



I N S T I T U T E F O R D E F E N S E A N A L Y S E S

Working at the Institute for Defense Analyses (Presentation)

Jessica G. Swallow

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INSTITUTE FOR DEFENSE ANALYSES
4850 Mark Center Drive
Alexandria, Virginia 22311-1882



The Institute for Defense Analyses is a nonprofit corporation that operates three Federally Funded Research and Development Centers. Its mission is to answer the most challenging U.S. security and science policy questions with objective analysis, leveraging extraordinary scientific, technical, and analytic expertise.

About This Publication

This work was conducted by the Institute for Defense Analyses (IDA) under contract HQ0034-14-D-0001. The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

For More Information

Jessica G. Swallow, Project Leader
jswallow@ida.org, 703-845-2490

Leonard J. Buckley, Director, Science and Technology Division
lbuckley@ida.org, 703-578-2800

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Executive Summary

The Institute for Defense Analyses works on behalf of U.S. government sponsors to answer the most challenging security and space policy questions with objective analyses leveraging extraordinary scientific, technical, and analytic expertise. IDA manages three Federally Funded Research and Development Centers, including the Systems and Analyses Center (SAC) focused on issues of relevance to the Department of Defense and the Science and Technology Policy Institute (STPI), which works on questions relevant to the Office of Science and Technology Policy in the Executive branch. IDA hires a diverse range of professionals in all areas of science and technology, including recent graduates with bachelor's and graduate degrees and former military service members. This talk will illustrate what it is like to start a career at IDA. Projects will be described in areas such as modeling the human effects of non-lethal weapons, understanding the Li-ion battery industrial base, and analyzing how the intersection of materials science and data science can be exploited by the DoD. At IDA, employees have the opportunity to broaden their experience beyond their academic training and apply their technical training to unique technical questions of importance to National Security.



Working at the Institute for Defense Analyses

Dr. Jessica Swallow

Research Staff Member

Science and Technology Division

B.S., Chemical Engineering, Caltech, 2012; Ph.D., Materials Science, MIT, 2017

01/27/2020

jswallow@ida.org

Institute for Defense Analyses

4850 Mark Center Drive • Alexandria, Virginia 22311-1882

IDA: Rigorous Analysis, Trusted Expertise, Service to the Nation

- Founded in 1956
- Operates 3 Federally Funded Research and Development Centers (FFRDCs)
 - **Systems & Analyses Center (SAC)**, Science and Technology Policy Institute (STPI), Center for Communications & Computing

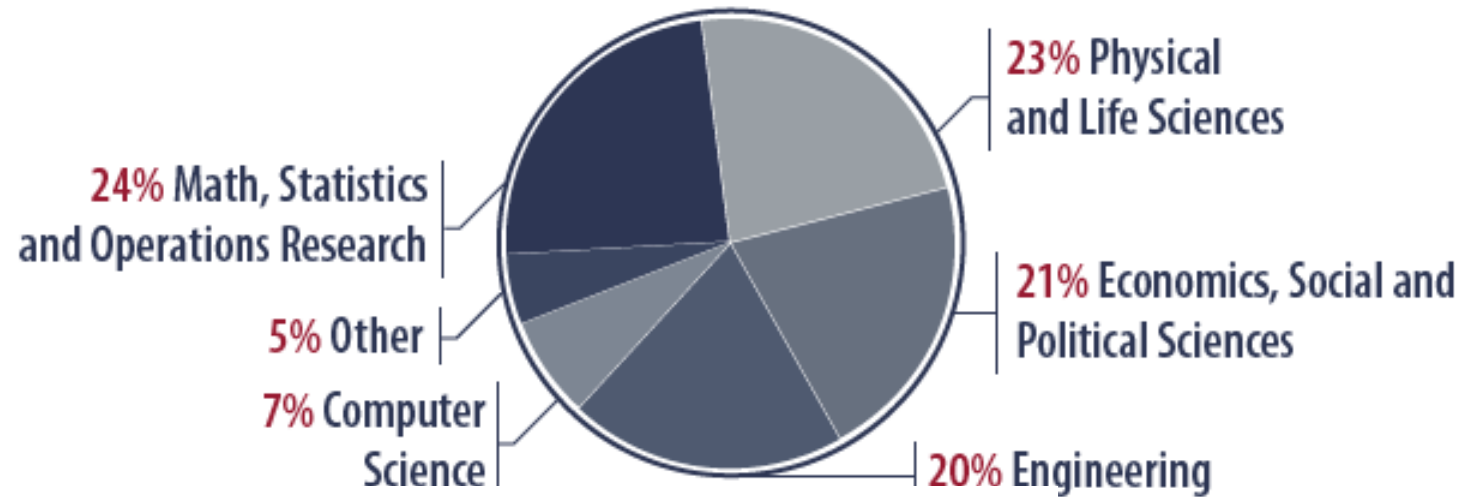


IDA answers the most challenging U.S. security and space policy questions with objective analyses leveraging extraordinary scientific, technical, and analytic expertise.

IDA Employees



66% of our research staff hold **Doctorates**.



20% of employees are veterans



IDA hires a diverse range of experienced professionals, new graduates (undergraduate & graduate), skilled technicians and military veterans.

Systems & Analyses Center (SAC)

- Work with government sponsors
 - Office of the Secretary of Defense, Defense Agencies, Joint Staff, Combatant Commands, Joint Agencies
 - Sponsors can also be from outside DoD
- Work on issues of importance for National Security
 - Intelligence, surveillance, & reconnaissance; chem-bio-radiological-nuclear defense; technical & analytic support for testing; resource allocation; readiness & workforce; space; cyber; systems & acquisition ...



Systems and Analyses Center (SAC) Divisions

- Cost Analysis and Research
- Intelligence Analyses
- Joint Advanced Warfighting
- Operational Evaluation
- **Science and Technology**
- System Evaluation
- Strategy, Forces and Resources
- Information Technology and Systems



<https://www.ida.org/ida-ffrdcs/systems-and-analyses-center>

The SAC has a flat organizational structure and interacts closely with the Science & Technology Policy Institute.

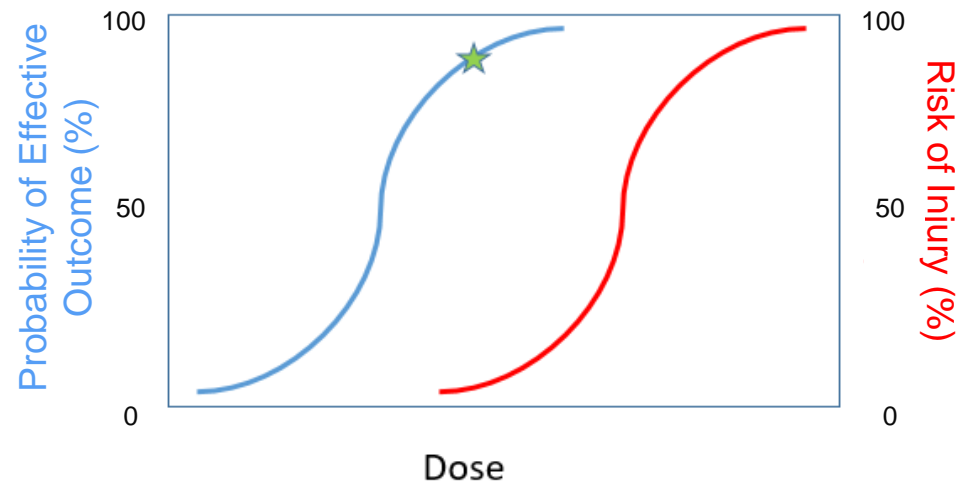
How it works

- Sponsor has a question or a problem they need solved ?
- Work with sponsor to develop a task description
- We do the analysis
 - We form our own teams, both within division or cross division
 - Teams can have many disciplines & experience levels
- Report in with sponsor regularly on progress, findings, next steps (varies from project to project)
- Provide final results to sponsor – sponsor decides what to do with them



Quantifying Uncertainty in Non-Lethal Weapons

- Non-lethal weapons provide a step between ‘shouting’ and ‘shooting’
- Counter-personnel and counter-materiel
- Usually very limited test data
- Modeling required to predict risk of injury and effectiveness



Responsible use of non-lethal weapons requires balancing between effectiveness and risk, informed by interdisciplinary scientific analysis.

Questions to consider

- Which injuries need to be modeled?
- How do we model those injuries given limited data?
- How do we aggregate the risk of multiple injuries and/or multiple targets?
- How can we estimate the uncertainty of predictions made by these models?
- How do we account for scenario variability?

Flashbangs: Auditory Non-Lethal Weapons

Uses: Move people, deny access, suppress individuals

- May be indoor or outdoor (e.g., crowd control scenario, warning shot scenario)

Single 'bang'

- MK20: Improved Flash-Bang Grenade
 - o Hostage rescue, room-clearing, operation in 'complex urban terrain'

Multiple 'bangs'

- Double, 6-bang, 9-bang, etc.
- Indirect Fire Munition (IDFM) in development

Non-pyrotechnic devices

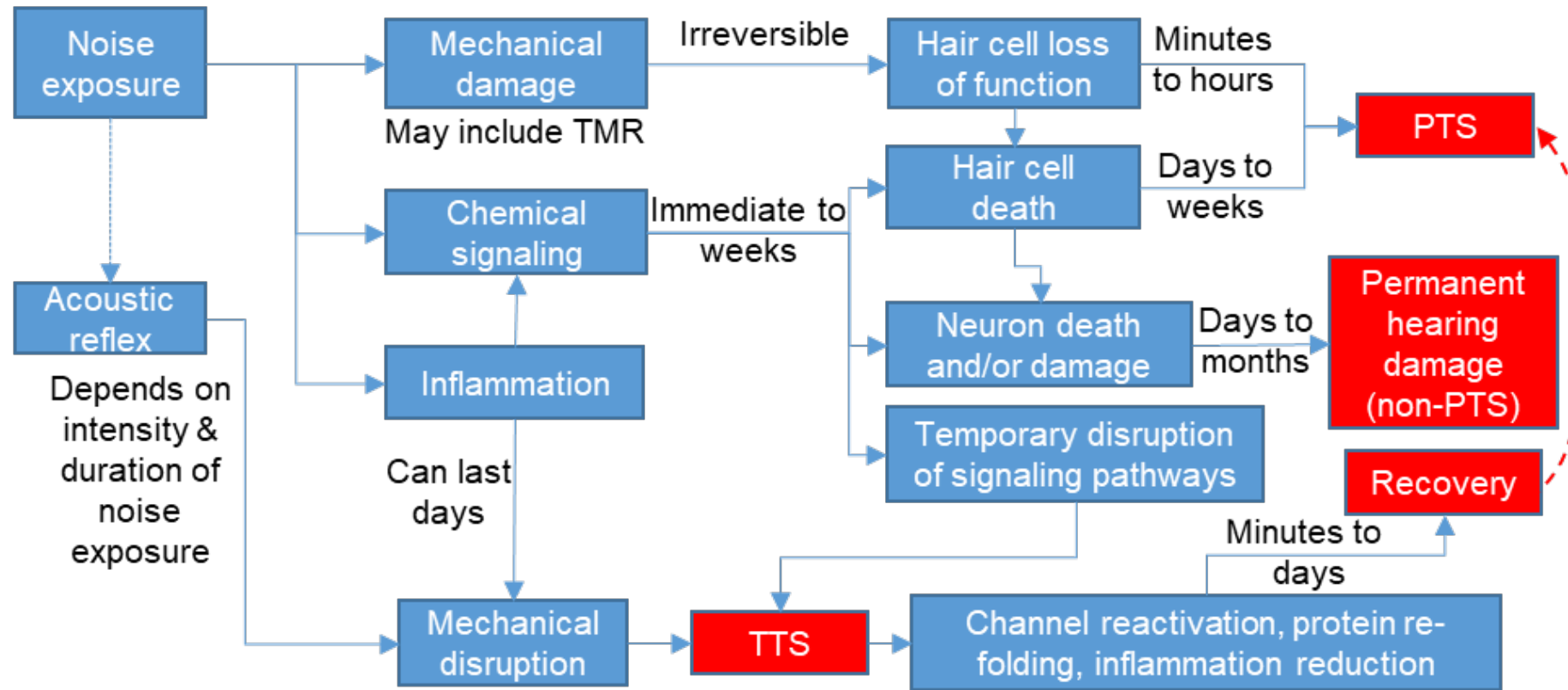
- Laser-induced plasma effect



IDFM Trifold, JNLWP, 2015

Flashbangs can reach sound pressure levels of up to 180 dB in reverberant environments.

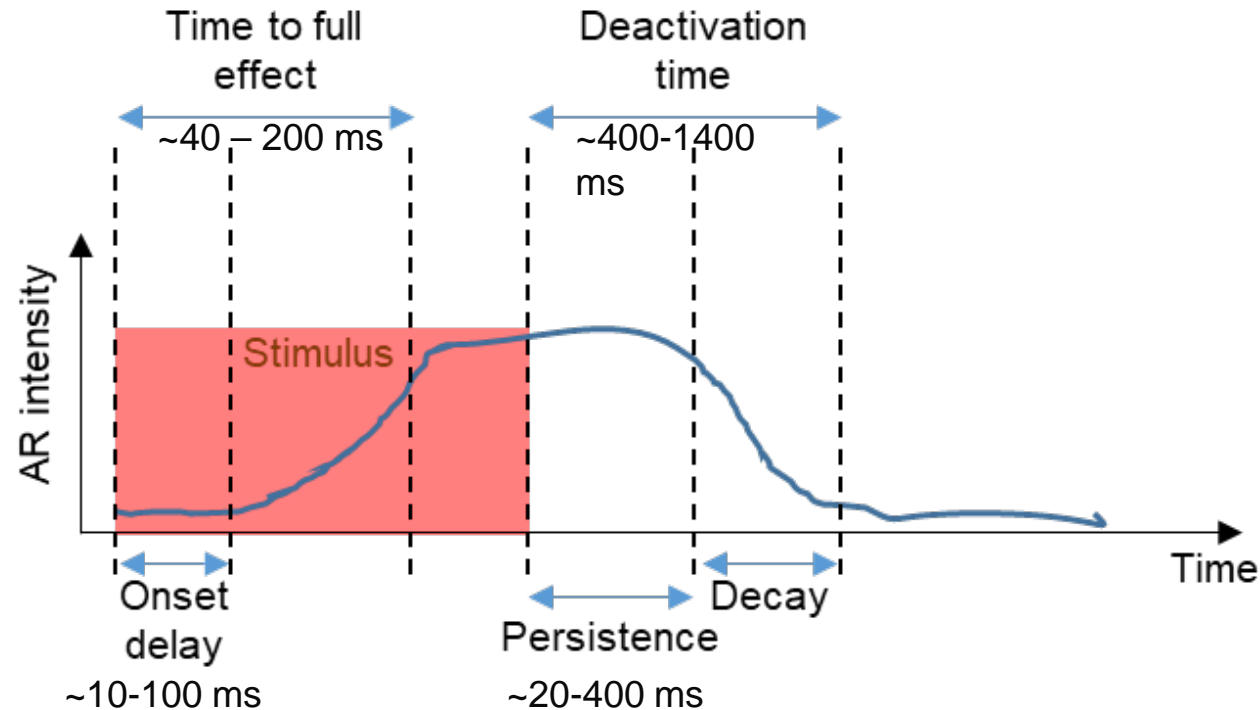
Mechanisms of auditory injury and recovery



Some mechanisms that lead to *irreversible* (permanent) threshold shift (PTS) are distinct from those that lead to *reversible* (temporary) threshold shift (TTS)

Wong & Ryan, *Frontiers in Aging Neuroscience*, 2015
 Kujawa & Liberman, *J. Neuroscience*, 2009
 Patuzzi, R. *Hearing Research*, 1998
 Swallow & Kramer (2019), IDA D-10722

The Acoustic Reflex (AR)



AHAAH: Price, *ARL-TR-8333*, 2018
Fletcher, *J. Acoust. Soc. Am.*, 1960
Dallos, P.J., *J. Acoust. Soc. Am.*, 1964
Church, *Ear and Hearing*, 1984
McGregor, *Int. J. Audiology*, 2017

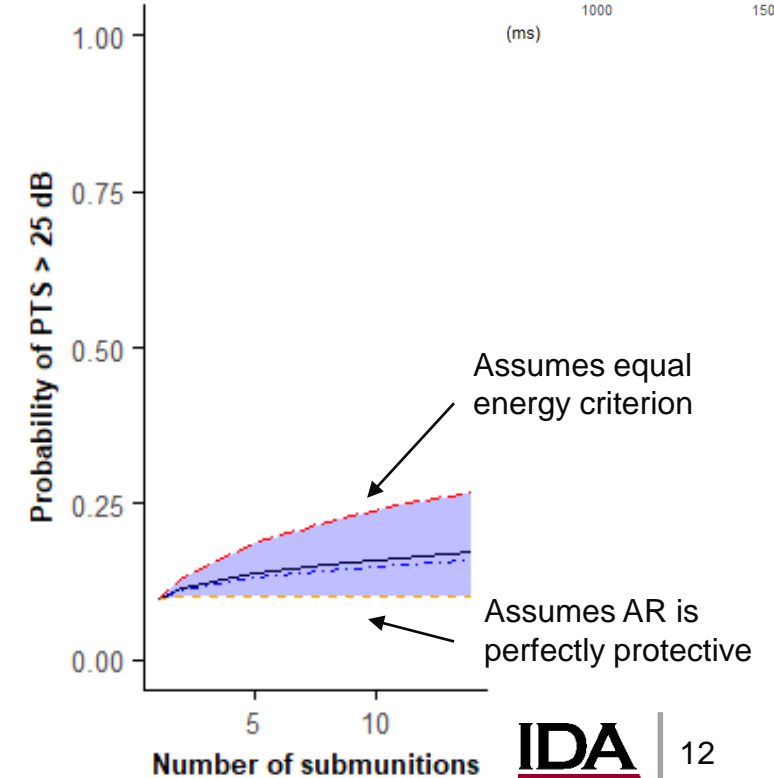
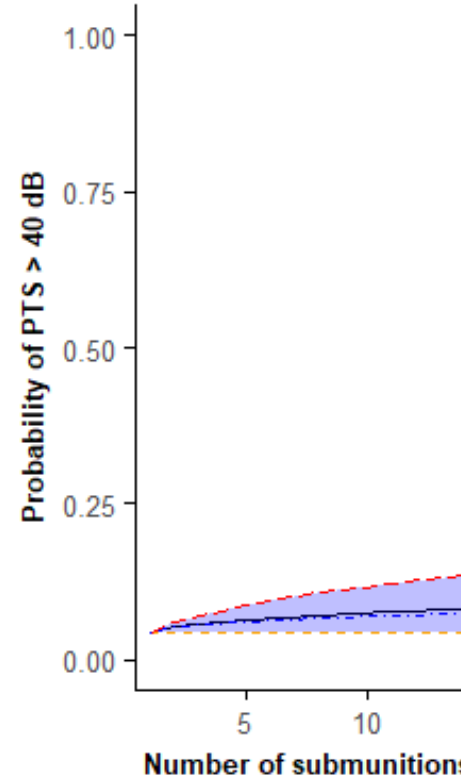
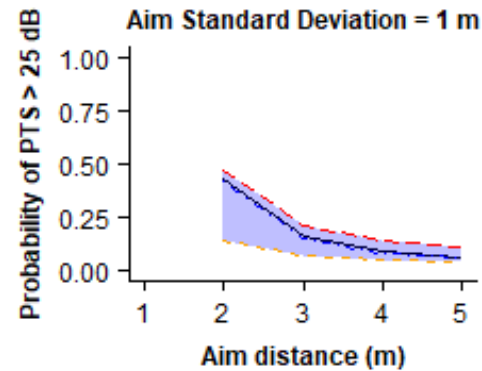
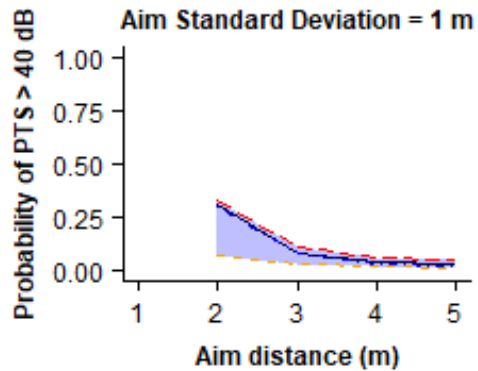
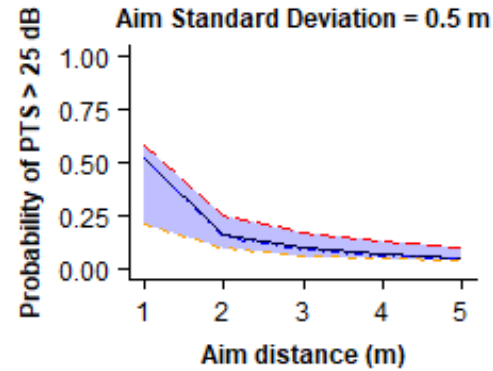
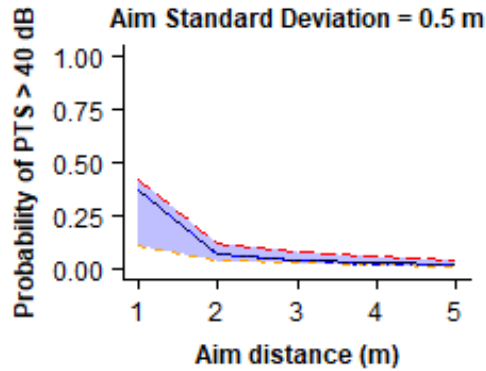
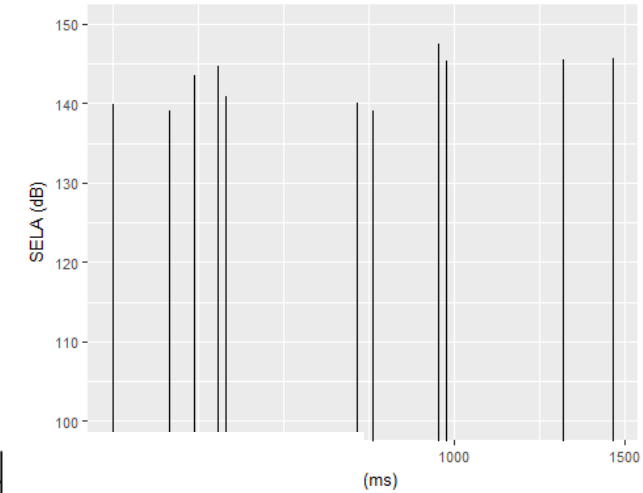
- Acoustic reflex strength and timing shows variability across the population
- Depends on stimulus characteristics & subject attention/anticipation, and can be triggered by non-acoustic events
- Relevant for **multi-bang** scenarios

Swallow & Kramer (2019), IDA D-10722

Accumulated Dose Uncertainty

- Simulate weapon patterns and/or crowd characteristics
- Compute estimated dose accumulation using a range of rules
- Report range of expected injury risk

Simulated IDFM pattern

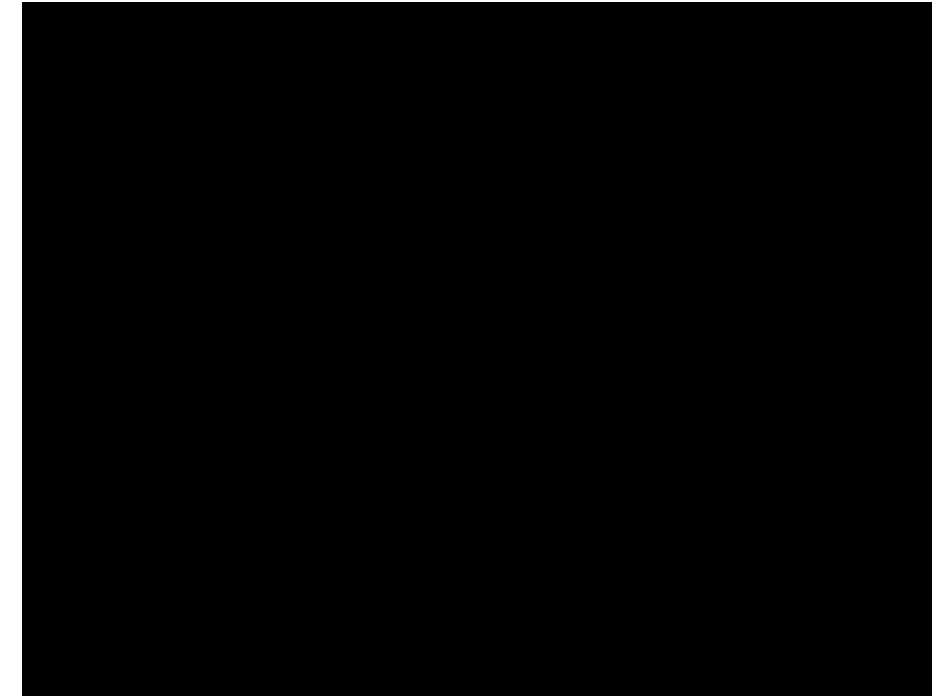


Blunt Impact Injury Modeling/ATBM

The Advanced Total Body Model is a collection of finite element models of the human body developed by JNLWD to simulate Kinetic Energy Non-Lethal Weapon impacts on the human body.

FEMs include: torso, head, eye, facial bones, extremities, lower abdomen and neck

- The finite element model geometry is built from CT images of a real human (Visible Human Project or Zygote); runs with LS-Dyna solver
- Different tissues are represented by specific material models (simple elastic, viscoelastic, hyperelastic, etc.- mostly commercial models in LS-Dyna packages) with material properties (density, Young's modulus, poisson ratio, etc.) defined from the literature
- In conjunction with a projectile model, ATBM predicts internal physical quantities of interest, such as stress, strain, deformation of tissue or bone for a given impact
- ATBM does not incorporate mechanical features of injury (i.e. model dynamics can exceed injury threshold)



Purpose of ATBM

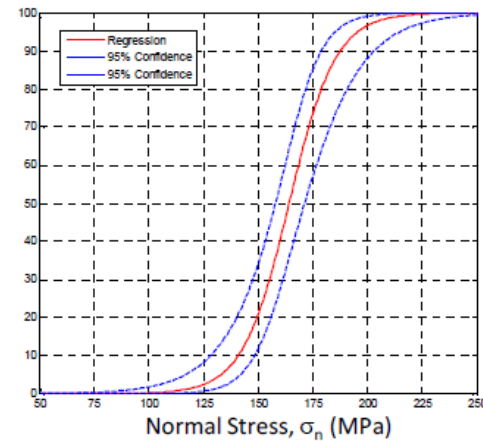
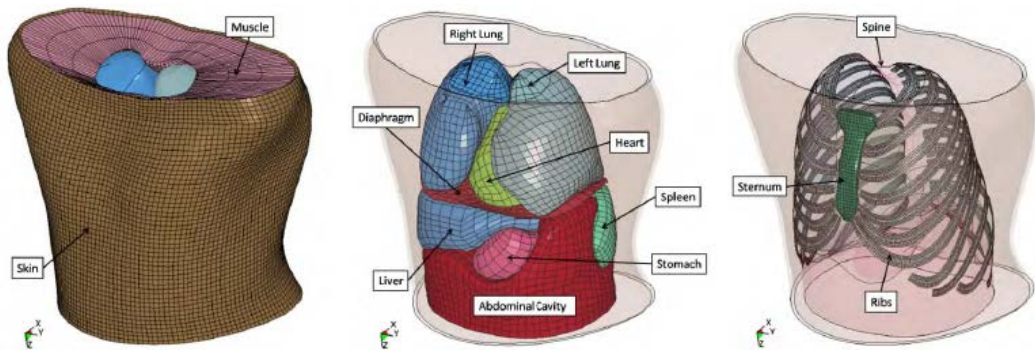
Develop a tool to:

- evaluate non-lethal blunt impact weapons (Key System Attributes [KSAs] that deal with risk of injury to the target)
- design weapons for effectiveness/risk optimization

Method:

- Biofidelic model of human/projectile interaction
- Risk curves for associated injuries
- Assessment of significance of injury

$$RSI = \sum P_{significant|injury}$$

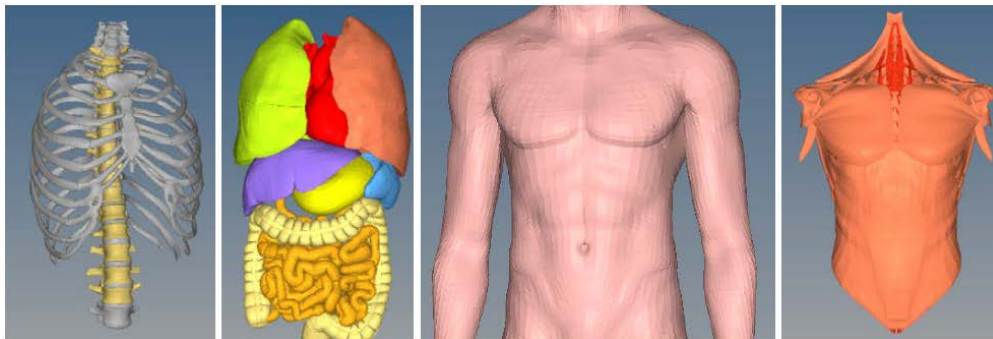


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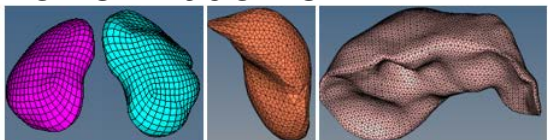


Body Parts and Injuries

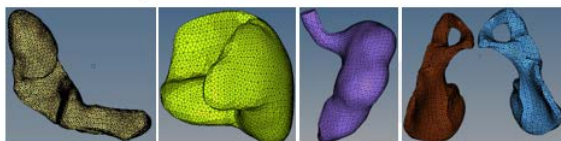
Torso



Lower Abdomen

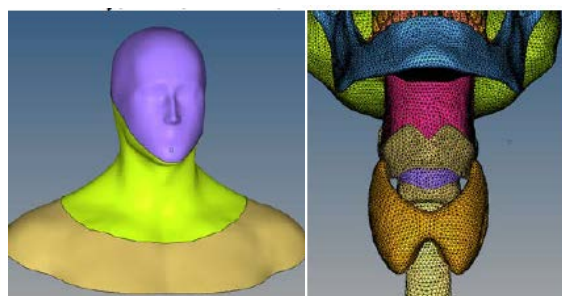


Kidney Gallbladder Liver

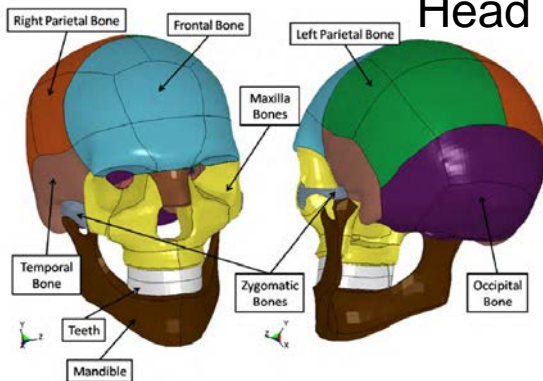


Pancreas Spleen Stomach Pelvis

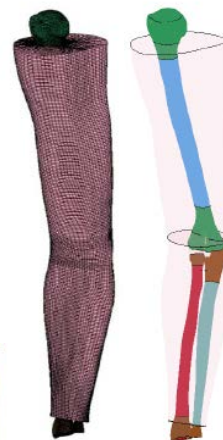
Neck



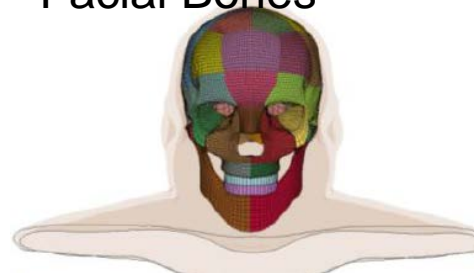
Head



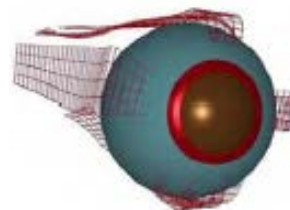
Arm



Facial Bones



Eye



ATBM

Thorax

- Rib Fracture
- Pneumothorax
- Lung Contusion
- Liver Laceration
- Heart Rupture
- Heart Lesion

Head

- Skull Fracture
- Concussion
- Contusion
- Subdural Hematoma
- Subarachnoid Hemorrhage

Eye

- Globe Rupture
- Hyphema
- Retinal Damage
- Lens Dislocation
- Corneal Abrasion

Arm

- Radius Fracture
- Ulna Fracture
- Humerus Fracture

Leg

- Femur Fracture
- Tibia Fracture

Neck

- Laryngeal Cartilage Fracture
- Tracheal Cartilage Fracture
- Carotid Artery Damage
- Jugular Vein Damage
- Vertebral Fracture

Lower Abdomen

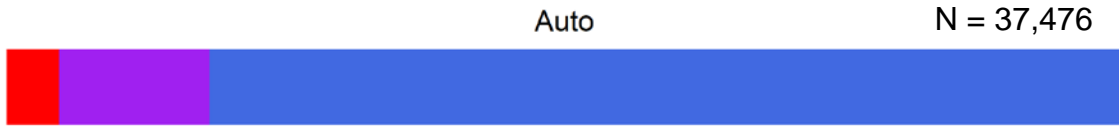
- Intestinal Contusion
- Stomach Contusion
- Spleen Laceration
- Kidney Contusion
- Pancreas Rupture

Facial Bones

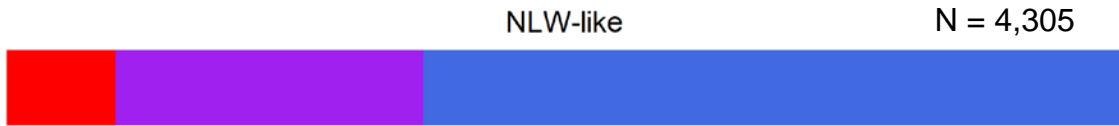
- Maxilla Fracture
- Mandible Fracture
- Zygomatic Arch Fracture

Development Priorities: National Trauma Data Bank

Brain injuries are very likely (~75% chance) with skull fractures, but not *vice versa*

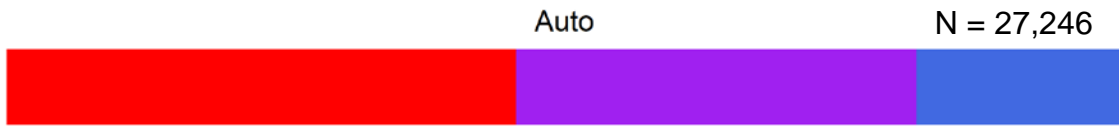


Injury Legend: Brain Injury (Blue), Skull Fracture (Red), Skull Fracture and Brain Injury (Purple)

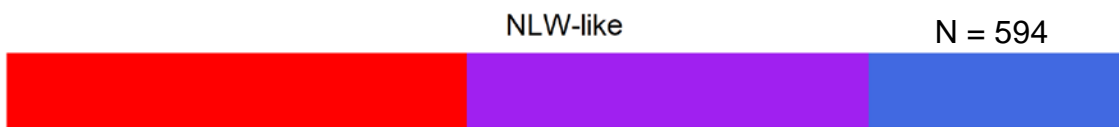


Injury Legend: Brain Injury (Blue), Skull Fracture (Red), Skull Fracture and Brain Injury (Purple)

Rib fractures and pneumothorax show similar profile for auto & NLW-like impacts, and are not highly correlated



Injury Legend: Pneumothorax (Blue), Rib Fracture (Red), Rib Fracture and Pneumothorax (Purple)

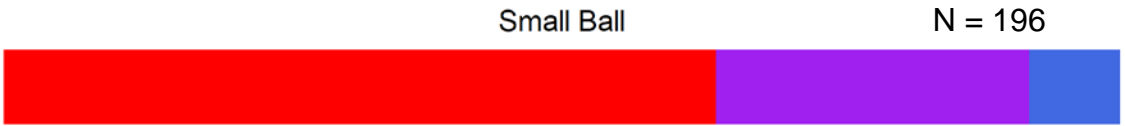


Injury Legend: Pneumothorax (Blue), Rib Fracture (Red), Rib Fracture and Pneumothorax (Purple)

Automotive accidents, small sports ball impacts, and launched projectile impacts have very different eye injury profiles



Injury Legend: Globe (Blue), Orbit Fracture (Red), Orbit Fracture and Globe (Purple)



Injury Legend: Globe (Blue), Orbit Fracture (Red), Orbit Fracture and Globe (Purple)



Injury Legend: Globe (Blue), Orbit Fracture (Red), Orbit Fracture and Globe (Purple)

Shaded areas correspond to proportion of total number of cases N that contain the designated injuries. Data analyzed for ages 14-50, without protective devices (e.g., helmets, safety goggles).

Effect of Age on Bone Mechanical Properties: Extremities Model

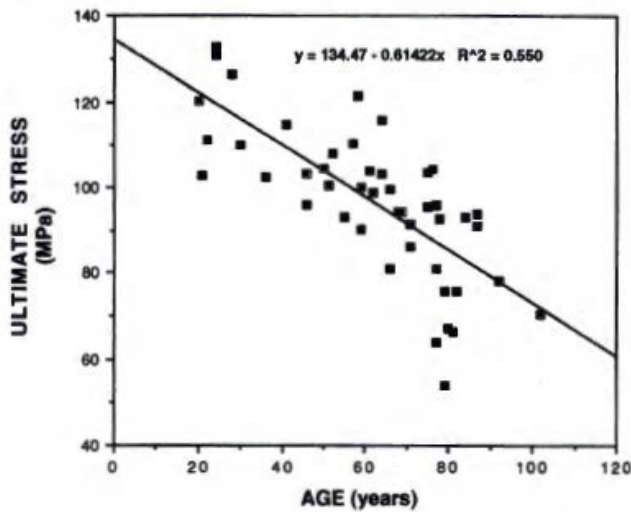
Arm fracture injury model is based on PMHS arm bone ‘fracture stress’

- Population age 50-70: Older than the general population or the target population

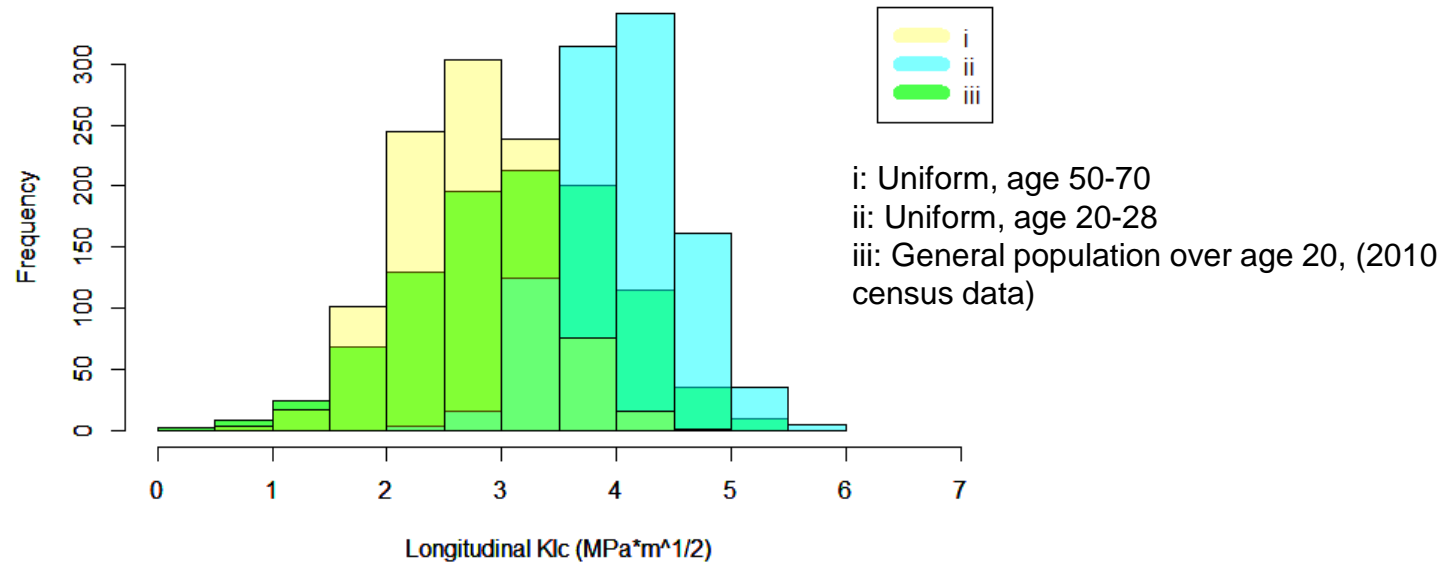
Fracture stress is not an intrinsic material property – depends on the size of the sample & flaw distribution

- Simulated fracture toughness of three sample populations shows clear shift in expected fracture toughness depending on age distribution (Same trend occurs for bone density)

Cortical bone, human femur



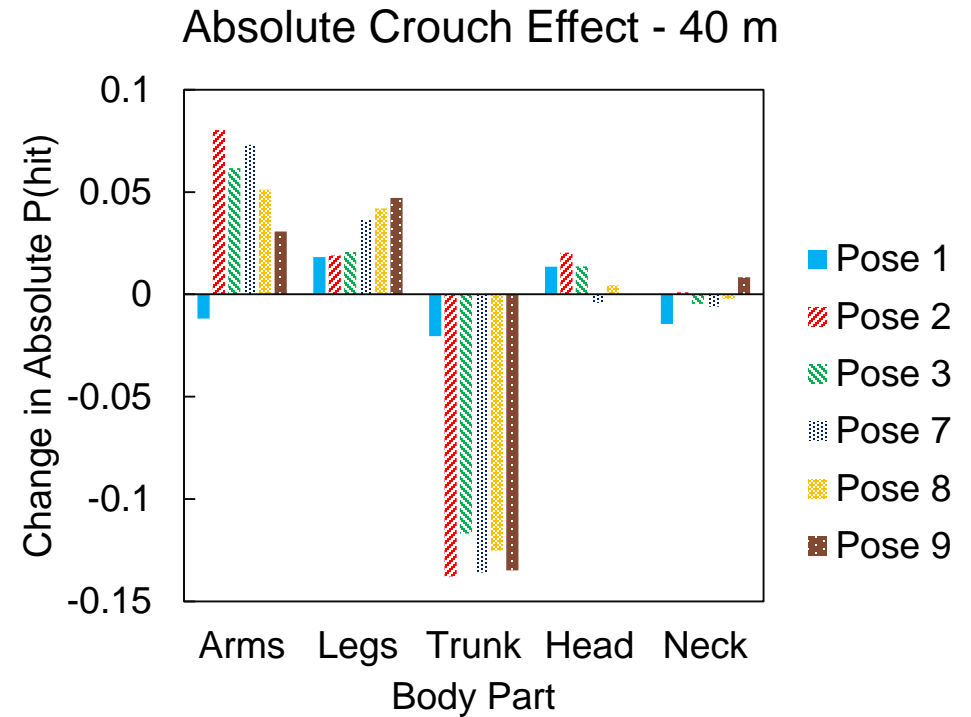
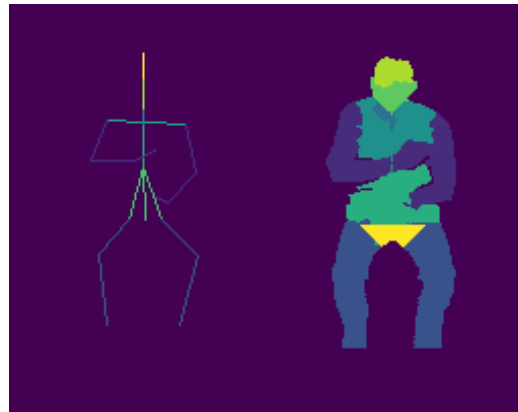
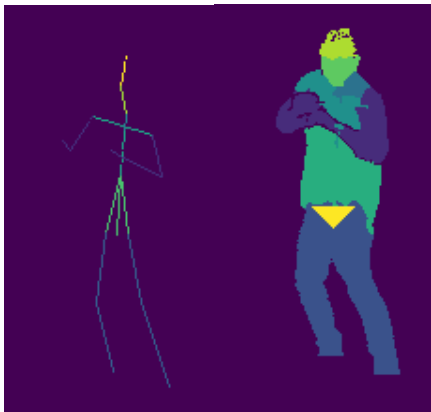
McCalden et al., J. Bone Joint Surg., 1993



Based on statistical analysis of literature results & test data, we recommended shifts to injury correlates to account for age & strain rate effects.

Probability of Hit

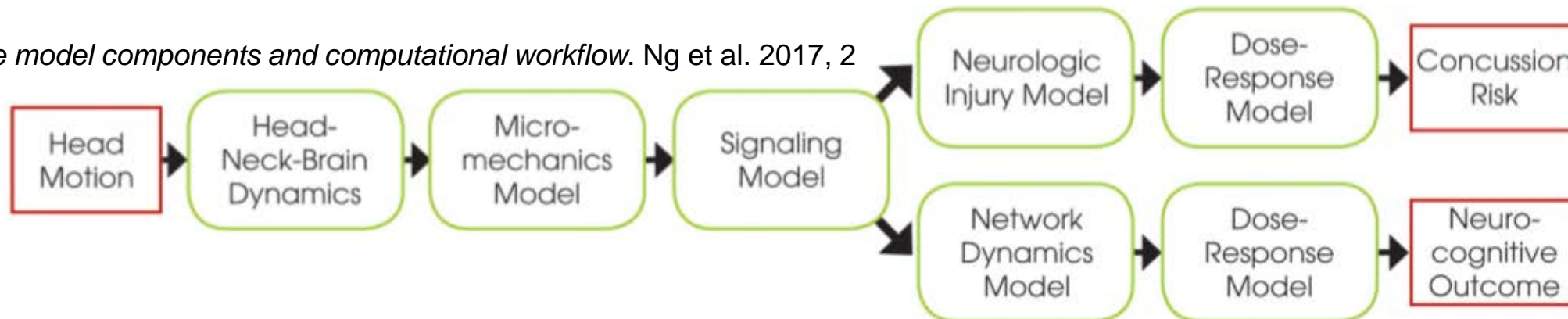
- How sensitive is P_{hit} to target pose & biovariability?
- Acquire depth images using a Kinect (also tracks joint positions)
- Image segmentation algorithm identifies body regions
- Approach:
 - Set of poses specified based on experimental data
 - Images of the pose-set collected for adults with a representative range of bio-variability
 - Analyze $P(hit)$ as a function of range & dispersion



Using actual images & segmentation we can explore how pose & biovariability affect $P(hit)$

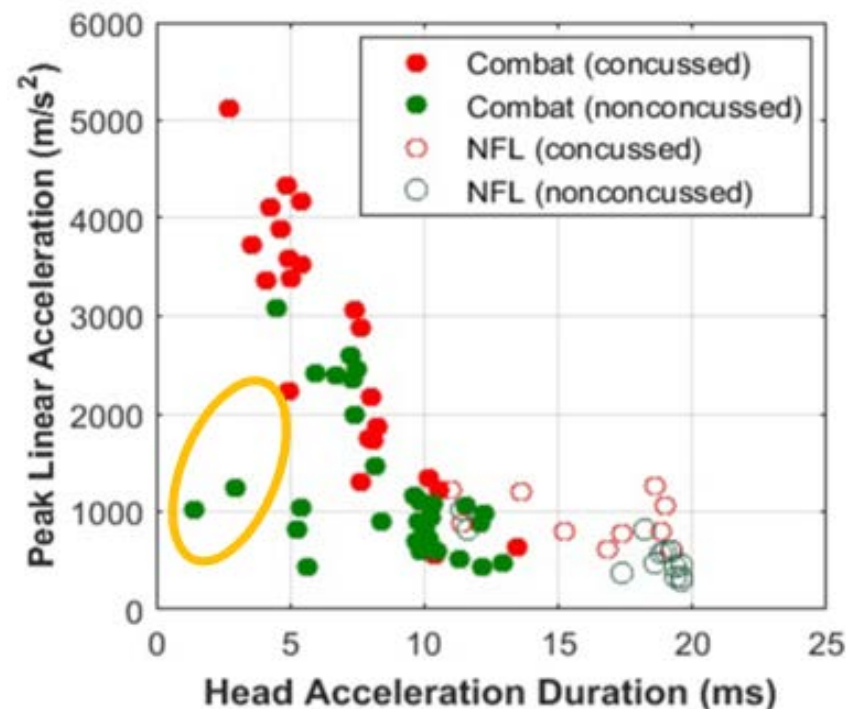
Concussion Model Initial Assessment

Schematic of the model components and computational workflow. Ng et al. 2017, 2



Government-owned fast running model based on proprietary industry finite element model of the brain
 Several Components require independent validation

- Head motion
 - Sanchez EJ et al.; (2019) A reanalysis of football impact reconstructions for head kinematics and finite element modeling. *Clinical Biomechanics*, 64: 82-89.
- Strain measurements
 - Alshareef, AA et al., (2019) Human Brain Deformation During Controlled Dynamic Rotation of the Head. *Proceedings of the International Research Council on the Biomechanics of Impact (IRCOBI), IRC-19-97*. Florence, Italy. September 11-13



Central Research Projects (CRPs) and Professional Development

- CRPs: internal funding to conduct independent research
- Uses:
 - Developing employee knowledge and skills
 - Exploring topics for potential new sponsored work
 - Writing publications
- Some CRP Titles:
 - Lithium Ion Battery Industrial Base in the U.S. and Abroad
 - Data Science for Materials in Extreme Environments
 - Additive Manufacturing Working Group
 - Annotating Organisms of Interest to DoD



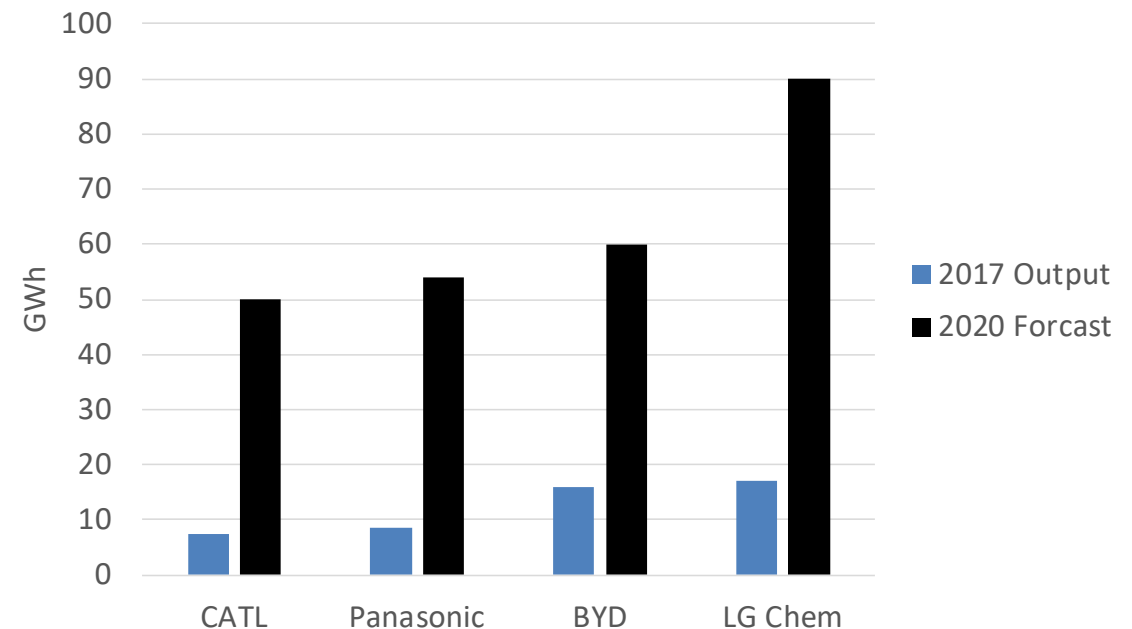
Images from: en.wikipedia.org

IDA also offers summer associate positions, fellowship positions, and opportunities for professional development, such as internally-taught courses and the IDA Scholar Award

CRP: Lithium Ion Battery Industrial Base in the U.S. and Abroad

- Electric vehicles are a rapidly growing global industry
- Batteries are of significant strategic importance, both for domestic and DoD needs – collaboration between SAC & STPI
- Many automobile and battery manufacturers competing to dominate the industry
- Intense R&D in all aspects of battery manufacturing

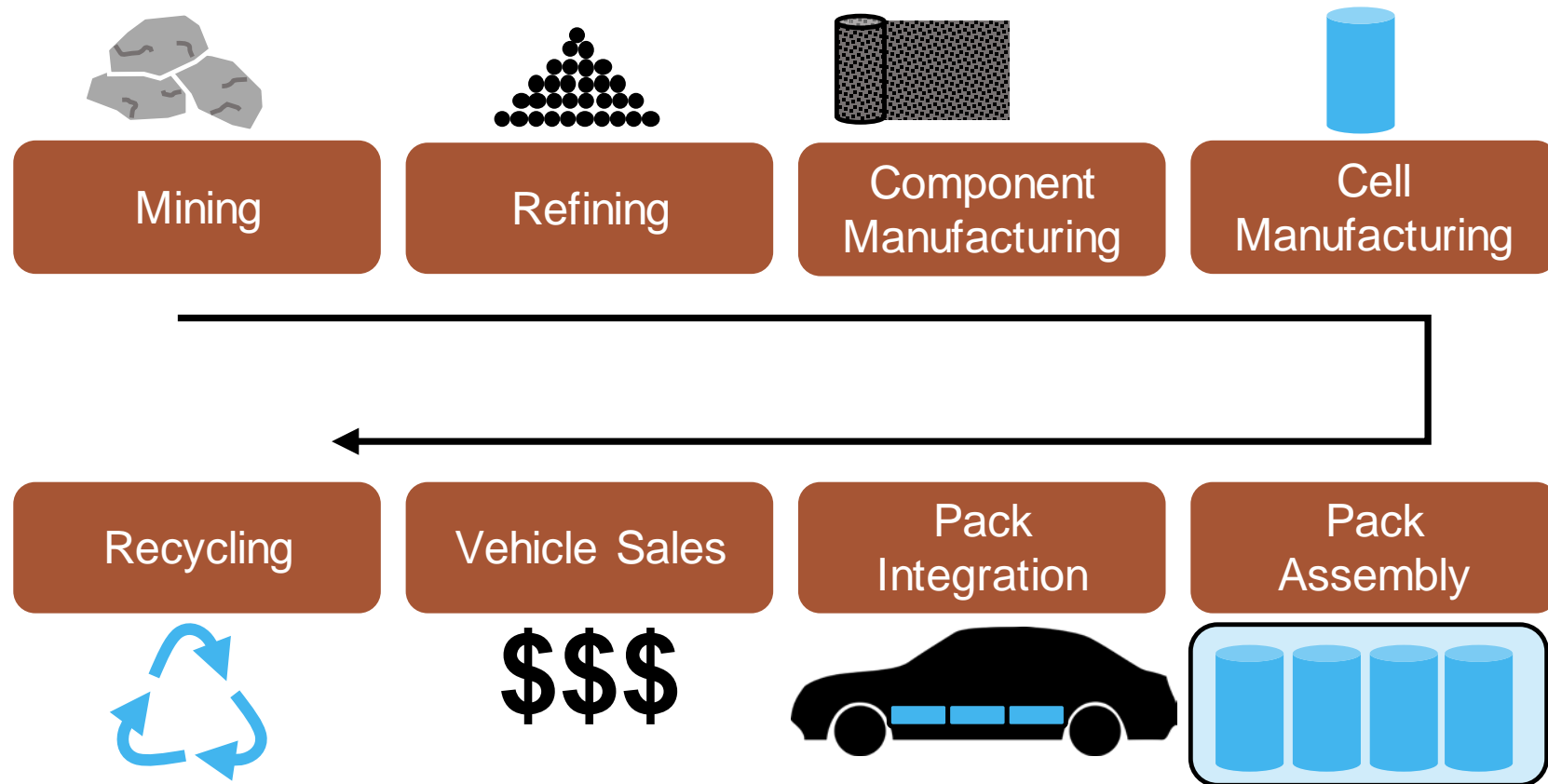
Current and projected Li-ion manufacturing capacity for several top manufacturers



Rotondo, Swallow, & Goldman (2019), IDA D-11032

Where does the United States sit in this global industry?

The Electric Vehicle Battery Supply Chain

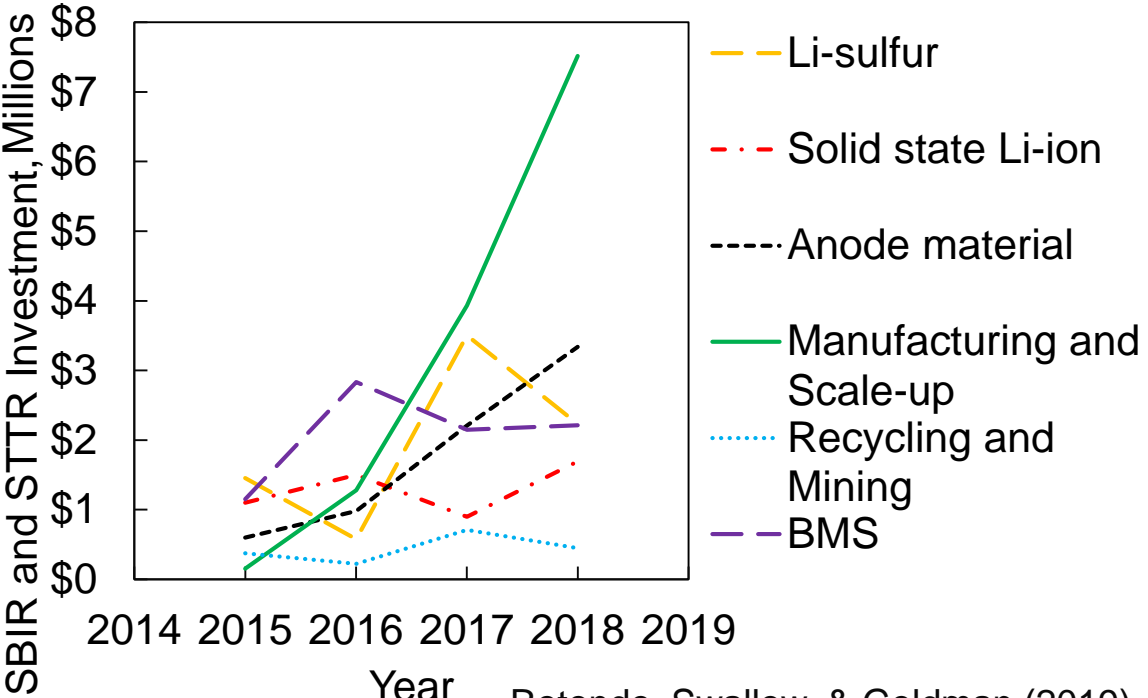
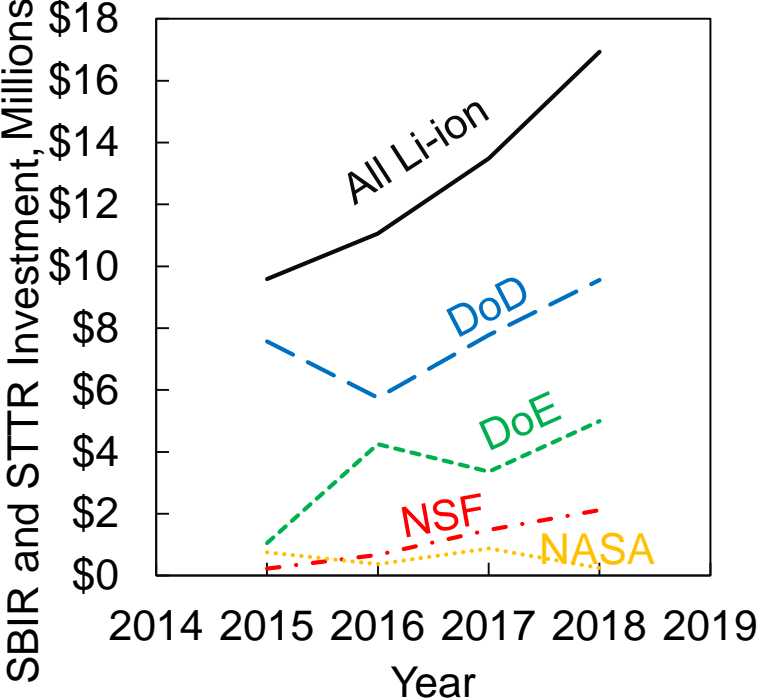


Rotondo, Swallow, & Goldman (2019), IDA D-11032

Today, most U.S. involvement in this supply chain is at the pack assembly and pack integration level, with a few notable exceptions.

Government Investment in Battery Research and Technology Transfer

Small business innovative research (SBIR) and Small business technology transfer (STTR) grants help companies transition technology into the commercial sector.

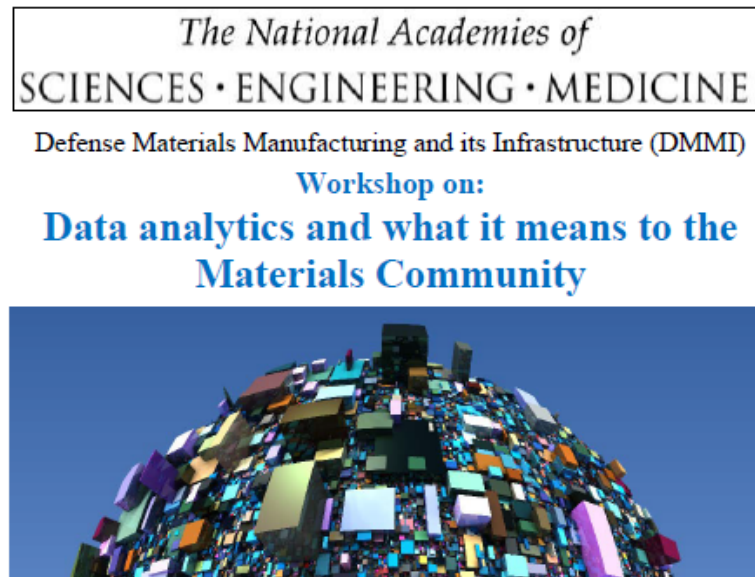


Rotondo, Swallow, & Goldman (2019), IDA D-11032

The U.S. is a leader in R&D in novel battery technologies – how can we best capitalize on our domestic innovation ecosystem?

The Intersection Between Materials Science and Data Science

- The DoD has been increasing its focus on this problem
- 8th Persh Workshop (hosted at IDA): “Materials and Processes Data Management and Exploitation – Opportunities and Barriers”
- Defense Materials Manufacturing and its Infrastructure (DMMI) meetings

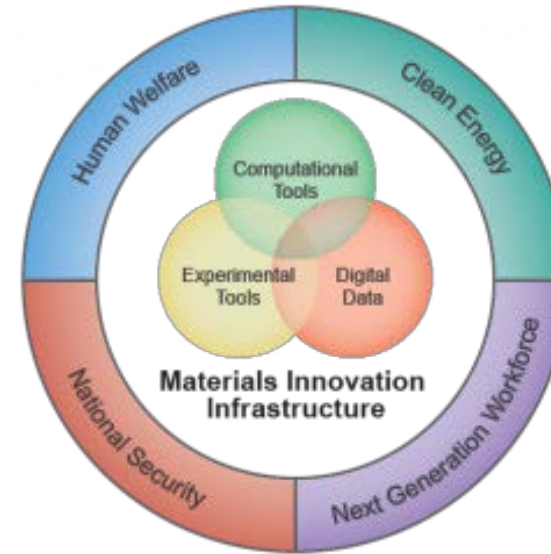


<https://www.nap.edu/author/NMMB/division-on-engineering-and-physical-sciences/national-materials-and-manufacturing-board>

Data is essential to ensuring repeatable, reliable manufacturing of parts, especially when additive manufacturing is involved.

Existing Materials Data Infrastructure

- Materials databases:
 - Computationally generated
 - Literature results
 - Curated standards
 - Practical/surveillance
- Data repositories
- Resource registries
- Analysis tools
 - PyMKS, scikit-image
 - DREAM.3D



NIST



ASM
INTERNATIONAL



re3data.org
REGISTRY OF RESEARCH DATA REPOSITORIES

These tools can help us improve data-driven design of materials – but what needs does the DoD have that are currently underserved?

Data Science for Materials in Extreme Environments

What is an 'extreme' environment?

- High or low temperature
- Corrosive, reducing, or oxidizing conditions
- High pressure or vacuum
- Radiation exposure
- High strain rates or stresses
- Combinations of the above (and more)
- Context-dependent

Material limits define component limits (e.g., usage temperatures, maintenance cycles, etc.)

Hot corrosion, marine



<https://www.technology.matthey.com/article/25/3/94-105/>

Hypersonics: temperature, pressure, stress, and (possibly) radiation

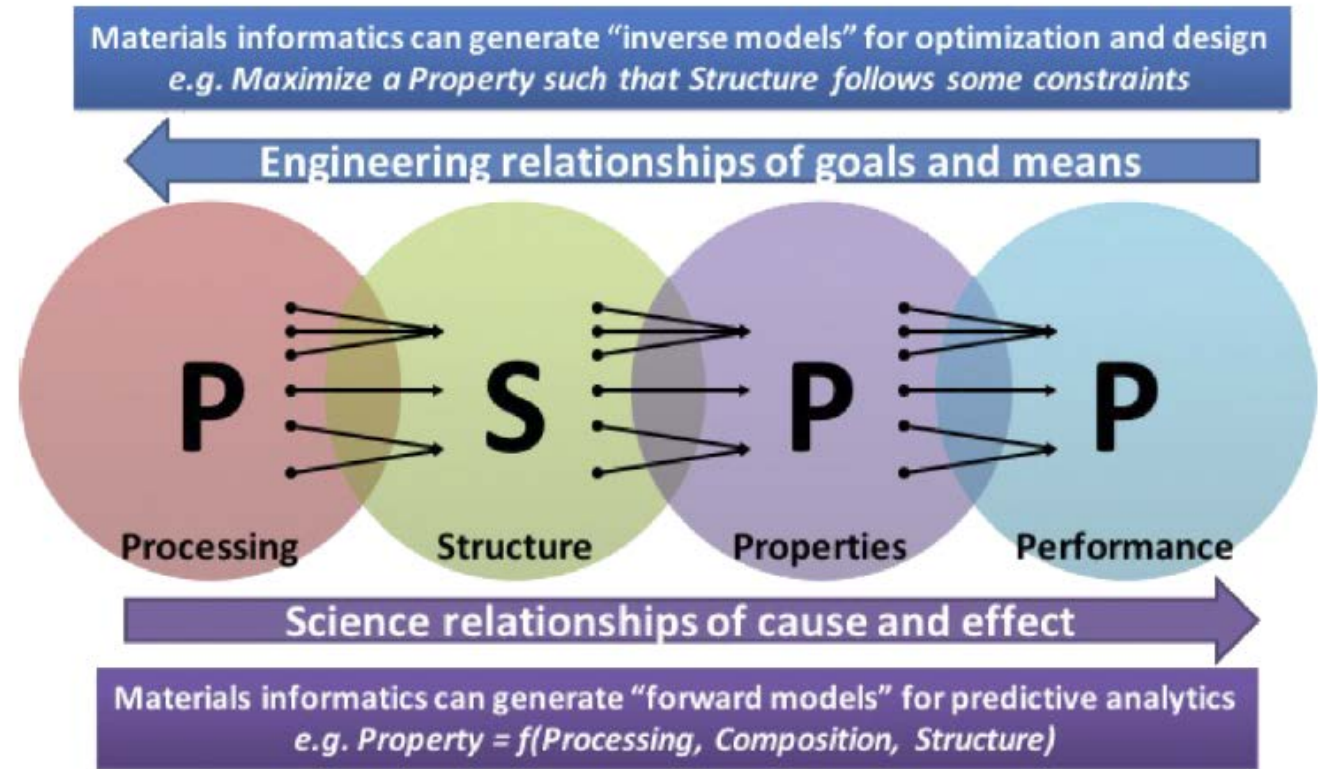


www.nasa.gov

DoD systems are constantly exposed to extreme environments – how can we better maintain, monitor, and manufacture these components?

The Goal: Establish process-structure-property relationships in materials

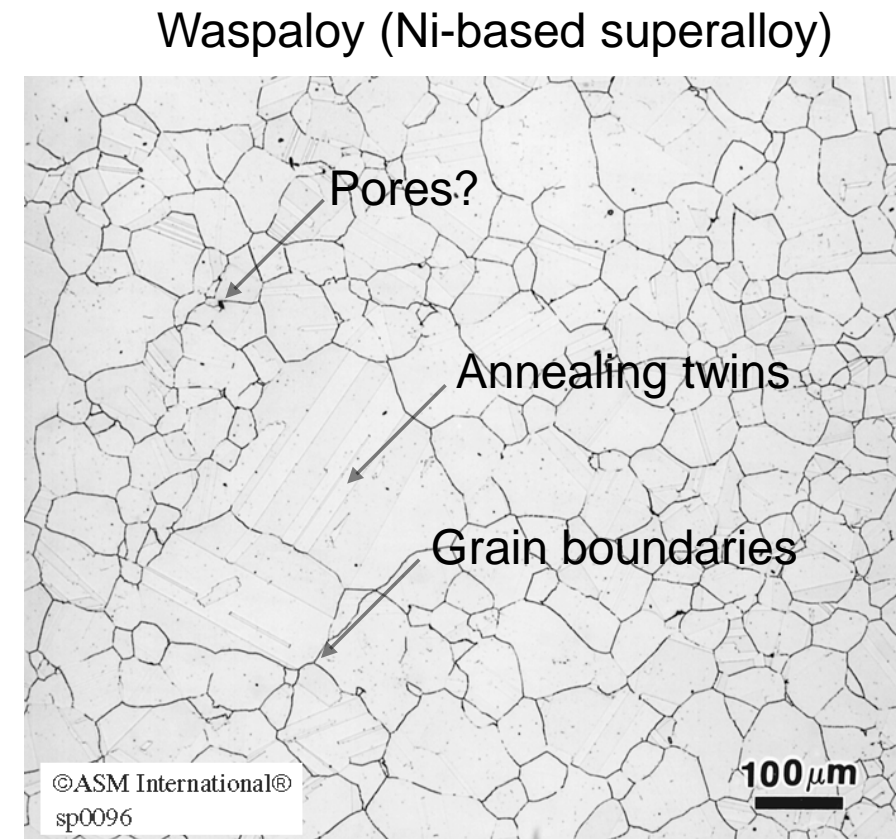
- Design materials to handle particular environmental challenges
- Predict when materials should go in for maintenance or when they should be replaced
- Identify ‘bad batches’ early in the manufacturing process



Agrawal & Choudhary, APL Mater., 2016

Material survival vs. failure – consider the microstructure

- Microstructural features (e.g., grain boundaries, pores, precipitates) can facilitate or arrest local material failure
 - Active sites for chemical reactions
 - Stress concentrators
 - Barriers to deformation and/or diffusion
- Challenging to independently control microstructural features
- Different features matter on different length scales



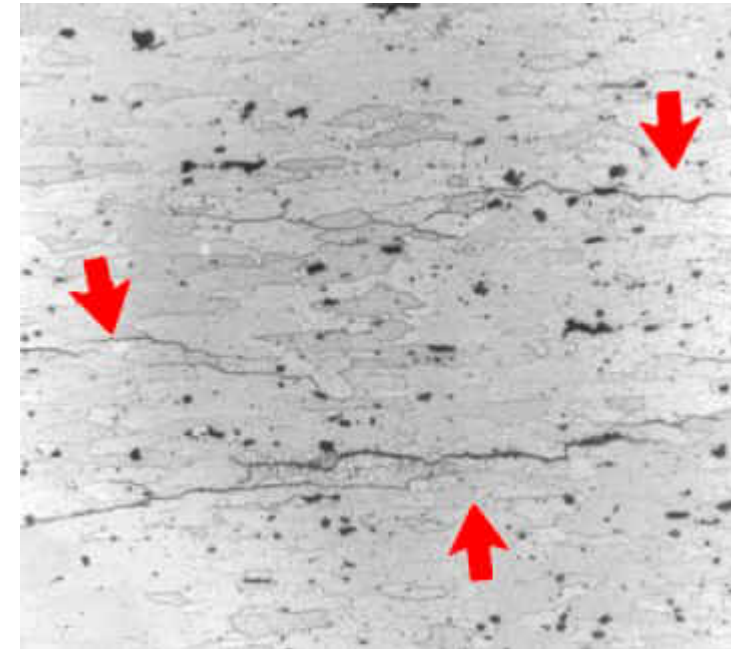
*From ASM Micrograph database

Materials design involves a huge *variety* of data with a lot of *uncertainty*.

Variable interaction in complex environments

- Example: intergranular corrosion in metals:
 - Grain structure directly influences strength of metals (smaller grains, higher strength)
 - Corrosion along grain boundaries can eventually pull materials apart
 - Temperature, chemical environment, and material loading can all contribute to such effects
- Similarly, radiation damage involves interaction between microstructure, exposure, and failure modes

Intergranular corrosion: 7075-T6 aluminum aircraft component

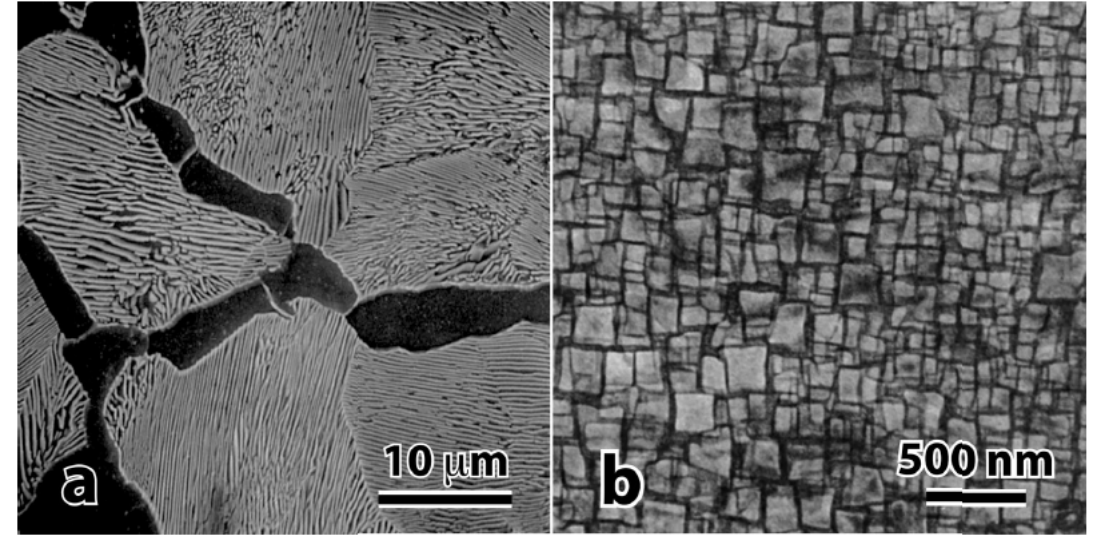


www.nace.org

Mechanisms of material failure in extreme environments involve many interacting variables & are often poorly understood or difficult to model

How do we describe microstructure?

- Feature size and shape
 - Grains, pores, precipitates, etc.
- Phase content
 - E.g., matrix and precipitated phases
- Feature alignment/texturing
 - Oriented grains
 - Elongation
 - Fiber alignment in composites
- Feature distribution
 - Evenly distributed, segregated to grain boundaries, interconnected, etc.



(a) “pearlitic steel showing co-continuous plates of α -ferrite and Fe_3C cementite” (b) “nickel based superalloy showing high volume fraction of discrete, coherent cuboid Ni_3Al precipitates”

D.B. Miracle, *Mat. Sci. Tech.* 2015

Material microstructure is not fully described by one image, measurement, or spectrum.

Target areas for DoD

- High entropy alloys/complex concentrated alloys/high entropy ceramics
 - Early stage, small community → opportunity to build integrated computational and experimental database
- Material surveillance data, particularly for corrosion and radiation
 - Exposure conditions, initial composition, microstructure and property tracking
 - Surveillance data are already collected for structural materials for nuclear reactors (IAEA Reactor Embrittlement Database)
 - NRL maintains database of corrosion testing data
 - Use data for damage models and maintenance prediction
- Process monitoring and quality assurance (QA) for high temperature materials

QA and material surveillance are ideal areas for automated image analysis and microstructure quantification

IDA Projects Make Use of a Broad Range of Technical Skills and Knowledge

Here are some subjects & skills *I've* used while working at IDA:

- Organic chemistry
- Mechanics of materials
- Electronic, optical, and magnetic properties of materials
- Computer programming
- Process control
- Newtonian mechanics
- Probability, statistics, and machine learning
- Differential equations and complex analysis
- Design of experiments
- Technical writing

IDA tasks are extremely diverse in subject matter– Colleagues of mine have worked on problems in optics, particle physics, biology, behavioral science, cost analysis, geology, meteorology, text analytics, and more. IDA

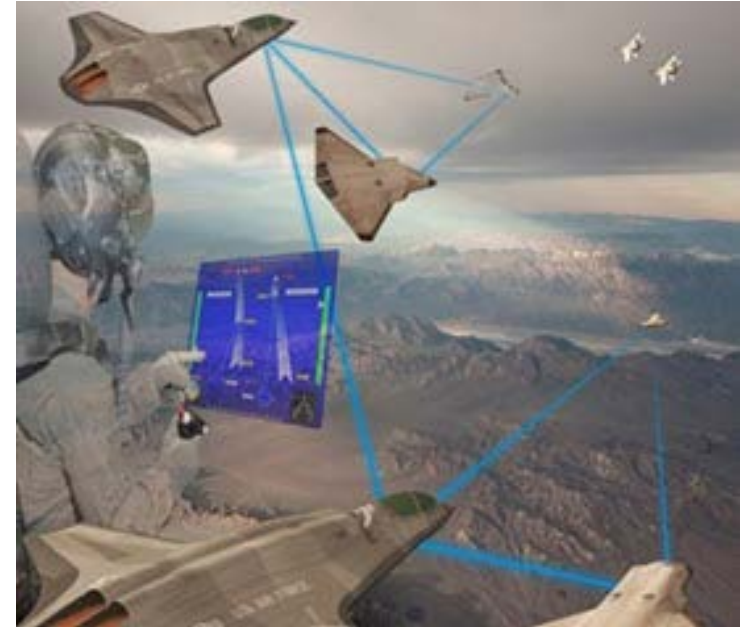
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- Great people with a diverse array of experience
- Meritocracy
- A job with an impact
- Constant opportunities to learn and expand to new areas of science and technology
- Work-life balance
- Your job is to give the most accurate possible answer to the sponsor: truthful, data-driven, unbiased analysis

IDA occupies a unique position at the intersection of industry, academia, and government.

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U.S. citizenship is required

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