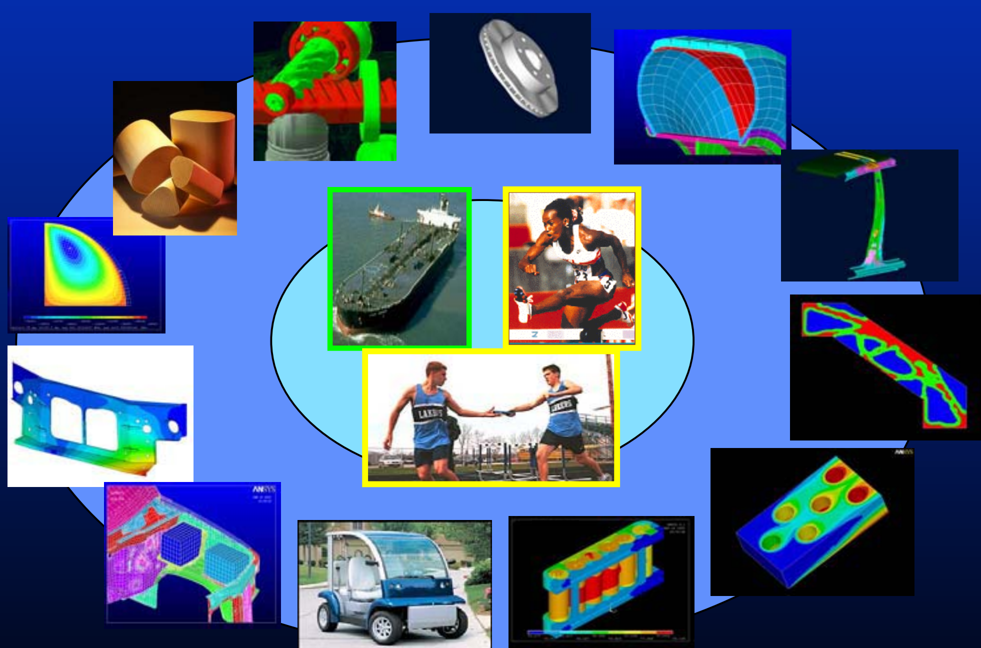
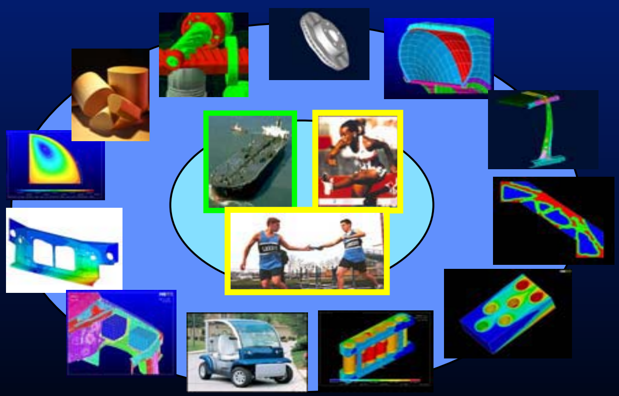
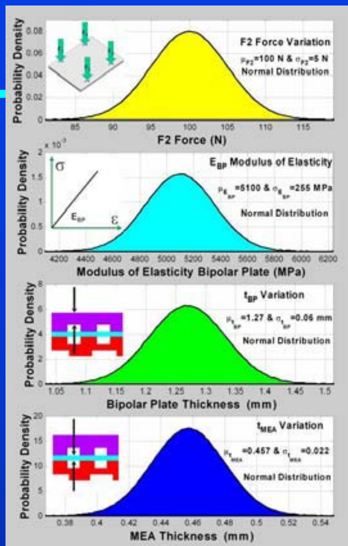






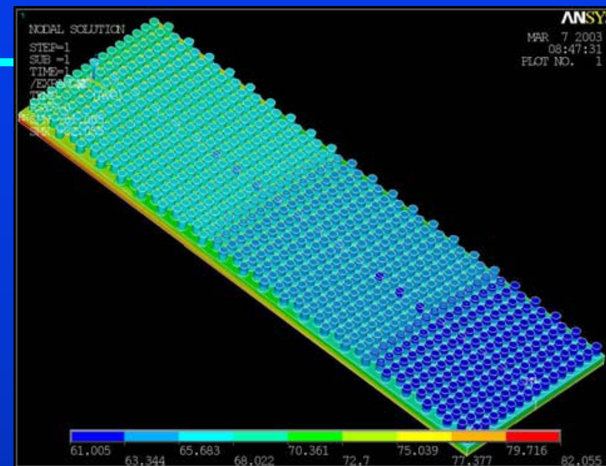
Robust Designs of Fuel Cell Components

-Thermal analysis

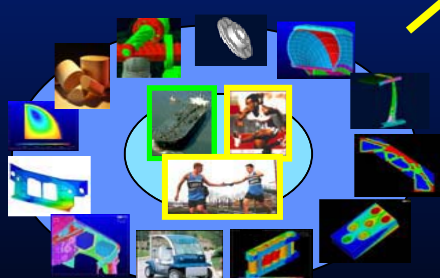
-Structural analysis

-Topology optimization

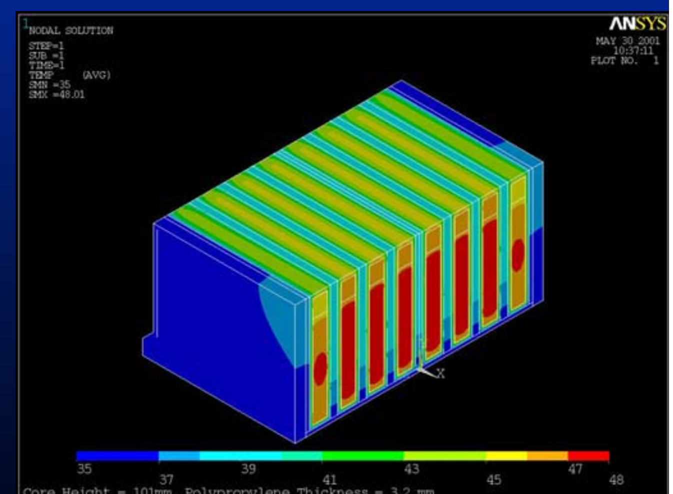
- High temperature stack



Behavioral Modeling for Power Electronics Cooling

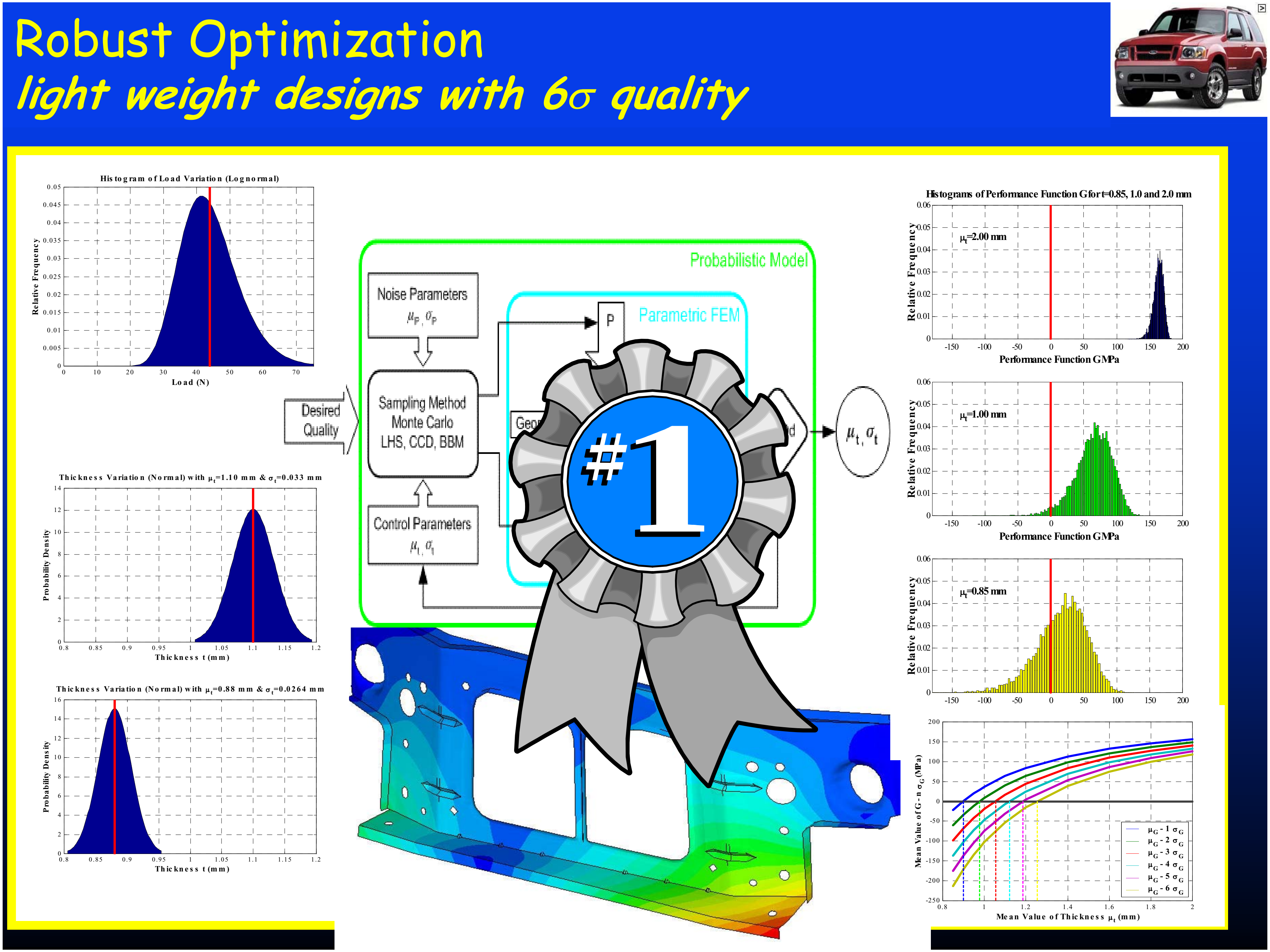


Design for Six-sigma Techniques for Battery Thermal Management

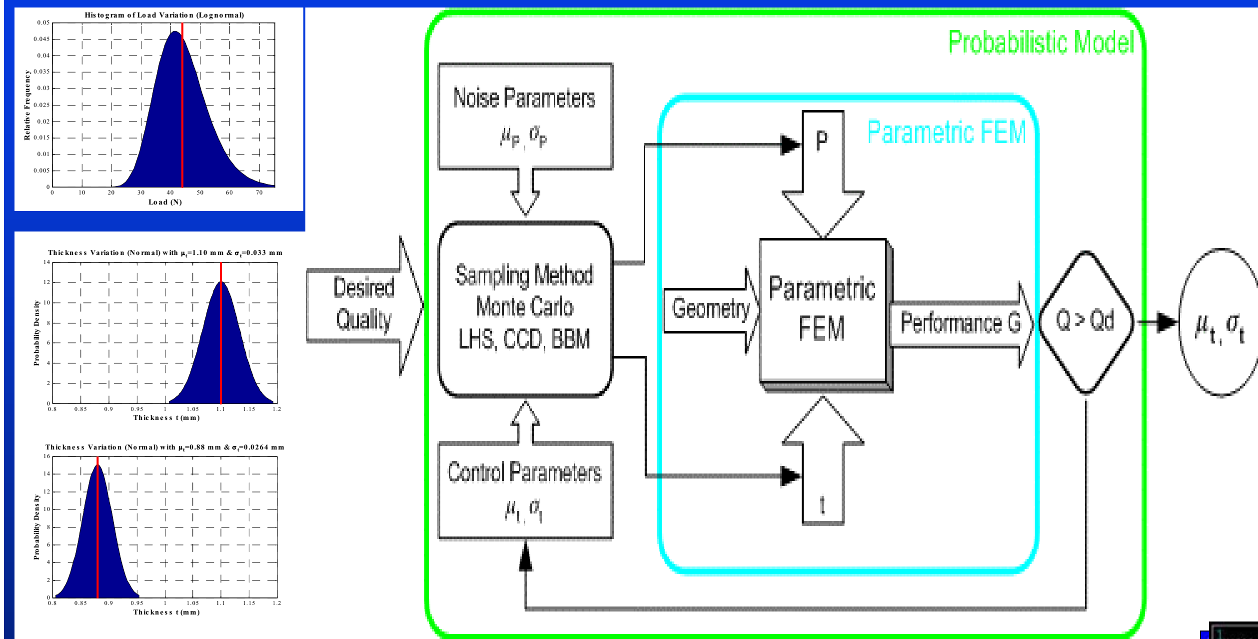


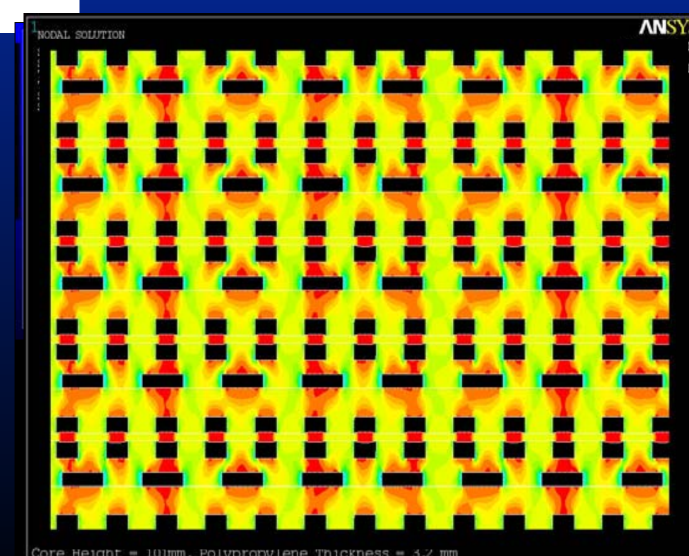
Robust Optimization

light weight designs with 6σ quality



Robust Optimization **reusable workflow template**





Plug Power

ASME / RIT Fuel Cell Conference

USABC / Ford

American Society of Quality

Ford Motor Company

SAE – IBEC 2001

DaimlerChrysler

SAE Powertrain Conference

Transferring the Tools to Industry

Reliability Based Optimization within the CAD Environment

Andreas Vlahinos
Advanced Engineering Solutions, LLC
Subhash Kelkar
Ford Motor Company
Stefan Reh, Robert SeCaur, Steve Pilz
ANSYS Inc.

Abstract

Great advances have been achieved over th… this process is still executed by deploying tr… accommodate potentially contradictory desi… life cycle, and environmental impacts is bei… technically less adept competitors.

02FCC-51

Energy Efficient Battery Heating in Cold Climates

Andreas Vlahinos, Ph.D.
…incipal, Advanced Engineering Solutions
Ahmad A. Pesaran, Ph.D.
…, National Renewable Energy Laboratory

02IBECA-28

Designing For Six-Sigma Quality with Robust Optimization using CAE

Andreas Vlahinos, Ph.D.
Principal, Advanced Engineering Solutions, LLC
Subhash G. Kelkar, Ph.D.
Staff Technical Specialist, Ford Motor Company

01IBECA-6

Body-in-White Weight Reduction via Probabilistic Modeling of Manufacturing Variations

Andreas Vlahinos, Ph.D.
Principal, Advanced Engineering Solutions, LLC
Subhash Kelkar, Ph.D.
Staff Technical Specialist, Ford Motor Company

02FCC-68

Robust Design of a Catalytic Converter with Material and Manufacturing Variations

Andreas Vlahinos
Principal, Advanced Engineering Solutions, LLC
Danet Suryatama, Mustafa Ullahkhan, Jay T. TenBrink, Ronald E. Baker
DaimlerChrysler Corporation

ABSTRACT

A design is robust when the performance targets have been achieved and the effects of variation have been minimized without eliminating the causes of the variation such as manufacturing tolerances, material properties, environmental temperature, humidity, operational wear etc. In recent years several robust design concepts have been introduced in an effort to obtain optimum designs and minimize the variation in the product characteristics [1,2]. In this study, a probabilistic design analysis was performed on a catalytic converter substrate in order to determine the required manufacturing tolerance that results in a robust design. Variation in circularity (roundness) and the ultimate shear stress of the substrate material were considered. The required manufacturing tolerance for a robust design with 1,2 and 3 sigma quality levels was determined. The same manufacturing tolerance for a reliability based design with reliability levels of 85%, 90% and 95% was also determined and compared. The methodology for implementing robust design used in this research effort is summarized in a reusable workflow diagram.

INTRODUCTION

Robust design is a methodology that addresses product quality issues early in the design cycle. The goal of … of available resources. The probabilistic design process has not been widely used because it has been intimidating and tedious due to its complexity.

In this research effort, probabilistic modeling of manufacturing and material variations for a catalytic converter substrate was considered. Typical shapes of catalytic converter substrates are shown in Figure 1. The substrate used in this study has a cylindrical cross section and is enclosed in a cylindrical steel cover. If the substrate is not a perfect cylinder the steel cover applies a non-uniform pressure along the circumference. Assuming that the maximum diameter of the substrate is Φ_{max} and the minimum diameter is Φ_{min}, we can characterize the variation in circularity or roundness δ with their difference $\delta = \Phi_{max} - \Phi_{min}$. Due to manufacturing variations δ is considered a random input variable.

ASME International

First International Conference on Fuel Cell Science, Engineering and Technology
April 21-23, 2003, Rochester, New York, USA

EFFECT OF MATERIAL AND MANUFACTURING VARIATIONS ON MEAS PRESSURE DISTRIBUTION

Andreas Vlahinos[1], Kenneth Kelly[2], Jim D'Aleo[3], Jim Stathopoulos[4],

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ASQ TECHNICAL PAPER SERIES

American Society for Quality ASQ

Empowering Engineers to Generate Six-Sigma Quality Designs

Andreas Vlahinos
Advanced Engineering Solutions, LLC
Kenneth Kelly, Ahmad Pesaran & Terry Penney
National Renewable Energy Laboratory

Press & Analyst Community

"Engineering Quality into Digital Functional Vehicles," IDPS2002, 2002 June 2002

"Mixing CAD with simulation gives designers new power" September 2002 Machine Design Magazine

"The Probability of Optimum Design" October 2002 Desktop Engineering Magazine

"The Probability of Quality" March 2003 Desktop Engineering Magazine

MACHINE DESIGN

September 2002

CAD

Mises stresses for one load case. Users can ask for a screen capture of such a display. From the display option, users choose other load cases for which they need graphs, plots, and images.

In addition, the software presents general results such as maximum, minimum, and average for requested values. Information and explanations are in French, so there is no misunderstanding. And automated HTML reports of analyses can be sent to others.

A dialog box from PTC's Behavioral modeling extension shows the optimization setup with a goal of minimum weight. The lower portion shows design variables and their limits for a box beam. Optimization is easily substituted for a sensitivity study that determines and plots effects of any Pro/E design variable to the natural frequency, or the probability of failure.

Another example for a battery tray finds the sensitivity and response distribution (stress, stiffness, fatigue life) from the scatter of several variables, such as modulus of elasticity, thickness, and loading, when they are defined in terms of probability distribution functions. Monte Carlo and response-surface sampling determine the response distribution. Six-sigma design criteria can be used to size the components and compare this design to one developed using traditional nominal-value figures. The example uses a battery, composite tray, and interface elements. The automatic reliability-based optimization reduced the tray's weight by 17%.

MIXING CAD WITH SIMULATION GIVES DESIGNERS NEW POWER

Combining the analysis capabilities of two independent design programs let designers with **Ford Motor Co.** go from functional goals and sizing parameters to the best designs that meet the company's quest for six-sigma quality. The software packages are Behavioral Modeling Extension (BMX) from **PTC,** Needham, Mass. (*www.PTC.com*), and Ansys Probabilistic Design System (PDS) from **Ansys Inc.,** Cannonsburg, Pa. (*www.ansys.com*)

BMX lets designers start with a goal and a few constraints. For instance, a bottle might need to hold exactly a quart and not exceed a particular height, width, or length. BMX in Pro/E calculates many containers that meet the goal and presents the results in a graph. The designer then selects a best one. "BMX drives designs through engineering requirements instead of dimensions, as most are," says Andreas Vlahinos, Principal of Advanced Engineering Solutions LLC, Castle Rock, Colo.

PDS software, on the other hand, lets user consider variability in material properties and dimensions. This lets users answer questions such as: If input variables for a simulation model fall within a range, what is the scatter of the output values? Or, which input variables contribute most to the scatter of an output parameter and to the probability of failure? "You can ignore variations and pay later, or incorporate them in the design and analysis and get an expected behavior," says Vlahinos.

For example, a designer can change a hole in a radiator support and the combined software package updates the bracket thickness to meet a quality criteria and minimum weight. "A good analyst with lots of time can do this already," says Vlahinos, "But it's too complex for a designer at early formation stages."

Geometric dimensions, such as the average part thickness can be controlled by designers. Uncontrollable or noise factors such as manufacturing imperfections (standard deviation of the thickness), environmental variables (loading), or product deterioration (material properties) are sources of variations that cannot be eliminated, explains Vlahinos. A rugged design should reduce a product's variation by reducing its sensitivity to the sources of variation rather than by *controlling* the sources.

Ford engineers would like designers to produce the same work as experienced analysts. To this end, they have collaborated with Vlahinos to integrate BMX and PDS. "We developed a little program with a lot of brains behind it that's usable by designers," he says. "Essentially, we automatically capture and reuse the expert's knowledge. This way, when designers shape something, certain design variables update automatically to assure that the design meets certain quality criteria. "Six-sigma has been implemented effectively in management and these techniques let us introduce six-sigma methods into engineering design." ■

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What related topics would you like to see covered? What additional information on this topic would you find useful?

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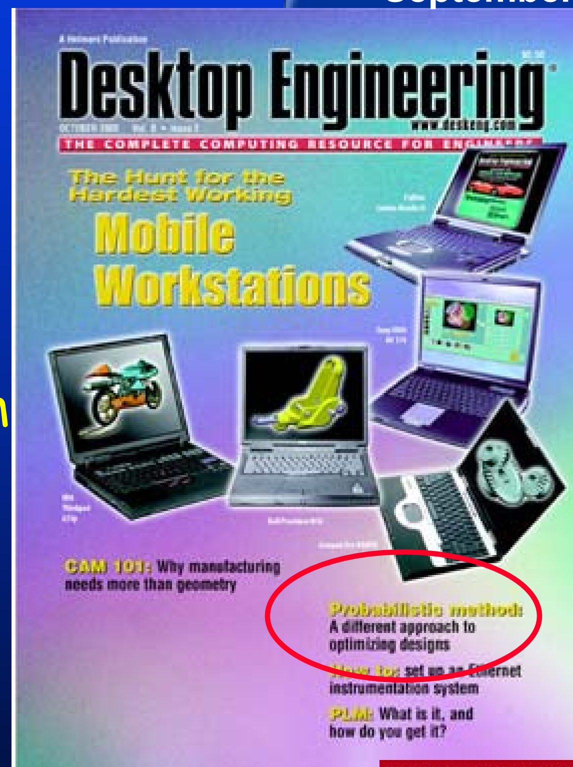


daratech iDPS2002

Intelligent Digital Prototyping Strategies

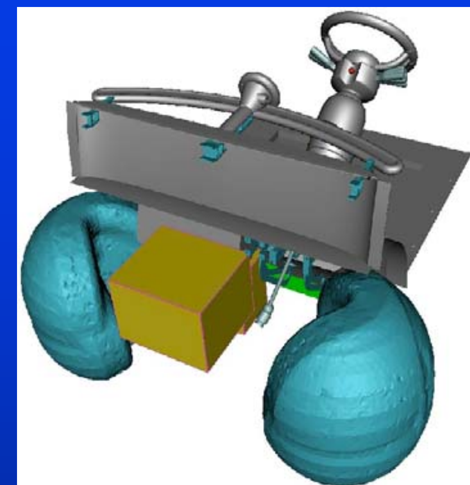
Applications

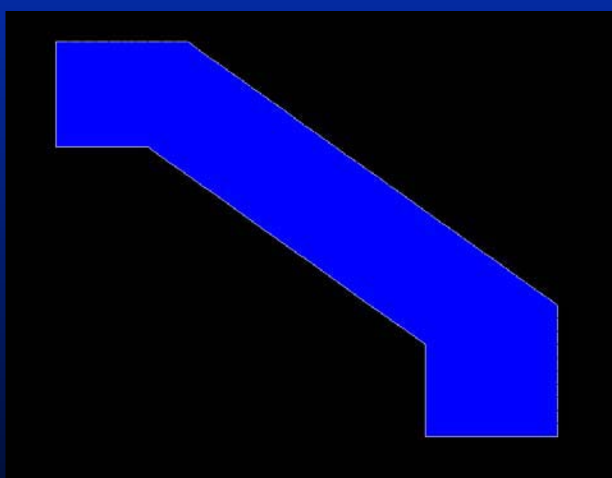
- Overall Integrated Design Process
- FORD Think Mobility Design Optimization
- Robust Design of Fuel Cell Stack
- Power Electronics Cooling with Behavioral Modeling
- Design For Six-sigma in Battery Thermal Management
- Design of Experiments Techniques for Road Load Reduction
- Catalytic Converter

FORD Think Mobility Design Optimization

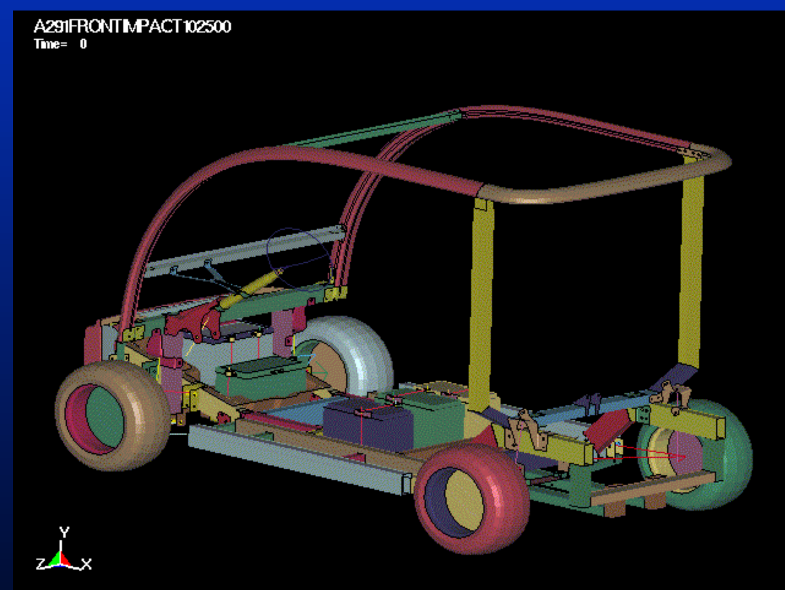
Time to Market

Space Claim
Envelope
Suspension
Optimization





Topology Optimization



Crash Simulation

Applications

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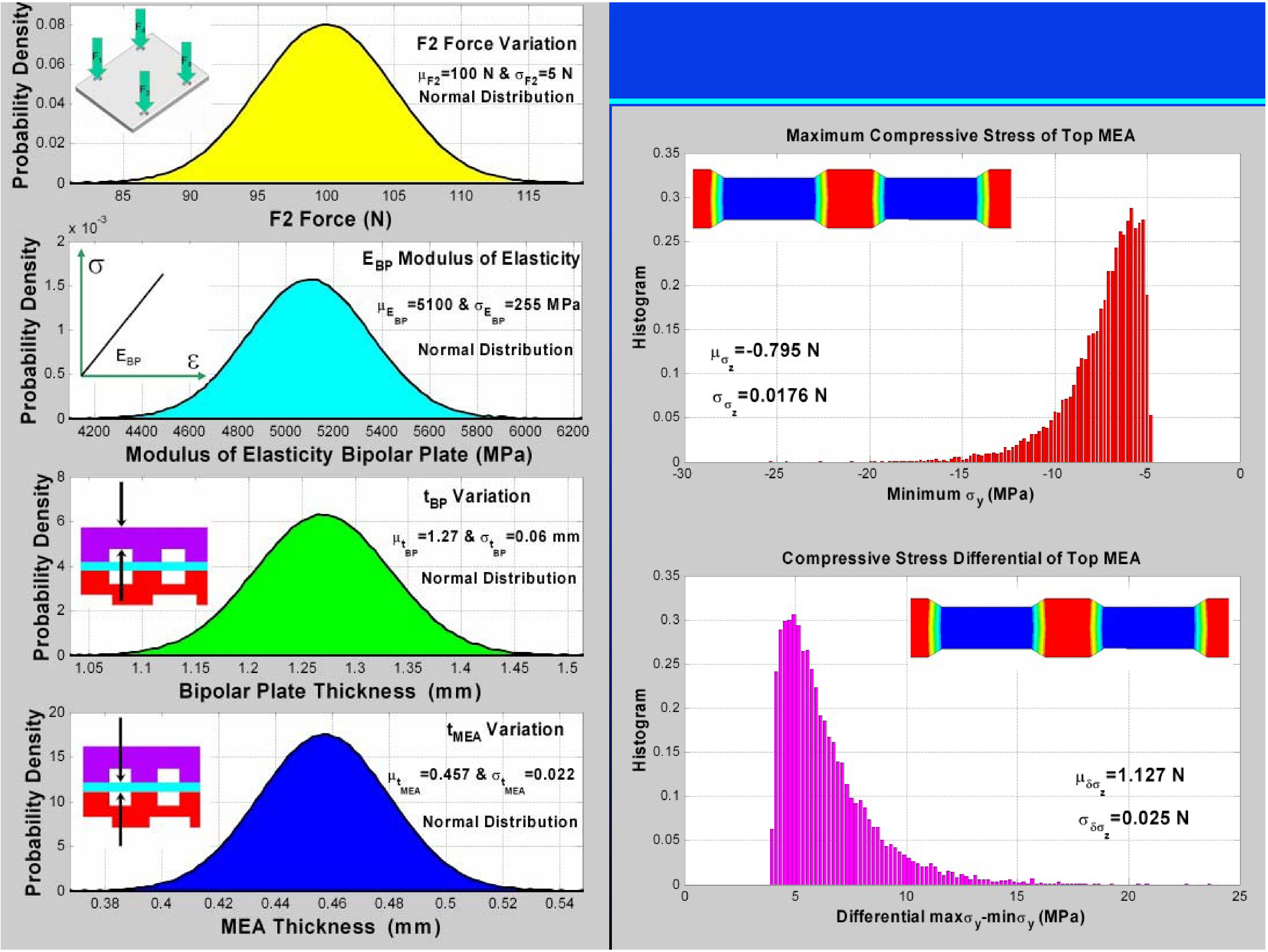
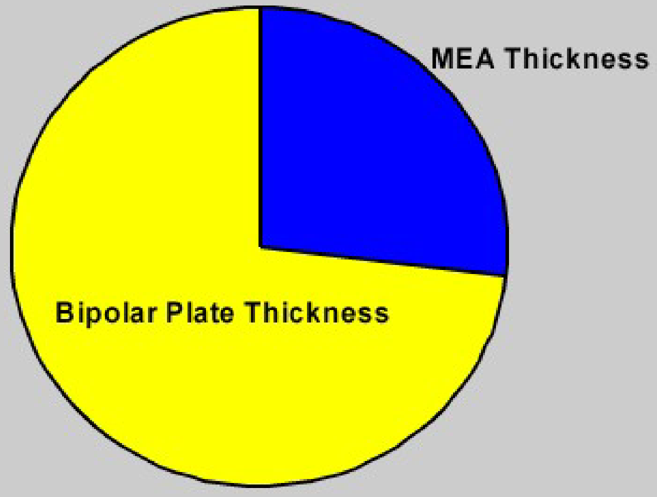
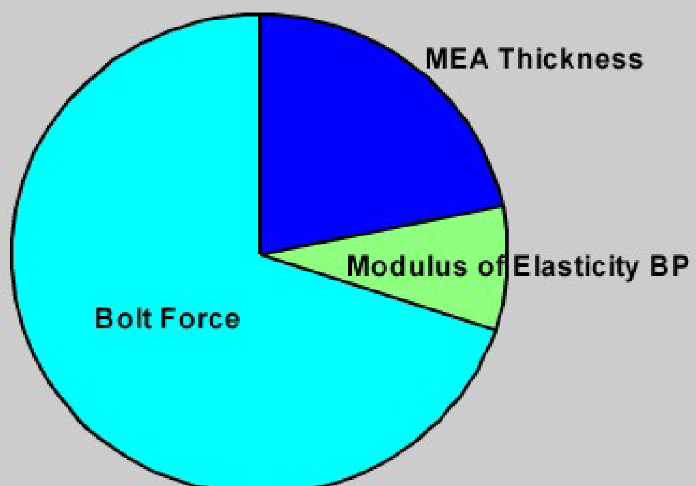


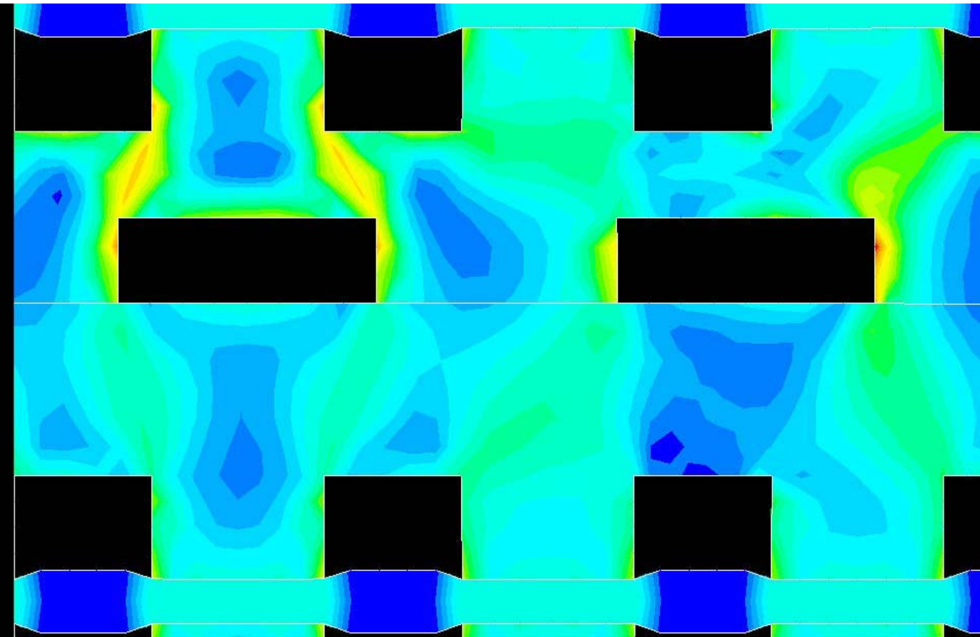
F2 Force Variation
μF2=100 N & σF2=5 N
Normal Distribution
Probability Density
F2 Force (N)
EBP Modulus of Elasticity
μEBP=5100 & σEBP=255 MPa
Normal Distribution
σ
ε
EBP
Modulus of Elasticity Bipolar Plate (MPa)
tBP Variation
μtBP=1.27 & σtBP=0.06 mm
Normal Distribution
Bipolar Plate Thickness (mm)
tMEA Variation
μtMEA=0.457 & σtMEA=0.022
Normal Distribution
MEA Thickness (mm)
Maximum Compressive Stress of Top MEA
Histogram
μσz=-0.795 N
σσz=0.0176 N
Minimum σy (MPa)
Compressive Stress Differential of Top MEA
μδσz=1.127 N
σδσz=0.025 N
Differential maxσy-minσy (MPa)

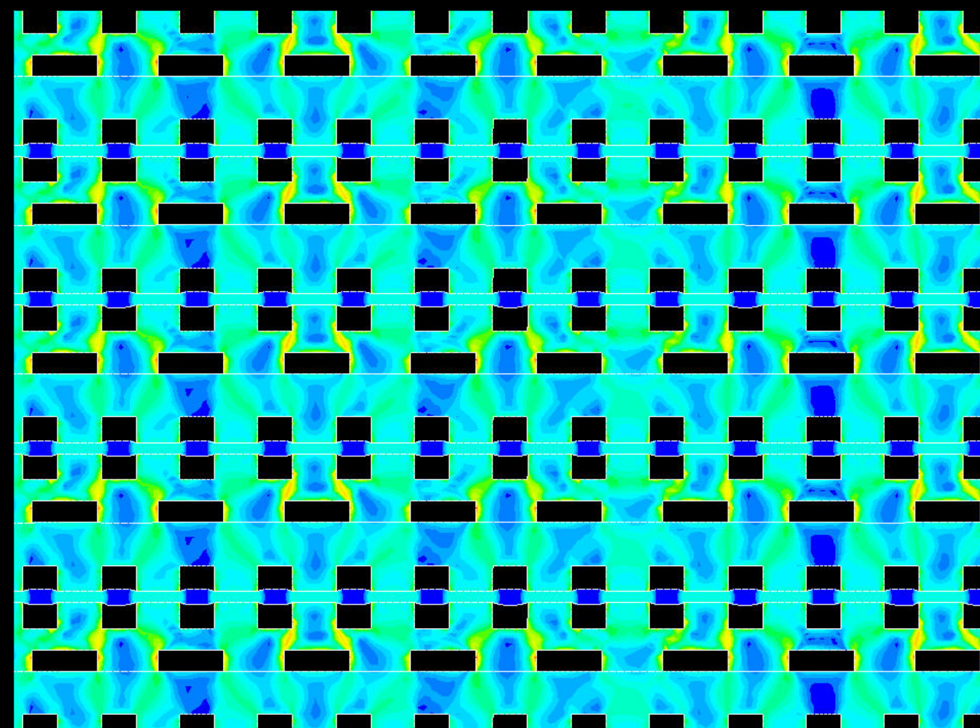
Sensitivity of Design Variables on Pressure Uniformity $\Delta\sigma_z$ of First Membrane



Sensitivity of Design Variables on Pressure Uniformity $\Delta\sigma_z$ of Middle Membrane







Applications

- Overall Integrated Design Process
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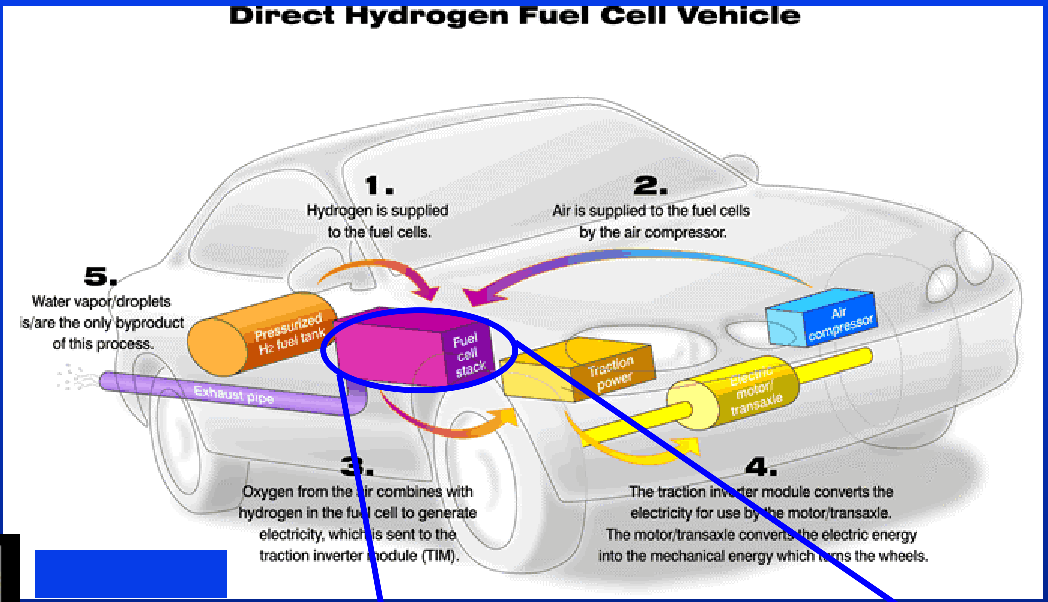
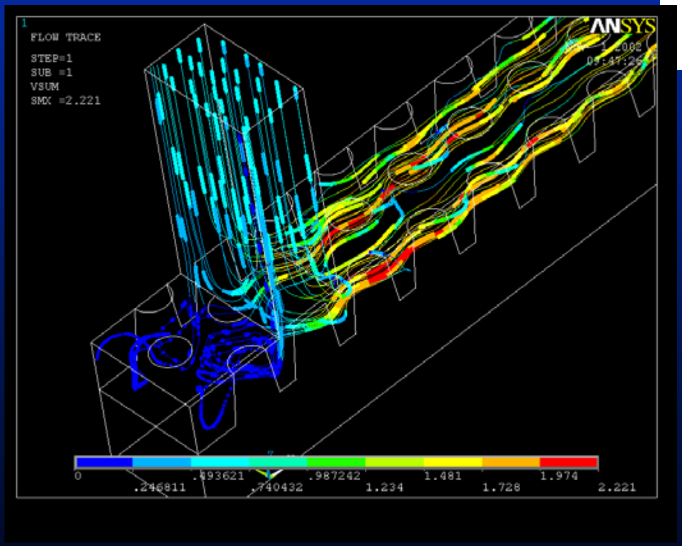
Power Electronics Cooling with Behavioral Modeling

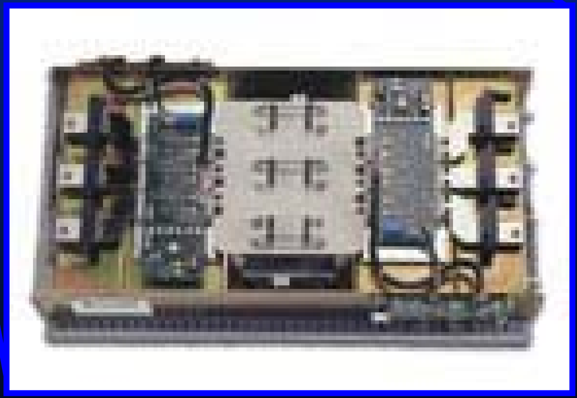
Enabling Critical Technologies

Multi-Physics Modeling

conjugate solutions of thermal,
structural,
fluid-flow,
electromechanical problems







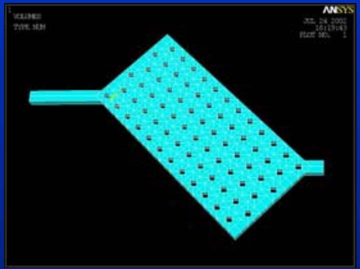
Power Electronics Cooling with Behavioral Modeling

Project Goal :

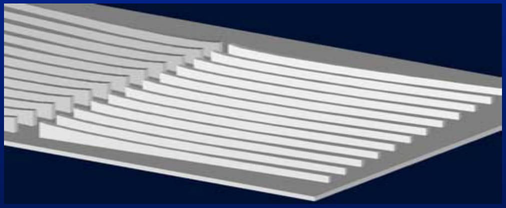
Develop a heat exchanger design to efficiently remove heat from AIPM and reject it into the vehicles coolant loop with uniform cooling, minimum cost, volume and pressure drop.

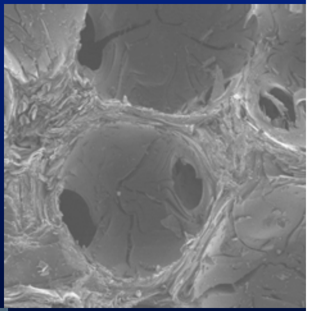
Objective:

Identify which cooling concept the NREL team should pursue further:

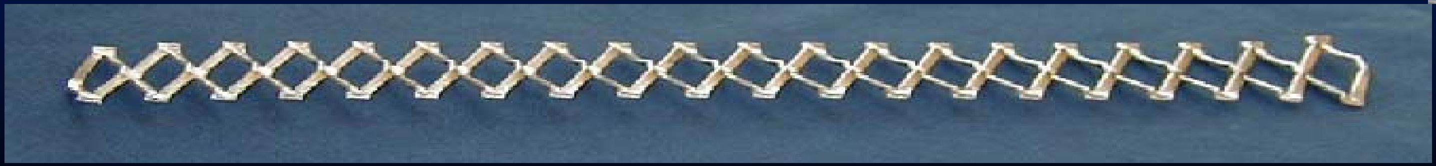


1. Pin-Finned Design
2. “Cook-top” serpentine flow field

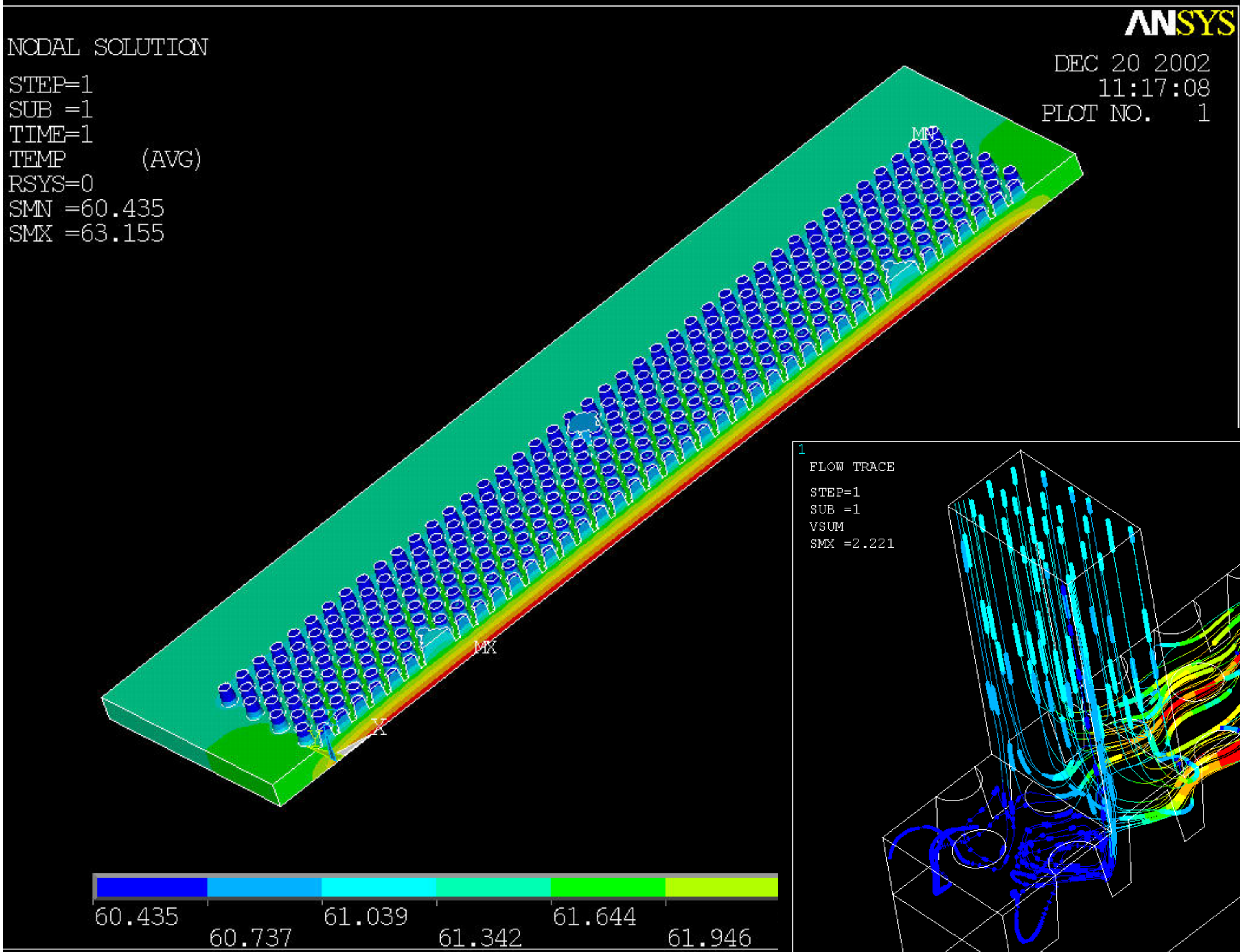


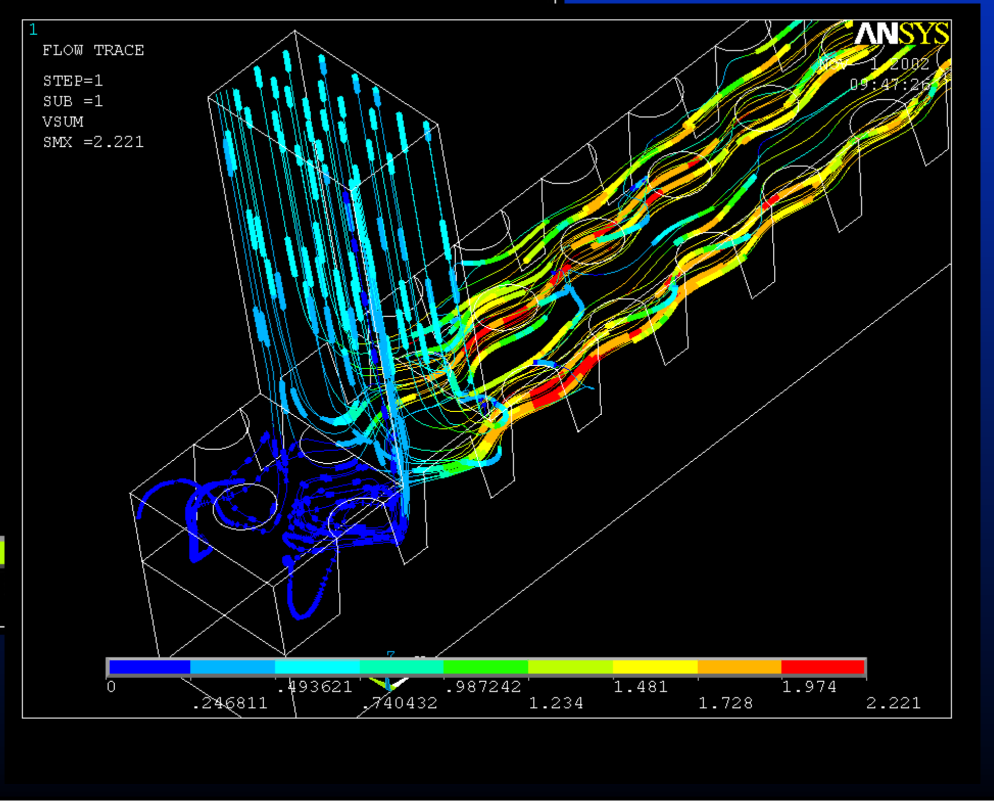


3. “Fish bone” fins
4. Carbon Foam
5. Aluminum Extrusion with Expanded Metal Turbulator

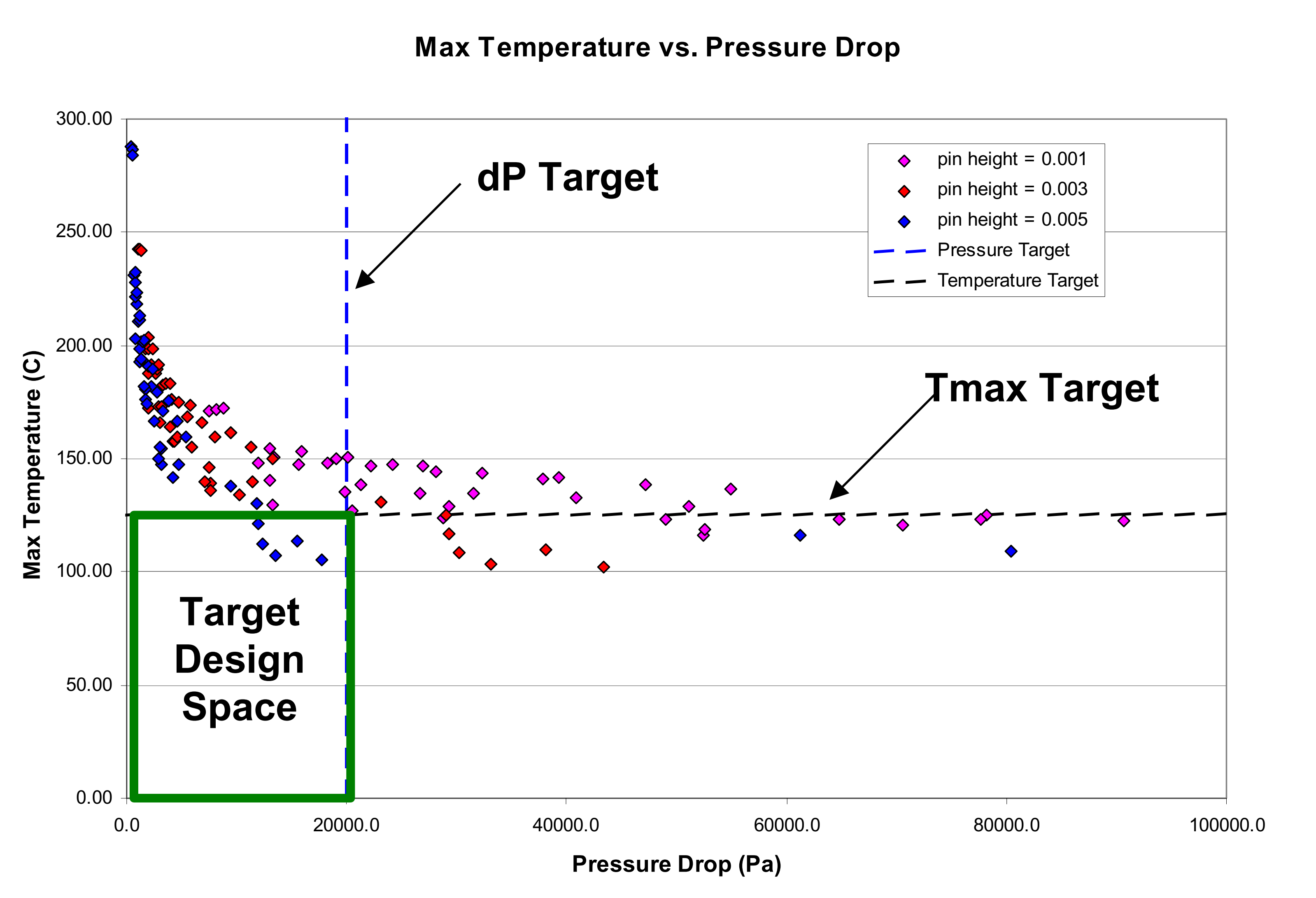


Conjugate Solution of CFD and Heat Transfer





Parametric Modeling - Rapid Investigation of Design Space



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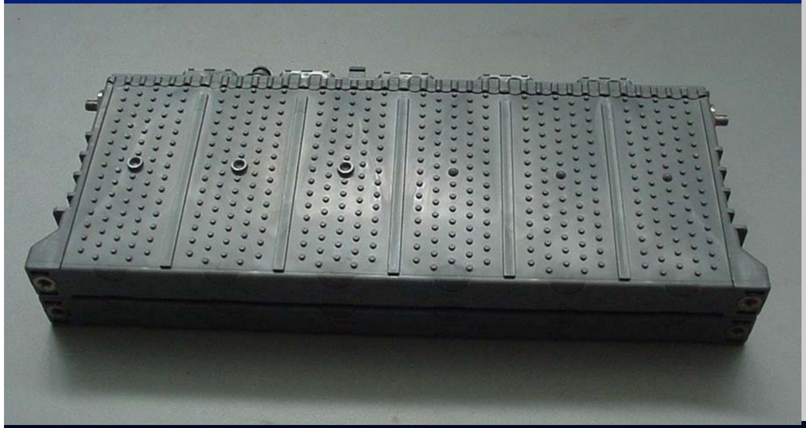
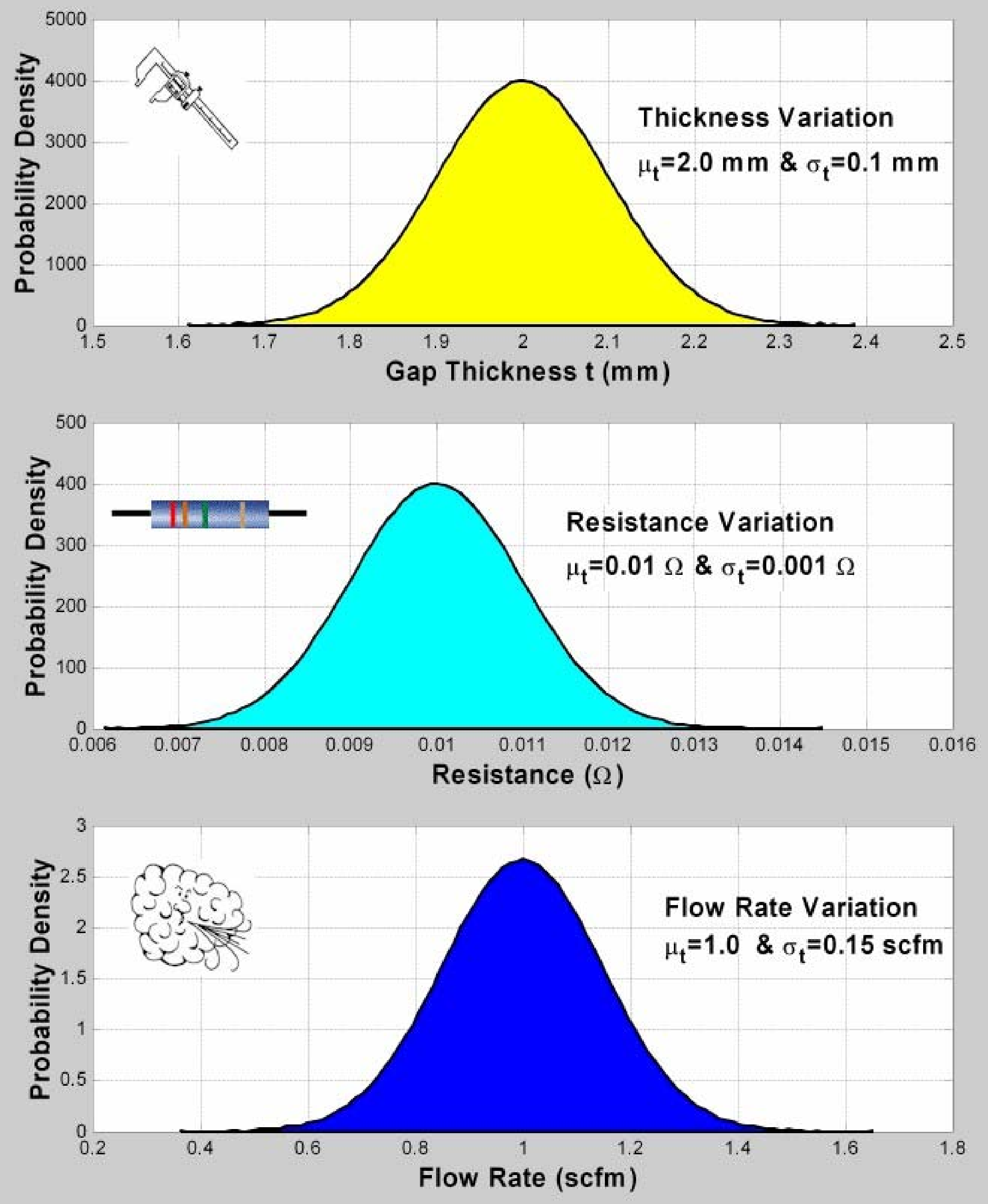
Inputs with Variation

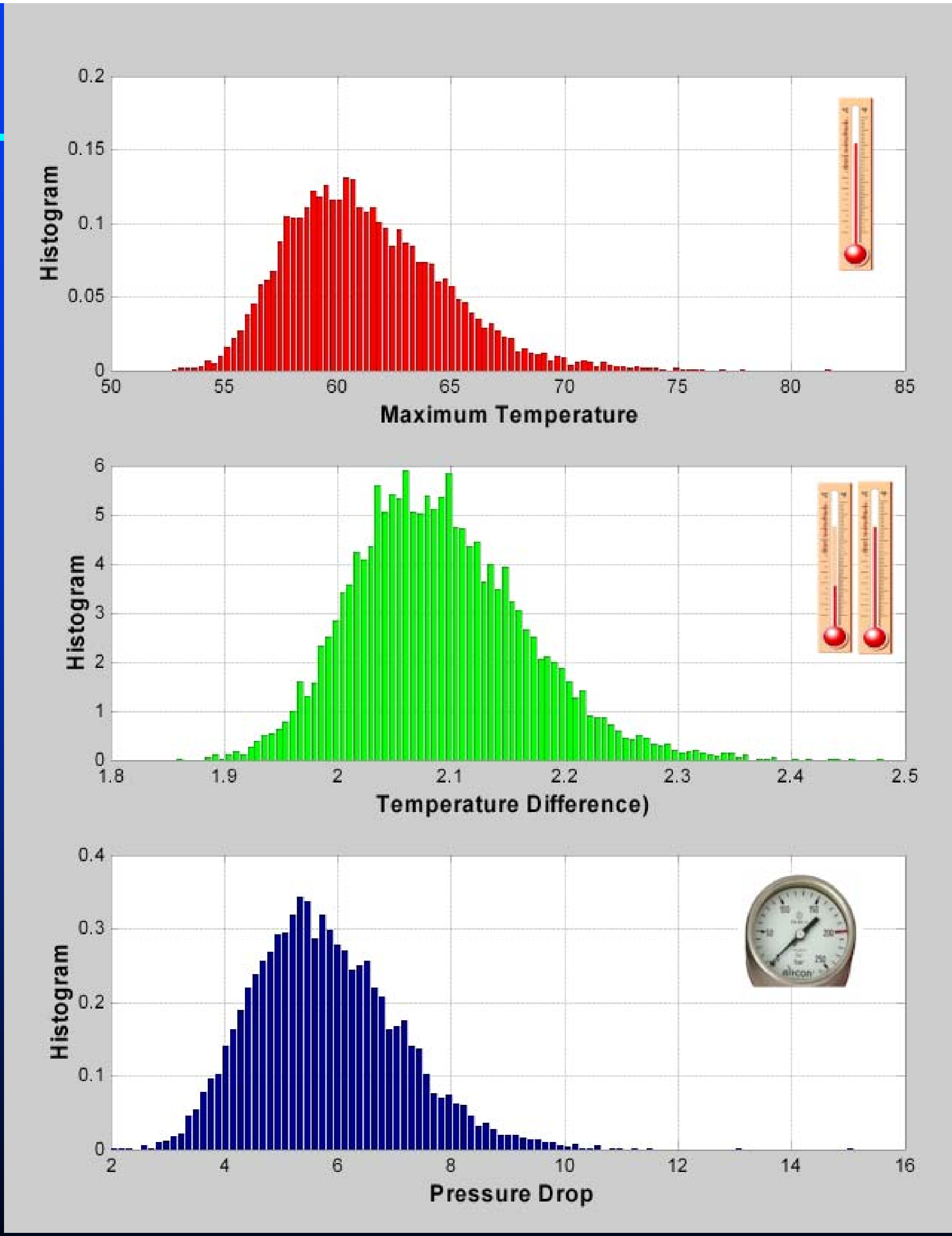
- Gap Thickness
- Cell Resistance
- Flow Rate
- Six input parameters:
  1. μ_{tgap}
  2. σ_{tgap}
  3. μ_R
  4. σ_R
  5. μ_{Frate}
  6. σ_{Frate}





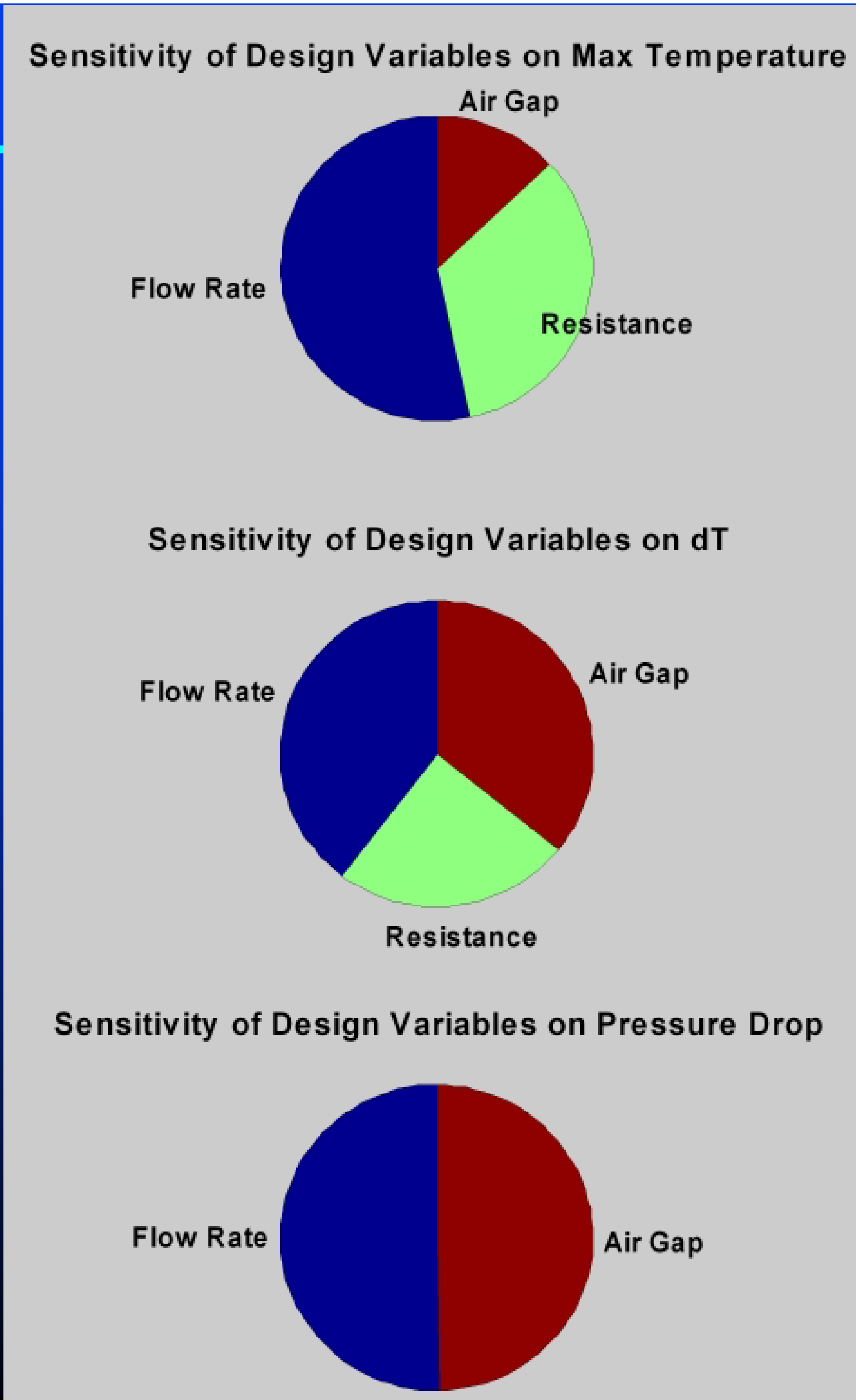
Outputs

- SMART Attributes
  - Simple
  - Measurable
  - Agree to
  - Reasonable
  - Time-based
- Outputs – variation
  - max temperature
  - differential temperature
  - pressure drop
- Six input parameters:
  - μ_{Tmax}, μ_{dT}, μ_{dP}
  - σ_{Tmax}, σ_{dT}, σ_{dP}

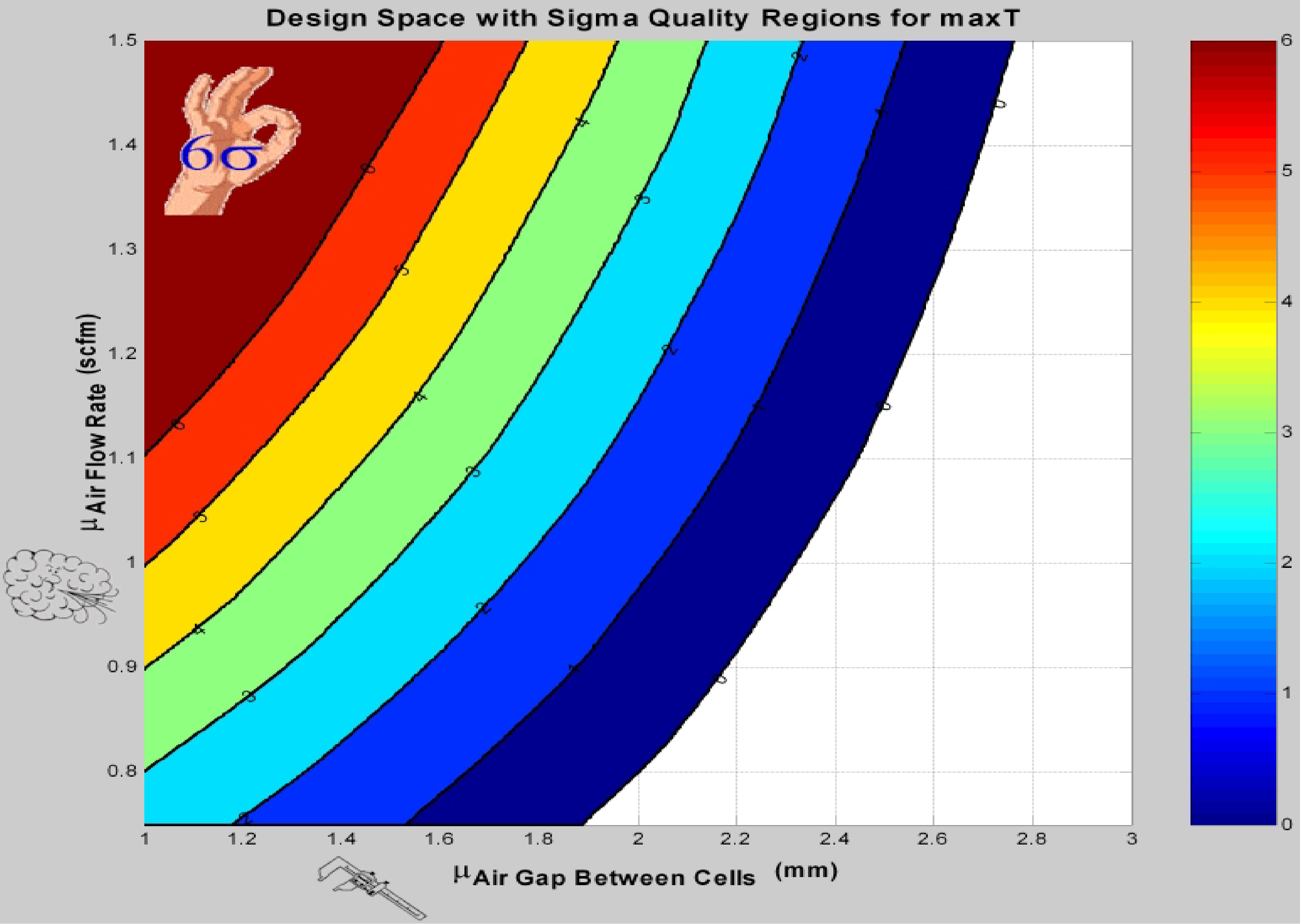


Sensitivity Analysis

- Sensitivity of the design variables on the response attributes
  - The flow rate has the most impact on the maximum temperature
  - All three input design variables have about equal effect on the temperature differential
  - The internal battery resistance has no effect on the pressure drop.



Design Space with σ Quality Regions T_{max}



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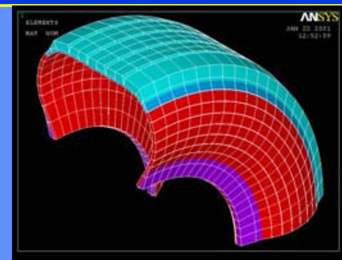
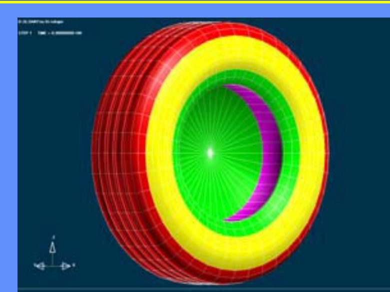
Design of Experiments Techniques for Road Load Reduction

NREL Parametric Tire Data
(Geometric, Material, Loading, Modeling)



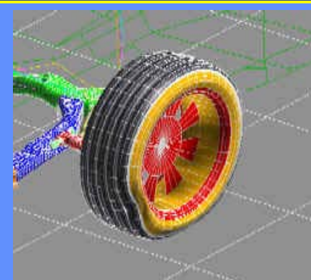
Parametric Solid Model



FEA Model

Execution at ORNL Supercomputer

3600 CPU hours



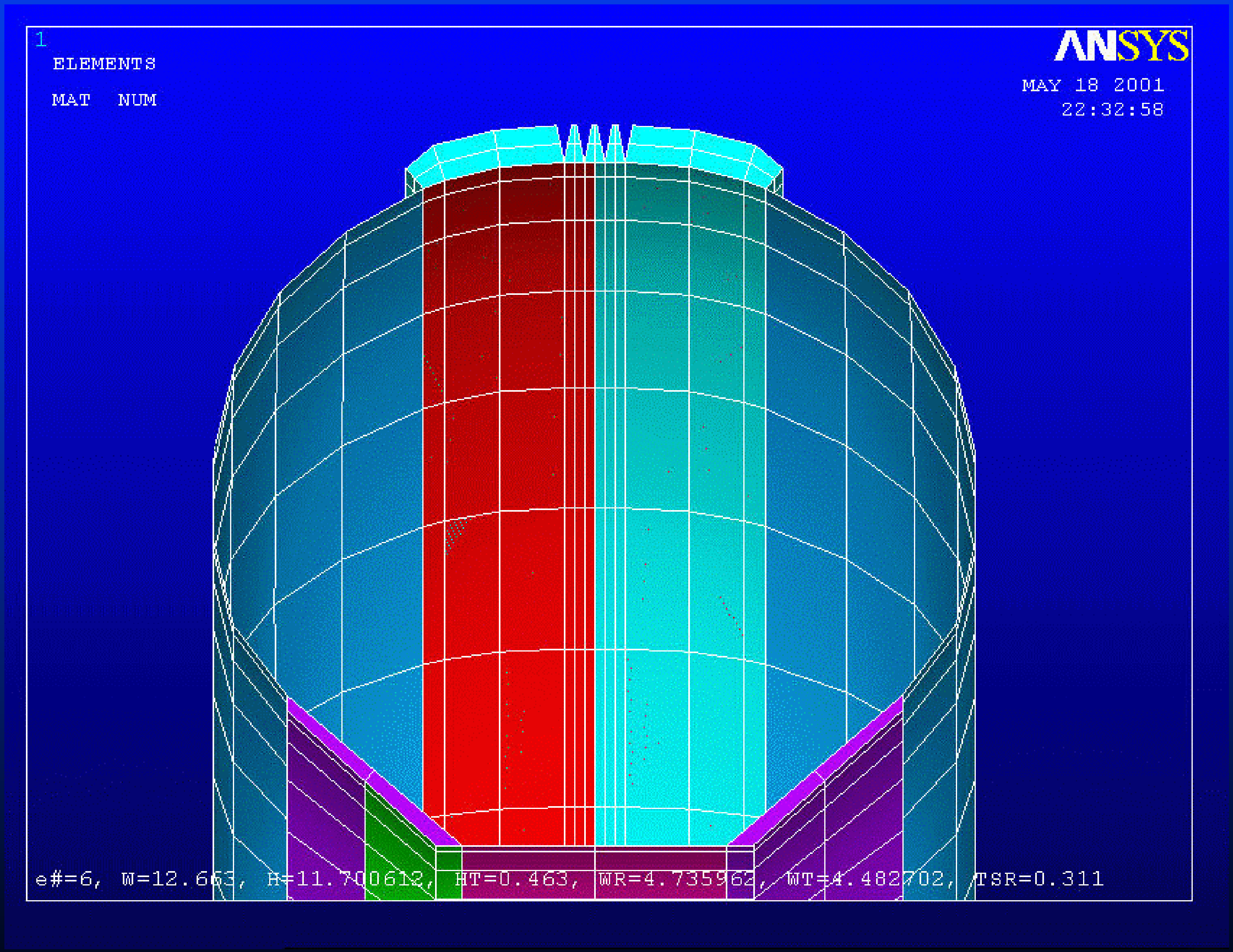
FEA Results

DOE

Optimization Enrich - Data Base

- Improving the loads prediction capability using an accurate tire model would assist in minimizing vehicle weight while creating durable vehicle structure

Tire Geometry Morphing



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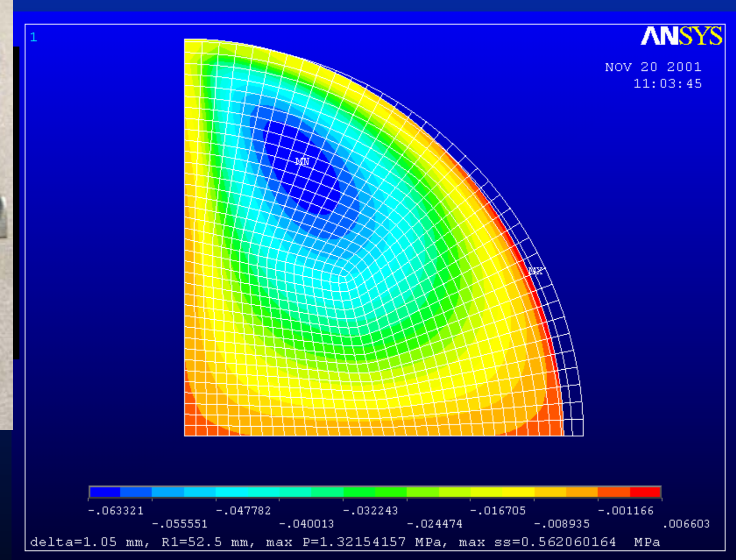
Catalytic Converter Section

Catalytic Converter Failure Avoidance Study

- If $\Delta = \Phi_{max} - \Phi_{min}$, $\tau_{allowable}$ exhibits a given variation identify the supplier specification (maximum standard deviation of Δ) in order to achieve six-sigma quality



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Inverters

How can you use these techniques in your program ?