NIST Center for Automotive Lightweighting

NIST Center for Automotive Lightweighting

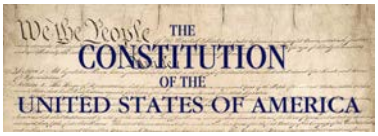
- **Tim Foecke, Director**
- Slowly assembled over the last 12 years
- 8 permanent staff (2 more coming), 3 guest researchers (4 post-docs coming)

Mission: ***Help the US Auto industry reach their CAFE goals by helping develop lightweight, multimaterial auto and truck bodies via new metrology, standards, data and models.***

National Institute of Standards and Technology

Mission: To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

(Colloquially: We make sure you know what you think you know)



Article I, Section 8: The Congress shall have the power to …*coin money, regulate the value thereof, and of foreign coin, and fix the standard of weights and measures*

- Oldest federal lab (established in 1901)
- Metallurgy started in 1905
- Essentially, NIST is industry's national lab

But the locals know us for . . .

NIST Programs

© R. Rathe

NIST Laboratories

- Provide measurement and standards solutions for industry and the nation

Maksim Dubinsky/shutterstock.com

Hollings Manufacturing Extension Partnership

- Nationwide network helps smaller manufacturers compete globally

National Advanced Manufacturing Program Office

- Enhances technology transfer in U.S. manufacturing industries and helps companies overcome technical obstacles to scaling up production of new technologies

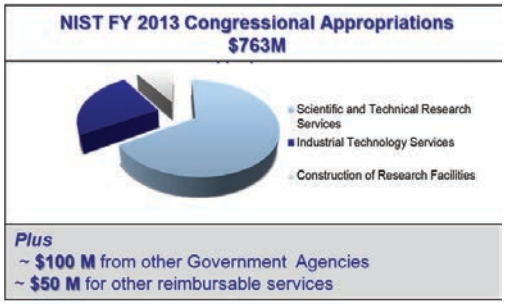
Poudre

Baldrige Performance Excellence Program

- Strengthens performance excellence in U.S. organizations

NIST-at-a-Glance

- ~ 3,000 Employees; 1,800 Scientists and Engineers
- ~ 2,800 Associates and Facilities Users
- ~ 400 NIST Staff on ~1,000 national and international standards committees



NIST has two main campuses.....

Gaithersburg, MD
62 buildings; 578 acres

Boulder, CO
26 buildings; 208 acres

+ two sites housing NIST radio stations:

- Ft. Collins; 390 acres
- Kauai; US Navy 30 acre site

and six joint institutes

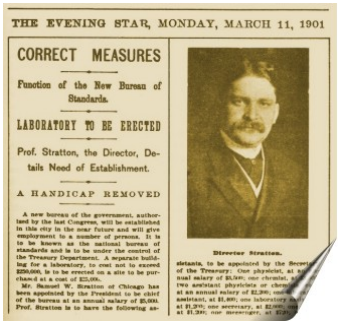
- JILA – *applied physics*
- JQI – *quantum science*
- IBBR – *biotech*
- HML – *marine science*
- NCCOE – *cybersecurity*
- CHIMAD – *materials discovery*

NIST (NBS) established in 1901

"It is therefore the unanimous opinion of your committee that no more essential aid could be given to

- **manufacturing**
- **commerce**
- **the makers of scientific apparatus**
- **the scientific work of Government**
- **schools, colleges, and universities**

than by the establishment of the institution proposed in this bill."



THE EVENING STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

House Committee on Coinage, Weights and Measures ... on the establishment of the National Bureau of Standards (now NIST) May 3, 1900

Organic Act of 1901

Functions and activities of the Institute include:

- **custody and dissemination of national standards.**
- **determination of physical constants and the properties of materials,**
- **comparison of US national standards with those of other nations**
- **solutions to measurement and standards problems of other government agencies**

Organic Act of 1901 - Updated in 2008

Functions and activities of the Institute include:

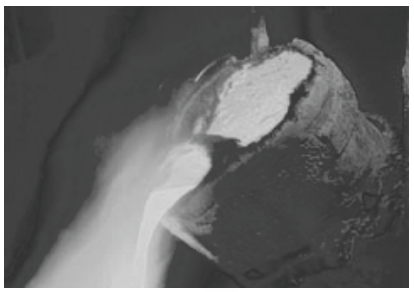
- **Custody and dissemination of national standards**
  - Calibrations, Certified Reference Materials, Reference Data, . . .
- **Determination of physical constants and the properties of materials,**
  when such measurements, standards and data are of great importance and are not to be obtained of sufficient accuracy elsewhere.
- **Comparison of US national standards with those of other nations**
- **Solution of standards problems for industry and other government agencies**

- **Assistance to industry by**
  - development of measurements, measurement methods and basic measurement technology
  - development of technology and procedures needed to improve quality, modernize manufacturing processes, ensure product reliability and cost-effectiveness, promote more rapid commercialization …
  - operation of National User Facilities

A Long History Supporting Manufacturing

1905

- **Standard samples program begins with "standardized irons" in collaboration with the American Foundrymans Association.**



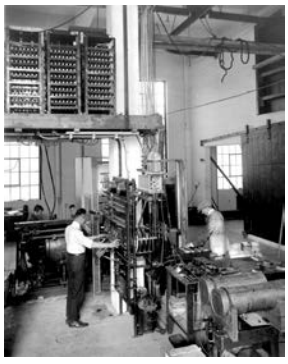
1906

- **At the request of the Association of American Steel Manufacturers, the Bureau began work on certification of 17 types of steel.**

A Long History Supporting Manufacturing – cont'd

1920s

- **Auto engines in the dynomometer lab**



1980s

- **Automated Manufacturing Research Facility**

2000s -

- **Material property data/ models/tests/standards for automotive lightweighting**

ASTM E-2492: Springback Cup Test

U.S. Innovation Agenda – NIST has an increasing role

Advanced Manufacturing

- NIST Labs
  - Precision Measurements
  - Bio and Nanomanufacturing
  - Smart Manufacturing
  - Advanced Materials
- NNMI
- MTAC
- AMTech

Cybersecurity

- Executive Order – Framework for Critical Infrastructure
- National Cybersecurity Center of Excellence

Advanced Communications

Forensic Science

We (NIST) want to make sure that our programs are focused on
what we "Should Do" rather than what we "Could Do"
to strengthen U.S. Manufacturing and Innovation."

Current State of the US Automotive Industry

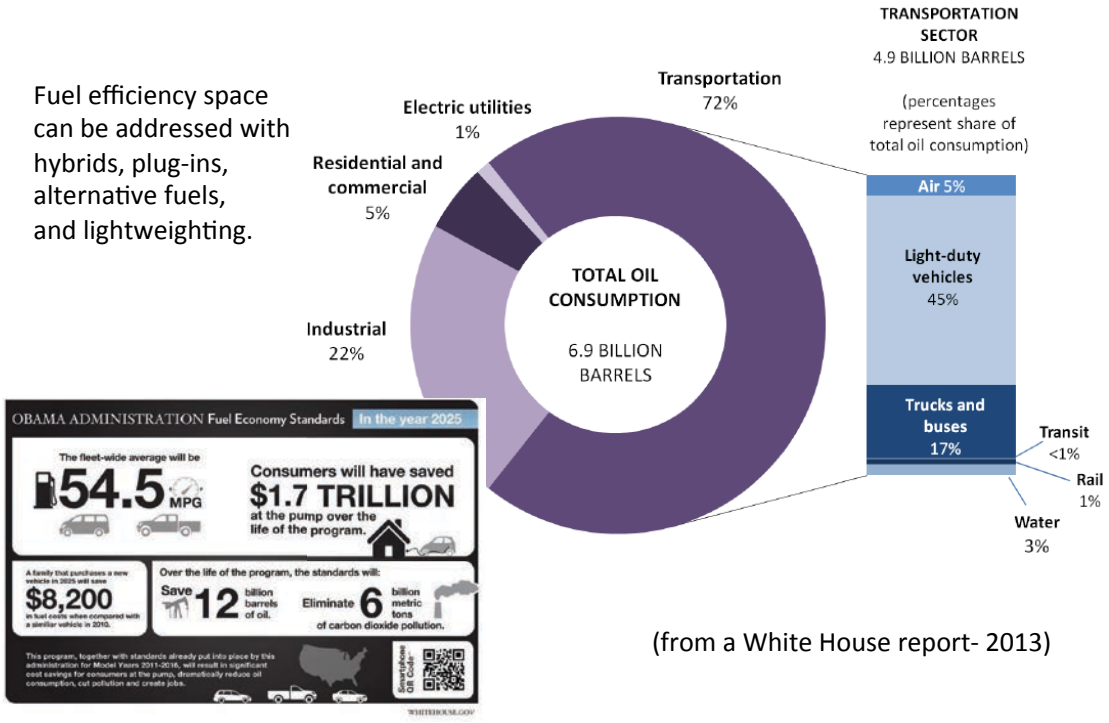
The US Automotive Industry

"We are an industry of empiricism." – Tom Stoughton, GM Fellow

- **Is highly reliant on empiricism and experience:**
  - There is "a guy" who knows how to fix various problems
  - There is "a guy" who guides trial-and-error developments
  - Design tools trained on data from existing materials, fail with new ones
  - No way to capture what "the guy" knows, and if s/he leaves . . .
- **Is risk-averse regarding new materials, but wants to incorporate**
  - Knows that lightweight multi-material vehicles will be the norm
    - 25% steels, 25% aluminum, 25% polymers, 25% other
- **Uses design paradigms that do not facilitate adoption of new materials**
  - Empirically-trained models with many assumptions
  - Strain-based simulations (extrinsic) vs. stress-based (intrinsic)
- **Is mostly aware of what it needs to know, but needs help developing it**

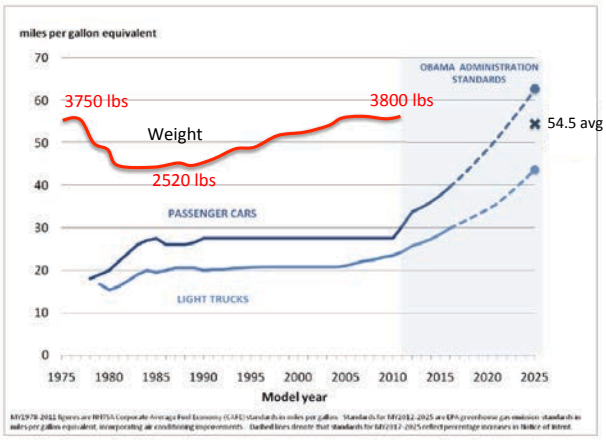
NIST Center for Automotive Lightweighting - Motivation

Fuel efficiency space can be addressed with hybrids, plug-ins, alternative fuels, and lightweighting.



(from a White House report- 2013)

NIST Center for Automotive Lightweighting - Motivation

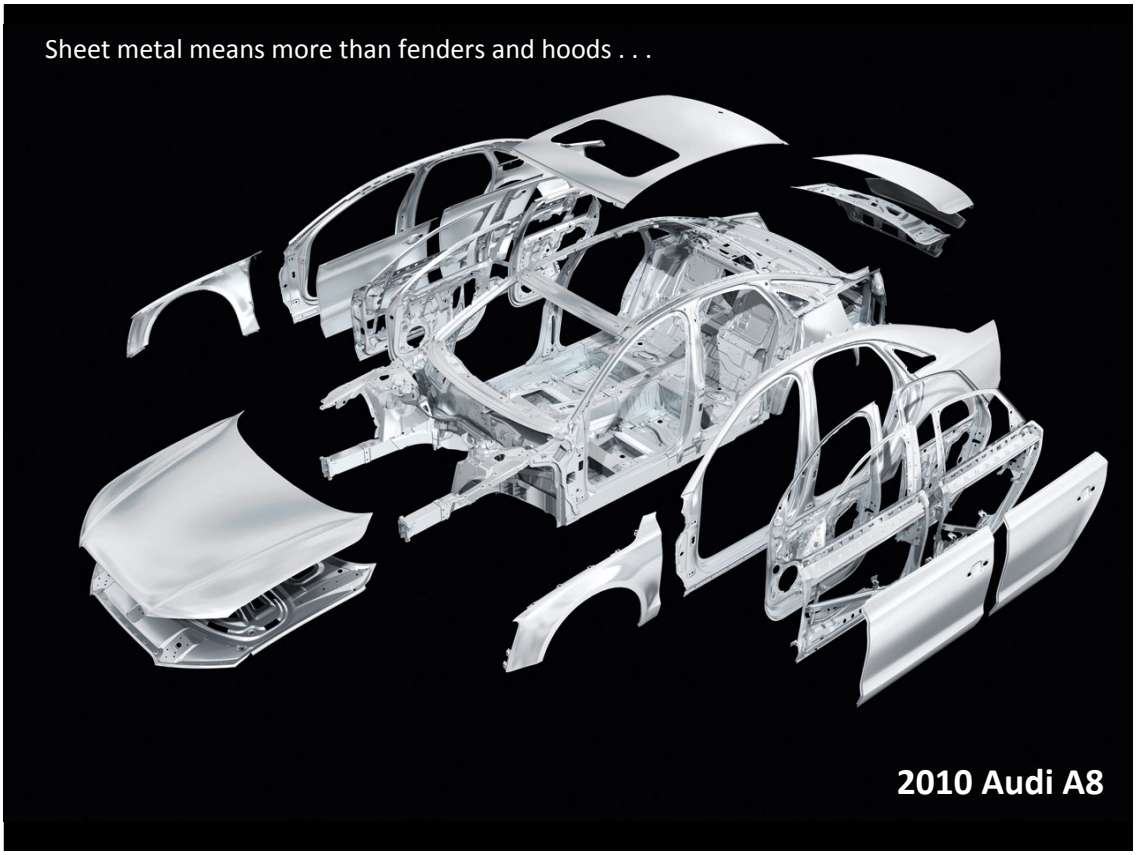


- CAFE standards flat for 25 years, despite rising fuel costs
- Average vehicle weight in 2009 EQUALS 1975
- Several factors:
  - SUVs and pickups
  - Accessories
  - Performance

Lightweighting metrics:

- Save 26M gallons of fuel, per pound off each car, over fleet lifetime
- 10% weight savings ➔ 6-7% increase in fuel economy

US Auto industry has identified lightweighting as primary way to meet goals . . .



NIST Center for Automotive Lightweighting - Motivation

- Industry Design Requirements:
  - Crashworthiness
  - Specific Stiffness (The "Shopping Cart Standard")
  - Aesthetics
  - Manufacturability
  - Performance (0-60, Stopping, . . .)

Aluminum Body-in-White

- Currently: Auto Body Die Design Models Are ***Experience-Based*** (100+ years with steel)
  - Aluminum – Large Springback, Surface Roughness, Sudden Failures, Welding
  - Advanced High Strength Steel – Fails Unexpectedly, Weld Strength
  - Polymer Composites – Too Slow To Manufacture, Joining
  - Magnesium (Holy Grail) – Can't Form Cold, Brittle, Corrosion, Joining . . .(MGI)

Problem: Simulations Give Incorrect Die Designs Because of Inadequate Material Models

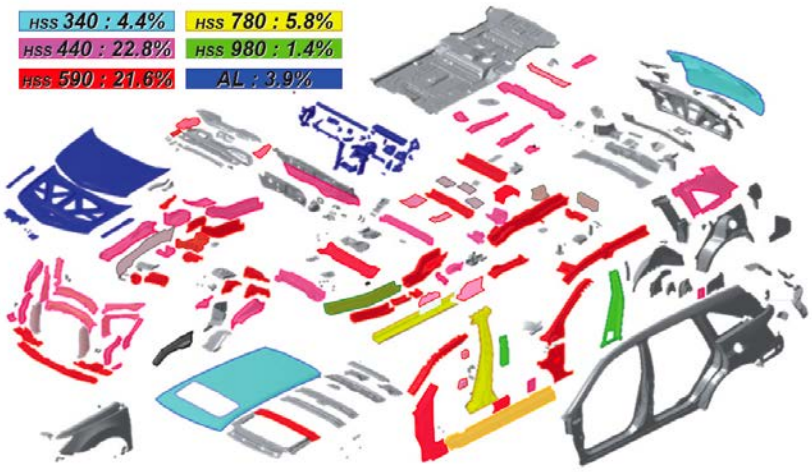
Industrial Need From NIST: Better Standard Tests and Material Data Utilized Across the Entire North American Industry

NIST Center for Automotive Lightweighting – Scale of Problem

- Die tryout **wastes $400M and 37 weeks/cycle across the industry – using mild steel**
- US Auto Industry is moving to Advanced High Strength Steel, Aluminum, & Magnesium

Example of problem:

2010 Camaro rail die – *113* tryouts AND *10 months* with an AHSS (SAE news)



Acura MDX, Great Designs in Steel 2008

From the mouth of industry . . .

Traditional Metal Stamping

Advantages

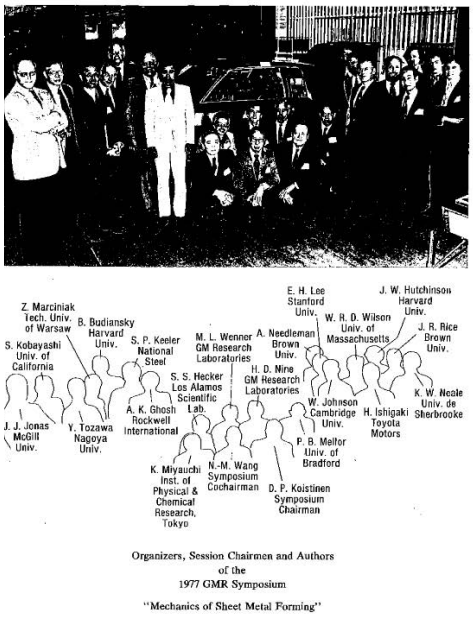
1. Low Cost Raw Materials
2. High Speed Manufacturing
3. **Experienced Workforce**

Economy of Scale Through Mass Production

Disadvantages

1. High up-front engineering costs
2. No experience with:
   - New materials
   - New manufacturing processes
   - New product design & requirements

1977 General Motors Research Symposium



Organizers, Session Chairmen and Authors
of the
1977 GMR Symposium
"Mechanics of Sheet Metal Forming"

Mechanics of Sheet Metal Forming

Symposium Summary

B. Budiansky
Harvard University
GM Consultant

Budiansky's Dream

"I imagined a black computation box …into which we could feed a mathematical description of …[the product] shape …the thickness of the sheet …a catalog number of the material --- and then push a button.

The computer then spits out the die shape,
the blank configuration
…draw beads …orientation and configuration.

If it's possible to make the part – the computer tells us this.
If it's not possible, it tells us that too!"

B. Budiansky
Harvard University
GM Consultant
1977

Problems Prohibiting His Dream:

- Material properties not well understood
  - Mechanical tests too simplistic and unrealistic
- Modeling complex paths a nightmare
- Everything described in terms of strain, not stress
- New materials require starting all over again

One Potential Solution: Tie Complex Properties To Material Microstructure and History

- Stress is a state variable, with a "unique" value for failure
- Complicated strain paths, with proper constitutive laws, can be mapped to corresponding stresses, independent of material
- Springback compensation more direct
- Introduction of new materials more straightforward

Our Boundary Conditions

- Want a "NIST-y" role
  - Measurements, data, standards, helping industry
- Broad-based Impact on the Industry
- Don't "Pick Winners and Losers"
- Timely and Appropriate Impacts
  - Both long-term and short-term help

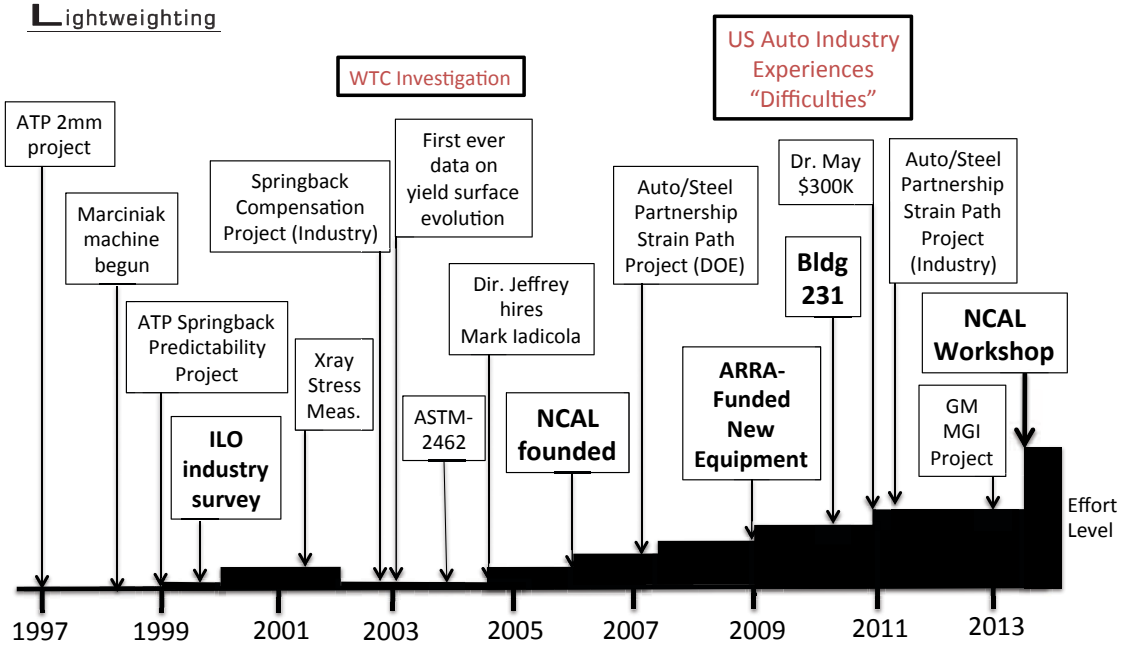
NIST Center for Automotive Lightweighting

Organizations

Academic Partners

Industrial Partners

NCAL Timeline – Quite a Ride



NCAL Workshop

May 23-24, 2013

Purposes:

- Assessment of current activities and new facilities of NCAL
- If we expand, what are the prioritized list of needs?
- Consortium discussion

Participants:

- Automotive - Ford, GM, Chrysler, Toyota, Honda
- Steel Companies – Arcelor Mittal, Nucor, USS, Severstal, Thyssen-Krupp
- Aluminum Companies – ALCOA, Novelis
- Polymer Companies – DuPont, Dow, SABIC, PPG, BASF
- Academics – NWU, CMU, Wayne State, Colo. School of Mines, UCF, Ga Tech, OSU, MSU, Mich Tech, UNH
- Other government: DOE, OSTP, ONR, Army, NSF, ORNL

Industry-Authored Report on Industry Needs

NCAL Workshop

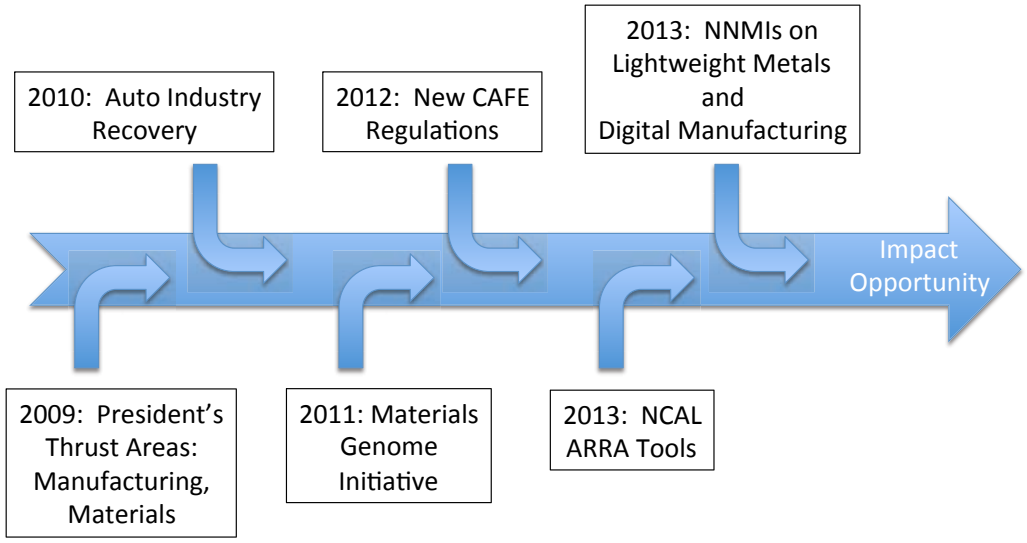
May 23-24, 2013

Results:

- NCAL staff are essential partners, national resource
- Go-to partners for measurements and data
- If NCAL is expanded, the priorities are:
  - **Polymer composites** – constitutive laws, failure, high rate
  - Multipath multiaxial stress-strain data – in progress
  - New constitutive laws
  - Digital Image Correlation standards and best practices
  - Retained Austenite and Residual Stress measurement – in progress
  - Friction
  - Bulge Testing, Hole Expansion, . . . (direct simulative tests)

- Lightweighting Consortium
  - "Great Idea", "The sooner the better" (GM), "Does it have to be a check or can it be a P.O.?" (Ford)
  - HOW?

Timely Convergence



Working With Industry – Lessons Learned

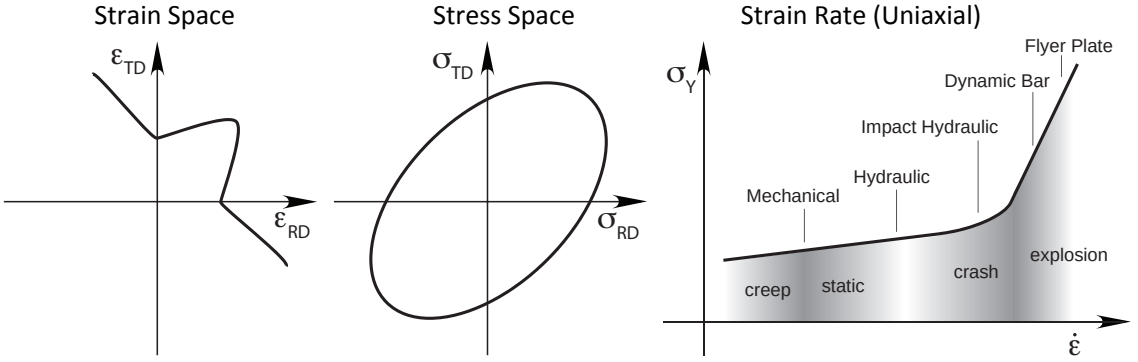
- Bring patience and fresh eyes
- Consortia + Individual Interactions
- Be clear and consistent in the NIST role
- Management support essential (impact meas.)
- Find "open space" and welcome others there

NIST Center for Automotive Lightweighting

Purpose: Developing the next-generation test methods, standards and metrology to assist the US auto industry with introducing lightweight materials into vehicles.

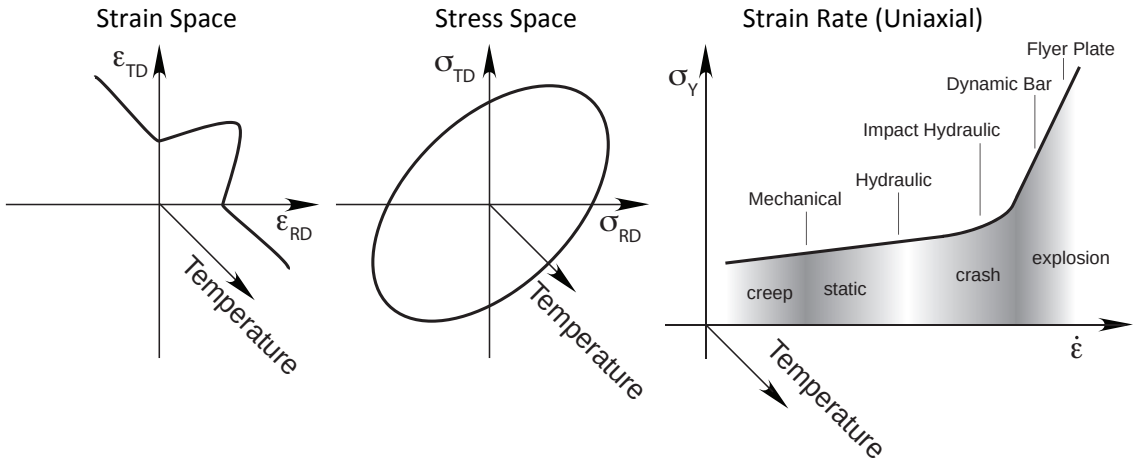
NCAL Interests

- Test Method Development
- Measurement Issues & Accuracy
- Underlying Material Mechanisms



NCAL Interests

- Test Method Development (esp. high ε)
- Measurement Issues & Accuracy
- Underlying Material Mechanisms



NCAL Interests

- Test Method Development
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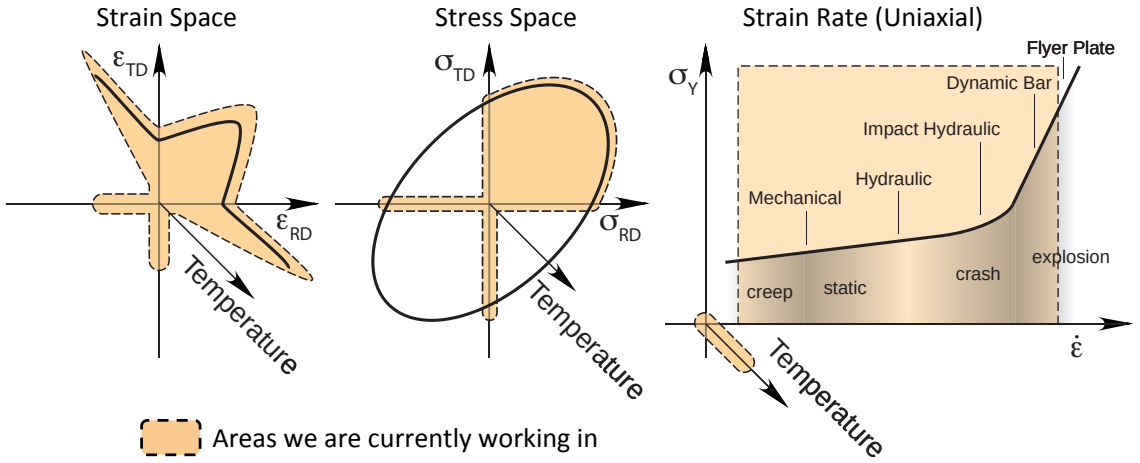
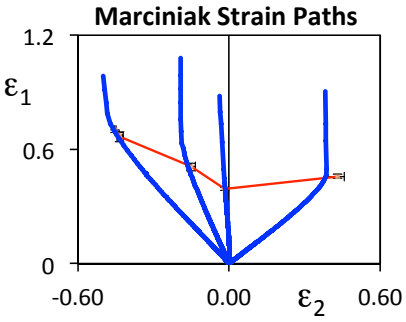


Marciniak Machine

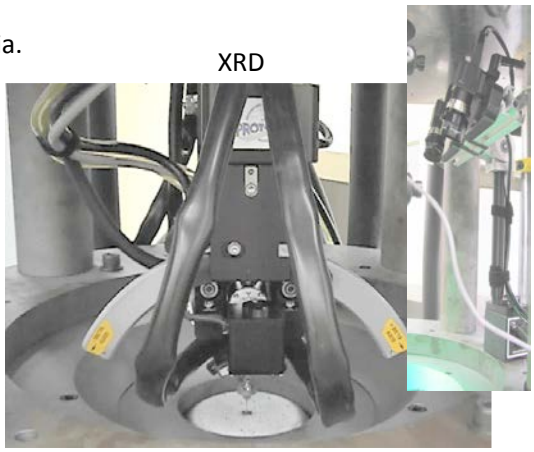
Capabilities:

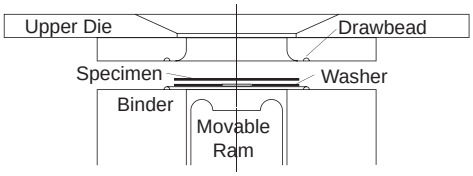
- Marciniak Style Tooling: 100 mm / 200 mm dia.
- Capacity:
  - Max. clamp & ram forces = 500 kN
  - Max. ram stroke = 200 mm
  - Max. ram speed = 40 m/s
- Different blank geometries for different strain ratios
- Open top for metrology: DIC & XRD



DIC

XRD



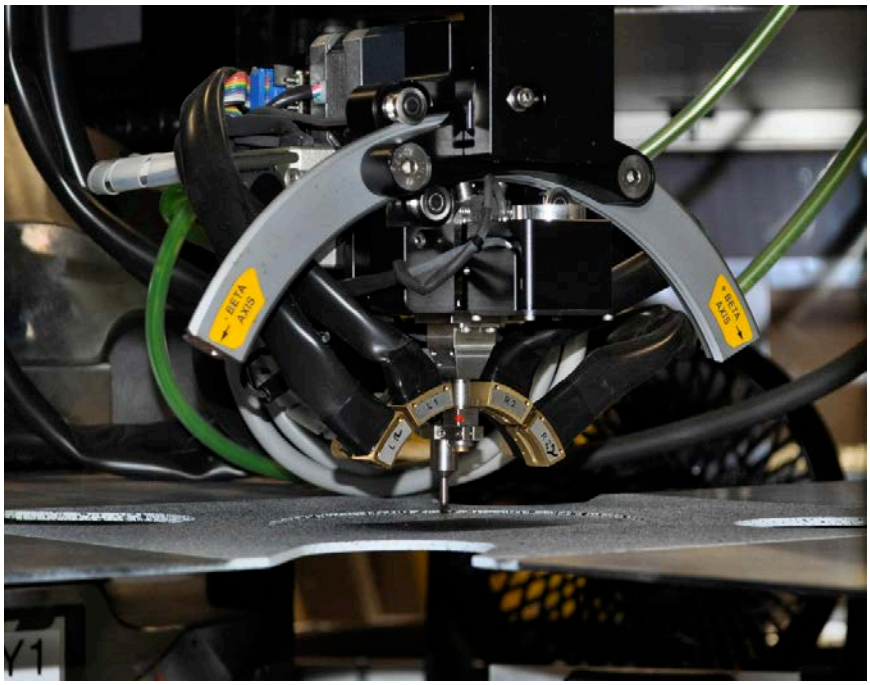


NIST Center for Automotive Lightweighting – ARRA funded tools

Next-Generation Metal Formability System

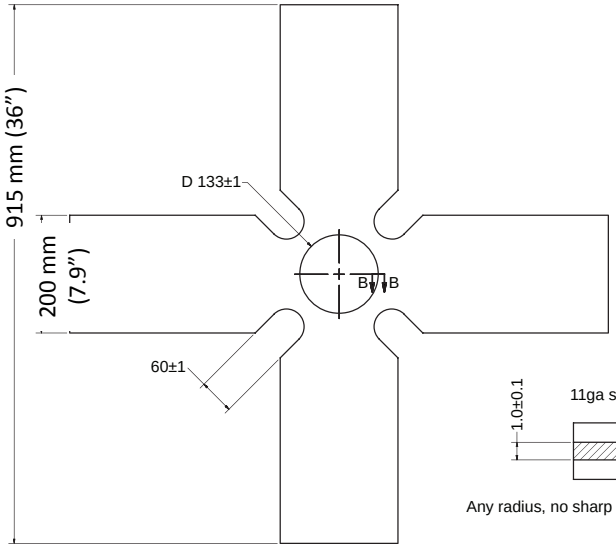
NIST Center for Automotive Lightweighting – ARRA funded tools

Next-Generation Metal Formability System



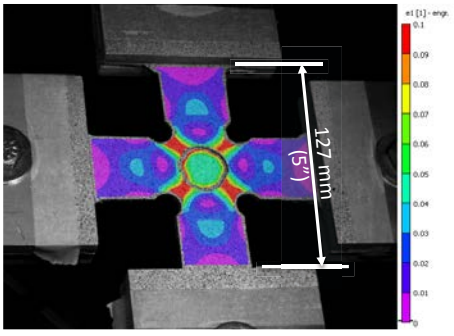
Cruciform Biaxial Specimen Development

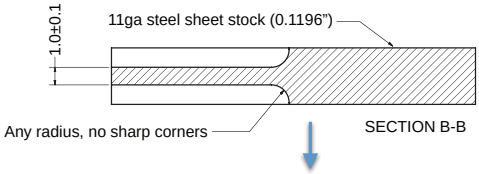
Full-Size Specimen



(Dimensions in mm)

Reduced-Size Specimen





An alternative to thinning is to clad the sample by adhesive or welding

NIST Center for Automotive Lightweighting – ARRA funded tools

Crashworthiness Standard Test Development

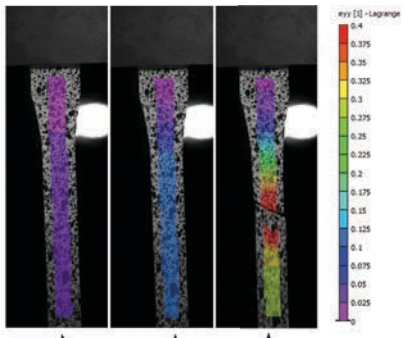
High-Rate Tension Uniaxial Servohydraulic Machine (ARRA Purchase)

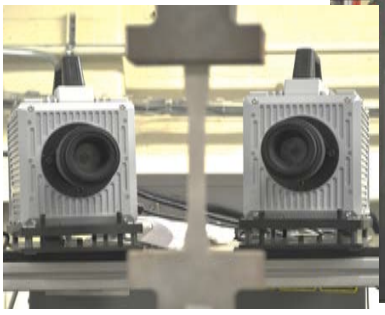
Capabilities:

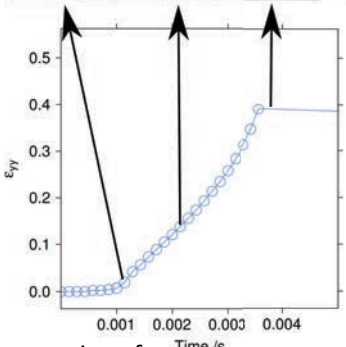
- Strain rates 1 to 800 s^{-1}
- Ultra-high-rate, 3D, surface-strain mapping (max. 300k fps)
- Temperature control chamber
- Typical specimen size: ASTM E8

NIST Focus:

- Sample Geometry
- Metrology
- Data Analysis





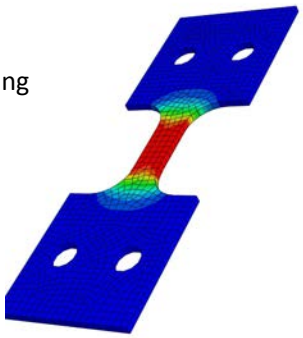


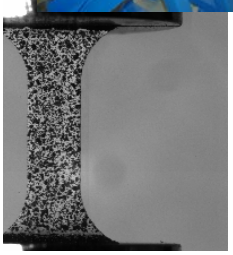
http://www.nist.gov/lightweighting/high-rate-testing.cfm

Ultra High-Rate Tension Uniaxial Testing

Compression Kolsky (Split-Hopkinson) Bar
- Strain rates from 10^3 to 10^4 s^{-1}
- Ultra-high-rate, 3D DIC, surface-strain mapping (max. 250k fps)
- Temperatures to 1000 °C
- Heating rates to 6000 °C/s
- Typical specimen size: diam. = 4 to 10 mm

New Tension Kolsky (Split-Hopkinson) Bar
- Strain rates from 5 x 10^2 to 10^4 s^{-1}
- Ultra-high-rate, 3D DIC, surface-strain mapping (max. 250k fps)
- Temperatures to 1000 °C
- Heating rates to 6000 °C/s
- Integrated finite element modeling
- Typical specimen size:
  gauge length = 4 to 8 mm
  width = 4 mm

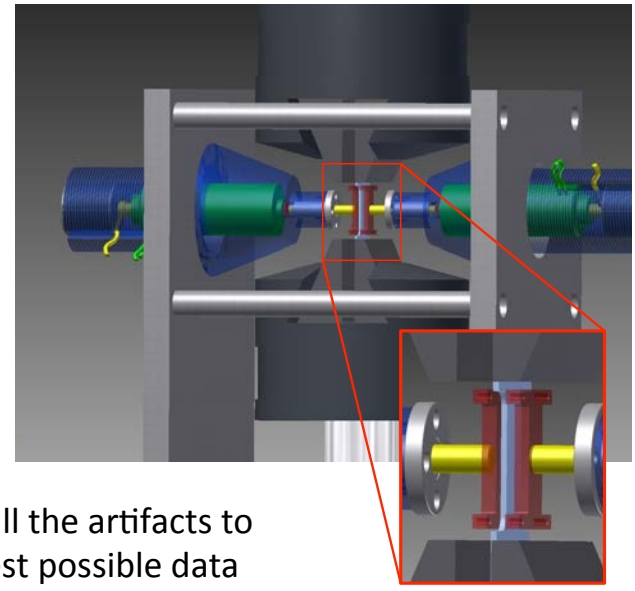




Proposal into NIST Management
- Biaxial Tension Kolsky
  (ballistic biaxial σ - ε)

Uniaxial Tension/Compression Testing
(under development)

Design Capabilities:
- Max. axial load ±100 kN
- Using anti-buckling guides
  - Closed loop force control
  - Max. 30 kN (piezoelectric)
  - Option to release during tension cycle
- Specimen size:
  gauge length ≈ 40 mm
  width ≈ 20 mm
  thickness = 0.8 to 2 mm
- DIC strain measurement

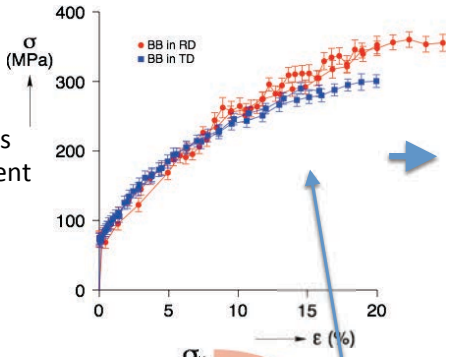


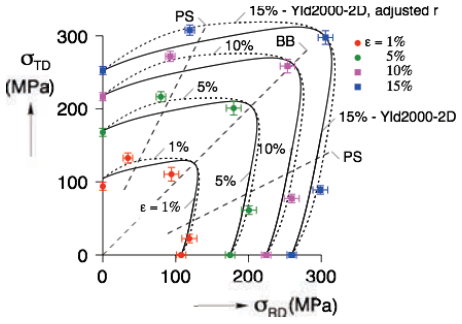
Goal: to quantify all the artifacts to achieve the cleanest possible data

Underlying Material Mechanisms

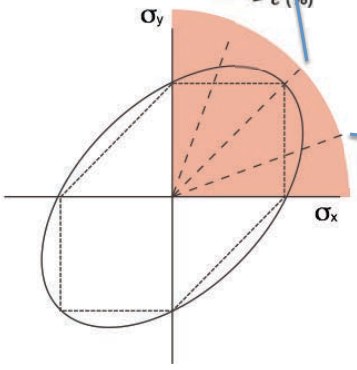
Multi-axial Tension

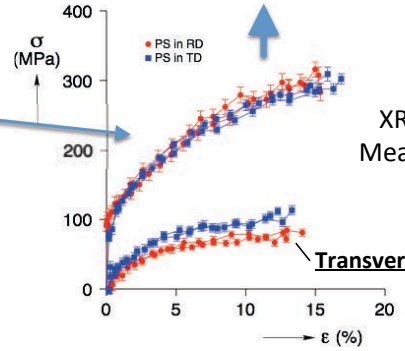
XRD Stress Measurement





Forming Machine (Marciniak)

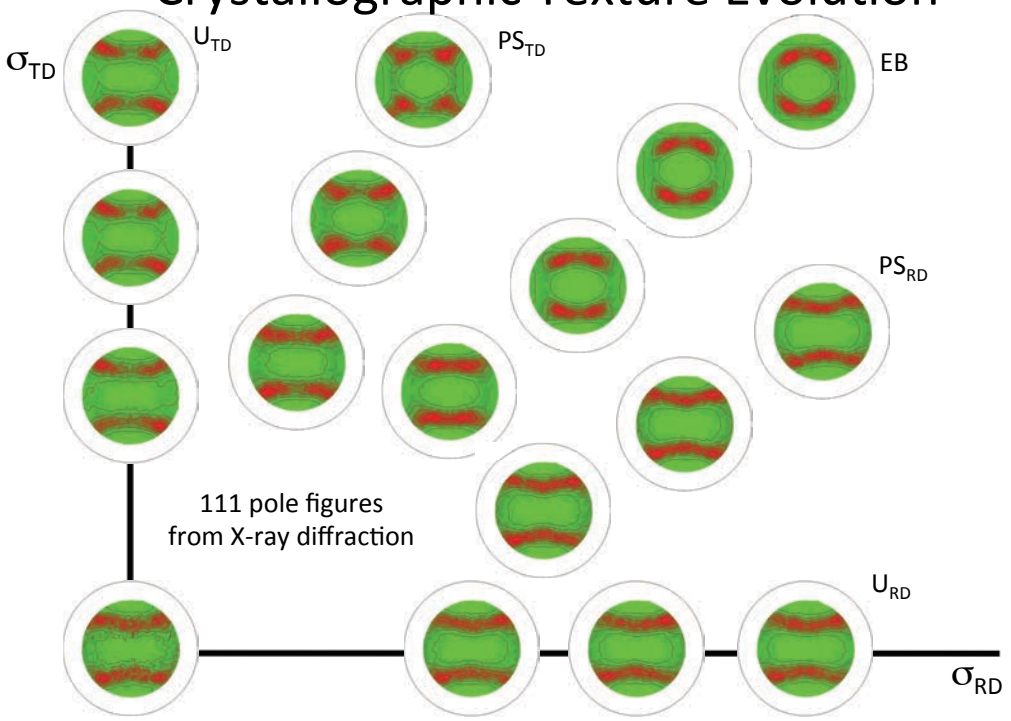




XRD Stress Measurement

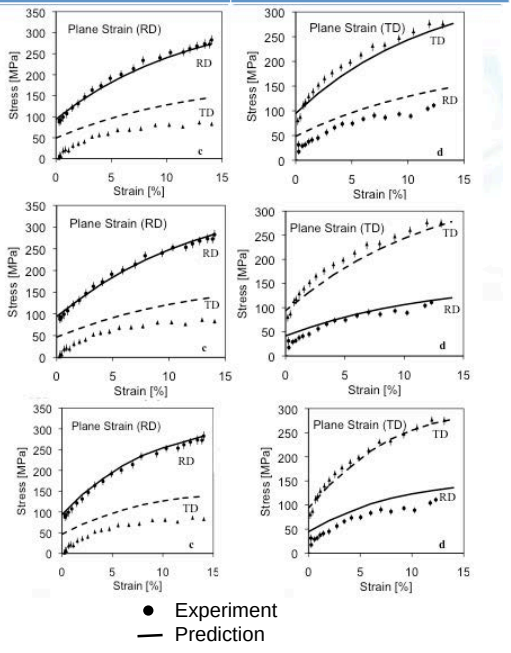
Transverse Stress

Crystallographic Texture Evolution

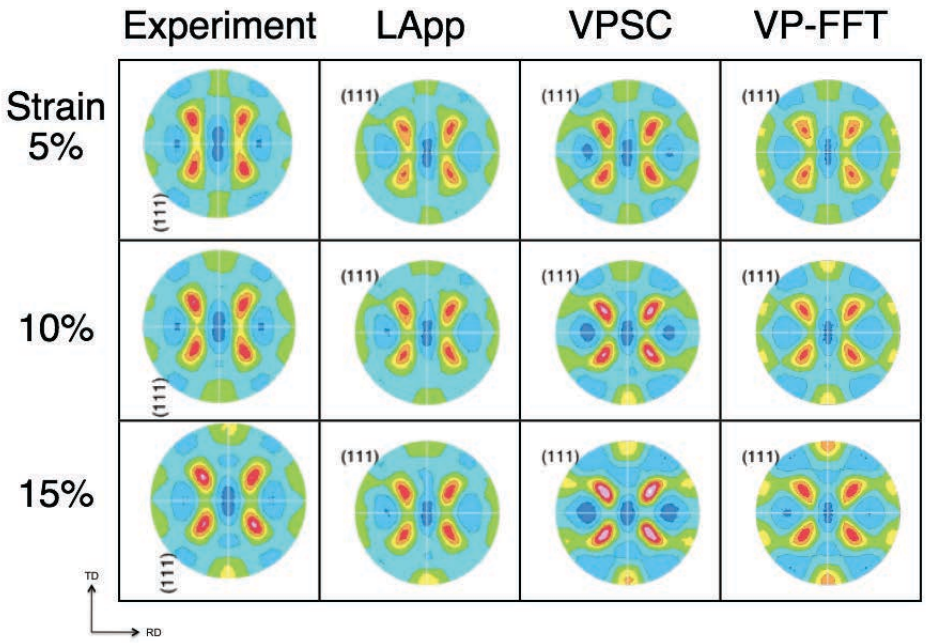


Crystallographic Texture Evolution Modeling

	Grain Interaction	RD	TD
LApp (Los Alamos Polycrystal Plasticity code)	Uniform strain		
VPSC (Viscoplastic Self-consistent code)	Grain to medium interaction		
VP-FFT (Viscoplastic using Fast Fourier Transform)	Voxel to voxel interaction		



Texture Evolution Comparison: Uniaxial TD



Current Industrial Interaction Projects

Current Industrial Interactions and Projects: Auto/Steel Partnership

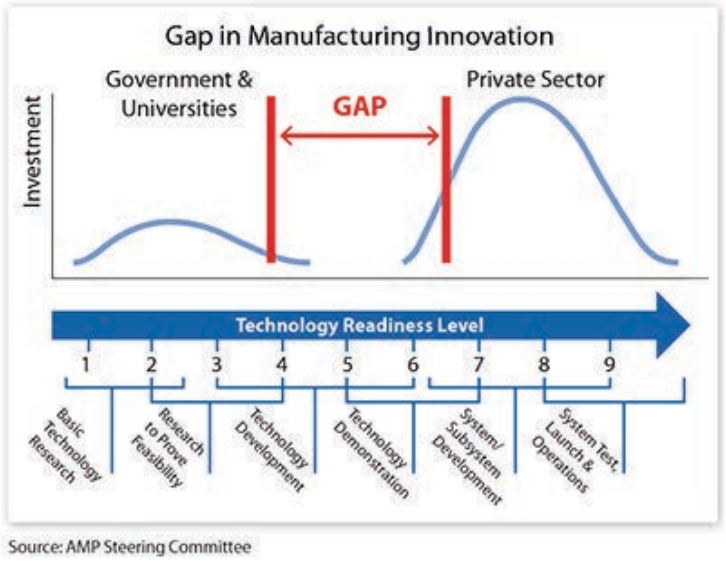
- Highly Non-Linear Strain Paths (061) project
- Develop data and models to explain unexpected failures
- Complex experiments and metrological issues

Current Industrial Interactions and Projects:

ALMMII American Lightweight Materials Manufacturing Innovation Institute

plus

15 other universities
6 Fed labs and FFRDCs
70+ companies



Source: AMP Steering Committee

- $70M/5 years from ONR, $85M match, $20M from MI, OH
- On Board of Directors, Gov't Steering Committee, Work Teams
  - NCAL is a full member of ALMMII (CRADA pending)

Current Industrial Interactions and Projects: AMTech

- Funded by AMNPO (Jian Cao, NWU lead)
- Roadmap of advanced metal forming technologies and needs
- Consortium on advanced metal forming
- 24 months starting now
- Another on joining technologies in touch with us

Current / Planned Industrial Interactions / Projects: Polymer Composites

- High rate failure constitutive behavior

- ICME of CFRP (DOE-VTC) – *JUST FUNDED*

- New NNMI on Polymer Composites 

+ . . .

Planned Industrial Interactions and Projects: Fracture in 3rd Gen AHSS

- Adjunct to a $3M DOE-funded 3rd Gen AHSS (advanced high strength steel) project
- Allison Beese, Penn State
- Dirk Mohr, MIT Fracture Consortium

- How do complex, multi-phase steel fail?
- How to codify failure criterion for Finite Element Models?
- How does loading mode, strain history, fatigue affect things?

NIST Center for Automotive Lightweighting

http://www.nist.gov/lightweighting