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Boundary Layer Lubrication

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2009 DOE VEHICLE TECHNOLOGIES PROGRAM ANNUAL MERIT REVIEW

Project ID #
vssp_01_ajayi

Overview

Timeline

- Start date - 2003
- End date - 2011
- Percent complete – 75%

Budget

- Total project funding
  - DOE share – 2,500K
  - Contractor share
- Funding
- FY08 – 500K
- FY09 - 500K

Barriers

- Barriers addressed
  - Safety, durability, and reliability
  - Computational models, design and simulation methodologies
  - Higher vehicular operational demands

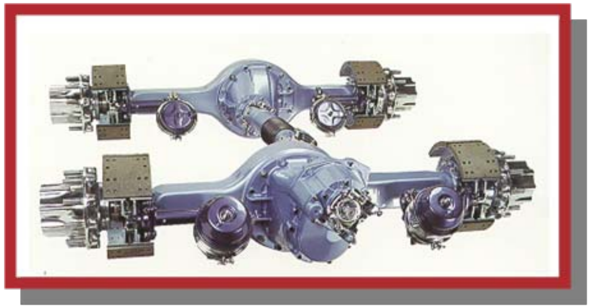
Partners

- Interactions/ collaborations
  - Caterpillar Inc.
  - Eaton Corporation
  - Castrol-BP
  - Oakland University

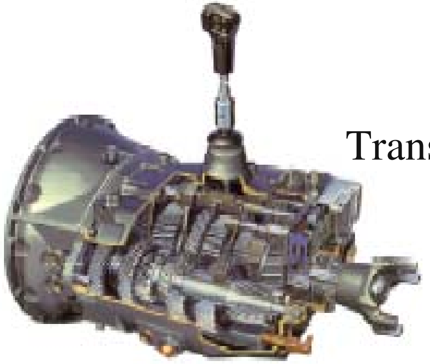
Project Description

Project Conception:

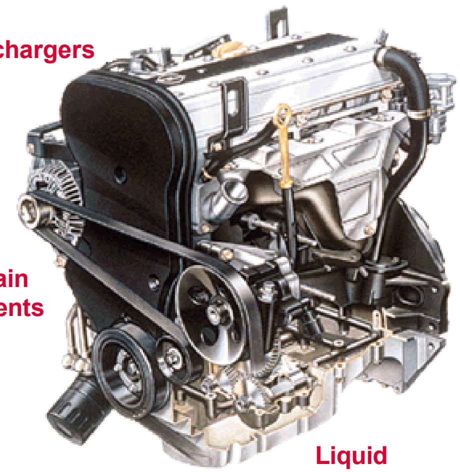
- Friction reduction in vehicle lubricated components and systems translates to improved efficiency.
- Increased power density results in size reduction and fuel saving.
- High friction and high power density failures occur in poorly understood boundary lubrication regime.



Axle -2%



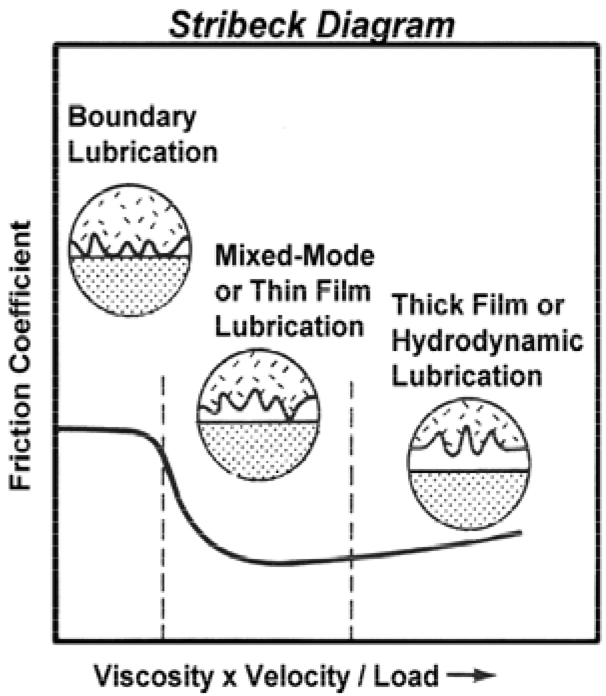
Transmission – 3%



Engine – 4-5%

Overall Project Objectives

– Achieve sustainable friction reduction and increase power density in lubricated components and vehicle systems by developing a better understanding of boundary lubrication mechanisms
  - *Determine the mechanisms of boundary layer formation and loss rates as well as the film properties*
  - *Determine the mechanisms of catastrophic failure by scuffing*
  - *Develop integrated low-friction, high power density interface*



Significant Previous Technical Accomplishments

- Extensive characterization of the dynamics of near surface material changes during scuffing process by cross-sectional microscopy

- Developed and validated a scuffing model for metallic materials:
  - Scuffing initiates by adiabatic shear instability – can predict shear strain required for scuffing initiation

$$\gamma = \frac{n\rho C_v}{0.9\frac{\partial\tau}{\partial T}}$$

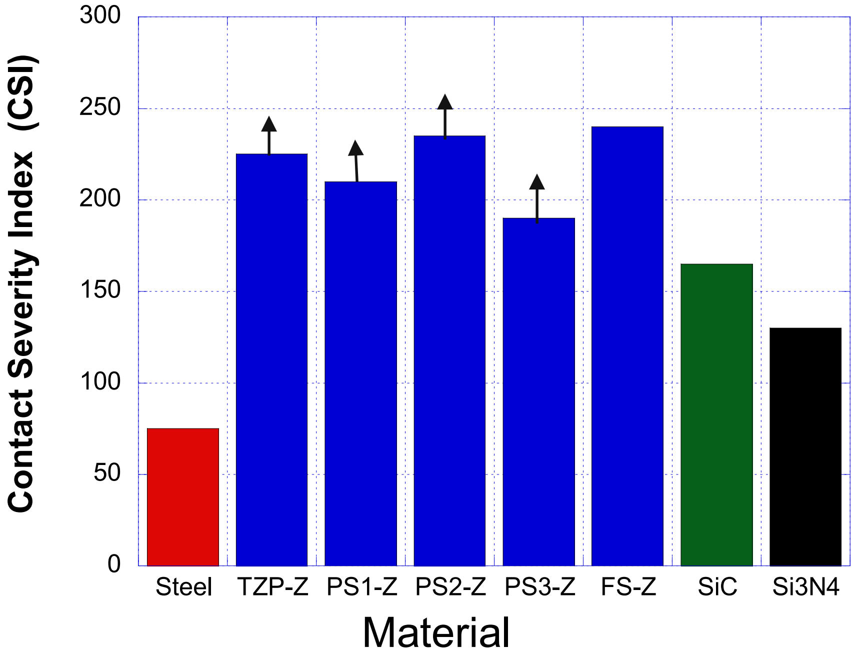
  - Scuffing propagates by contact interface heat management

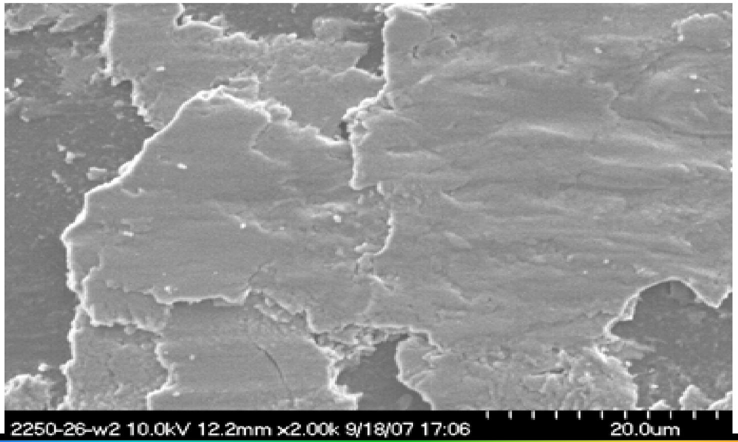
$$V = \frac{d\delta}{dt} = \frac{\frac{\beta\tau\dot{\gamma}}{\rho C} - \frac{\lambda}{\rho C}\left(\frac{\partial^2 T}{\partial X^2}_{\delta} - \frac{\partial^2 T}{\partial X^2}\right)}{\frac{\partial T}{\partial X}_{\delta}}$$

- Both scuffing initiation and propagation can now be quantitatively connected to material properties

Significant Previous Technical Accomplishments

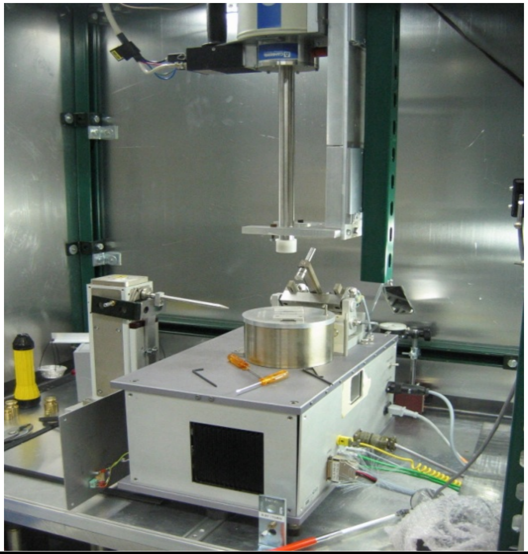
- Based on material properties, ceramic/contact pairs showed significant scuff resistance.
  - CSI =μLS -measures frictional energy to cause scuffing
- Scuffing in ceramic/metal pairs involves metal transfer to ceramics
- Other energy dissipation mechanisms were observed
  - Phase transformation, cracking

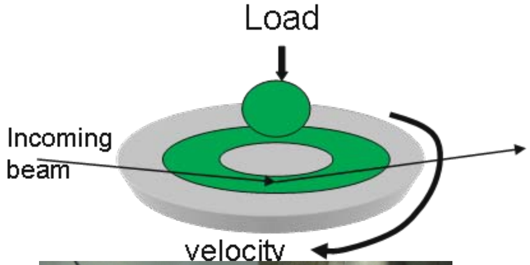


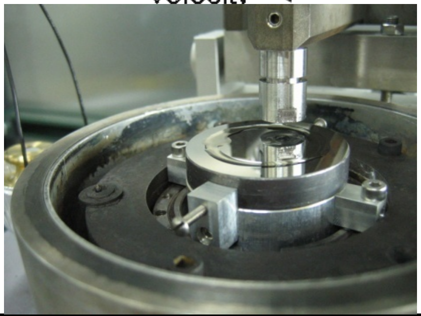


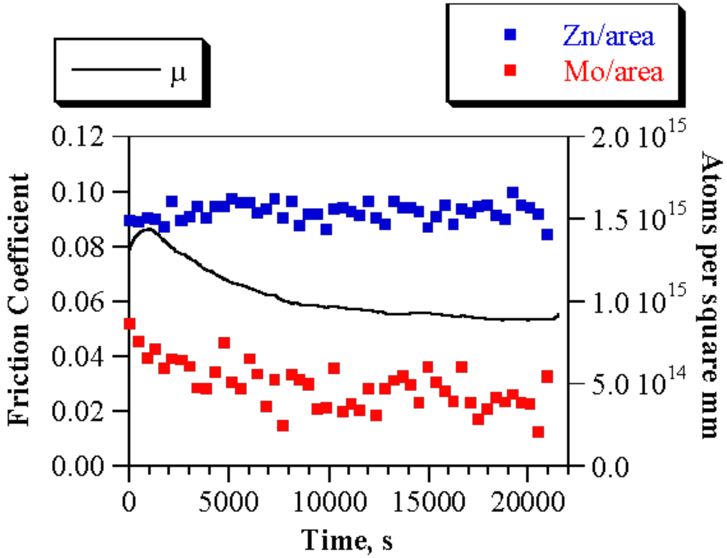
Significant Previous Technical Accomplishments

- Demonstrated usefulness of x-ray based surface analytical techniques for boundary layer characterization at APS in Argonne
  - X-ray fluorescence, x-ray diffraction, X-ray reflectivity
- Designed and constructed x-ray accessible tribometer for XRF
- Useful results, but more information needed
  - Plan to redesign rig – suitable for in-situ testing at APS





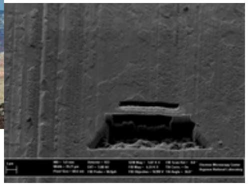




FY08/09 Project Objectives

- **Since the frictional performance, reliability and durability of boundary film is dependent on the structure of the films, structural analysis of different boundary layer films will be conducted**
  - **Profilometry**
  - **FIB and TEM (e.g. from nature)**

Learning from nature



- **Initiate measurement of mechanical properties of boundary films**

- **Quantify the effect of contact temperature on the formation and frictional behavior of boundary films.**

FY08/09 Milestones

- **Develop and demonstrate techniques for boundary film structural characterization - Dec. 08**
- **Quantify the effect of temperature on boundary film formation kinetics and frictional behavior - April 09**
- **Measure the mechanical and frictional properties of boundary films - Oct. 09**

Technical Approach

Project Plan and Structure

Materials

Near-surface-material dynamic changes: - scuffing

Basic mechanism of scuffing failure
Prediction and prevention

Role of surface modification:
- coatings

Determine basic mechanisms of poorly understood near surface material and surface chemical boundary films. Integrate three structural components of lubrication

Chemical Films

Boundary film formation and loss rate:
- APS, other surface analysis tools

Mechanical and friction properties of boundary films measurement

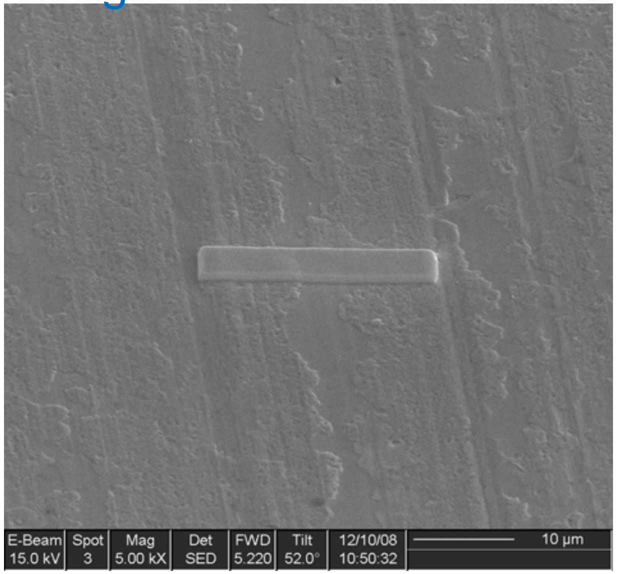
Models for film formation, mechanical and frictional behavior

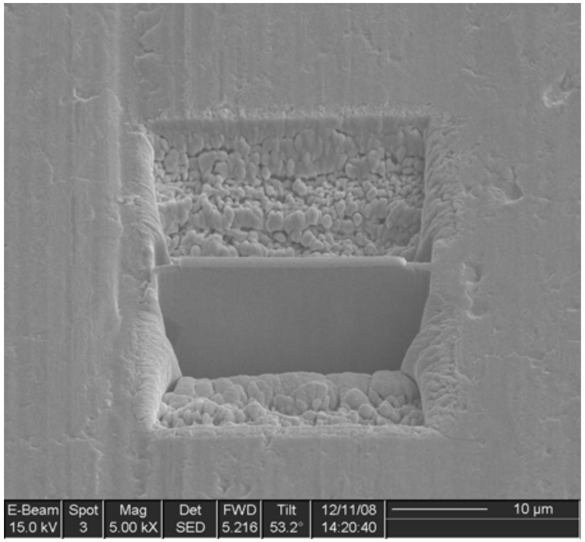
Integrate both elements with EHD and HD lubrication to formulate failure/performance prediction methodology for lubricated components

FY 08/09 Technical Accomplishments:

- **Developed and demonstrated a unique technique for boundary film structural characterization by combining ion beam milling (FIB) and transmission electron microscopy (TEM)**

Pt deposited to protect the boundary film during ion beam milling

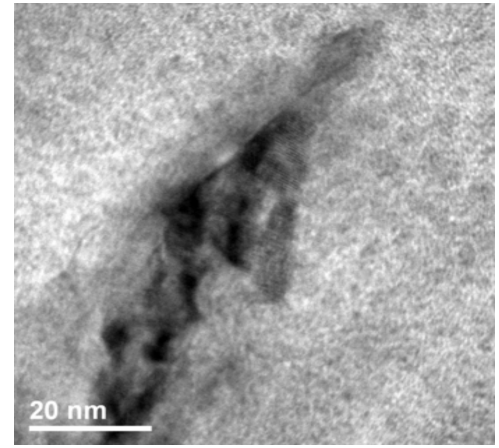




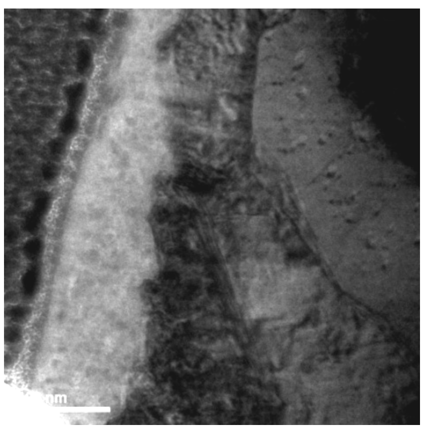
Cross-section TEM sample prepared by FIB

FY 08/09 Technical Accomplishments:

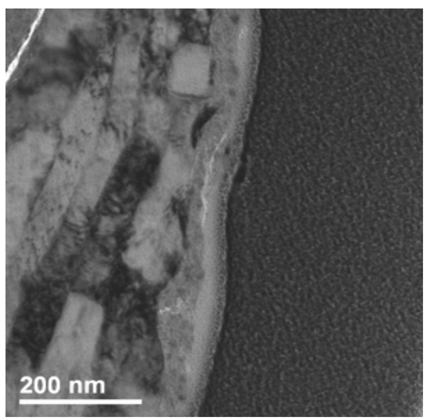
- **TEM analysis showed different features of boundary films produced from different lubricants**
  - **Film thickness 80 – 120 nm range**
  - **Some regions are nano crystalline**
  - **Other regions are amorphous**



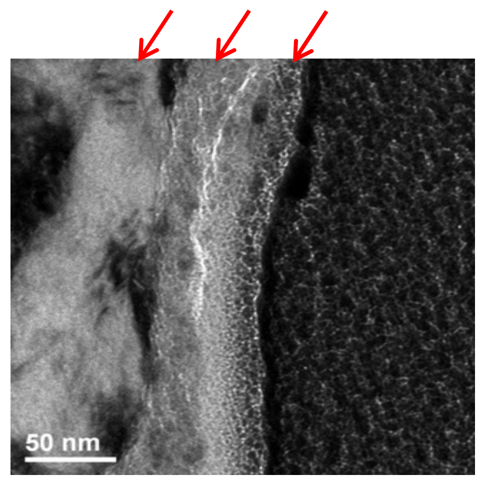
Amorphous region



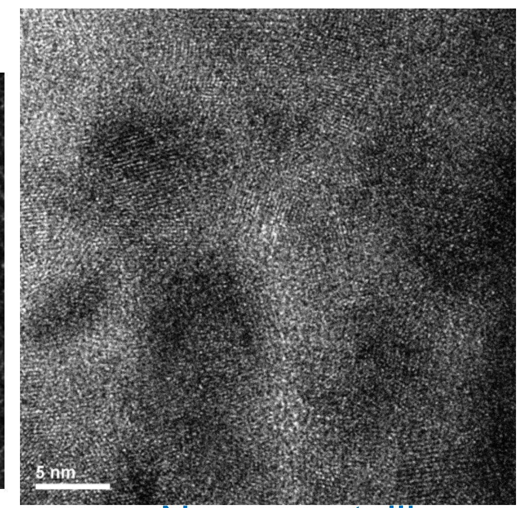
Monolayer film



Bi-layer film



Tri-layer film



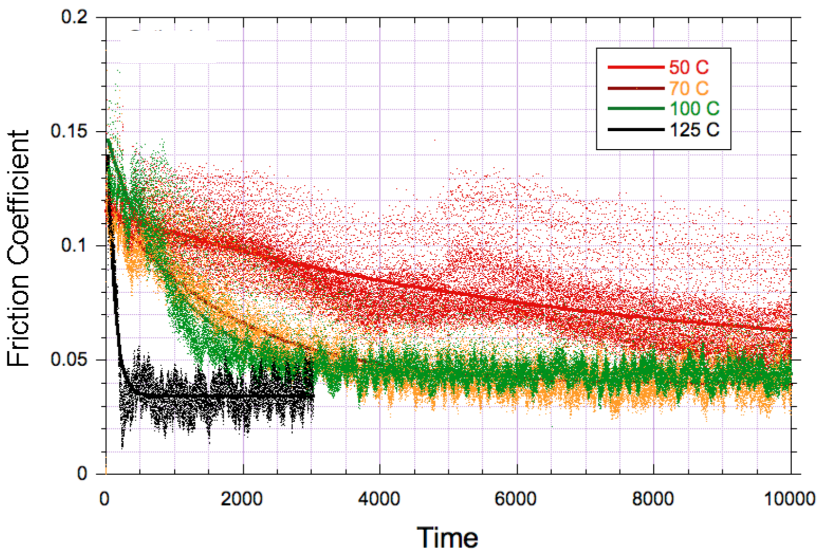
Nano crystalline region
(5-10 nm crystal size)

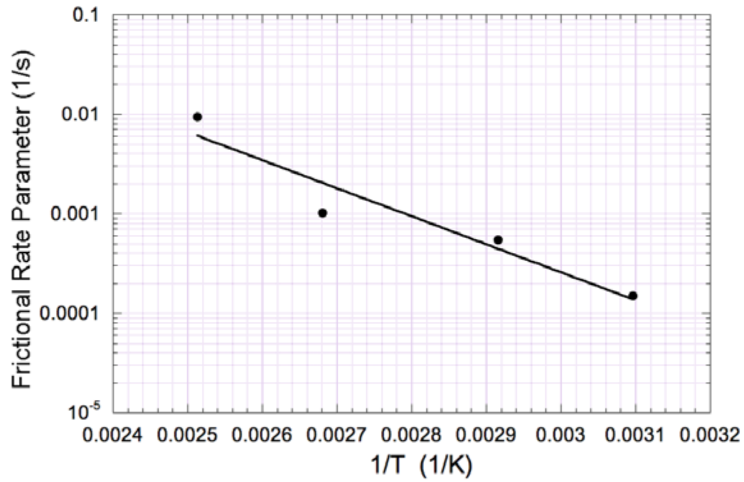
FY 08/09 Technical Accomplishments:

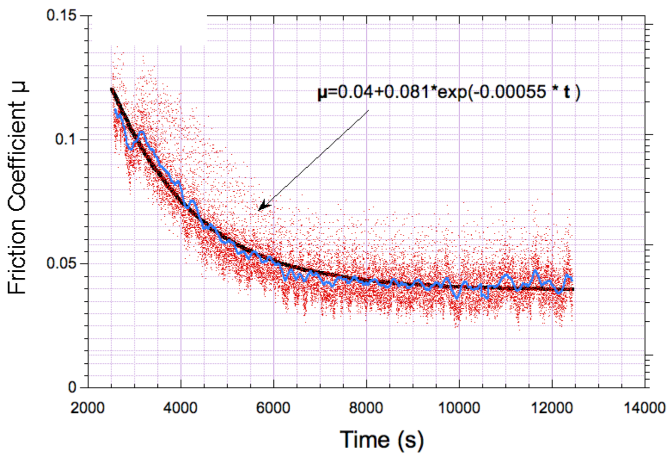
Evaluated the impact of contact temperature on boundary film formation and frictional behavior

- **Pathway for film kinetic modeling**
- **Input for frictional behavior modeling**

- **Arrhenius type behavior for friction**
  - **Film formation?**
  - **Film mechanical properties?**







Future Work- FY2009 and FY2010

- Continue structural characterization of boundary films with differing tribological properties
  - FIB and TEM
  - Glancing incidence X-ray techniques at APS
  - Surface profilometry and AFM

- Measure nano mechanical and frictional properties of structurally different boundary films using a nano mechanical probe system
  - Provide pathway for structure-properties relationship formulation for boundary layer films
  - Indication of mechanical failure mechanisms of boundary films

  Milestone:– Nano mechanical and frictional properties of boundary film - April 2010

- In view of the impact of contact temperature on boundary film formation and frictional behavior, we plan to develop and refine the technique for the measurement of lubricated contact real temperature using the thermoelectric principle. Measurements will be conducted under various contact conditions.
  - Measurement essential to modeling boundary film formation kinetics
  - Input for boundary lubrication friction prediction
  - Assess the correlation of measured and calculated contact temperatures

  Milestone:- Method for lubricated contact real temperature measurement - December 2009

Summary

- Increase in vehicle systems power density facilitated by this project through better understanding and prediction of scuffing will result in significant petroleum displacement
  - Size and weight reduction in many systems
  - Efficient and cost effective product development

- Boundary films can be optimized for low-friction and durable contact interface with adequate information on the formation and loss rates, the structure, mechanical and frictional properties that the current project will provide
  - Effective and efficient lubricant formulation for various materials.
  - Prediction of friction for real surfaces and lubricants.

- Results of the project have general applicability for all vehicle systems.

- Potential for 5 -15 % fuel savings increasingly achievable