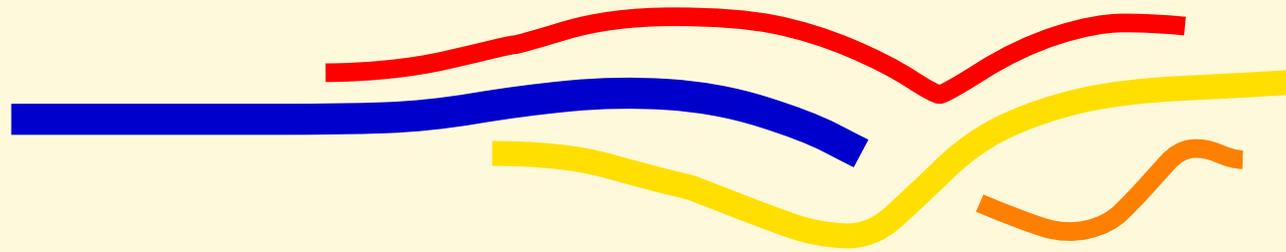


Center for Simulation of Advanced Rockets



University of Illinois at Urbana-Champaign



CSAR Legacy and Future

Michael T. Heath

9 February 2010

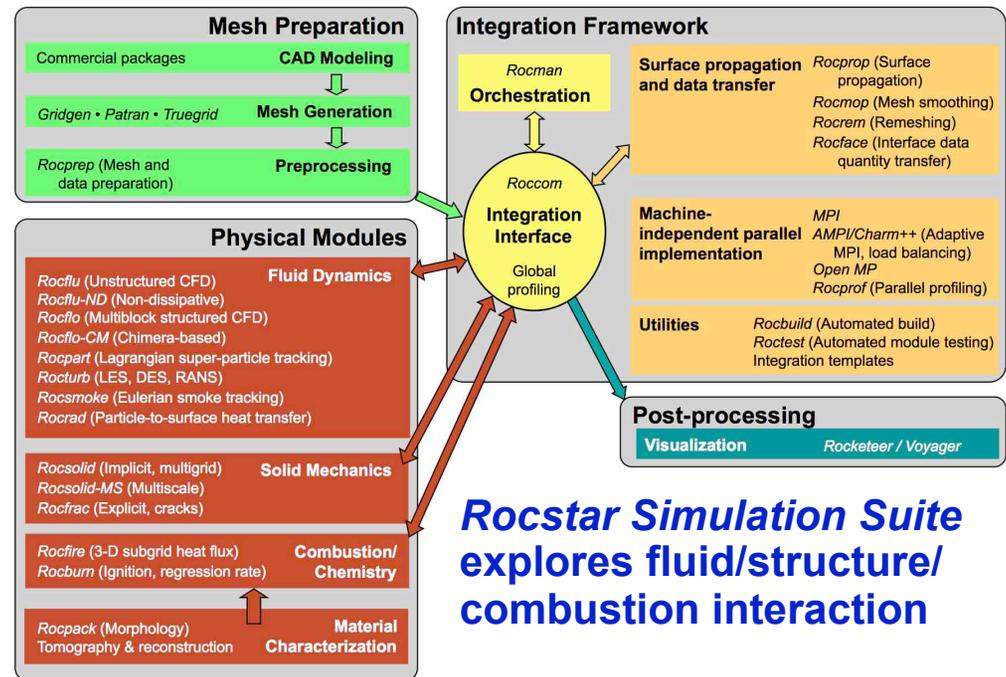




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Overarching Goal: Simulation of solid propellant rockets from first principles

- Detailed, whole-system simulation of solid propellant rockets under normal and abnormal operating conditions
- Accurate models of physical components
- Subscale simulations of materials and accident scenarios
- Software framework to facilitate component integration
- Computational infrastructure to support large-scale simulations
- Research collaborations with government laboratories and rocket industry



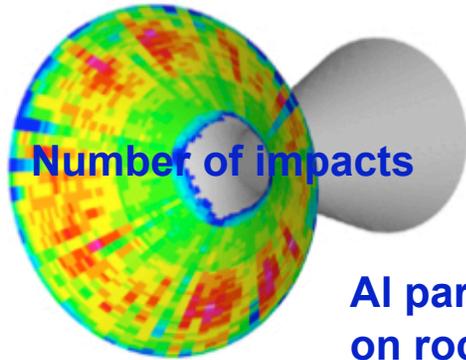
Rocstar Simulation Suite explores fluid/structure/combustion interaction

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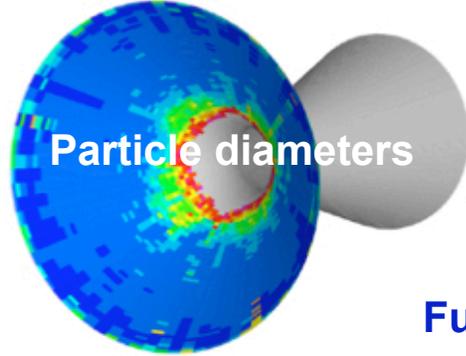


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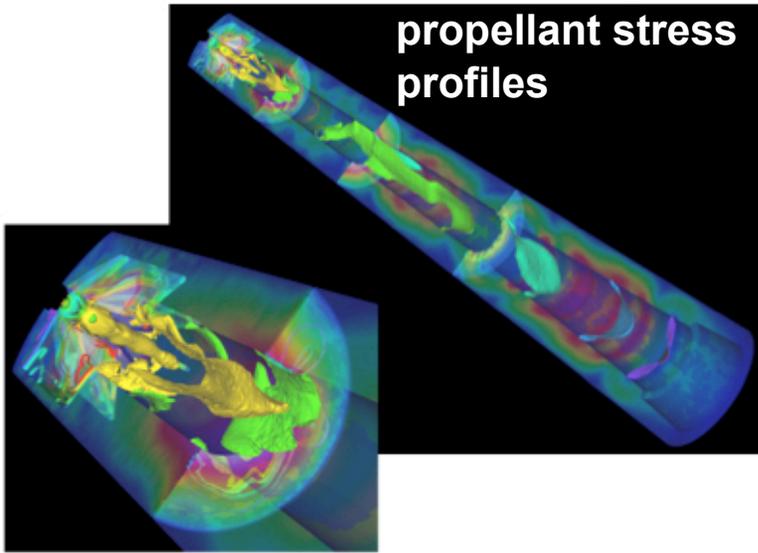
Rocstar Results



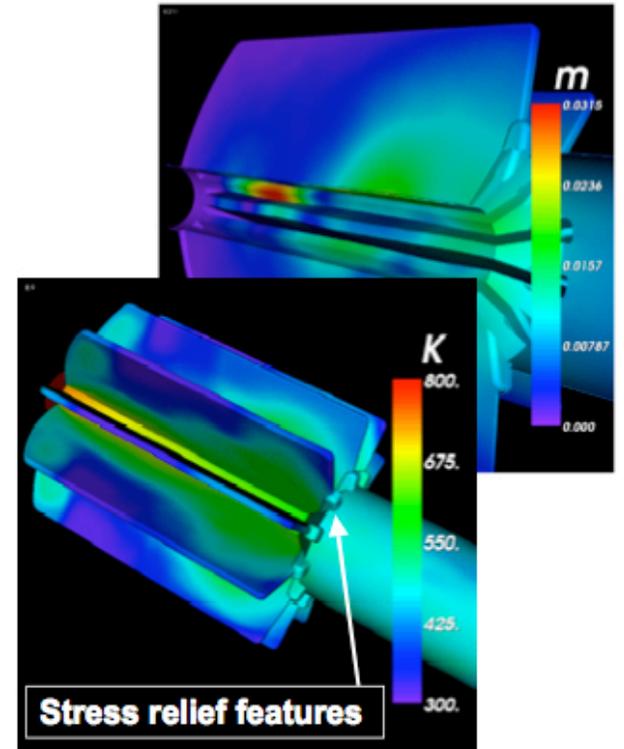
Al particle impacts on rocket motor nozzle



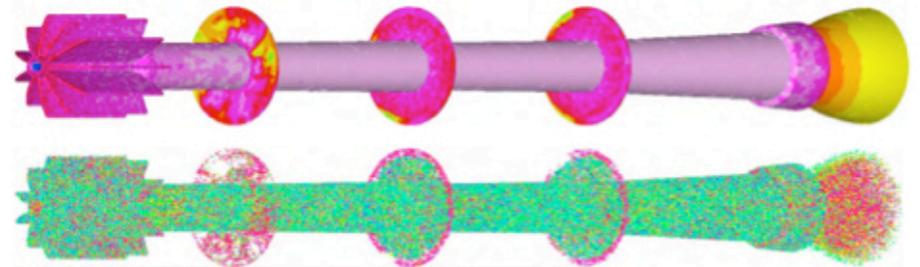
Fully-coupled RSRM — fluid temperature and propellant stress profiles



Ignition studies: RSRM headend



RSRM internal surface temperature and Al particle locations

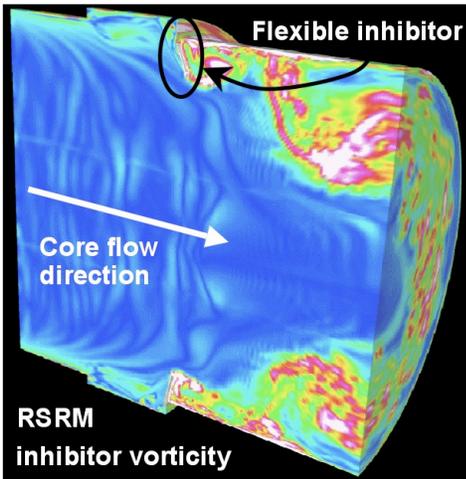


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Demonstrated *Rocstar* Capabilities

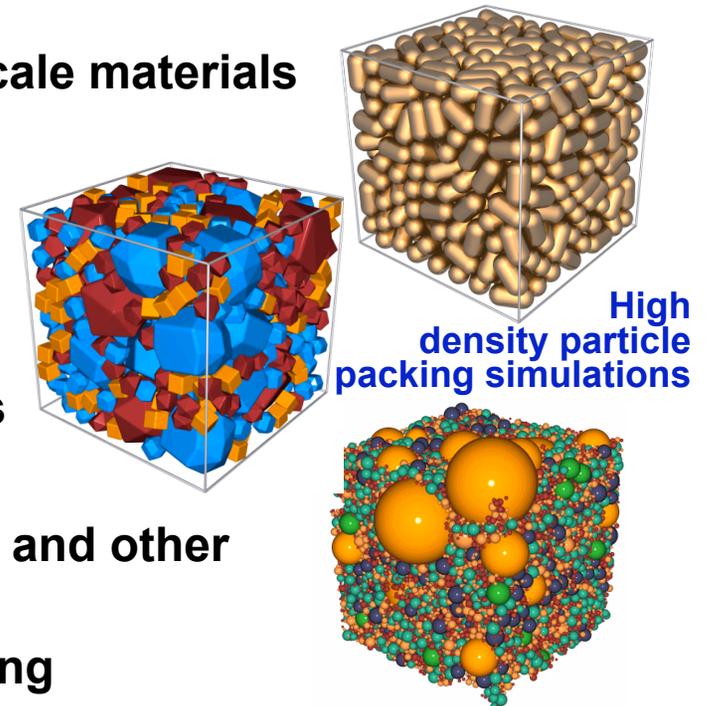


■ Engineering science

- High-fidelity fluid/structure interaction simulations
- Combustion, CFD, energetic materials, predictive science
- Multiphysics, multiscale materials modeling

■ Application areas

- Solid propellant rocket simulations
- Particle packing
- Environmentally benign (green) propellants
- General fluid-structure interaction
- Tomographic reconstruction of propellants and other granular materials
- Rocket motor acoustics and particle damping
- Insensitive munitions modeling



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Verification, Validation, and Uncertainty Quantification

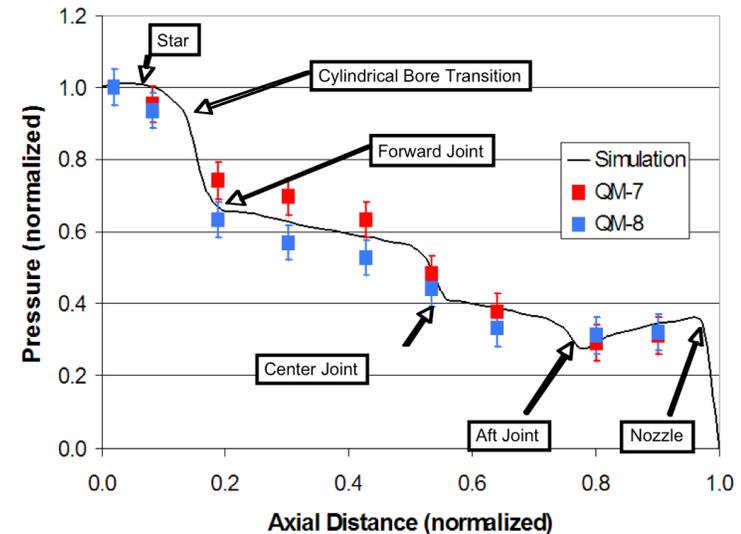
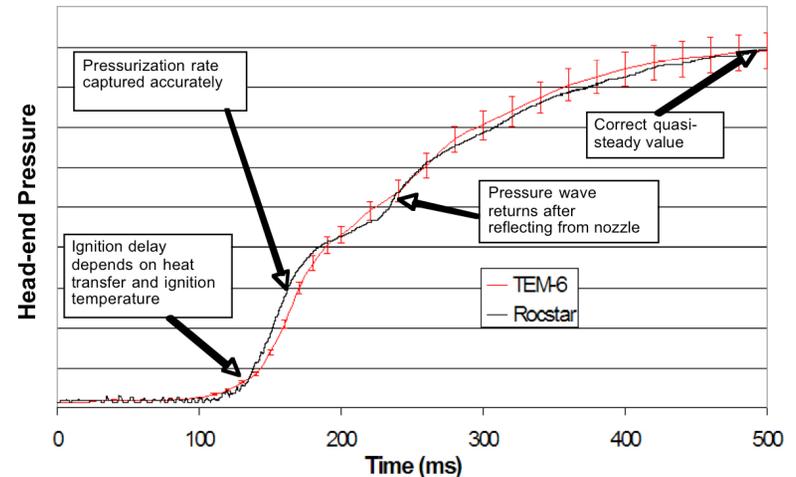
■ Verification

- Convergence studies
- Comparison with analytical solutions
- Method of manufactured solutions
- Comparison between codes
 - e.g., do *Rocflo* and *Rocflu* give similar results for same problem?
- Code coverage
- Coupled codes — verify component codes first

■ Validation

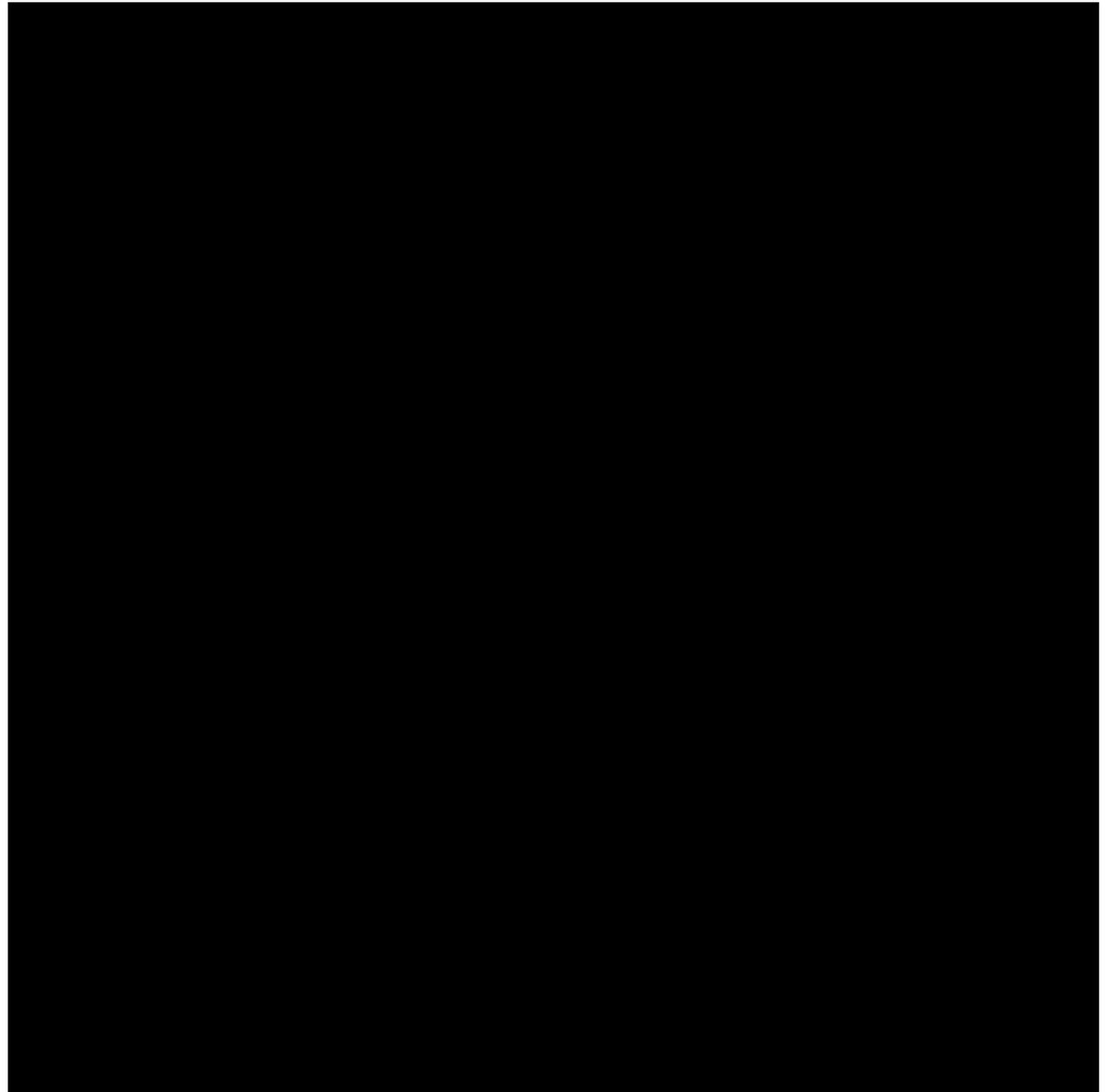
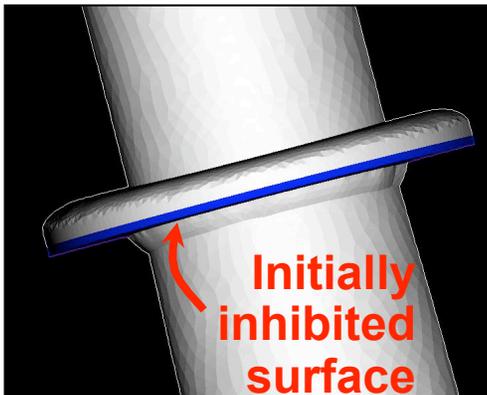
- RSRM (ATK/Thiokol & NASA)
- Titan IV (Lockheed Martin)
- 15 and 70 lb BATES (AFRL)
- Lab scale rocket (NAWC)
- Attitude Control Motor (Aerojet)
- Shock tube with thin steel panel

■ New sampling techniques for UQ



NASA RSRM

- **Burnout simulation**
 - Red is burning propellant; blue is at insulated surface
- **Viewing**
 - Propellant/fluid interface
 - Inhibited surfaces
- **Unique capabilities**
 - High rate “time zooming”
 - Significant burnout — never seen in industry
 - Case constraints
 - Propellant walkback
 - Inhibitor regression
 - Dynamically changing topology



Computational Science and Engineering

Education Program

Computational Science & Engineering Option

State funded
\$590K per year
17 departments
140 faculty
affiliates
130 grad students
10 graduate
fellows

Research Program

Center for Simulation of Advanced Rockets

DOE NNSA funded
\$4-5M per year
13 year program
5 (25) faculty
6 (40) GRA
5 undergrads
7 (20) AP staff
Ending Sep 2010

Midwest Structural Sciences Center

AFRL funded
\$5M+ over 5+
years
10 faculty
15 students &
postdocs

MURI for Stress Wave Mitigation

ARO funded
\$6M+ over 5
years
6 faculty
12 students &
postdocs



Campus Impact

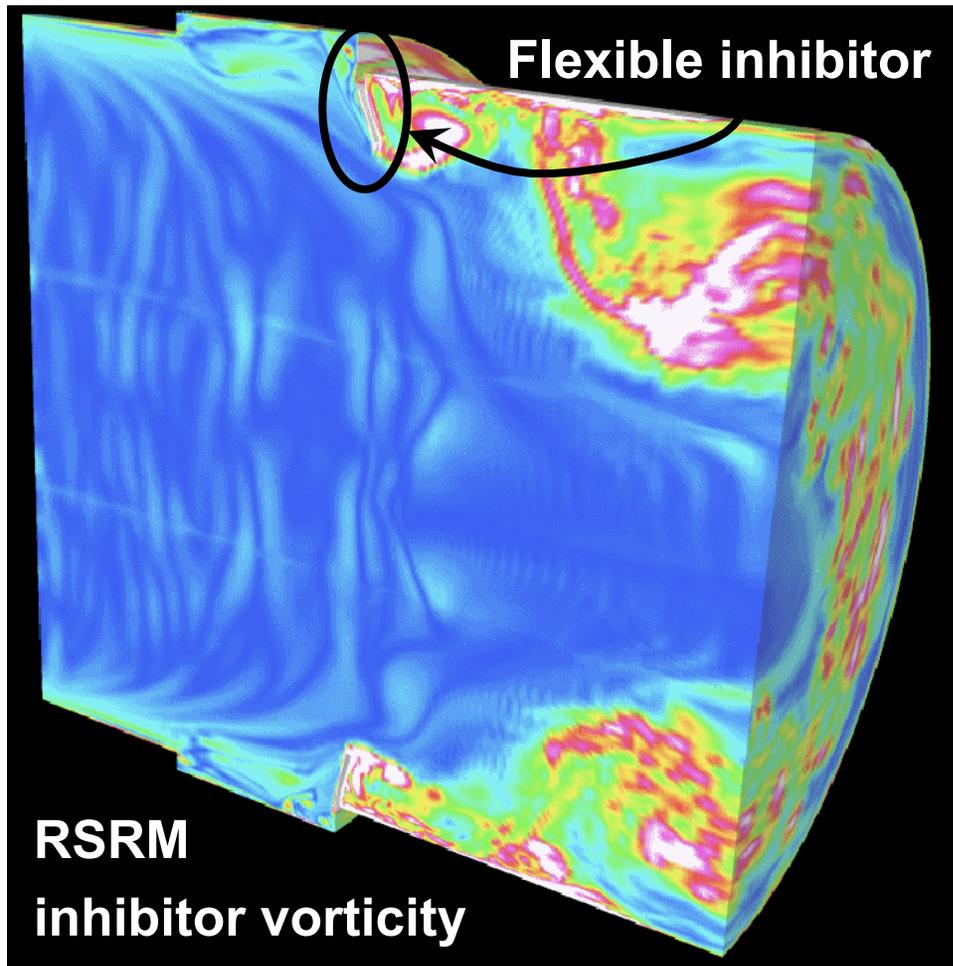
- **CSAR put CSE “on the map”**
- **CSAR followed by three additional centers hosted by CSE**
 - **Center for Process Simulation and Design (NSF/DARPA)**
 - **Midwest Structural Sciences Center (AFRL)**
 - **MURI for Stress Wave Mitigation (ARO)**
- **CSE seen as “center of centerness” on campus, advising other groups seeking or establishing centers**
- **CSE taken as model in developing other new interdisciplinary programs (e.g., bioinformatics, energy)**
- **CSE’s *Turing* cluster**
 - **Established value of large-scale computing facilities for local users**
 - **Financial commitment from campus administration**

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State and Local Impact



- **Economic development through industrial collaborations**
 - Boeing, Caterpillar
 - Buckmaster Research
 - IllinoisRocstar
- **Visibility of simulation promoted through various venues**
- **Recurring appearances in media (TV, newspapers)**

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National and International Impact

- **Publications (~1200 journal articles and proceedings)**
- **Conference sessions**
- **Industrial collaborations**
 - **ATK**
 - **Aerojet**
 - **Boeing**
 - **Caterpillar**
- **Other government agency funded research**
 - **USAF**
 - **US Army**
 - **NASA**
- **Technology transfer to and from NNSA labs**
- **Participation in Integrated Product Team for USAF solid propulsion program**

Center for Simulation of Advanced Rockets



Human Resources

- Supported 160 graduate students, about 40 of whom have gone on to DOE labs and many others to positions in government or industry
- Recruited and developed 50 research staff members, many of whom have gone on to positions at DOE labs, industry, and academia
- Contributed to faculty career development (promotions, awards, etc.), counter to conventional wisdom about collaboration

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CSAR Students and Staff in DOE/NNSA Labs

■ Former CSAR Students Now at DOE Labs (37)

- Tyler Alumbaugh, LLNL
- Balakumar Balasubramaniam, LANL
- Michael Bange, LANL
- Benjamin Chorpening, SNL
- William Cochran, SNL/ORNL
- Nathan Crane, SNL
- Zhiqun Deng, PNNL
- Erik Draeger, LLNL
- Michelle Duesterhaus, SNL
- Jeff Grossman, LBNL (LLNL)
- Arne Gullerud, SNL
- Thomas Hafenrichter, SNL
- Rebecca Hartman-Baker, ORNL
- Jason Hales, SNL
- Jonghyun Lee, ANL
- Vanessa Lopez, LBNL
- Xiaosong Ma, ORNL
- Greg Mackey, SNL
- Burkhard Militzer, LLNL
- Jeffrey Murphy, SNL-L
- Boyana Norris, ANL

- Michael Parks, SNL
- Jason Petti, SNL
- Ali Pinar, LBNL
- Jason Quenneville, LANL
- Christopher Siefert, SNL
- Donald Siegel, SNL
- Christopher Tomkins, LANL
- Michael Tonks, LANL
- Daniel Turner, SNL
- Jason Weber, BBL
- Bradley Wescott, LANL
- Amanda White, LANL
- Steven Wojtkiewicz, SNL
- Michael Wolf, SNL
- Jin Yao, LLNL
- Jack Yoh, LLNL

■ Former CSAR Staff Now at DOE Labs (6)

- Michael Ham, ORNL (LANL)
- Fady Najjar, LLNL
- Dennis Parsons, LLNL
- James Quirk, LANL
- Mark Short, LANL
- Jeff Vetter, LLNL (ORNL)

Gray now in other employment.

Strategy for Moving Forward

- **Diversify funding sources**
 - NASA, Air Force, Army, Navy
 - ATK, Boeing, Caterpillar
 - SBIR, STTR — IllinoisRocstar
- **Diversify *Rocstar* applications**
 - Continue code enhancement for rocket and non-rocket apps (e.g., *RocfloCM*, *Rocsolid-MS*)
- **Continue signature simulations**
 - Booster separation motor, abort motor
 - V&V and UQ
- **Continue doing fundamental science**
 - Multiscale modeling
 - Effects of heterogeneity
 - Accident scenarios

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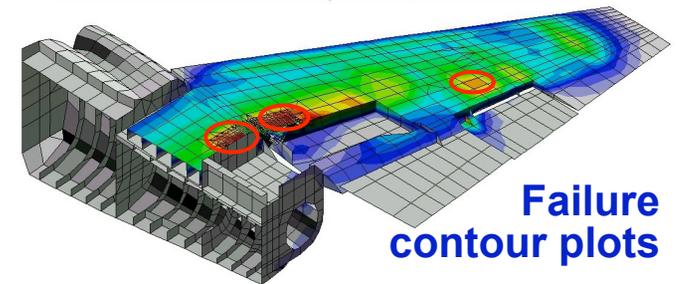
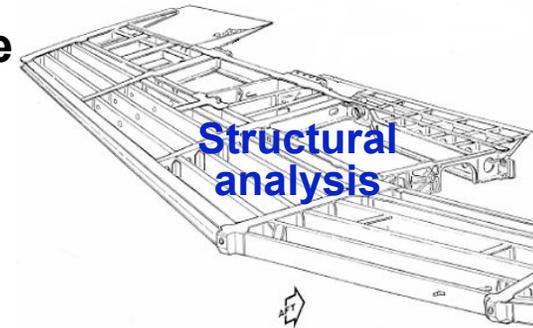
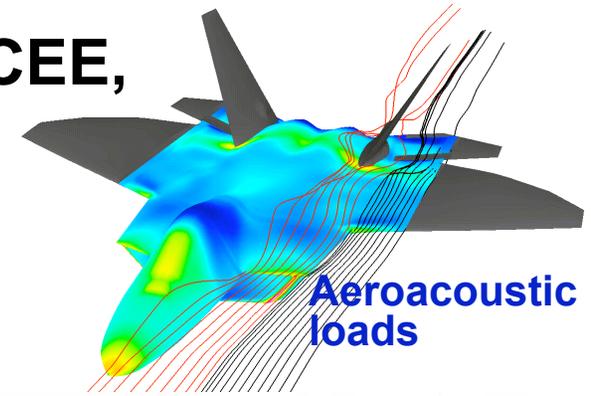
Midwest Structural Sciences Center

Spatially Tailored Aero-Thermal Structures

- Collaboration among Illinois (AE, CEE, CS, CSE, MechSE) AFIT, UT San Antonio, Wright State, AFRL Air Vehicles Directorate

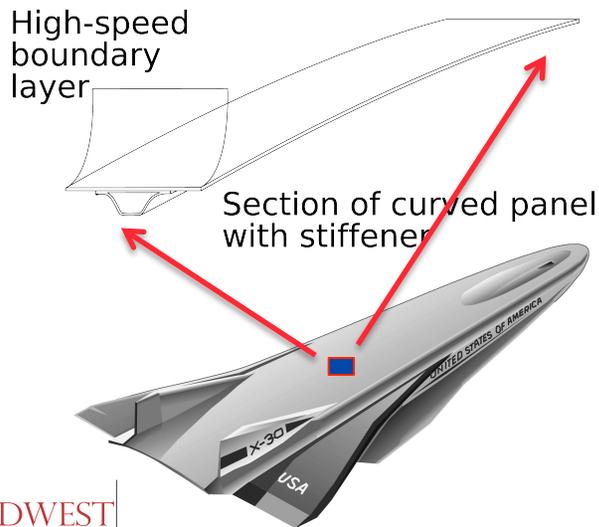
- Research foci

- Structures operating in combined extreme environments
 - Thermomechanical acoustic loading
- Risk-quantified design
- Integrated simulation framework



Key MSSC Projects

- **Mechanism-based cohesive failure model for functionally graded aircraft components and structures**
 - Demonstrate a cohesive zone model for functionally graded materials
- **Validation with uncertainties in both simulation and experimental results**
 - Develop methodology for validating computational results with experimental results when both have uncertainties



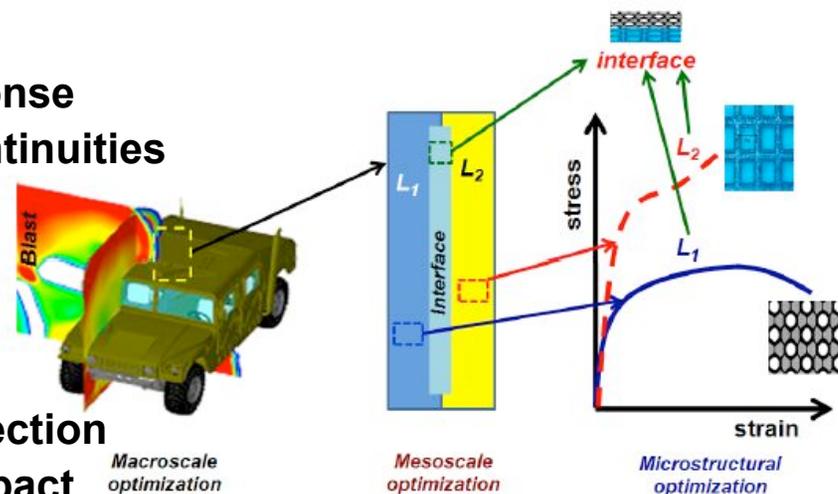
- **Integrated structural/acoustic interaction simulations**
 - Verify and validate design tool for combined response prediction of thin-walled panels in high combined loading environments, with identified applicability limits
- **Novel experimental techniques for thermomechanical fatigue at high temperatures**



Stress Wave Mitigation (SWAMI)

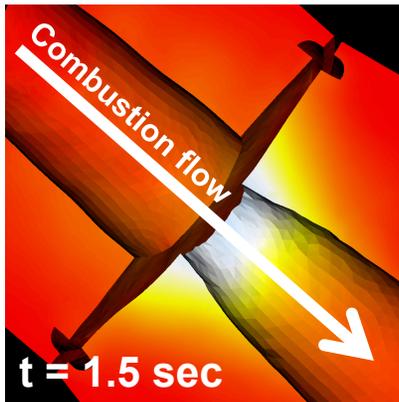
Employ strong nonlinearities in granular media to mitigate stress wave energy

- ARO/ARL MURI
- 5 years; \$1.25M/year
- UI (Aero, CSE, MatSE, MechSE) and Caltech
- Theory – Simulation – Materials – Experimental Validation
- Technical background
 - “Stress waves” regulate dynamic response
 - Travelling stress producing discontinuities
 - Carriers of information
 - Disturbances in complex networks
 - Applications
 - Insensitive munitions
 - Electronic device/component protection
 - Crashworthiness; (High speed) impact
 - Blast, earthquakes...



Industrial Collaboration Opportunities

■ Multiphysics and multiscale analyses

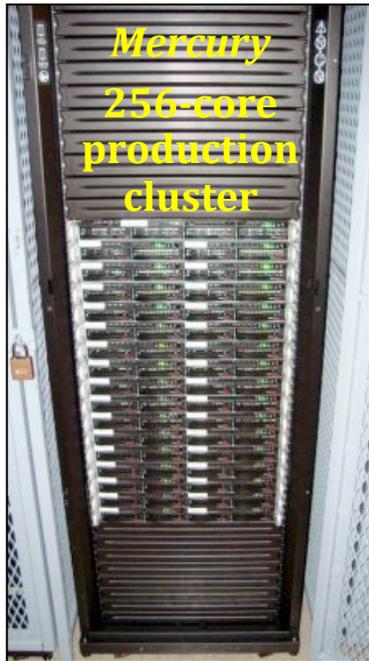


- Particle packing, aggregation, and granular media
- Particle flow in processes and combustion
- Multicode, parallel computation integration framework
- Parallel code acceleration (conventional CPU cores and GPU)
- Computational materials and mechanics
- Thermomechanical fatigue
- Stress wave mitigation





IllinoisRocstar LLC

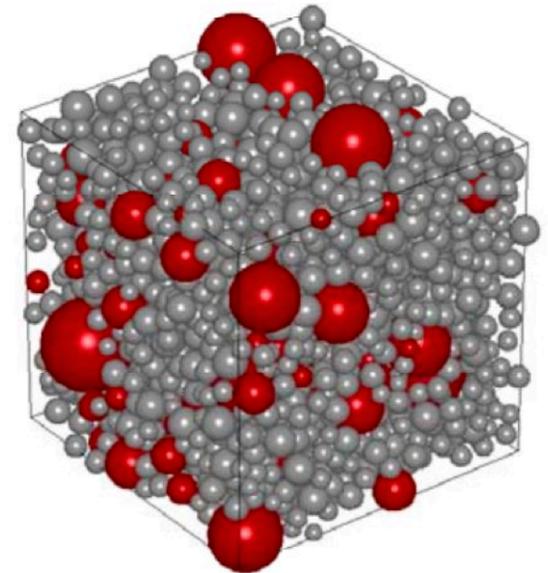


- Spin-off company from University of Illinois
 - Initial principals/members from UI CSAR
 - Perform engineering analyses
 - Customize and support simulation software
- Maintain DOE ASC legacy and commercialize *Rocstar* and modules
- Engineering science
 - High-fidelity FSI simulation
 - Multiphysics, multiscale
 - Combustion, CFD, energetic materials, predictive science
- Application areas
 - SP rockets
 - Nano-Al propellants
 - Materials modeling
 - Tomographic reconstruction of propellants
 - Fluid-structure interaction
 - Acoustics and particle damping
 - Cookoff/IM modeling



IllinoisRocstar LLC

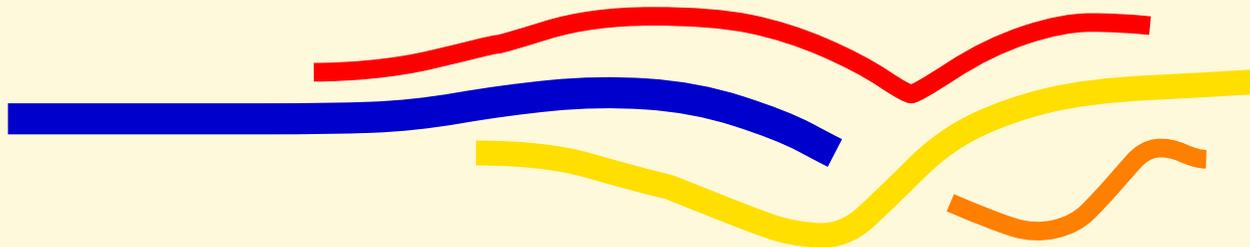
- Support from SBIR/STTR, other federal, industry, State of Illinois match
- Located in UI Research Park
- Business focus
 - Perform engineering analyses
 - Customize and support simulation software
- ~60% funded through SBIR and STTR
 - Army Redstone
 - Navy NAVAIR
 - Air Force: AFOSR; Edwards AFB; Arnold Engr Dev Center
 - NASA GRC
- Team with university partners, prime contractors, other small businesses
 - Returns ~\$1M to university partners



Particle pack simulated by IllinoisRocstar LLC and UI to model experimental nano-Al propellant formulated at Purdue. Course AP particles in red, fine AP in grey, void space is homogeneous blend of very fine AP and nano-Al fuel.



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<http://www.csar.uiuc.edu>

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