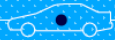




Robust Design

S. Ravi Shankar, Ph.D.



Objective & Agenda

Robust Design Overview & Successes

- Stochastics
- DOE/RSM
- Optimization

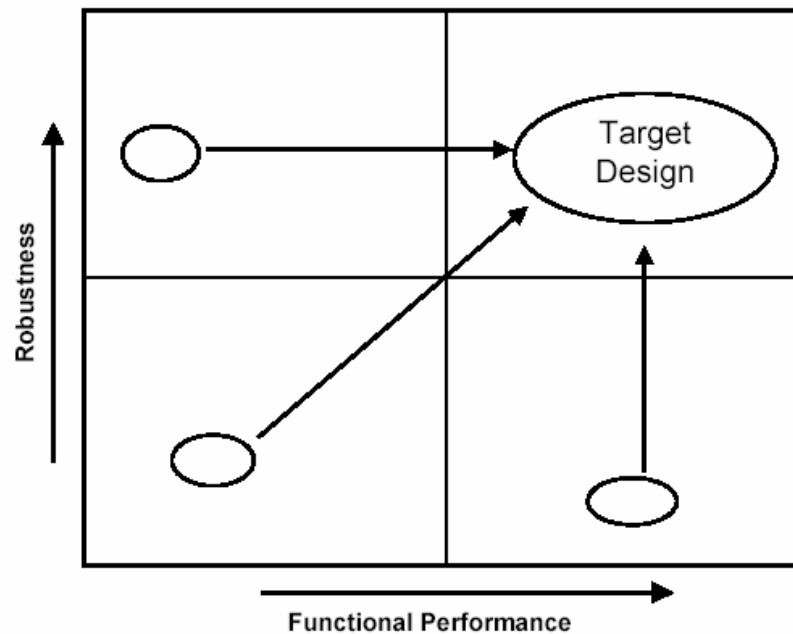
MSC Roadmap

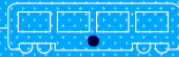
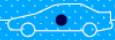
Open Discussion



What is a Robust Design?

A design that satisfies functional requirements and is insensitive to changes in parameters/environment





Relevant Technologies

Stochastic Methods

DOE and Response Surface

Optimization



Motivation

Why stochastic mechanics? Because Nature is stochastic.

What does “stochastic” imply:

- Impossibility to predict with arbitrary precision (in the presence of uncertainties only **estimation** is possible)
- Non-repeatability – you can’t manufacture two identical cars, or aircraft, etc. (because of tolerances)
- Unexpected events that lead to risk (failure)





Material and Load Scatter

MATERIAL	CHARACTERISTIC	CV
Metallic	Rupture	8-15%
	Buckling	14%
Carbon Fiber	Rupture	10-17%
Screw, Rivet, Welding	Rupture	8%
Bonding	Adhesive strength	12-16%
	Metal/metal	8-13%
LOAD TYPE	ORIGIN OF RESULTS	CV
Launch vehicle thrust	STS, ARIANE	5%
Transient	ARIANE 4	60%
Thermal	Thermal tests	8-20%

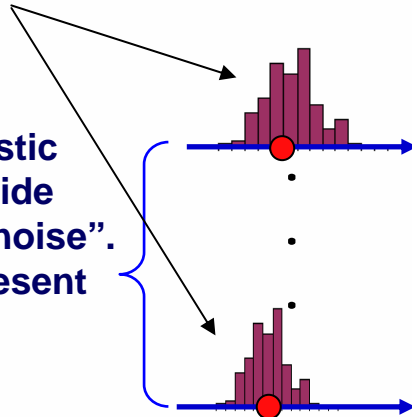
Source: Klein, M., Schueller, G.I., et.al., Probabilistic Approach to Structural Factors of Safety in Aerospace, Proceedings of the CNES Spacecraft Structures and Mechanical Testing Conference, Paris, June 1994, Cepadues Edition, Toulouse, 1994.



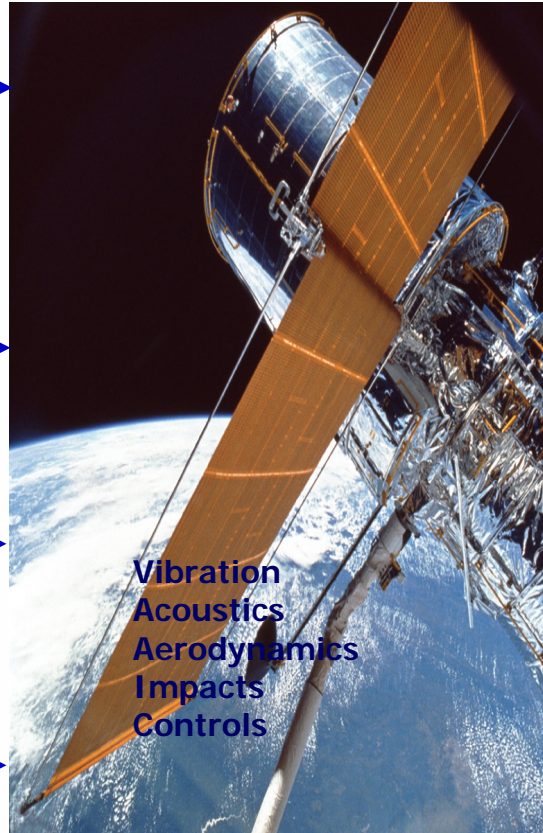
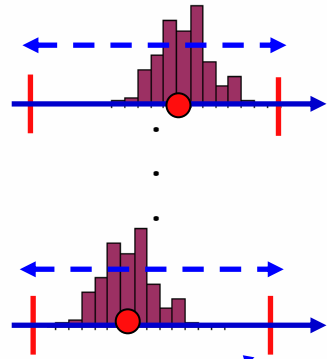
Definition of a Stochastic Problem

Physical tolerance

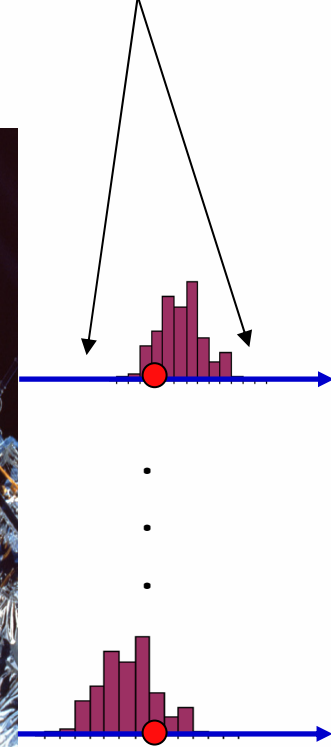
“Free” stochastic variables provide background “noise”. Typically represent tolerances.



Design variables. Large changes in mean values are allowed.



Performance scatter



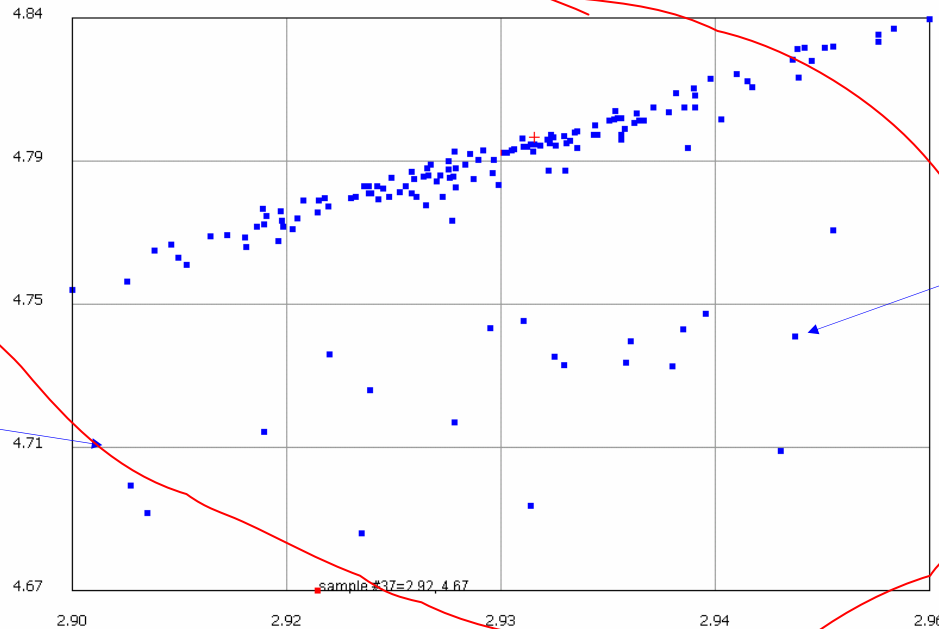
Allowed design interval

PRODUCT DEVELOPMENT CONFERENCE



From Analysis to Simulation

Collection
of computer
runs =
Simulation
(CAE tomorrow)



Single
computer
run =
Analysis
(CAE today)

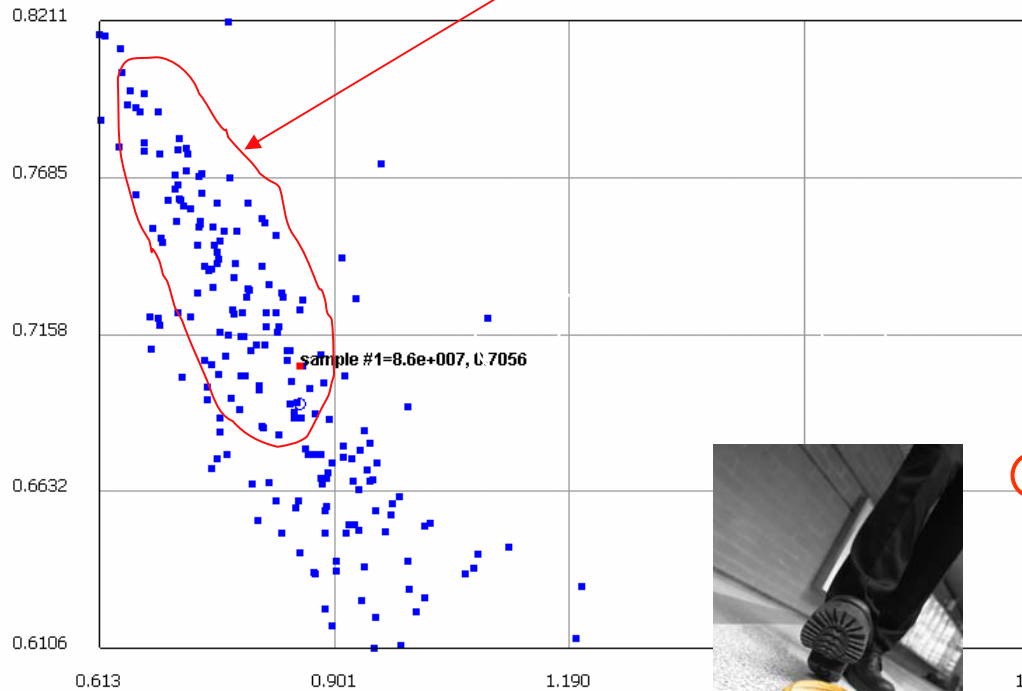
Understanding the physics of a phenomenon is equivalent to the understanding of the topology and structure of these clouds.

PRODUCT DEVELOPMENT CONFERENCE



Why Stochastics?

Find Most Likely Response



Find outliers – maybe dangerous:

- Lawsuit
- Warranty
- Recall



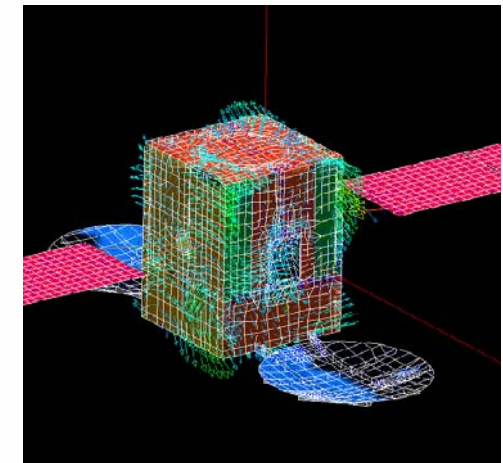
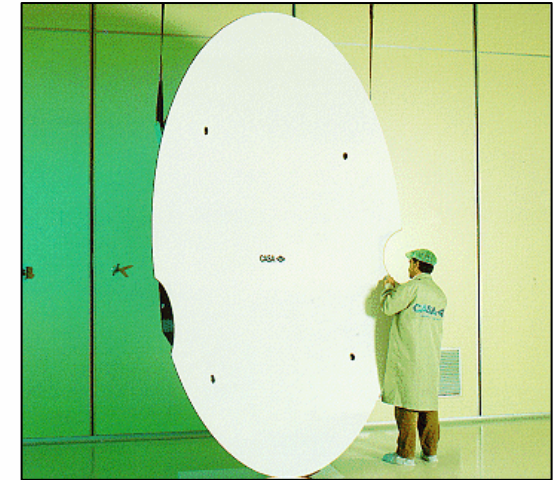
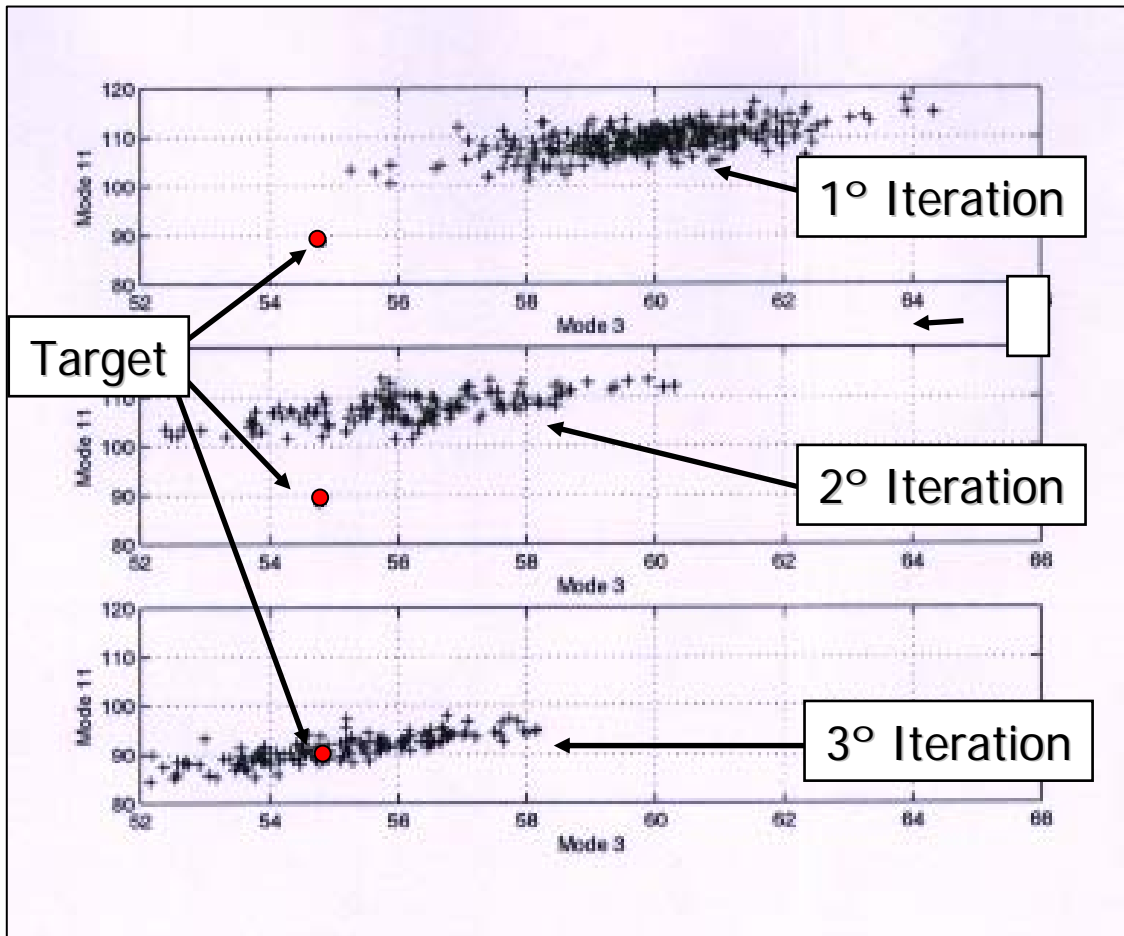
1,766

PRODUCT DEVELOPMENT CONFERENCE



Stochastic Design Improvement: “Moving Clouds”

Courtesy EADS-CASA Space Division





Stochastic Design Improvement

Problem:

Find a layup so as to achieve:

mass reduction

technological requirement

static relief factor and buckling performance

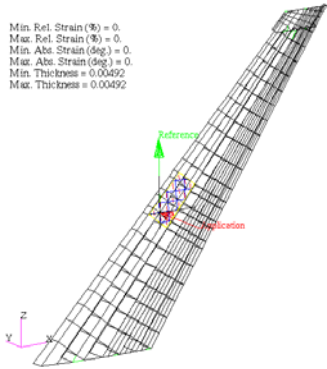
Highly Complex Problem

- multi target
 - 6 objectives (1 linear static + 5 buckling)*
 - 10 boundary conditions*
- discrete variables type
 - ply shape*
 - angle ply*
- high variables number (~ 650 to 1000)
 - 180 different plies shape*
 - a layup contains 350 to 500 plies*
 - a layup contains 300 to 400 ply angles*

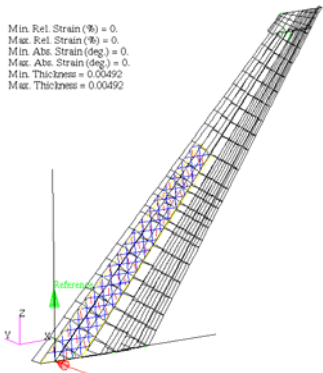
Result:

6% mass reduction, satisfying constraints

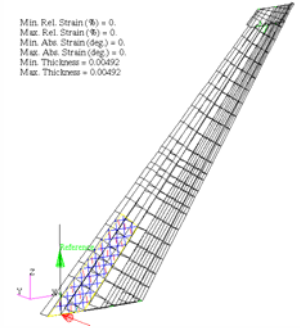
Min. Rel. Strain (%) = 0.
Max. Rel. Strain (%) = 0.
Min. Abs. Strain (deg.) = 0.
Max. Abs. Strain (deg.) = 0.
Min. Thickness = 0.00492
Max. Thickness = 0.00492



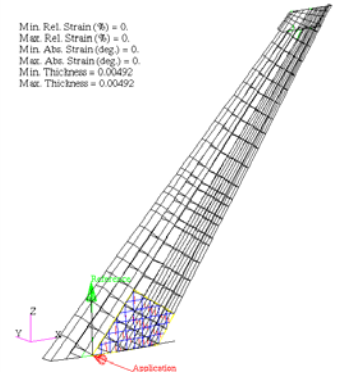
Min. Rel. Strain (%) = 0.
Max. Rel. Strain (%) = 0.
Min. Abs. Strain (deg.) = 0.
Max. Abs. Strain (deg.) = 0.
Min. Thickness = 0.00492
Max. Thickness = 0.00492



Min. Rel. Strain (%) = 0.
Max. Rel. Strain (%) = 0.
Min. Abs. Strain (deg.) = 0.
Max. Abs. Strain (deg.) = 0.
Min. Thickness = 0.00492
Max. Thickness = 0.00492



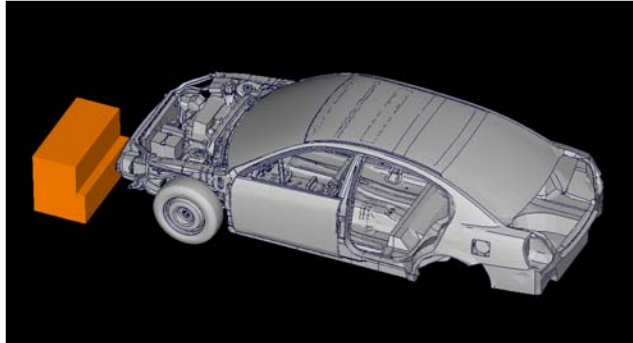
Min. Rel. Strain (%) = 0.
Max. Rel. Strain (%) = 0.
Min. Abs. Strain (deg.) = 0.
Max. Abs. Strain (deg.) = 0.
Min. Thickness = 0.00492
Max. Thickness = 0.00492



Courtesy, Alenia Aeronautica



Stochastic Design Improvement



Problem: reduce mass, maintain safety and stiffness

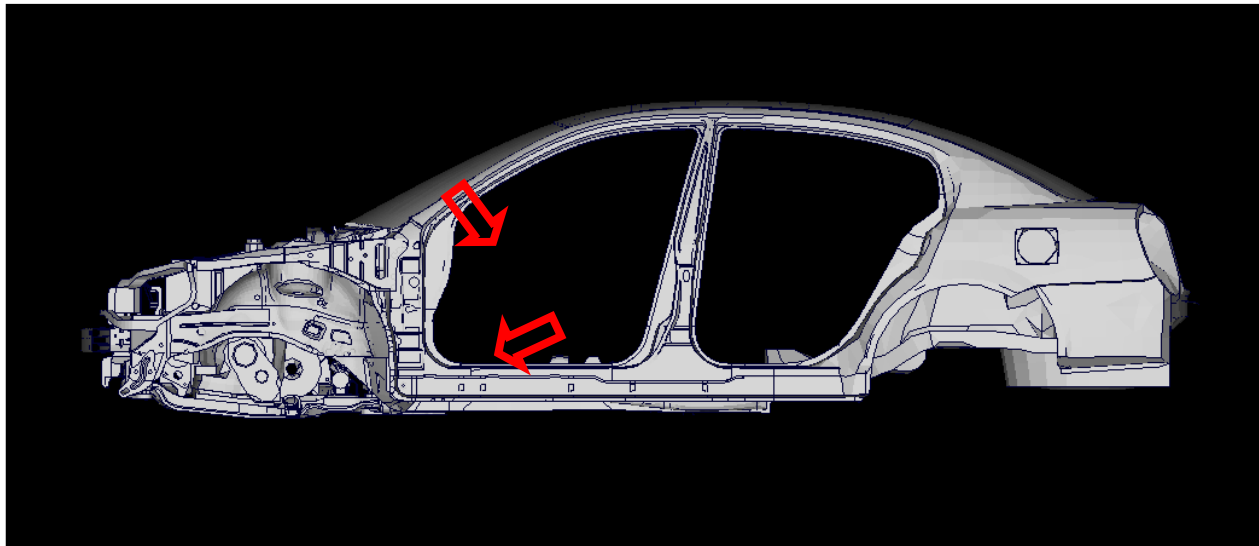
Result:

16 kg mass reduction

20% reduction of A-pillar deformation

40% reduction of dashboard deformation

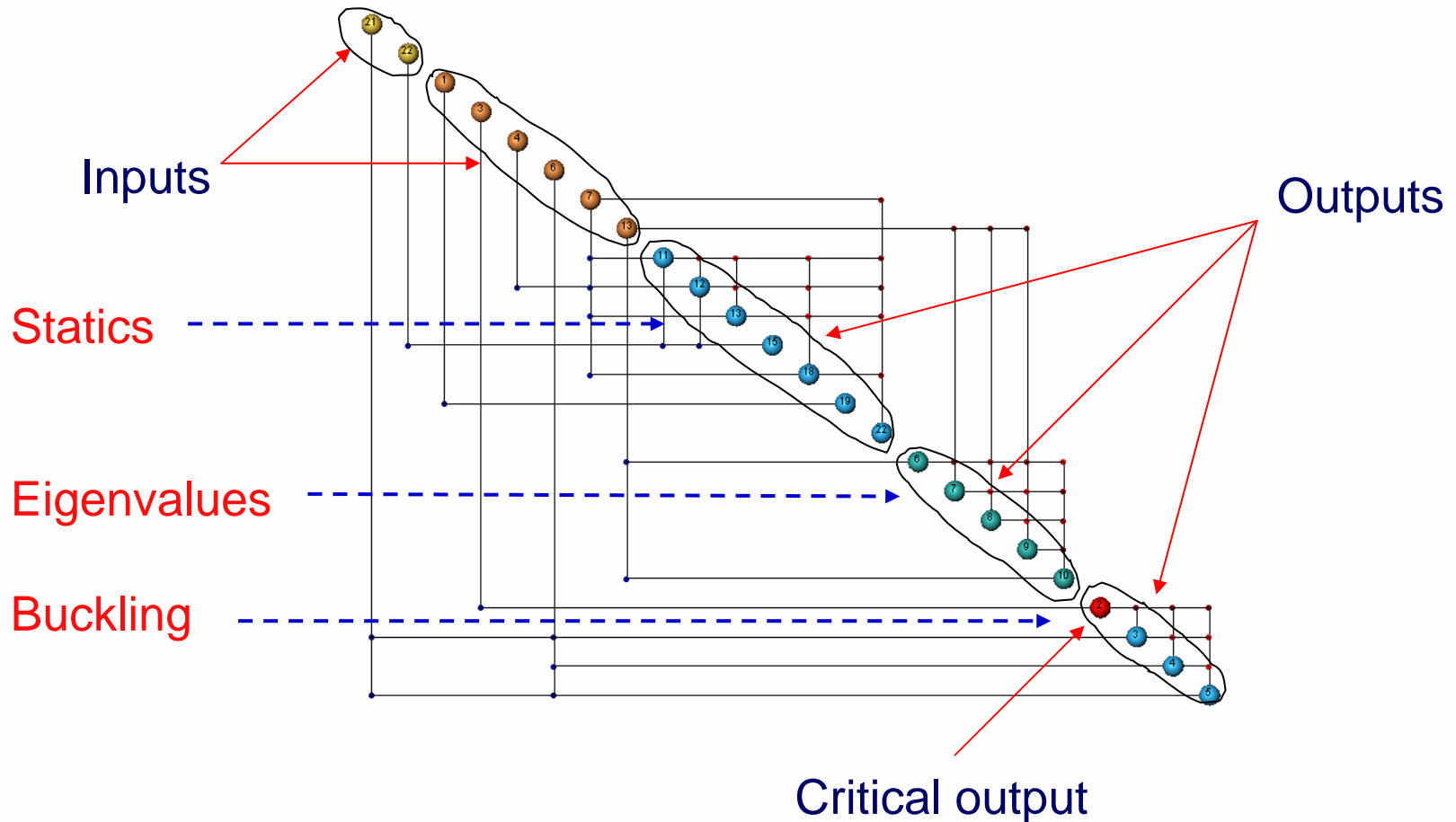
Cost = 60 runs (tolerances in all materials and thicknesses) of PAM-Crash and MSC.Nastran



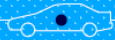
Courtesy, Nissan Motor Company



Decision Maps – Structured Information



PRODUCT DEVELOPMENT CONFERENCE

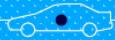


Relevant Technologies

Stochastic Methods

DOE and Response Surface

Optimization



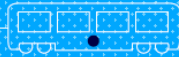
DOE/Response Surface

Design of Experiments (DOE)

- Methods and tools to plan and run a series of experiments
- Statistical techniques to analyze the results

Response Surface Methods (RSM)

- Allow you to create a simplified model that can act as a surrogate
- Measures available to determine how good the surrogate model is



Why DOE/RSM?

Surrogate models can provide almost instantaneous answers to “what-if” questions

Facilitates communication

- Interactive web pages

Provides information on sensitivities and interactions



Interactive Web Pages

Responses from Experiment "robustness" - Microsoft Internet Explorer

Address: C:\Ddrive\ADAMS_Insight_Training\Robustness\Chassis120_Example\rob\robustness.htm

Responses from Experiment "robustness"

Factor	Units	Current	Tolerance	Min	Nominal	Max	Description
x_tolerance	mm	3.0000	5.0000e-01	-3.0000	0	3.0000	UCA Front Bushing x tolerance
y_tolerance	mm	6.0000e-01	5.0000e-01	-3.0000	0	3.0000	UCA Front Bushing y tolerance
z_tolerance	mm	3.0000	5.0000e-01	-3.0000	0	3.0000	UCA Front Bushing z tolerance

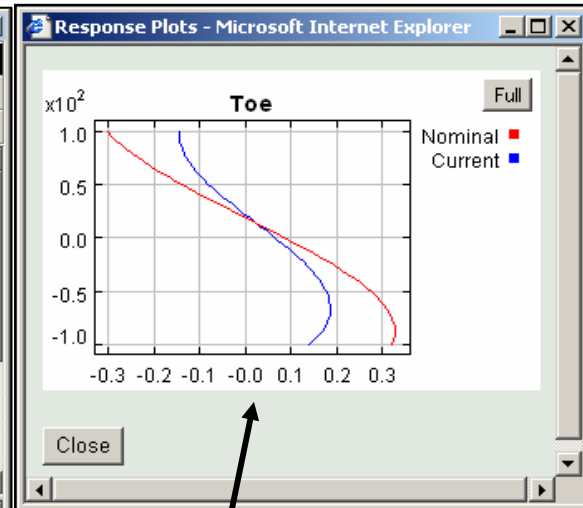
Update Reset Contribution Stats Effects Nonscalar Plots... Info...

Response	Units	Current	Tolerance	Description
MAX_TOE	deg	1.9920e-01	3.5916e-02	Maximum Left Front Toe

Main Effects for Response: MAX_TOE

Factor	From	To	Effect	Effect %
y_tolerance	-3.0000	3.0000	3.9650e-01	-110.96
z_tolerance	-3.0000	3.0000	-1.2150e-01	35.84
x_tolerance	-3.0000	3.0000	-9.3000e-02	-27.43

Created 2002-03-15 22:15 with ADAMS/Insight 12.0 (MDD)



Response curve is dynamically updated based on user input

Specify factor values and hardpoint tolerance values here

Sensitivities displayed here



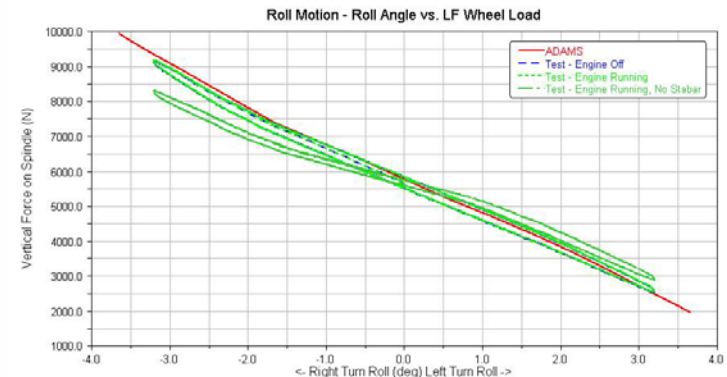
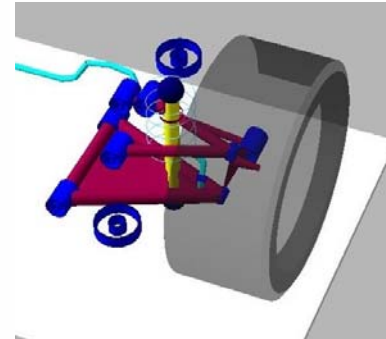
Case Study: Visteon

Business: Automotive Tier-1 Supplier

Challenge: Develop a statically and dynamically correlated model of a competitive vehicle

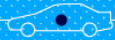
Solution: MSC.ADAMS + Response Surface Methods

Value: Obtained well-correlated model despite quality of input data



“Response Surface Methods allowed simultaneous correlation of many attributes”

Published at SAE Automotive Dynamics and Stability Conf, 2002



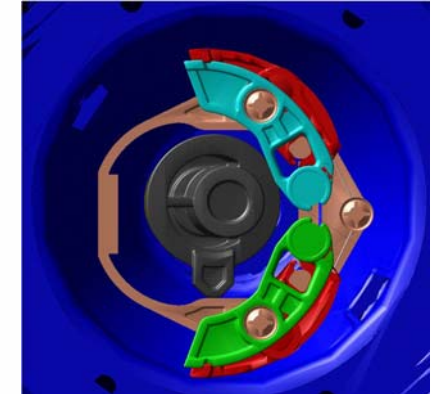
Case Study: Whirlpool

Business: Appliance manufacturer

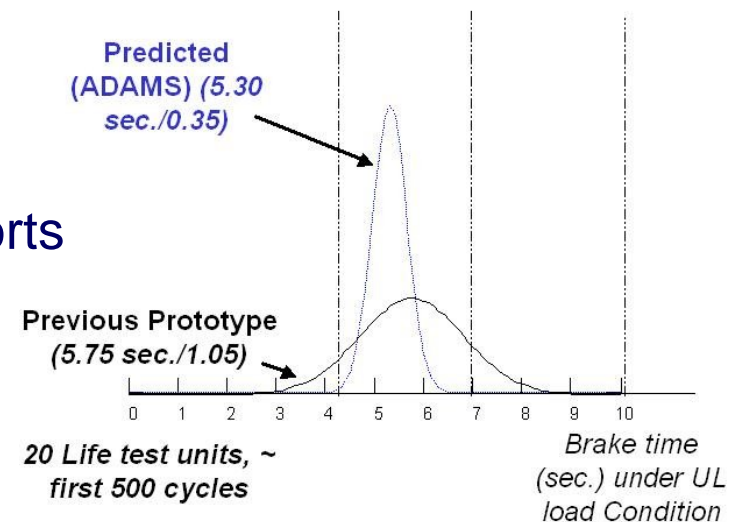
Challenge: Meet UL requirement for washing machine braking

Solution: Built complete virtual washing machine; used Six Sigma and DOE to ensure robust design

Value: Achieved certification;
Got to market on-time;
Rated #1 by Consumer's Reports



Brake Time: Predicted Optimum Vs Original



"Virtual prototyping provided insights that physical testing would not have revealed."

-- Brenner Sharp
The Whirlpool Corporation



Relevant Technologies

Stochastic Methods

DOE and Response Surface

Optimization

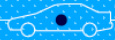


Optimization

Automated modifications of the analysis model parameters to achieve a desired objective while satisfying specified design requirements

Wide range of methods

- Sequential Linear Programming, Hill Climbing, Genetic Algorithms, ...



Why Optimization?

Can yield peak performance

May be able to leverage in-house experience



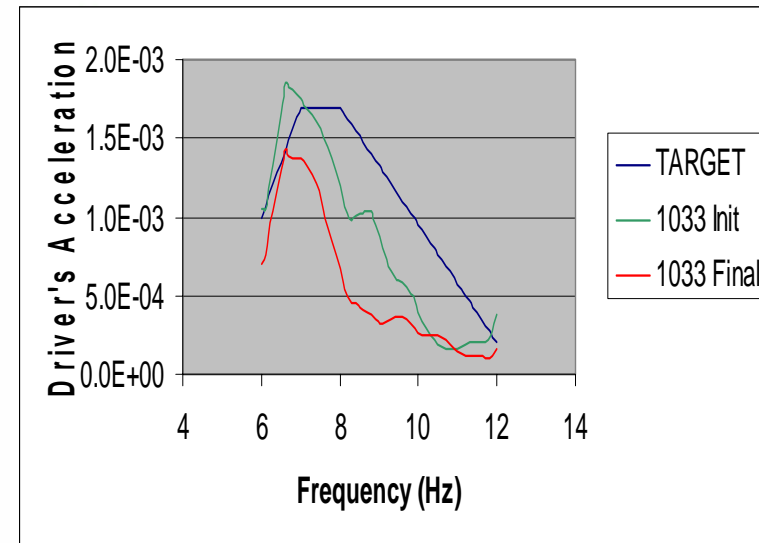
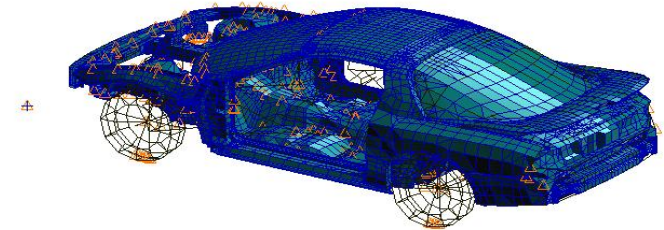
Case Study: General Motors

Business: Major Automotive Manufacturer

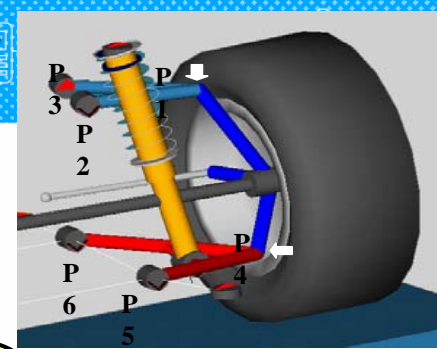
Challenge: Design vehicle for optimal response to road input

Solution: MSC.Nastran Optimization

Value: Reduced response levels below target; replaced time-consuming trial and error process



Work presented at the AIAA Conference 2003



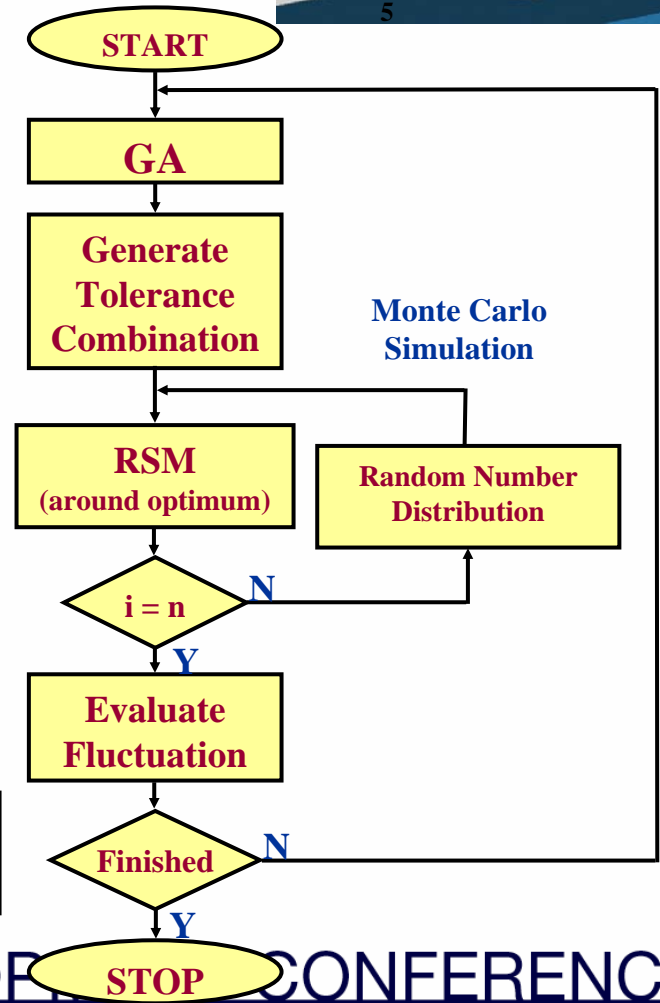
Case Study: Honda R&D

Business: Major Automotive Manufacturer

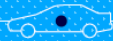
Challenge: Suspension Design subject to multiple constraints

Solution: MSC.ADAMS + Combination of Genetic Algorithms, Response Surface, Monte Carlo Simulation

Value: Solution was obtained in one-fifth the time it took for the original development

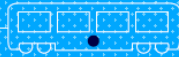


Work presented at the Advanced Vehicle Control Conference 2002



Comparison of RD Methods

Method	Strength	Best Suited For
Stochastics	Ease of use; Scalable solution – cost of computation is independent of number of variables; Handles variability	Widely applicable; Where problem domain has complex behavior; When managing risk is a critical need
DOE/RSM	Surrogate models are very fast; Enables cross-group collaboration	Where the behavior is known to be continuous; When working with early conceptual models
Optimization	Can give you peak performance; Wide range of techniques which might yield faster answers in some cases	When used in conjunction with above methods



Current Offerings

MSC.Robust Design

- Stochastics (Monte Carlo Simulation), SDI
- MSC.Nastran and MSC.Marc (via SOL 600)

ADAMS/Insight

- DOE/RSM/Stochastics
- MSC.ADAMS, ADAMS/Car, ASCII Conduit

MSC.Nastran Optimization

- Design Sensitivity Analysis, Math Programming
- MSC.Nastran



Where we are headed

Our objective is to ensure that our customers have access to each of the three main techniques – Stochastics, DOE/RSM, MDO – in each of our main solutions suites. We will focus on the following:

- Expand solver support
- Selectively add support for new investigation strategies e.g., Genetic Algorithms
- Enhance conduit maturity
- Smart method selection



SimOffice

Increasing breadth of Robust Design technology

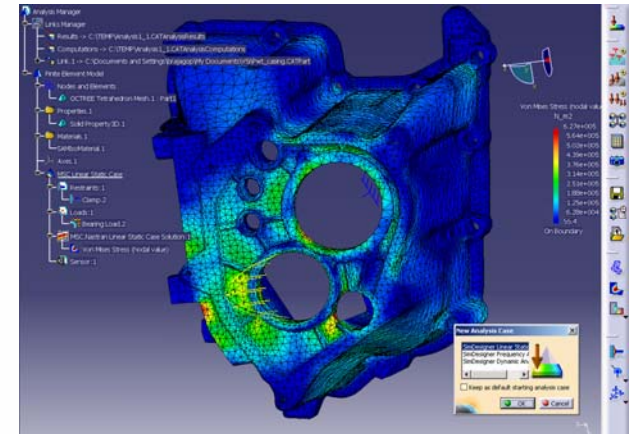
- MSC.Robust Design support for MSC.Nastran Implicit Nonlinear – April 2004
- Random weld failures in MSC.Nastran 2004
- ADAMS/Insight support for MSC.EASY5 for Aero/Hydraulics/Controls – 2005
- ADAMS/Insight conduit for MSC.Patran
- Links between MSC.Robust Design and ADAMS/Insight to enable use of a larger set of investigations strategies across a larger set of solvers
- Common set of investigation strategies and common user experience across all primary MSC solvers

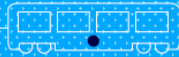


SimDesigner

Increasing access of Robust Design technology within the CAD environment

- Parameterization of geometry, material properties and loads within SimDesigner environment with initial focus on Stochastics
- Expand support for multiple solvers within the SimDesigner environment
- Expand support of other investigation strategies and tools for results exploration

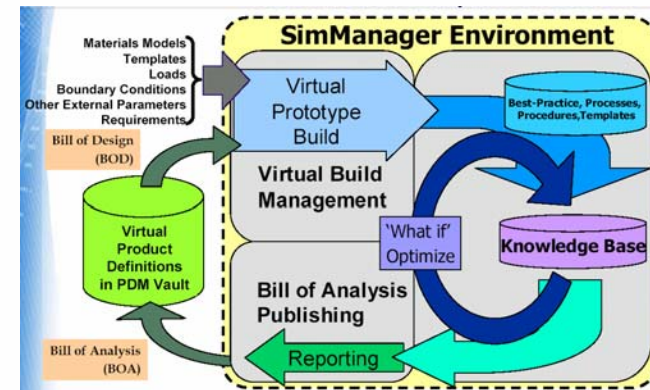


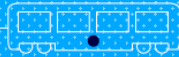


MSC.SimManager

Deploying Robust Design technology in an enterprise-wide simulation environment

- Job submission and data coordination
- Support for multiple, sequential solver runs
- Data mining for large data sets





Services

Pilot or full-scale projects to implement Robust Design techniques on customer models

64 CPU Linux cluster in Munich for stochastic simulations



Discussion

Do you have a better understanding of RD methods and where they should be applied?

Have we increased your interest in RD?

Do you understand our general RD direction?

What are your priorities with respect to RD?

Note: Workshop with MSC.Robust Design scheduled for Wed Oct 20
Please see conference schedule for time and room