The MathWorks MATLAB®&SIMULINK®

Reliability Analysis and Robust Design Using MATLAB® Products

Stuart Kozola, Technical Marketing
Ascension Vizinho-Coutry, Application Engineering Group

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Agenda

- Overview of reliability analysis and robust design
- Overview of MATLAB®
- Demonstration
- Summary of products shown
- Additional resources
- Question and answer

Benefits of Reliability Analysis and Robust Design

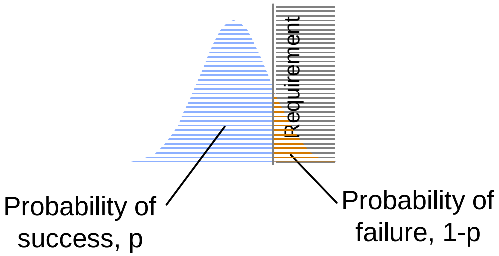
- Gain more knowledge about design
  - Understand failure rates / mechanisms
  - Sensitivity to changes in design parameters
  - Capture variation in design process and operation

- Better designs
  - Improved performance
  - Reduced variability
  - Improved quality

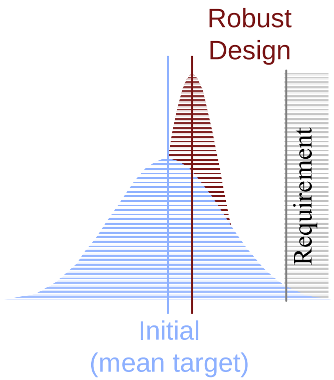
- Reduce development cost/effort
  - Fewer prototypes
  - Faster design iterations
  - Shorter development cycle

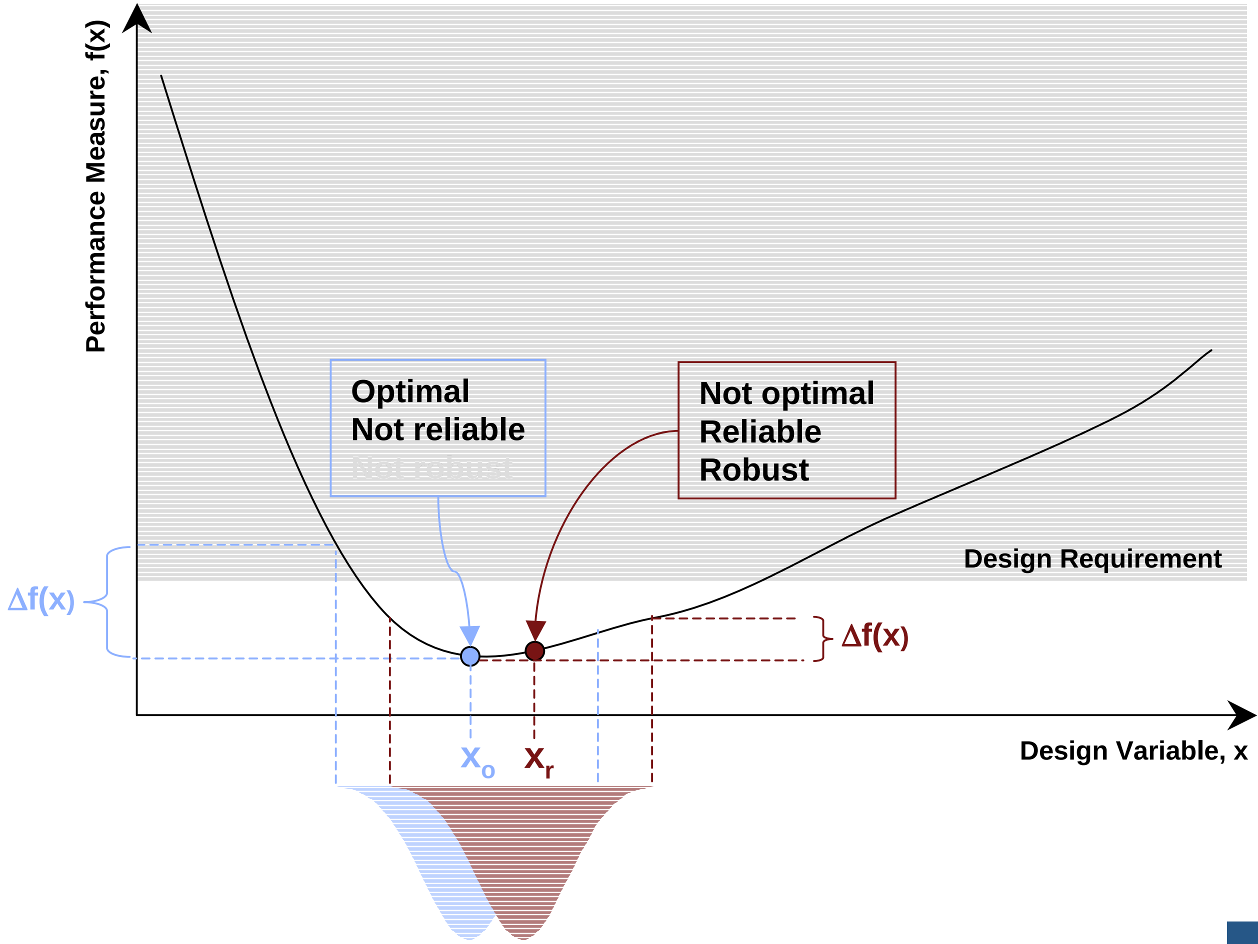
What is a Reliable and Robust Design?

Reliability – probability of satisfying a requirement

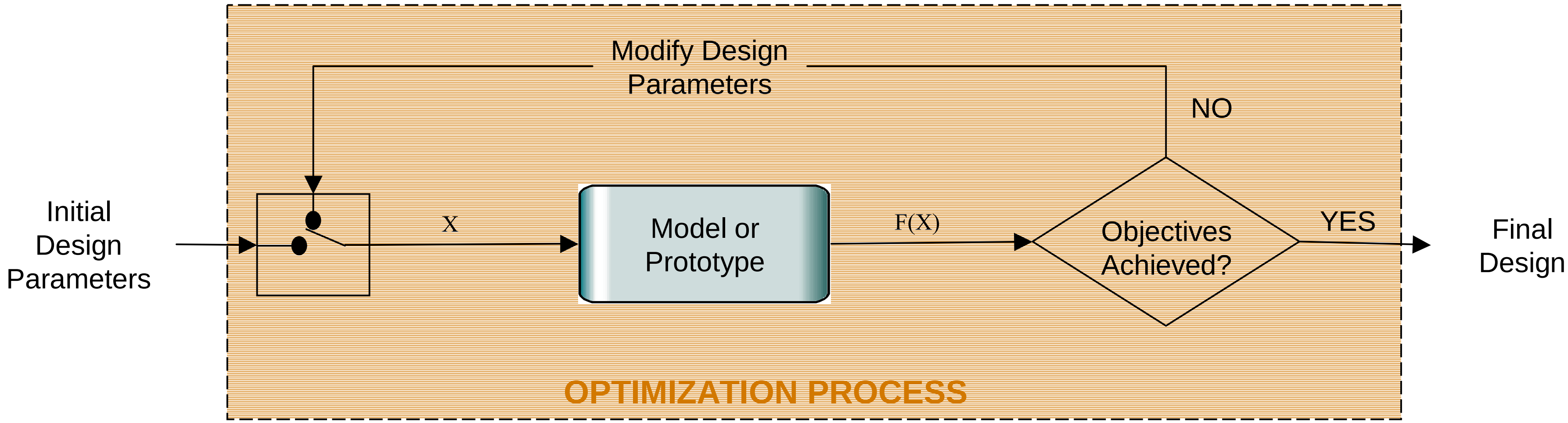


Robustness – ability to handle variation without loss of performance





Engineering Design Workflow



Design process can be performed:

- Manually (trial-and-error or iteratively)
- Automatically using optimization techniques

F(X) = Goal or min/max F(x)
By changing X
Subject to Design Requirements

Optimization benefits include:

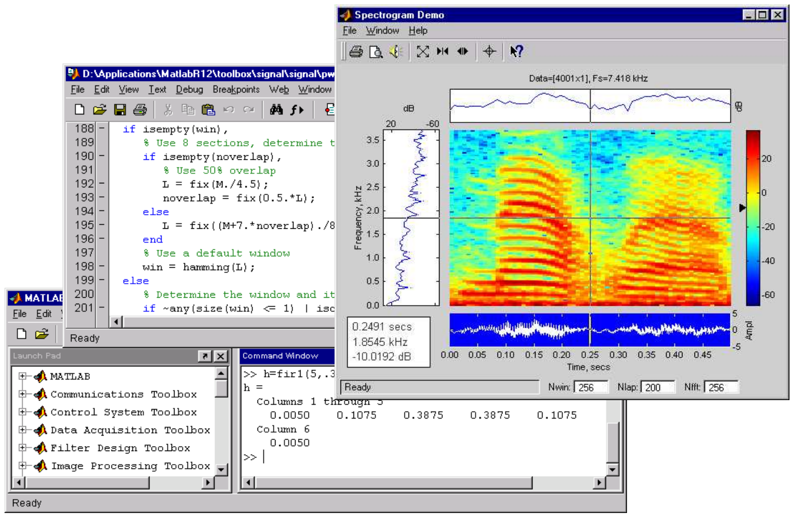
- Finding better (optimal) designs
- Speeding up design evaluation
- Reducing labor/effort
- Finding non-intuitive designs

MATLAB Provides the Foundation for Engineering Analyses

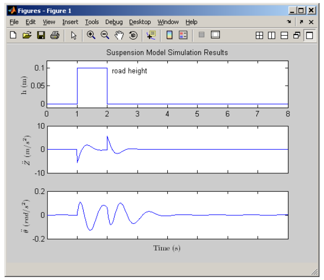
MATLAB®

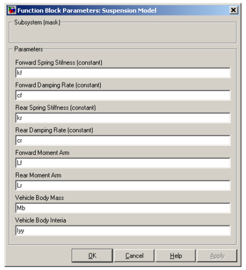
The leading environment for technical computing

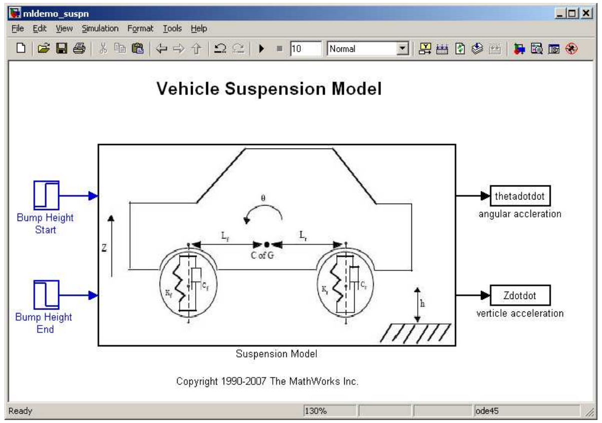
- Customizable
- Numeric computation
- Data analysis and visualization
- The *de facto* industry-standard, high-level programming language for algorithm development
- Toolboxes for statistics, optimization, symbolic math, signal and image processing, and other areas
- Foundation of the MathWorks product family



Demo: Automotive Suspension System Design







- Task: To design the suspension system for a new luxury car model
- Solution Approach:

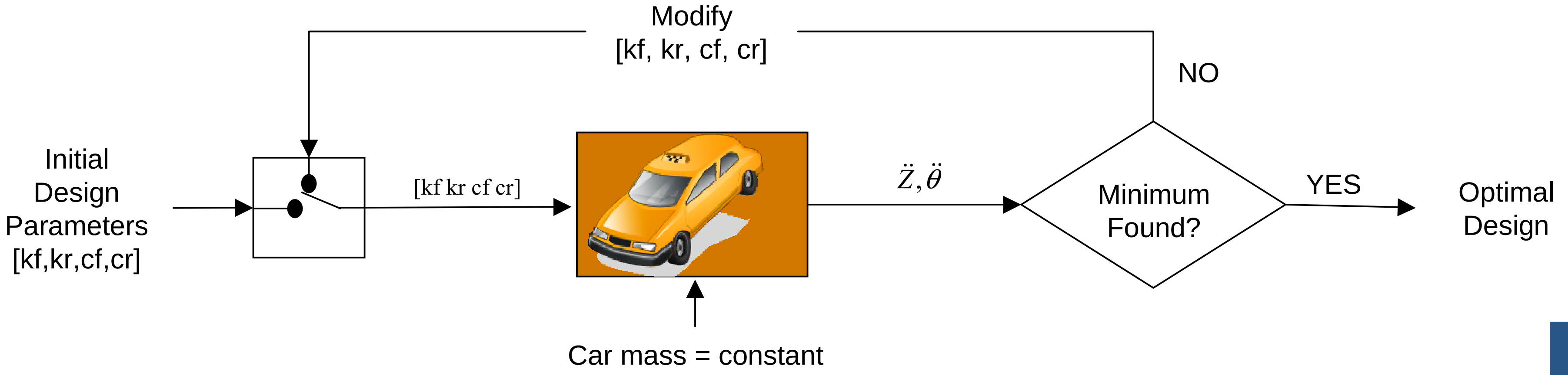
Model → Traditional Approach → Reliability and Robust Design

Design Optimization – Traditional Approach

Minimize passenger vertical and rotational acceleration $\ddot{Z}, \ddot{\theta}$

Design Variables: front/rear springs kf, kr
front/rear shock absorbers cf, cr

Constraints:
- Level car
- Available parts
- Low natural frequency
- Required damping ratio

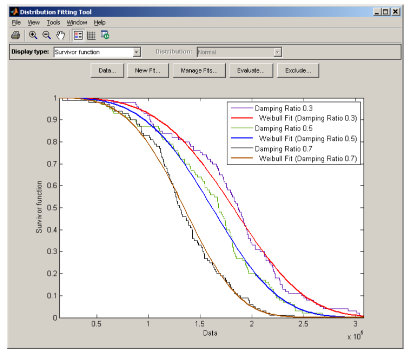


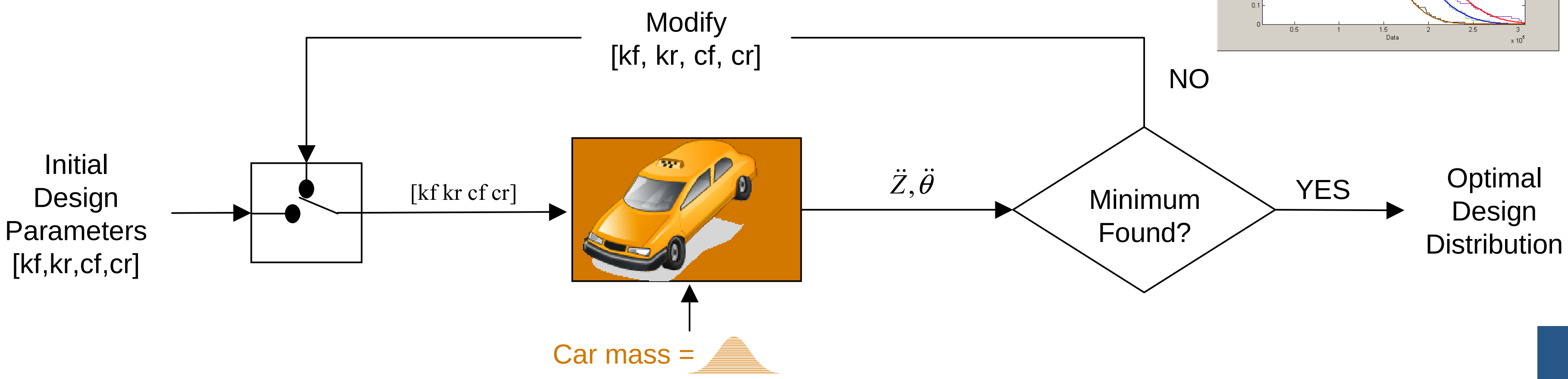
Design Optimization – Reliable and Robust Design Approach

Minimize passenger vertical and rotational acceleration $\ddot{Z}, \ddot{\theta}$

Design Variables: front/rear springs kf, kr
front/rear shock absorbers cf, cr

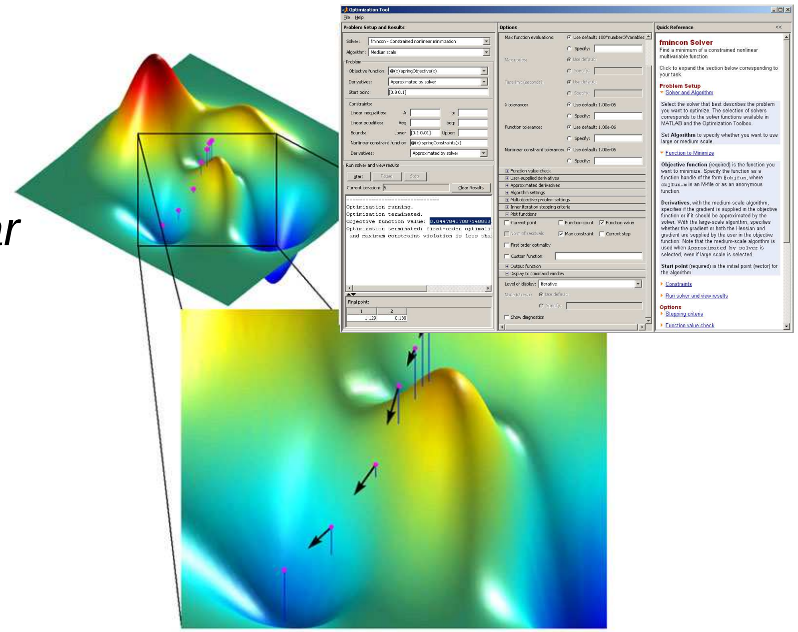
Constraints:
- Level car
- Available parts
- Low natural frequency
- Required damping ratio range
- Reliability constraint on strut
- Uncertainty in vehicle mass





Optimization Toolbox™

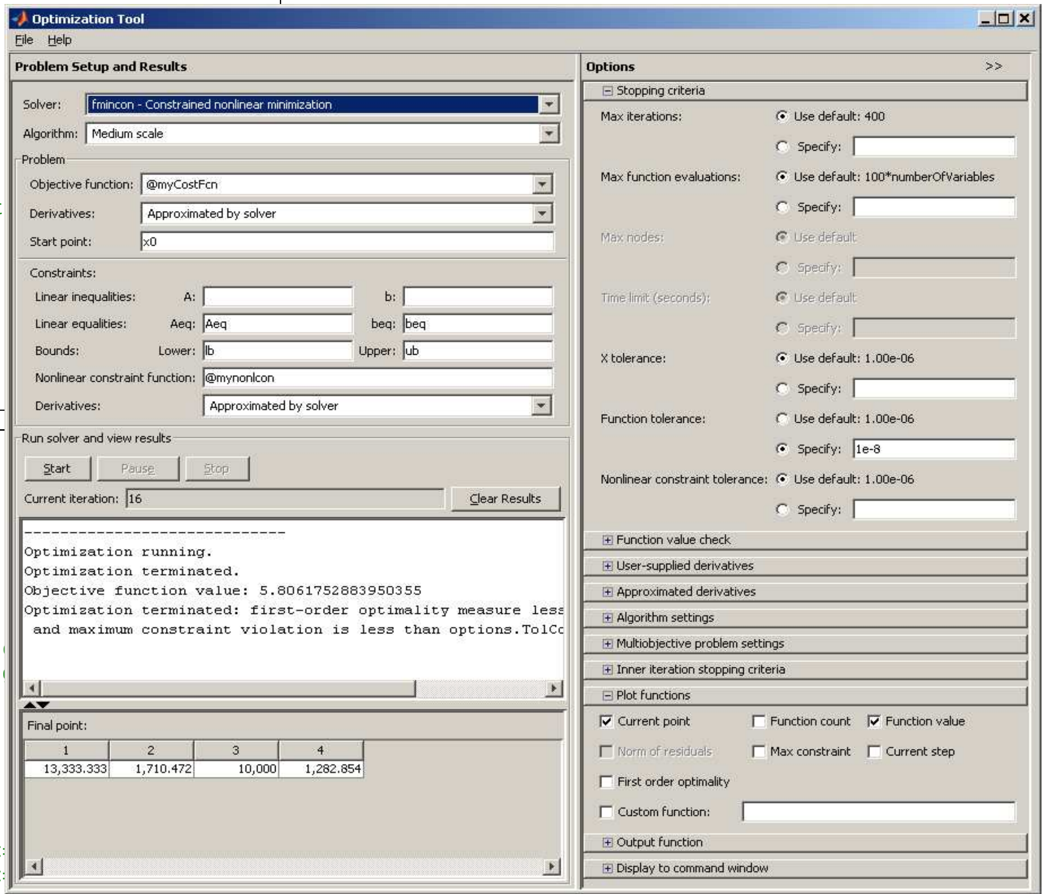
- Graphical user interface and command line functions for:
  - *Linear and nonlinear programming*
  - *Quadratic programming*
  - *Nonlinear least squares and nonlinear equations*
  - *Multi-objective optimization*
  - *Binary integer programming*
- Customizable algorithm options
- Standard and large-scale algorithms
- Output diagnostics



Our example

```
function mycost = myCostFcn(x,simParms)

%% Extract suspension variables (called by Simulink Model)
kf = x(1); cf = x(2);
kr = x(3); cr = x(4);
struct2var(simParms);

%% Run Simulink Model
simTime = [0 8];
sim('mldemo_suspnfast.mdl',simTime); % returns

%% Compute total acceleration
rf = 0.5*Lf;                  % location of front
rr = 0.9*Lr;                  % location of rear

totalAccel = (Zdotdot + rf * thetadotdot).^2 +
             (Zdotdot - rr * thetadotdot).^2;

%% Return a single (scalar) value
mycost = sum(totalAccel);
```

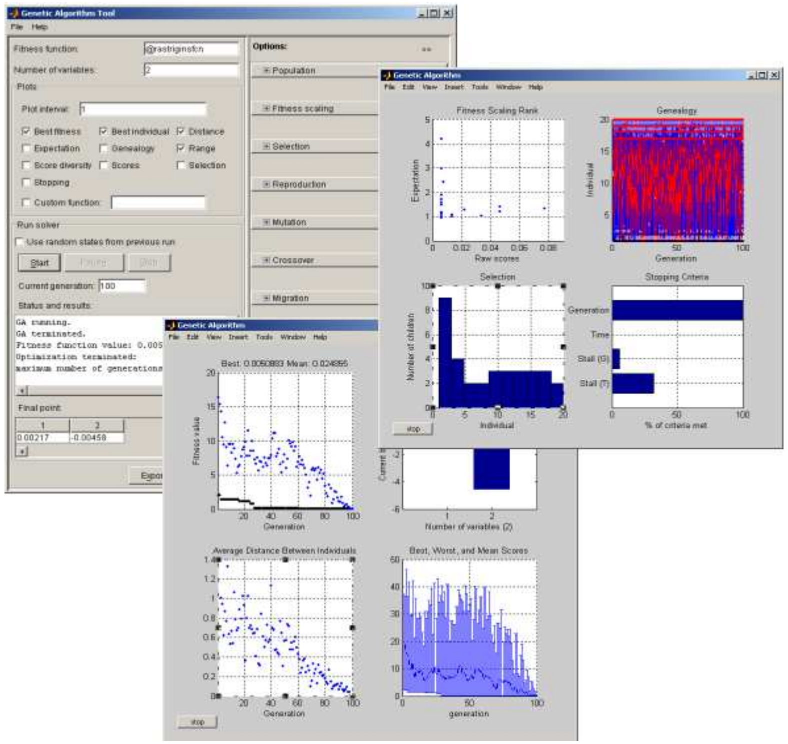
```
function [c,ceq] = mynonlcon(x,simParms)

%% Extract suspension variables
kf = x(1); cf = x(2);
kr = x(3); cr = x(4);
struct2var(simParms);

%% Define desired damping ration range
cupper = 0.5;      % upper limit for dampin
clower = 0.3;      % lower limit for dampin

%% Define mass distribution on tires
Mf = Mb*Lr/(Lf+Lr)/2;
Mr = Mb*Lf/(Lf+Lr)/2;

% Inequality constraints c <= 0
c = [sqrt(kf/Mf)/(2*pi)-2;...         % fn <
     sqrt(kr/Mr)/(2*pi)-2;...         % fn <
     cf/(2*sqrt(kf*Mf))-cupper;...    % damping ratio for
front
     clower-cf/(2*sqrt(xkf*Mf));...
     cr/(2*sqrt(kr*Mf))-cupper;...    % damping ratio for rear
     clower-cr/(2*sqrt(kr*Mf))];

% Equality constraints ceq = 0
```



Genetic Algorithm and Direct Search Toolbox™

- Graphical user interface and command line functions for:
  - *Genetic algorithm solver*
    - *Single objective*
    - *Multi-objective with Pareto front*
  - *Direct search solver*
  - *Simulated annealing solver*

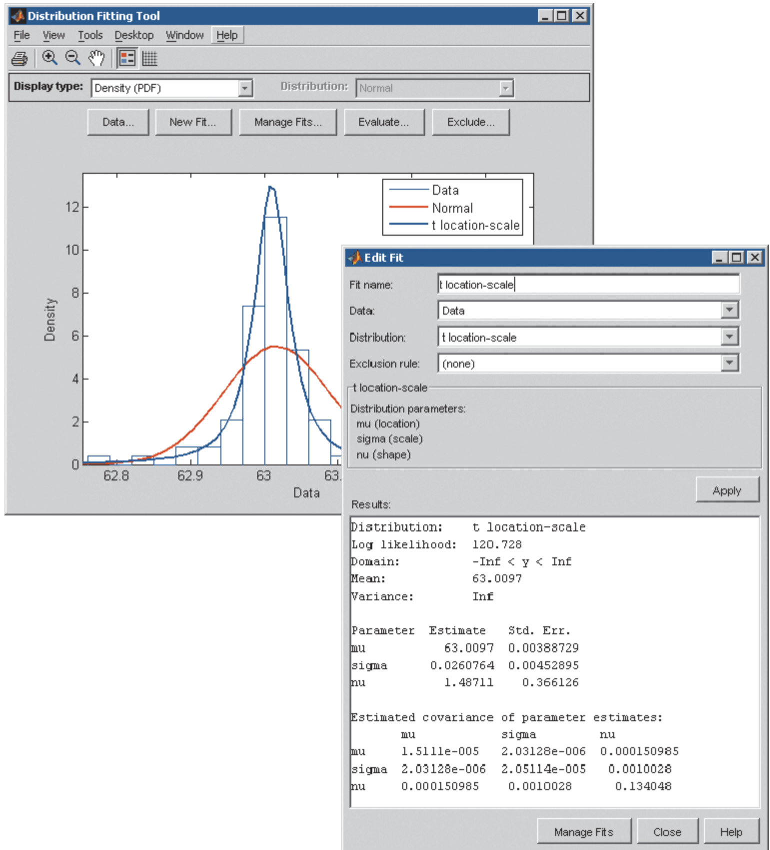
- Useful for problems not easily addressed with Optimization Toolbox™:
  - *Discontinuous*
  - *Highly nonlinear*
  - *Stochastic*
  - *Discrete or custom data types*
  - *Undefined derivatives*



Statistics Toolbox

Statistics Toolbox provides interactive and command line tools for:

- Data collection and management
- Descriptive statistics
- Multivariate statistics
- Probability distribution fitting and modeling
- Hypothesis testing
- Analysis of variance/covariance
- Linear and nonlinear modeling
- Visualization
- Statistical Process Control
- Design of Experiments

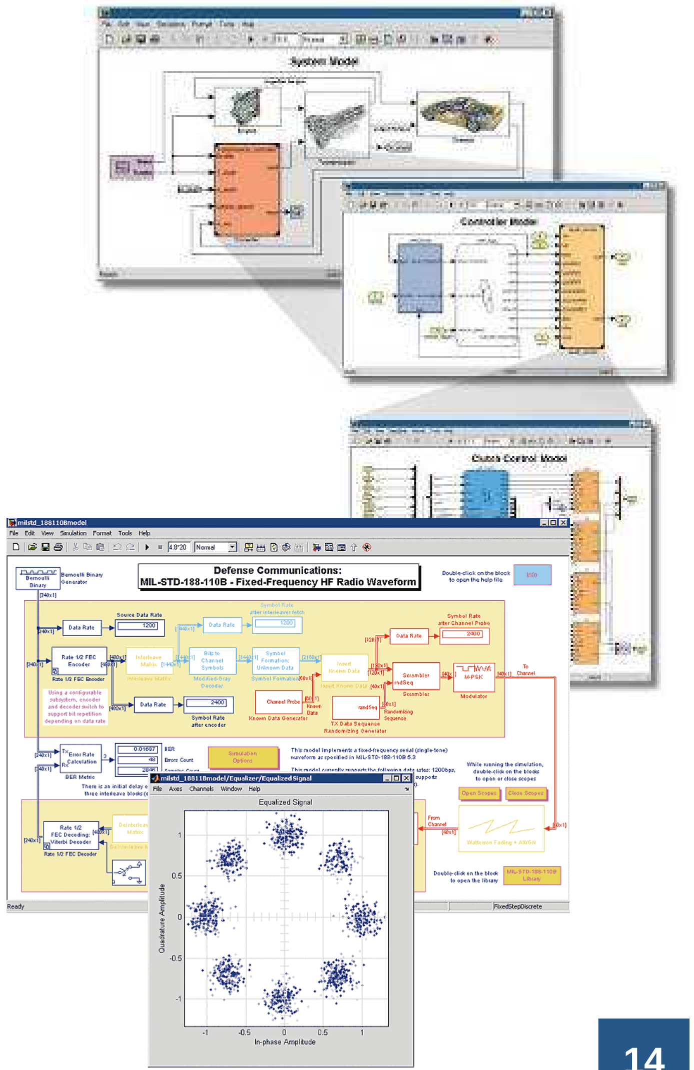


Simulink® for Modeling and Simulation

- Block-diagram environment for modeling, simulating, and analyzing dynamic systems

- Add-on tools extend functionality
  - Application specific (e.g. Simulink® Control Design, Signal Processing Blockset)
  - Physical modeling (e.g. SimMechanics, SimPowerSystems, SimHydraulics)
  - And more …

- Simulink specific optimization tools
  - Simulink Parameter Estimation
  - Simulink Response Optimization



Summary

- Models are not perfect and operate under uncertainty
- Accounting for uncertainty in upfront design process improves design performance and quality
- MATLAB® , Statistics, and Optimization products provide tools needed for reliability analysis and robust design
  - Capture and model uncertainty
  - Find optimal and robust design

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- Technical Literature
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Optimization Toolbox 3.1.1

Solve standard and large-scale optimization problems

The Optimization Toolbox extends the MATLAB technical computing environment with tools and widely used algorithms for standard and large-scale optimization. These algorithms solve constrained and unconstrained continuous and discrete problems. The toolbox includes functions for linear programming, quadratic programming, nonlinear optimization, nonlinear least squares, nonlinear equations, multi-objective optimization, and binary integer programming.

- Introduction and Key Features
- Defining, Solving, and Assessing Optimization Problems
- Nonlinear Optimization and Multi-Objective Optimization
- Nonlinear Least-Squares, Data Fitting, and Nonlinear Equations
- Quadratic and Linear Programming
- Binary Integer Programming

View data sheet (297k)

Free Technical Kit

News and Events

- Webinar: Distributed Computing for Communication Applications
- Seminar: Using MATLAB to Develop and Deploy Financial Models
- Press Release: The MathWorks Bundles Additional Products with Student Version R2007a
- Video: Learn how Toyota Racing Development uses the Optimization Toolbox to balance design tradeoffs
- Video: Hear how IAV uses the Optimization Toolbox for their engine calibration projects
- Technical Article: Optimization with MATLAB and the Genetic Algorithm and Direct Search Toolbox

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University of Waterloo
"Without Simulink, it probably would have taken us until the end of the three-year competition to complete the work required in the first year alone!"
- Matthew Stevens
» Read this story

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Links to Digest Articles of Interest for Reliable/Robust Design

- Designing for Reliability and Robustness

- Improving an Engine Cooling Fan Using Design for Six Sigma Techniques

- Using Statistics to Analyze Uncertainty in System Models

Contact Information

Ascension Vizinho-Coutry

- avizinho@mathworks.fr
- Tél: 01 41 14 88 30

Christophe Bouveur

- Christophe.Bouveur@mathworks.fr
- Tél: 01 41 14 87 79

Loic Noury

- Loic.Noury@mathworks.fr
- Tél: 01 41 14 87 85

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Questions?