

Materials for High Pressure Fuel Injection Systems

New: Caterpillar / ORNL CRADA

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Purposes of the Work

- (1) **Characterize** the effects of residual stresses, spray hole micro-geometry, and alloy microstructure on the performance of high-pressure fuel injectors.
- (2) **Develop** new test methods to quantify the fatigue of injector materials near spray orifices.
- (3) **Enable** better life-prediction models and an improved scientific basis for nozzle materials selection.



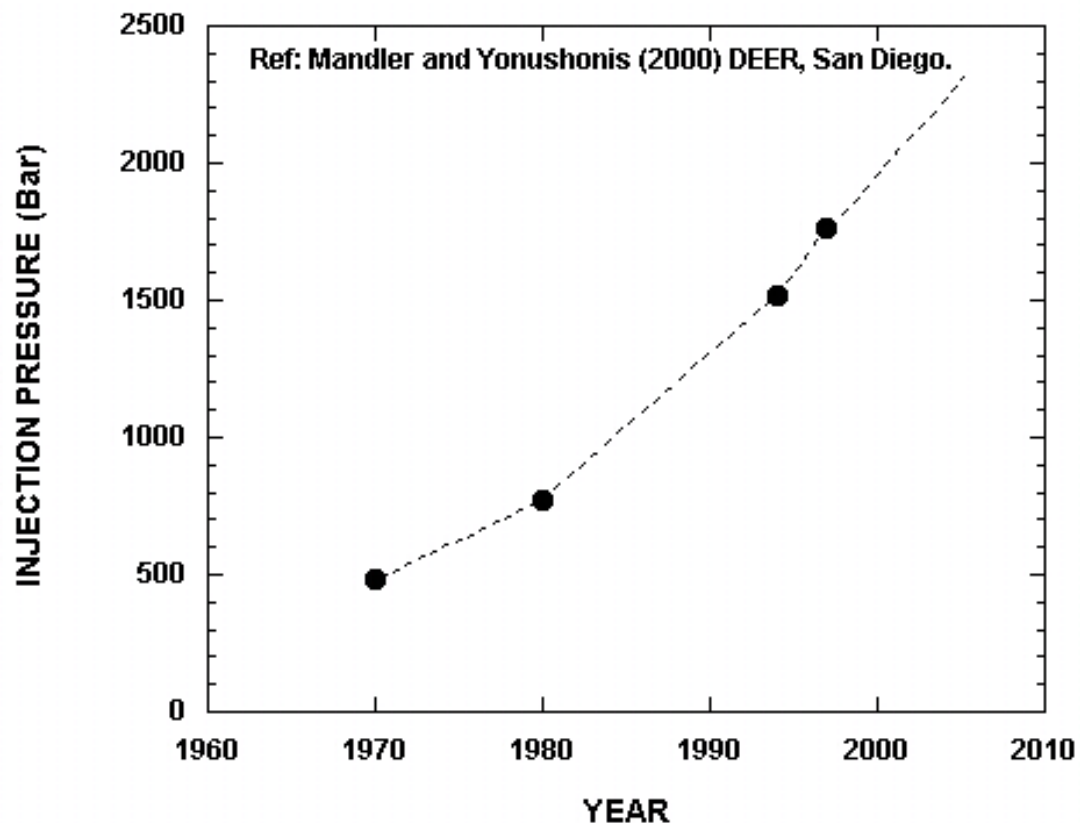
CAT ACERT Engine

Background

- Pressure demands on the materials for fuel injection systems have increased significantly, placing greater demands on materials and precision manufacturing.



**Caterpillar HEUI
diesel fuel injector**



<http://www.cat.com/cda/layout?m=40580&x=7>

Challenges in nozzle material selection:

- **Cavitation and erosion.** How do candidate materials for high-pressure injection systems respond to cavitation and erosion? Will coatings and surface modifications improve the cavitation and erosion resistance of the injector material?
- **Microdefects.** How does the size and distribution of microdefects in ultra-clean steels effect the fatigue resistance of the injector tip? Do we need new characterization methods for ultra-clean steels to establish statistical parameters for microdefects that are critical for advanced life prediction models?
- **Life prediction.** Multiple factors have direct effects on advanced life prediction models. How can we tie all of these into a life-prediction model to avoid extensive and expensive component and field testing of fuel injectors?

Barriers

- The injector nozzle, with its pattern of 50-300 μm diameter holes, is the key to precise fuel metering, combustion characteristics, and emission control.
- Holes must maintain dimensional tolerances and flow characteristics for tens of millions of pressure cycles.
- Nozzle materials must resist changes in shape, and allow holes to remain clear and open despite increasingly high injection pressures.
- Will current injector tip materials withstand the new design requirements?
- What are the roles of residual stress and high-cycle fatigue loading on nozzle performance?

Technical Approach

- 1) Develop and use state-of-the-art metallographic and metrology techniques to measure nozzle hole dimensions and internal roughness and communicate results to designers for CFD of mixture flow.
- 2) Conduct residual stress measurements of nozzle tips in the vicinity of the holes.
- 3) Develop and apply test methods to measure the effects of pressurization/de-pressurization fatigue on materials for injector tips.
- 4) Incorporate knowledge of microstructure, micro-geometry, residual stress, and materials behavior into new life prediction models for injector tips.

Hole bore characterization

- 1) Flow of gases through tiny orifices can be affected by the roughness of the hole walls.
- 2) Special metallographic and surface imaging techniques will be developed to quantify the bore roughness of holes that are 50 – 300 μm in diameter.

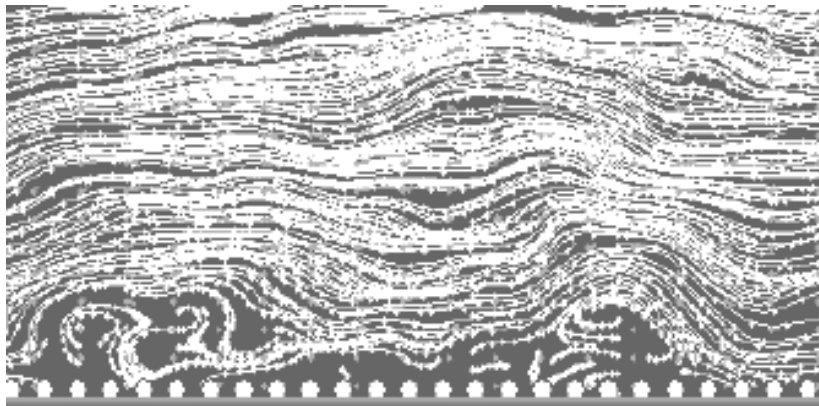


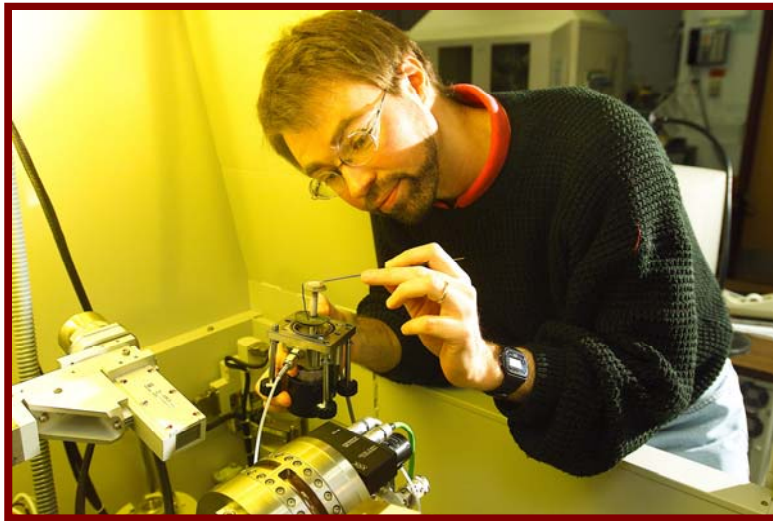
Figure 3.2(b) Boundary eddies

Wall roughness affects characteristics of fluid flow through a hole.

J. J. Leary (2007) *Proc. IASTED Europ. Conf. on Internet Media Systems and Applications*

Residual stress measurements

- ❑ **X-ray micro-tomography** ($\sim 1\ \mu\text{m}$ beam size): both nozzles and test plates with specific hole sizes and patterns
- ❑ **Residual stress of actual parts and test plates:** surface stresses (X-ray) and through-thickness stresses (neutrons, $\sim 1\ \text{mm}^3$) as a function of cycles.



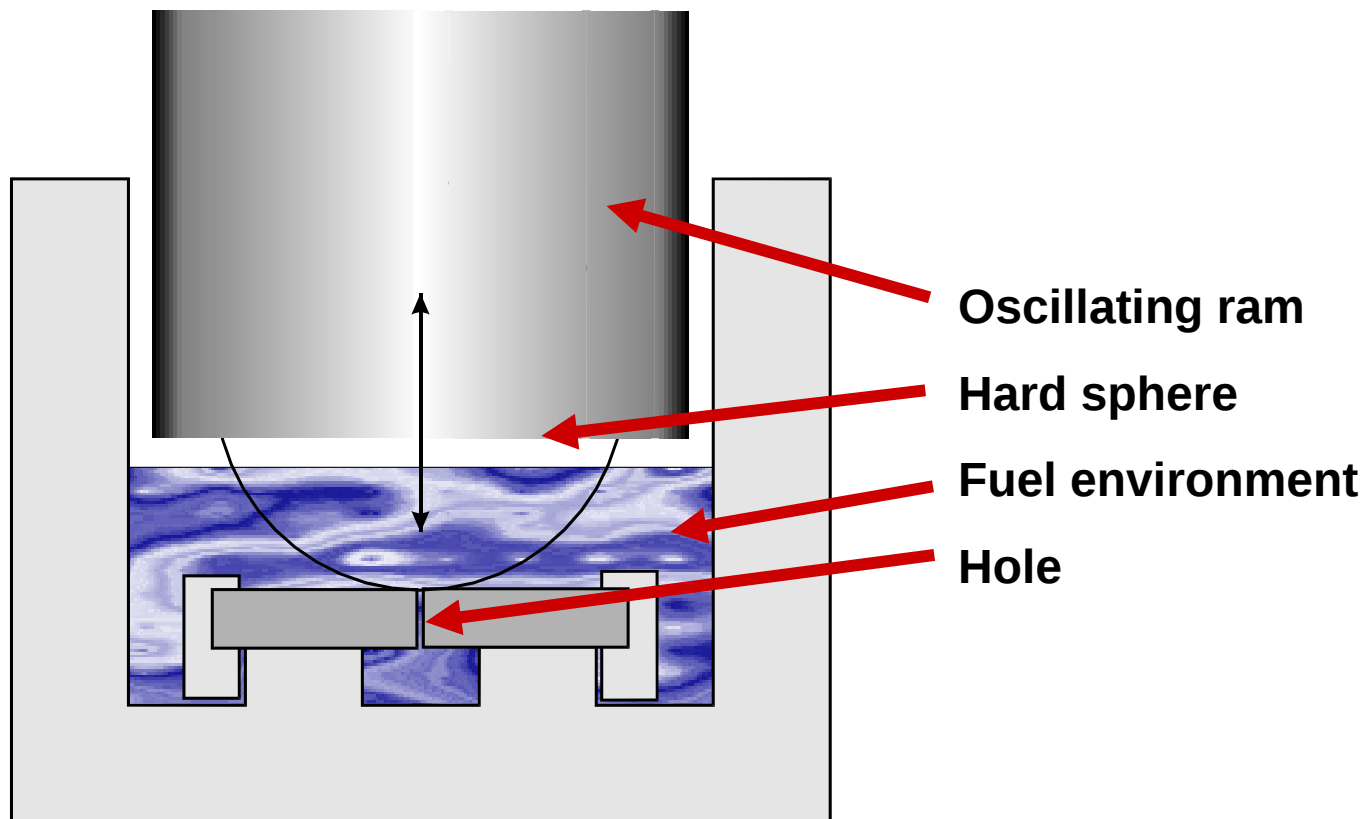
X-ray methods for near-surface residual stress measurement



Neutron sources for deeper penetration residual stress mapping

New testing concepts for nozzle hole integrity (proposed concept)

Fatigue testing of material surrounding injector holes using diesel fuel-lubricated Hertzian contact.



Research plan

YEAR 1

1) Develop specialized methods to characterize injector nozzle hole entrances, exits and interiors at various size scales (micro/nano)

2) Map the magnitudes and directions of residual stresses in the vicinity of fuel injector nozzle holes.

3) Develop a procedure to investigate the resistance of nozzle materials to pressure-pulse fatigue.

YEAR 2

4) Investigate effects of manufacturing method, alloy microstructure, and hole characteristics on residual stress, fatigue, and spray hole quality in selected nozzle materials

Performance Measures and Accomplishments

YEAR 1

- Demonstrate the ability to measure fine-scale surface roughness and image the topography on the inside of fuel injector holes.
- Establish appropriate methodology to obtain residual stress data on injector nozzle tips.
- Design and develop a test method to quantitatively assess spray holes' resistance to pressure pulse fatigue.

YEAR 2

- Quantify the effects manufacturing parameters on the stresses, durability, and micro-geometric features of fuel injector nozzle materials.

Technology Transfer

- As a CRADA this effort will involve frequent interactions, sharing of data, and dissemination of results.

Publications / Patents

- Publications (none – new effort)
- Patents: (none – new effort)

Plans for Next Fiscal Year*

- Apply the methods developed in Year 1 to materials of interest to the CRADA partner and make results available to fuel injector designers and those who select materials and processes for their manufacture.

* *Note:* As of the date of this review, the CRADA documents are in process. Completion in FY 2009 is contingent on a timely start in FY 2008.

Participants and Support

- DOE/EERE/OFCVT – Jerry Gibbs
- ORNL:
 - Peter Blau, Cam Hubbard, Ray Johnson, and Phil Maziasz
- Caterpillar:
 - Jeff Jensen and Mike Pollard