DOE/DOD Parasitic Energy Loss Collaboration

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Overview

Timeline
- Project start date: FY 10
- Project end date: FY 14
- Percent complete: 15%

Engine and Vehicle Efficiency
- Reduce consumption of imported petroleum

Reliability & Durability
- Extreme Tribological Environments (DOD/TARDEC)
- Low SAPS Lubricants (DOE)
- EGR-Tolerant Lubricants (DOE)
- Alternative-Fuel Lubricants (DOE)

Budget
- Total Project Funding: 325K
  - DOE Share: 325K
  - Contractor Share*: 250K
- FY 09: 0K
- FY 10: 325K

Barriers
- Engine and Vehicle Efficiency
- Reliability & Durability

Partners
- TARDEC
- Mahle
- DOD Vehicle OEMS (NDA – protected)
- Additive and Lubricant OEMs (NDA)

* TARDEC funding in FY09
Project Objectives - Relevance

- Commercial and military ground vehicles have a number of common issues and concerns related to parasitic energy losses, reliability, and durability.
- Both DOE and DOD have active programs that focus on the development of advanced strategies and technologies to overcome critical barriers.

**Project Objectives:**
- Identify critical barriers related to parasitic friction losses, reliability, and durability common to commercial and military vehicles.
- Establish DOE/DOD collaboration that utilizes key facilities and expertise to investigate, model, and understand fundamental tribological phenomena that impact fuel efficiency, reliability and durability.
- Develop and implement advanced tribological solutions (lubricant, materials/coatings, surface texturing).

**Goal –** Improve vehicle fuel efficiency while maintaining/improving reliability and durability.

**Milestones (new project for FY10)**
- Establish collaborative project on parasitic losses with DOD/TARDEC.
- Identify tribological requirements common/unique to commercial/military vehicles.
- Initiate/extend studies on impact of additives and materials on vehicle efficiency (friction) and reliability/durability (wear and scuffing).
Relevance - Fuel Efficiency/Consumption Challenges

- **Commercial Vehicles (DOE)**
  - On-road, urban/highway
    - 20 – 40+ mpg passenger car
    - 6 – 10 mpg heavy trucks
  - Well-established supply/delivery system
  - 12M bbl/day
  - $3-$4/gallon at the pump
  - 10 to 15% of fuel consumed by engine and drivetrain friction

- **Military Ground Vehicles (DOD)**
  - On-road & Off-road; high level of idle
    - HUMVEEs originally designed for 6-8 mpg actually experiencing 2 mpg
  - Complex logistics for delivering fuel to field operations
  - 0.4M bbl/day
  - $100 - $600/gallon delivered in the field
  - Driving schedule that includes long periods of idle increase frictional losses

Cost of delivering fuel to field operations can be complex and expensive

*Common goal to increase fuel efficiency:*
  a) **1-1/2 M bbl/day lost to friction** – motivating the commercial sector to reduce parasitic friction
  b) Increased fuel usage coupled with complex & costly fuel delivery logistics motivating the military sector to reduce parasitic friction
Relevance - Reliability/Durability Challenges

- **Commercial Vehicles (DOE)**
  - Implementation of emission control technologies
    - Aftertreatment devices require development of low-SAPS lubricants
    - Higher use of EGR introducing higher levels of soot and combustion products into lubricants
  - Development of alternative-fuel vehicles
    - Lubricity of alternative, non-petroleum based fuels
    - Fuel dilution of lubricants
  - Downsizing, lightweighting of vehicle components
    - Increased power density/stresses on critical engine and drivetrain components
    - Poor tribological properties of lightweight materials

- **Military Ground Vehicles (DOD)**
  - Accelerated failure of ground vehicles in SWA - extreme tribological environments
    - High temperatures – rapid degradation of lubricant properties
    - Sand/grit – accelerated wear of critical engine and drivetrain components
    - Vehicles must also function in arctic-temperatures – poor flowability
  - Loss-of-lubricant accidents
    - Survivability of engine, drivetrain, and other mission-critical components when lubricant supply is non-functional
  - Multi-function lubricants
    - Common lubricants for transmission and engine applications
      - compromised performance to achieve commonality in fluids.

*Common need to improve reliability and durability of lubrication systems*
Milestones

- FY 2010
  - Establish collaborative project on parasitic losses with DOD/TARDEC (completed)
    - Discussions in progress with industry
  - Identify tribological requirements common/unique to commercial/military vehicles (in-progress)
  - Initiate/extend studies on impact of additives and materials on vehicle efficiency (friction) and reliability/durability (wear and scuffing) – in-progress.
APPROACH

TEAM DEVELOPMENT

- Establish collaborations with key groups
  - TARDEC, vehicle OEMs, component suppliers, lubricant suppliers

- Define common/unique requirements & barriers
  - Efficiency – current state-of-art
  - Reliability - challenges

- Identify potential pathways to overcome barriers
  - Additive formulations
  - Materials
  - Surface finishing

- Establish technical goals
  - Efficiency/friction, reliability, durability

EXPERIMENTAL

- Benchtop tests
  - Quantify standard tribological properties of candidate solutions
  - Model friction and wear and impact of surface finish, lubricant, and boundary friction.

- Detailed characterization of tribo-film formation and impact of additives/materials
  - Leverage VT/Propulsion Material studies on friction modeling

- Engine validation studies with TARDEC, lubricant suppliers, Vehicle OEMs

- Implementation of technology
  - OEMs, lubricant suppliers
Accomplishments/Progress - Teams Established

- Established working relations / collaborations with key staff at TARDEC – Fuels and Lubricants Technology Team
  - Discussions on developing coordinated project on investigation of protective tribofilms that extend reliability and lower friction under severe conditions.

- Established contacts with DOD ground vehicle OEM (also commercial vehicle OEM) to develop collaborative project on parasitic energy losses.
  - Signed non-disclosure agreement identifying topics of interest

- Existing working relations / collaborations with engine component supplier(s)
  - Exchange of components, treatment of components, evaluation of components
  - Development of proprietary software (by supplier) to interpret experimental data on tribological properties
  - Exchange of prototype lubricants/additive formulations and exchange of data with lubricant OEMs
Accomplishments/Progress - Completed Initial Studies on the Impact of Additives on Scuffing

- Block-on-ring configuration used to quantify critical scuffing load (ASTM G77, D2714, D3704)
- Performed detailed study on the impact of 5 additives (boric-acid, tricresyl phosphate, boron nitride, graphite, and moly disulphide) on the scuffing resistance of a certified, mil-spec mineral oil

Friction behavior (left) and scuffing failure appearance (right)
Accomplishments/Progress - Scuffing - cont’d

- Two commercial additives identified that extended scuffing behavior during fully lubricated conditions
- Figure below shows measured scuffing loads for different combinations of speed, additive type, and additive concentration.
  - Tests and characterization efforts are continuing to examine microstructure of two additives (boric-acid and tricresyl phosphate.)

![Final Scuffing Loads (N) for 15W-40 Mineral Oil and Additives](image)
Accomplishments/Progress - Technical: Examined Impact of Additives on Oil-Off Scuffing Behavior

- Performed detailed study on the impact of 5 additives (boric-acid, tricresyl phosphate, boron nitride, graphite, and moly di-sulphide) on the scuffing resistance of a 15W-40 oil under starved lubrication conditions.

- Load adjusted to 600N, oil drained, measured time to onset of scuffing

- Failure time extended up to 100 %

- Frequently observed formation of low-friction film

![Graph showing friction coefficient, normal load, oil temperature, block temperature, and weld block temperature over time.](image)
Accomplishments/Progress - Technical: Formation of Low-Friction Tribofilm that Delayed Scuffing

- Frequent observation of a low-friction tribo-film during oil-off scuffing studies. When observed, the onset of scuffing was significantly increased.
  - Implications for energy efficiency
  - Implications for reliability and durability

- Applied advanced characterization technique (focused-ion-beam spectroscopy – FIBS) to examine structure and composition of tribofilms formed during tribolological interactions.
  - Understand fundamental mechanisms involved in the formation of protective, low-friction tribofilms – work in-progress
Collaborations/Coordination with Other Institutions

- Project involves collaborations with the following institutions to evaluate low-friction (fuel efficiency) and durability/reliability:
  - DOD/TARDEC [government] – Force Projection Technologies / Fuels and Lubricants Technology Team – provide guidance on DOD requirements, contacts with suppliers, and collaboration on lubricant characterization and testing.
    - Development of engine and drivetrain lubricants
  - DOD Ground Vehicle OEM [industry]- provide guidance on vehicle needs/requirements and potentially will provide samples of oil from vehicles used in the field.
    - Non-disclosure agreement signed
    - OEM also produces commercial utility trucks
  - Engine component supplier [Mahle - industry] – provide prototypic engine components
    - Rings, pistons, & liners
    - Modeling of friction and wear during benchtop tests
  - Lubricant supplier(s) [industry] – provide baseline and experimental oil formulations.
    - Mil-spec oil – engine & drivetrain
    - Commercial lubricants – nanoadditives
Proposed Future Work:

- Model impact of low-friction strategies on vehicle efficiency – commercial and military ground vehicles
  - Obtain input on ‘typical’ driving schedules (commercial vs. military)
  - Apply driving schedules (engine maps) to predict changes in friction mean effective pressure (FMEP)
  - Scale fuel economy to indicated mean effective pressure (IMEP)

- Evaluate the impact of candidate low-friction technologies (additives, component materials/coatings, and surface texture) on friction, wear, and scuffing performance.
  - Benchtop friction and wear tests using ring/skirt - on – liner tests
  - Benchtop scuffing tests - 4-ball, and block-on-ring configuration.
  - Comparison of baseline vs. advanced candidate technologies
    - Surface finish (plateau honing vs. slide honing)
    - Baseline mil-spec & commercial lubricant vs. advanced additized lubricants
  - Characterization of field-tested lubricants (commercial & military)
  - Validation of Friction/Wear modeling software (Mahle Virtual Tribology Laboratory)
    - Prediction of friction and wear performance based on surface texture and lubricant rheological properties

- Establish test program with TARDEC/Vehicle OEM to validate advanced concepts on engine/drivetrain simulation rigs
Summary:

- New project started in FY 10 builds on prior DOD collaboration - identifies common issues & concerns between commercial and military vehicles to leverage R&D projects to develop advanced fuel-efficient technologies.
- Relevance – project addresses DOE’s goals to improve vehicle efficiency and vehicle emissions
- Technical Accomplishments – preliminary studies on scuffing performance of mil-spec lubricants have identified two candidate additives that enhance the formation of low-friction tribo-films that are scuff-resistant. Demonstrated application of FIBS to characterize structural and chemical make-up of tribo-films.
- Collaborations – Coordination and collaboration of the project with key parties and co-sponsors: TARDEC – Fuels and Lubrication Technical Team, Heavy-Vehicle OEM*, Component Supplier (Mahle), and Lubricant OEMs*.

* - names with-held subject to non-disclosure agreements