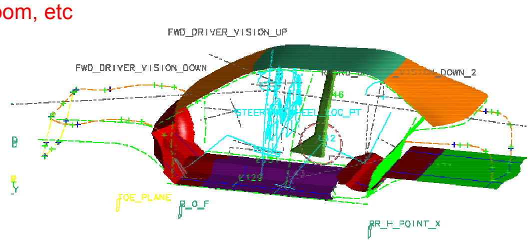
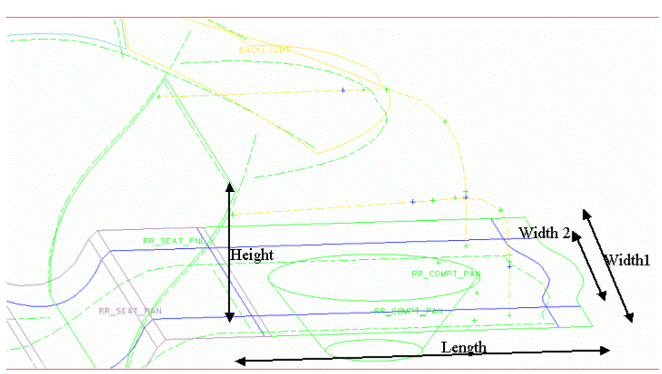
Packaging

- Geometric measures to check requirements
  - Occupant model
  - Engine compartment packaging
- Inputs
  - Occupant position - H-point, etc
  - Engine/transmission selection and position
- Outputs
  - Shoulder room, knee room, etc
  - Roominess measure
  - Packaging feasibility



Trunk Volume

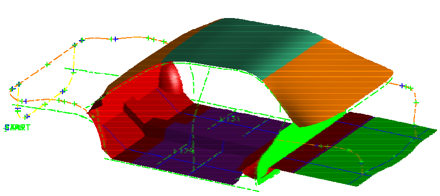


Linear Structures

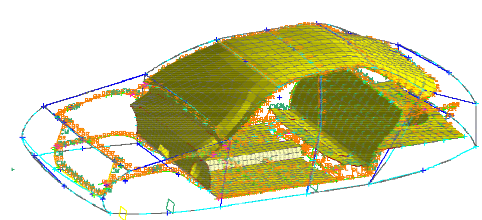
- FE model associatively linked to UG parametric model - UG Scenario
  - FE model is built once - automatically updated as geometry changes
  - Beams/Springs/Shells/Masses
    - Locations and properties associated to geometry (M, K, b, h, t, etc)
- Inputs
  - Parametric geometry specification
  - Component masses
  - Initial structures model
- Outputs
  - Vehicle mass
  - Structural modes

Tightly Coupling Representation to Analyses

- Analysis models remain synchronized with representation
- Example – CAD to CAE/structures: UG Modeling and UG Scenario
  - Automatically update hybrid beam/spring/shell/mass model from CAD model



Automatically update from CAD → to CAE

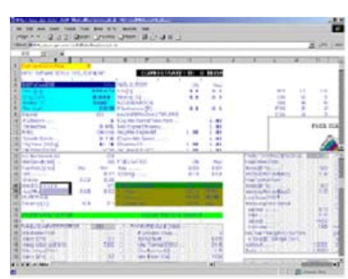


Aerodynamics

- Exterior aero surface linked to underlying structure CAD representation
  - Aero drag is approximated
  - Frontal area calculated in UG
- Inputs
  - Exterior shape
- Outputs
  - Aero drag
  - Frontal area

Energy

- Compute fuel economy, acceleration based on spreadsheet model
  - Depends on structures, aero, marketing disciplines
- Inputs
  - Cd
  - Drag
  - Frontal area
  - Powertrain, tires, etc.
  - Performance requirements
- Outputs
  - Fuel economy
    - (city, highway, combined)
  - Acceleration



Business

- Estimate sales, revenue, costs
  - Link performance to customer value
  - Link customer value to sales/revenue

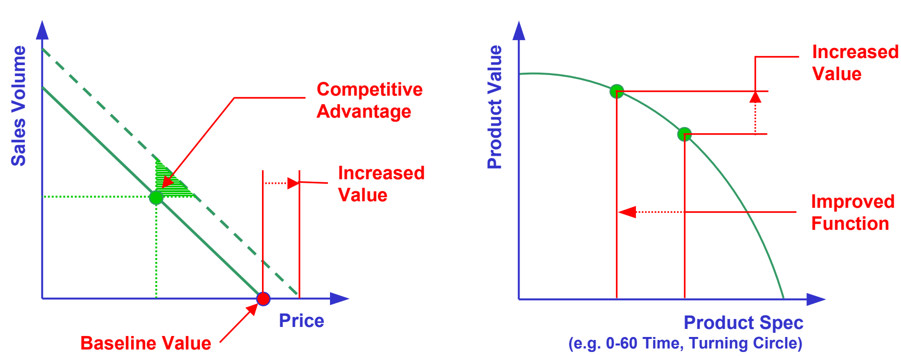
- Inputs
  - Competitors
  - Performance
  - Forming and assembly technology
  - Equipment, tooling costs
  - BOM/Parts - size, mass, material

- Outputs
  - Sales
  - Revenue
  - Cost
  - Net income, profit

One Approach to Link Market Demand, Value, and Performance: S-Model (Ref: H. E. Cook, 1997)

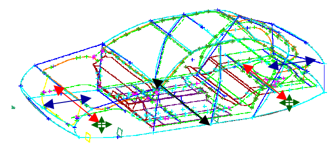
Customer-Perceived Value Drives Market Demand

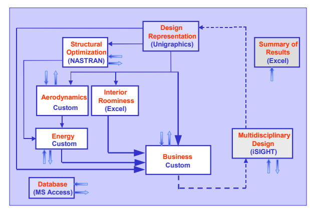
Product Specifications Drive Customer-Perceived Value



Example Problem - Dimensional Flexibility for Vehicle Architecture

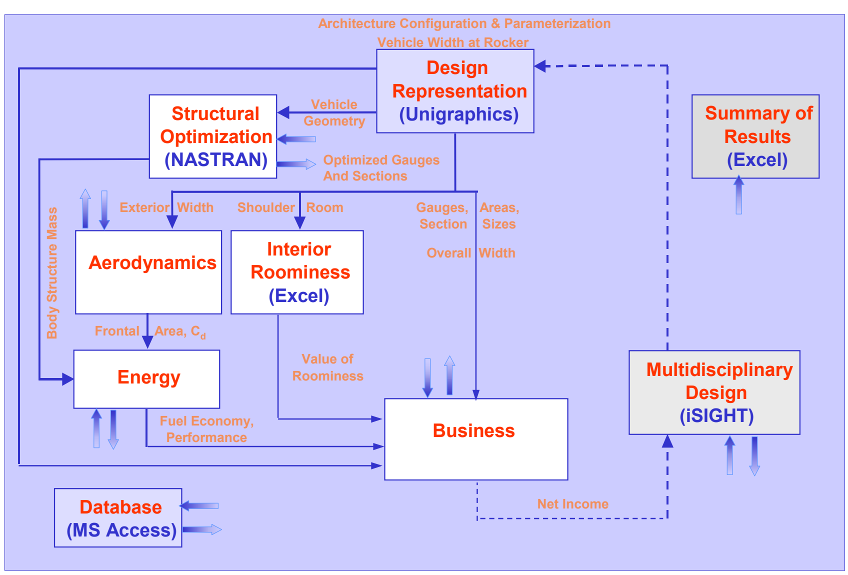
- Maximize net income while satisfying performance requirements
  - Discipline analyses: geometry, aero, fuel economy. packaging, business
  - Discipline sub-optimization: structures, business
- Specific vehicle configuration:
  - Body style
  - Powertrain and components
- Nine high level, architectural design variables
  - Vehicle width at rocker
  - Front and rear track width
  - Front and rear overhang
  - Front and rear axle location – vertical and horizontal
- Performed automated discipline analyses:
  - Perturbed representation
  - Generated analysis models
  - Exchanged data through database
  - Computed change in Net Income ("natural" objective)
- Generated sensitivities and optimized





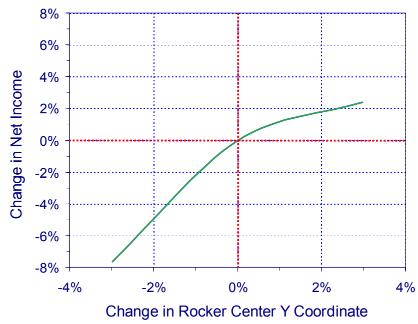
Example – Dimensional Flexibility

Data Flow and Analysis

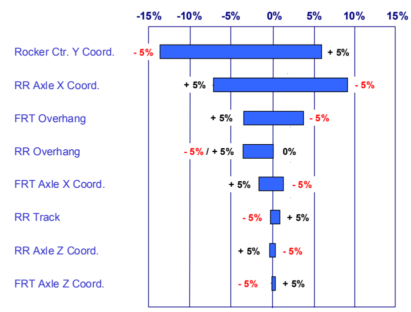


Framework Illustration: Analysis Outputs

Sensitivity of Net Income to Rocker Location



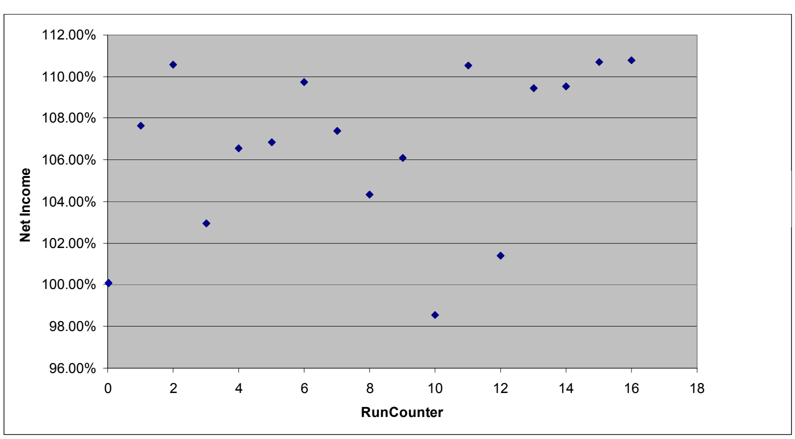
Relative Sensitivities for Other Architecture Parameters



- **Front and Rear Axle Position - L, H**
- **Front and Rear Overhang**
- **Front and Rear Track**

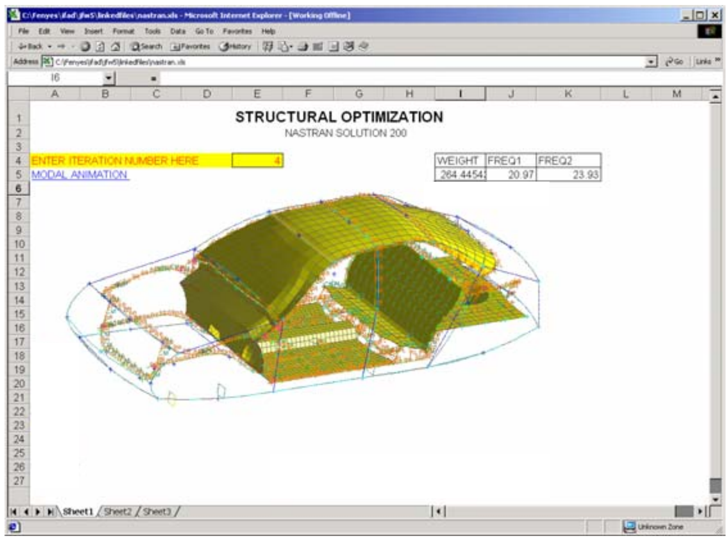
Iteration History - Dimensional Flexibility

- Sequential discipline analyses, sub-optimizations for structures and business
  - 10 iterations for gradients, 6 iterations for convergence



Reporting Analysis and Optimization Results:
View Database through Web Interface

- Iteration history may be reviewed



Other Automotive MAO Applications

- Crash, linear analysis, robust design
- Aero and acoustics

General MAO Challenges

- Problem Formulation
  - Determine key drivers and responses
  - MDO formulation – “natural” objective, multi-objective, preference modeling, etc.

- Consistent parametric representation
  - Consistent information shared by all disciplines
    - geometric data
    - non-geometric data (BOM, configuration, material properties, …)
    - analysis results history, gradients, approximations

- Discipline analysis to support tradeoffs
  - Analysis tightly coupled to representation
  - Key disciplines are supported
  - Balance analysis detail against design knowledge

- Support design and analysis strategies through quality, commercial software
  - Approximation strategies
  - Design approaches
    - DOE, optimization, decision support, Pareto frontiers,

Challenges to Widespread MAO Application

- Educational challenges
  - Educating corporations on optimization, then MAO
  - Educating the next generation of users and teachers

- Corporate cultural challenges
  - Organizing work for MAO

- Software challenges
  - Simpler to use, better GUI
  - More capable to handle distributed computation with broad range of analyses, database interaction, interactive data visualization, report generation, …

MAO Software Challenges

- Data Storage, Management, Communication
  - Consistent information requires database storage and communication with disciplines
  - Standards will be required to drive this (e.g. http://www.omg.org/)
    - Vehicle and Results databases used for:
      - Model building
      - Storing analysis results, history, gradients, approximations
      - Communication with commercial systems (ODBC, SQL) a must
- Full support for user defined design strategies, algorithms
  - Approximation strategies
    - DOE, neural net, response surfaces, etc.
    - Use gradients and Hessians as available
  - Simplify use of proprietary or other algorithms within commercial frameworks
- Data Transformations
  - Units, coordinate systems
  - Geometric relationships
  - Variable relationships
    - Parametric, DV linking

Challenges in Automotive MAO

- Level of detail and complexity
  - When and how should MAO be used in the vehicle and component design processes?
- Inclusion of more disciplines that have a strong linkage to the vehicle or component design problem
  - Vehicle design
    - Safety, reliability, aesthetics, vehicle dynamics, …

Summary

We have developed an MAO system for coarse balance and integration during the early vehicle development process which

- Enables use of math based decision tools for vehicle and architecture design
- Facilitates multidisciplinary analysis with consistent data
  - Extends math based beyond engineering to manufacturing and business
  - Provides consistent sharing of representation and analysis data through database
  - Simplifies storage and access of analysis results through database and GUI
- Quantifies discipline consequences of design and architectural changes

Much work remains !

Designing Great GM Cars and Trucks !