Platform-based and Model-based Engineering with HPC = Resiliency: A Case Study

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Background

- Case study of my experiences in several Goodyear projects that illustrate the benefits of ERS methodology

- Currently consulting for the U.S. Department of Defense's High Performance Computing Modernization Program (HPCMP)

- The opinions expressed are my own and do not necessarily reflect the views of The Goodyear Tire & Rubber Company or the HPCMP.

Goodyear Tire

- Headquartered - Akron, OH
- $22.8 B sales in 2011
- $356 M R&D expenditures
- 2,000+ R&D associates
- 53 production facilities in 22 countries
- $321 M net income
- 73,000 associates worldwide

Radical Change$_{1986}$

- **Objective**: create an automated process to speed the production of prototype tires.
- **Complication**: multiple computer systems located in Akron, Brussels, Cumberland, MD, Luxembourg, and several manufacturing facilities contained part of the information needed to accelerate the prototyping process.

Everyone wanted *their* system to become *the* solution.

Reaching Consensus

- A series meetings were held in Akron, Brussels, Cumberland, and Luxembourg to discuss/debate the appropriate solution without reaching agreement.
- Finally, 30 key stakeholders were sequestered in a hotel south of Akron for two weeks to agree upon a solution and a plan.

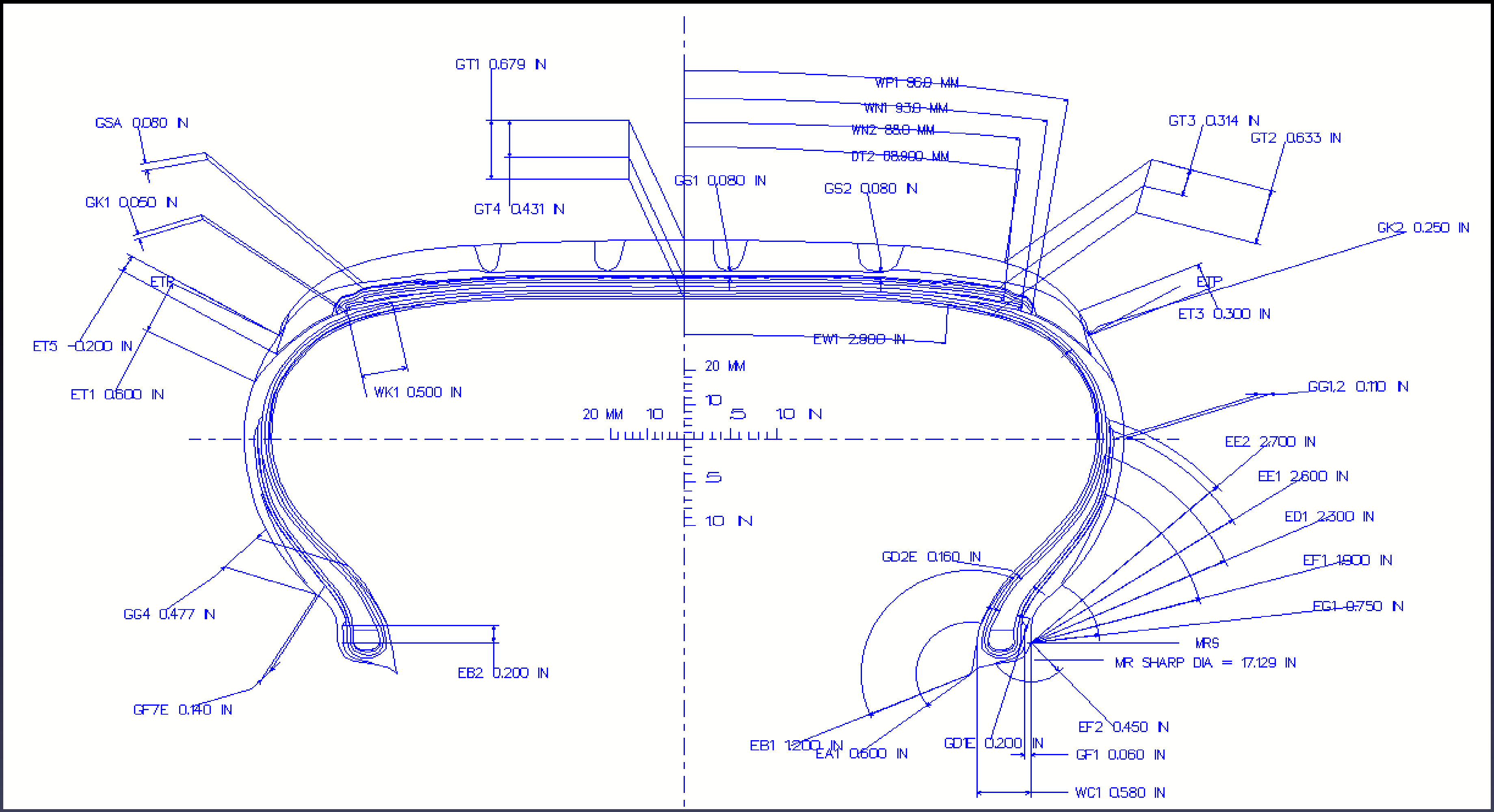
We weren't leaving without reaching consensus!

Resolution

- Goodyear, with the help of an external software developer, would create a parametric design system that could feed all the respective spec systems.
- **Challenges**:
  - State-of-the-art CAD systems$_{1986}$ were drawing tools.
    - "Parametric" had not entered the CAD lexicon.
    - Knowledge-based CAD software was non-existent.
  - Goodyear was in the process of fighting off a hostile takeover attempt.

Nevertheless, first $1 M allocated and the project began.

Platform-based Design System



Key component in what was to follow.

Radical Change$_{1992}$

- Failed takeover attempt had drained \$2 B of Goodyear's cash reserves.
- To reduce R&D expenditures, VPs of R&D looked at alternative product development processes:
  - More efficient prototype building and testing,
  - Extensive use of subsystem-level predictive testing,
  - Physics-based computational product development.

Physics-based computational product development was *only* alternative that might substantially *reduce* costs over time.

Difficult Computational Problem

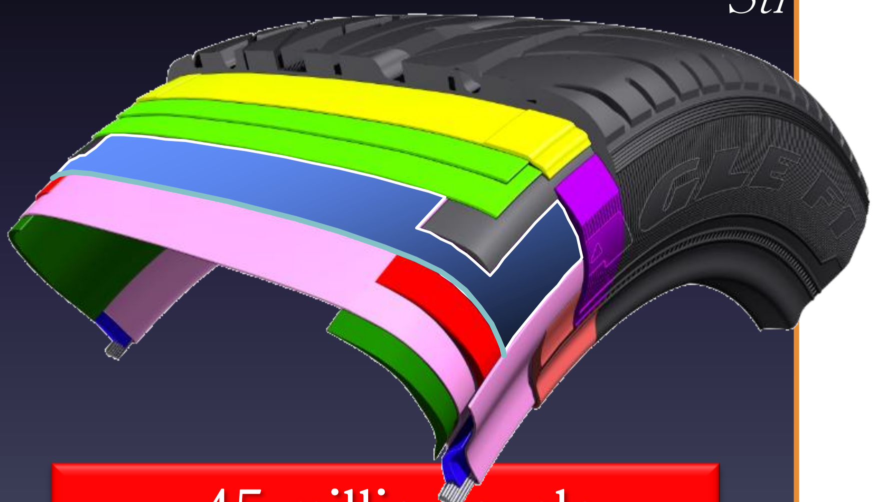
- Tires are surprisingly complex.
  - Tread geometry
  - Internal structure
  - Material properties
  - Service conditions
- In 1992, state-of-the-art computational performance prediction took months.

By the time designers got answers, they'd forgotten their questions.

Internal Structure

"The pneumatic tire represents one of the most formidable challenges in structural design."

Professors Noor and Tanner, Journal of Computers and Str



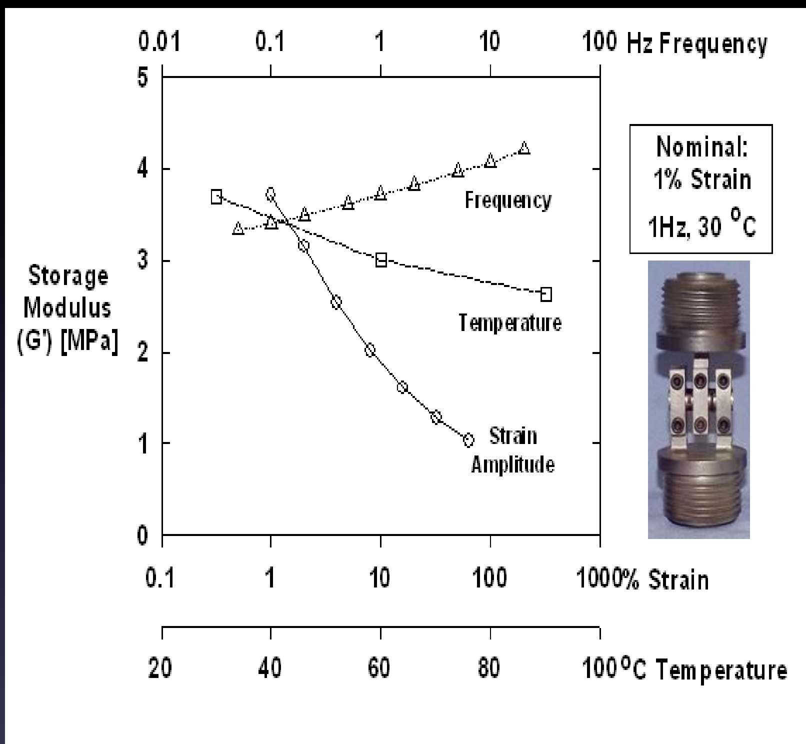
~ 45 million cycles during an 60,000 mile tire lifetime

Modeling Challenges

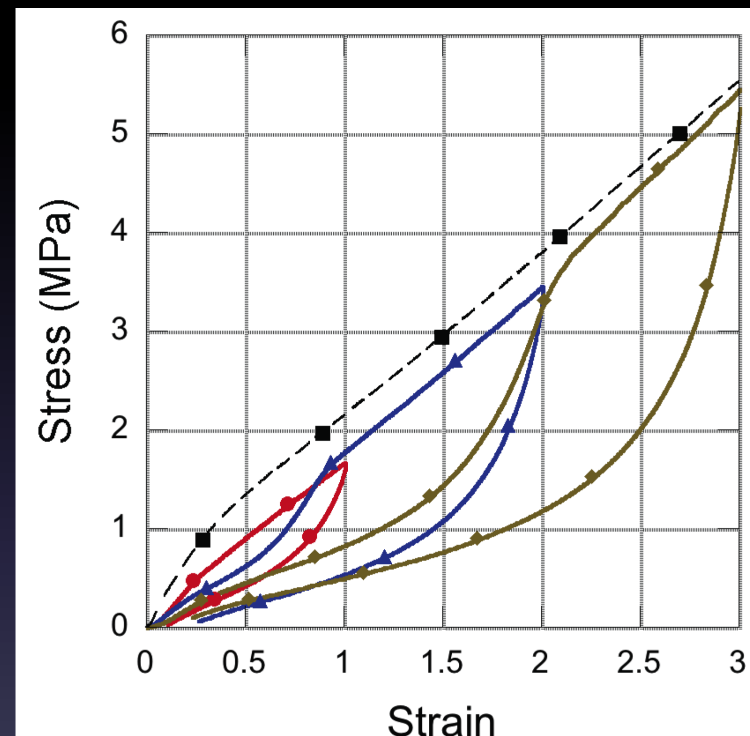
- Incompressible, non-linear visco-elastic material with high (~100%) cyclic strains (rubber)
- Inextensible fiber reinforcements (steel belts & polyester ply)
- Flexible structures (sidewall)
- Detailed tread patterns
- Wide eigenvalue spectrum
- Expensive, low fidelity solutions

Material Complexities

Payne Effect



Mullins Effect



Rubber is the most complex component.

Hanson, Hawley, and Houlton,
Los Alamos National Laboratory,
"A Mechanism for the Mullins Effect," 2006.

Many Customer Requirements

- Traction
- Treadwear
- Durability
- Ride
- Handling
- Noise
- Rolling Resistance
- Bruise Resistance
- Cut Resistance
- Uniformity
- Static-Loaded Radius
- Flatspotting
- Balance
- Stone Retention
- Cornering Ability
- First Harmonics
- Runout
- Conicity
- High Speed
- Snow & Ice Traction
- Plunger Energy
- Whine
- Running Temperature
- Lateral Pull
- Rolling Radius
- Bead Durability
- Rumble
- Separation
- Aspect Ratio
- Stopping Ability
- Standing Wave Growth
- Puncture Resistance
- Rim Chafing
- Drag
- Harshness
- Suppleness
- Joint Slap
- Revolutions per Mile
- On Center Feel
- Steering Precision
- Overturning Moment
- Impact Resistance
- Noise
- Hydroplaning
- Ton Mile per Hour
- Contact Pressure
- Load Carrying Capacity
- Road Hazard Resistance
- Enveloping

To name a few!

Unacceptable Computation Times

- **Static, smooth, axisymmetric tire model took *months* to converge using the best commercial non-linear solver.**
  - Solution times increased as the cube of the model size, $\mathbf{n^3}$.
- **Treadwear prediction required a tread pattern, rolling, at varying loading conditions and slip angles!**
  - Nothing very interesting happens sitting still in a parking lot.
  - Estimated minimum model size required to simulate tire wear was **more than 3x** the size of smooth, static model.

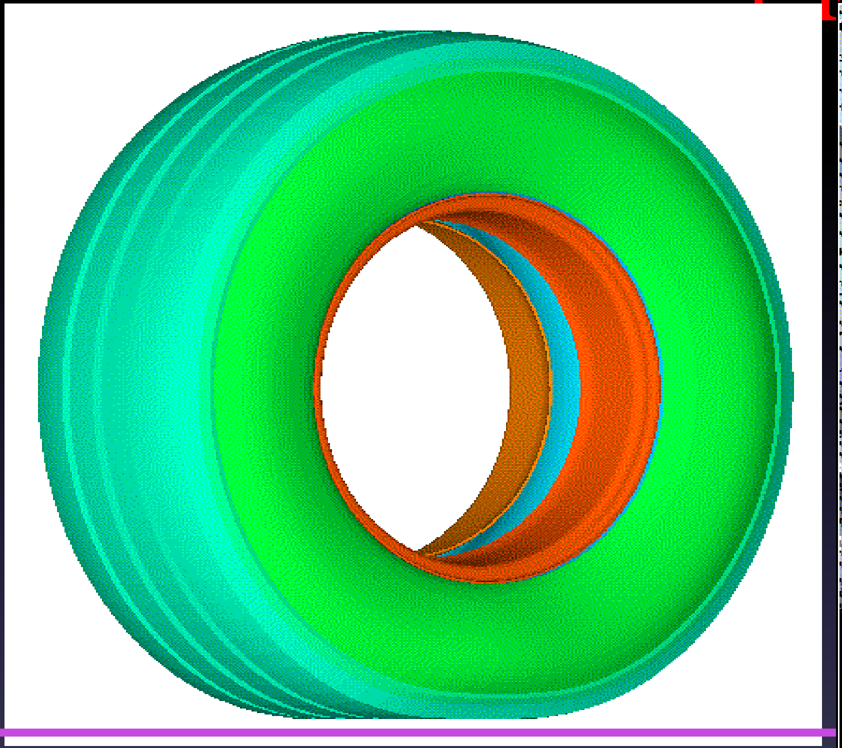
Solution time estimated at 15.6 years on Cray Y-MP.
Build and test for treadwear required 4 – 6 months.

Industry/Government Partnership

- Goodyear partnered with Sandia National Laboratories to develop new technologies to solve its "intractable problem."
- CRADAs included both experimental and computational projects.
- Goodyear created the tire-specific components of its model-based engineering system.

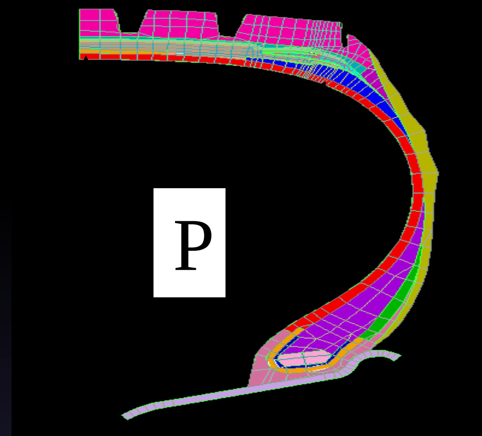
Win–win collaboration!

Model Fidelity & Solution Time

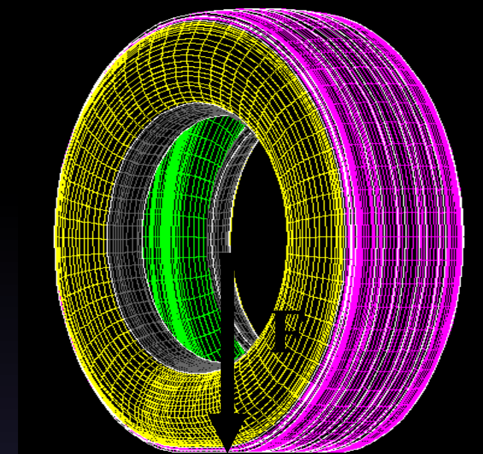


Solution time$_{2005}$ compressed from 32.2 years to 5 days!

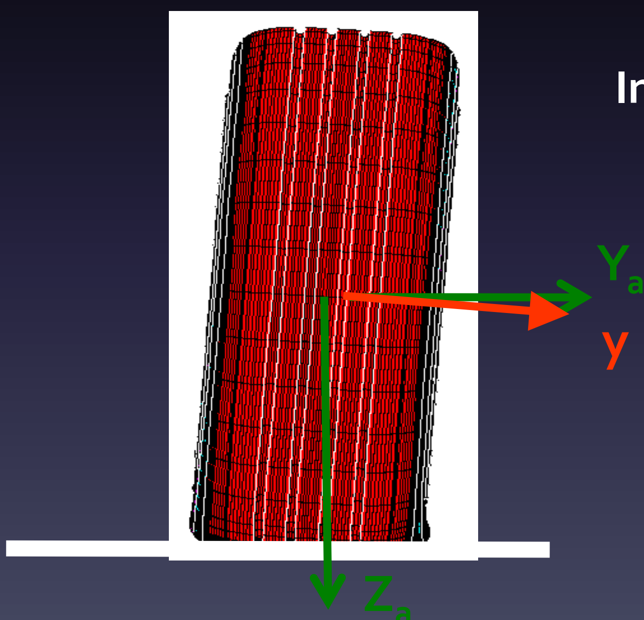
Model-based Engineering System



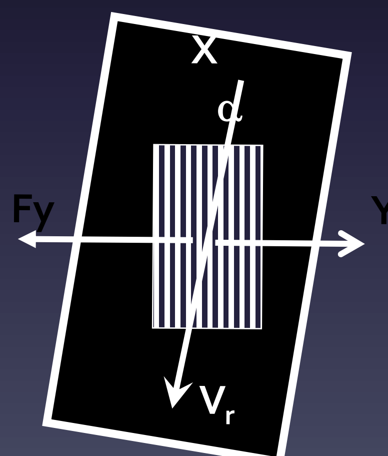
Inflation and Seating



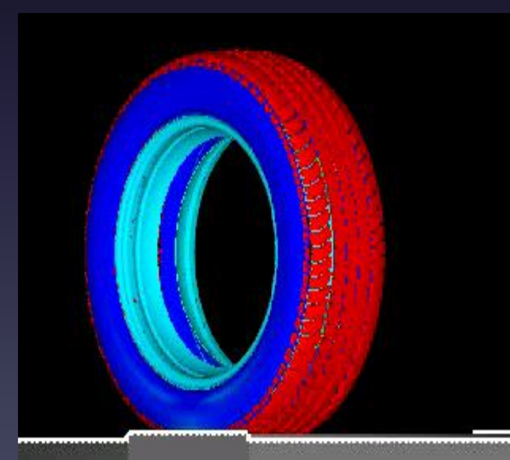
Vertical Load



Camber

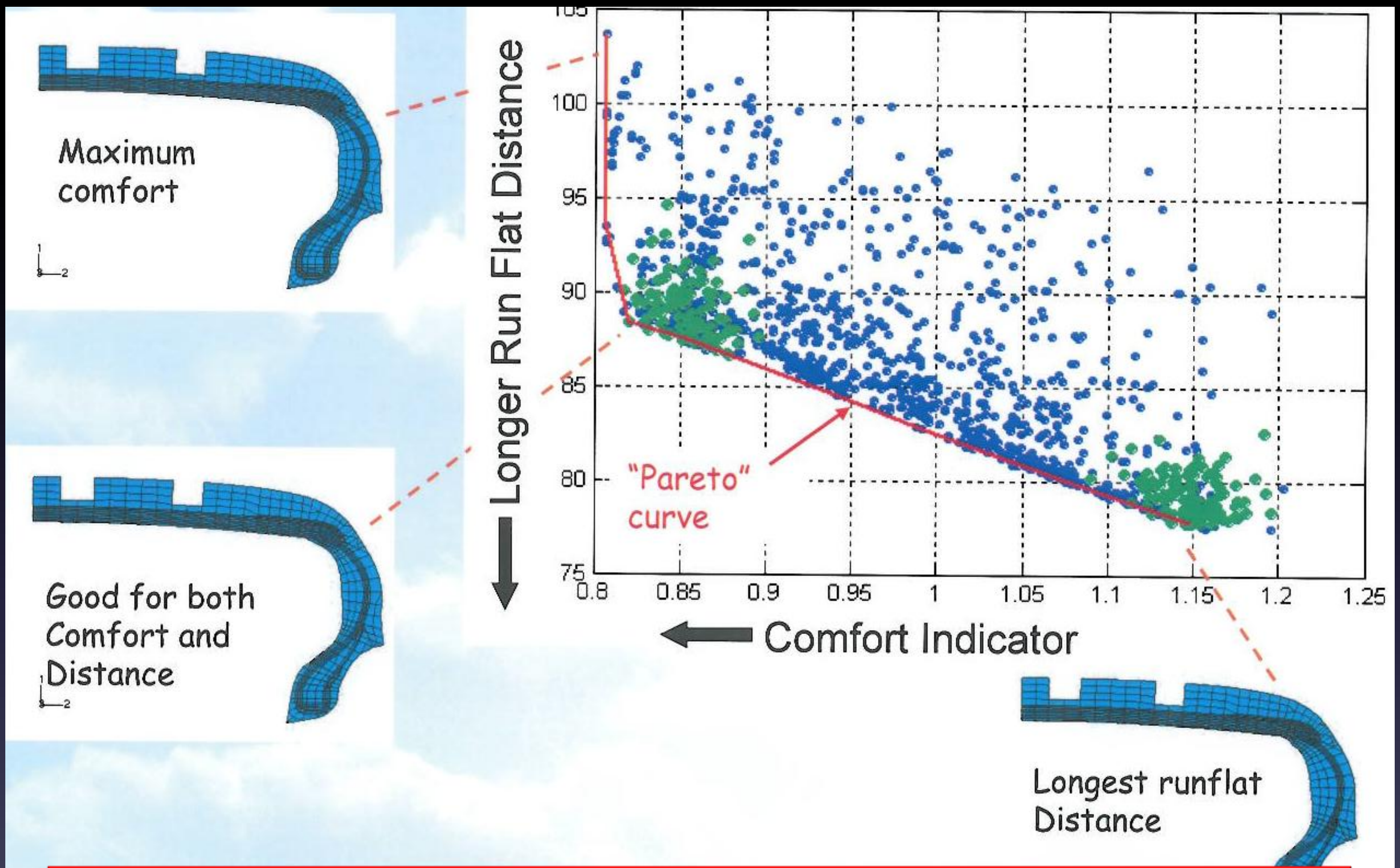


Rolling



Running Over Obstacles

Robust Optimization



Comfort and RunOnFlat distances optimized as part of an engineered resilient system.

Award-Winning Technology

1 of 5 most innovative
IT solutions of 2006

Bottom Line Results

- **Eliminated 75% of product development time** (from >3 to <1 year).
- **Eliminated 62% of prototype building & testing costs** (saving $100 M annually).
- **Unprecedented string of award-winning new products**, by evaluating many more new product alternatives computationally.
- "Our **innovation engine**, again, **delivered** in 2010. The **percentage of new products** in our overall lineup **is the highest ever**…" Rich Kramer, Chairman & CEO, February 10, 2011.
- "Our **new product engine** is poised to take advantage of the demand for high-value-added tires and to do so with **unmatched speed to market**." Bob Keegan, Chairman & CEO, 2009 Annual Report.

Unmatched speed to market is a huge competitive advantage!

Global Competition

- "Our global competitors are well aware of the great potential of computer simulation. Throughout Europe and Asia, governments are making major investments…"
- "We are in danger, once again, of producing world-leading science but leaving it to our competitors to harvest the technological and economic advantages."

Oden *et al.*, "Simulation-Based Engineering Science." U.S. National Science Foundation, May, 2006.

Leaving it to our competitors…

"The Attacker's Advantage"

Richard N. Foster, *Innovation: The Attacker's Advantage*, 1986.

- Which foreign power will invest in more test facilities, proving grounds, and defense laboratories than the U.S.?
- Imagine a security situation in which competing interests could develop and deploy more imaginative and capable systems faster than the U.S. – for less money!

- **How would you improve resiliency while cutting time and cost out of the weapons system development process?**

What will you do?

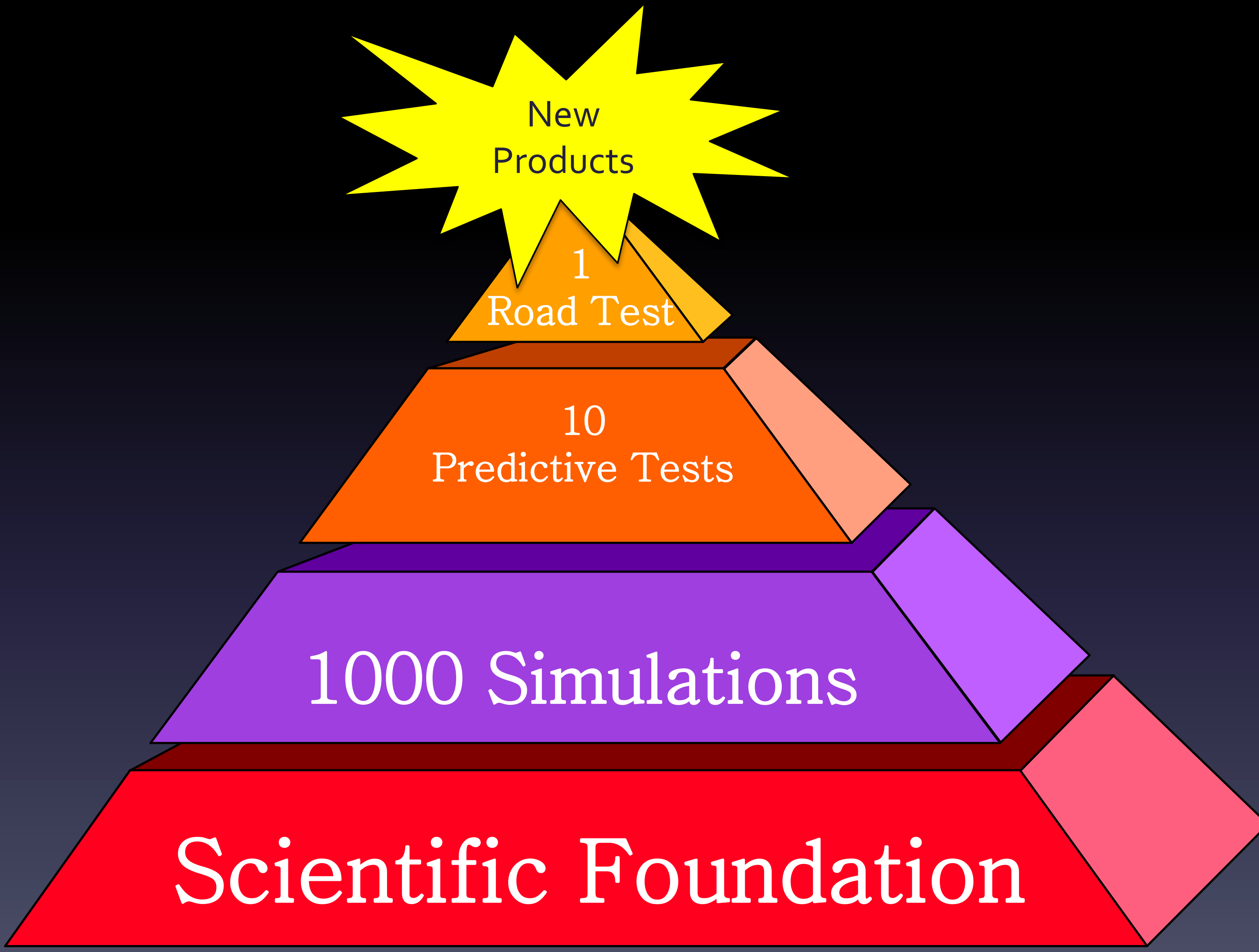
ERS

The Prince
Niccolò Machiavelli

“There is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle than to initiate a new order of things.

For the reformer has enemies in all who profit by the old order, and only lukewarm defenders in all those who profit by the new order, this lukewarmness rising partly from fear of their adversaries,...; and partly from the incredulity of mankind, who do not believe in anything new until they have had actual experience of it.”

Vision


New
Products
1
Road Test
10
Predictive Tests
1000 Simulations
Scientific Foundation