Courtesy of The T.R.U.T.H. Project

Efficiency Improvement through Reduction in Friction and Wear in Powertrain Systems

Mike Killian
February 28, 2008

This presentation does not contain any proprietary or confidential information

Efficiency Improvement through Reduction in Friction and Wear in Powertrain Systems

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
DE-FC26-04NT42263 / A000	Vehicle Systems	HV Systems Optimization	Exploratory Research	02/28/08

PURPOSE

To conduct research and development to reduce friction and parasitic energy loss by 30-50%, in truck transmissions and axles used in class 3-8 trucks, is the purpose of this project. Increased efficiency will improve fuel economy by 2-4%, producing a savings of 390 to 780 gallons per vehicle annually, without compromising performance and durability.

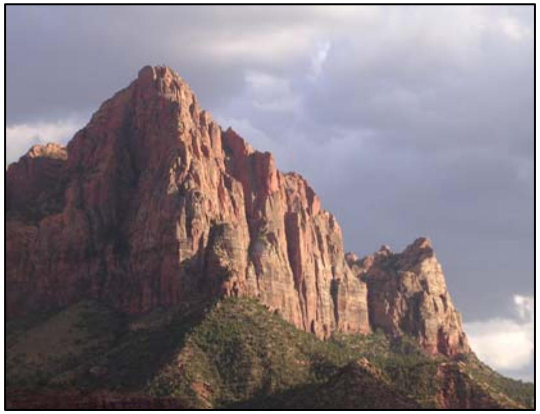
Technical Approach: Formulate an

IMPLEMENTATION STRATEGY

1. Churning losses
2. Surface roughness – super finishing
3. Lubrication effects
4. Coatings
5. Texturing

BARRIERS / RISKS

- Risk of gear and bearing damage with dry, low fill sumps
- Excessive gear pitting, wear and noise from low viscosity lubricants
- Hard debris from delamination and disbond of coatings
- Loss of oil film with excessively smooth, super finished surfaces
- Cost of the technology
- Convincing fleet users the technology provides a tangible benefit



LESSONS LEARNED

Advanced sumps to reduce churning loss (24-31%)

- Old “dry sump” hardware with spray tubes
- Low volume sump with electronic oil injection
- RISK: gear and bearing damage on inclines

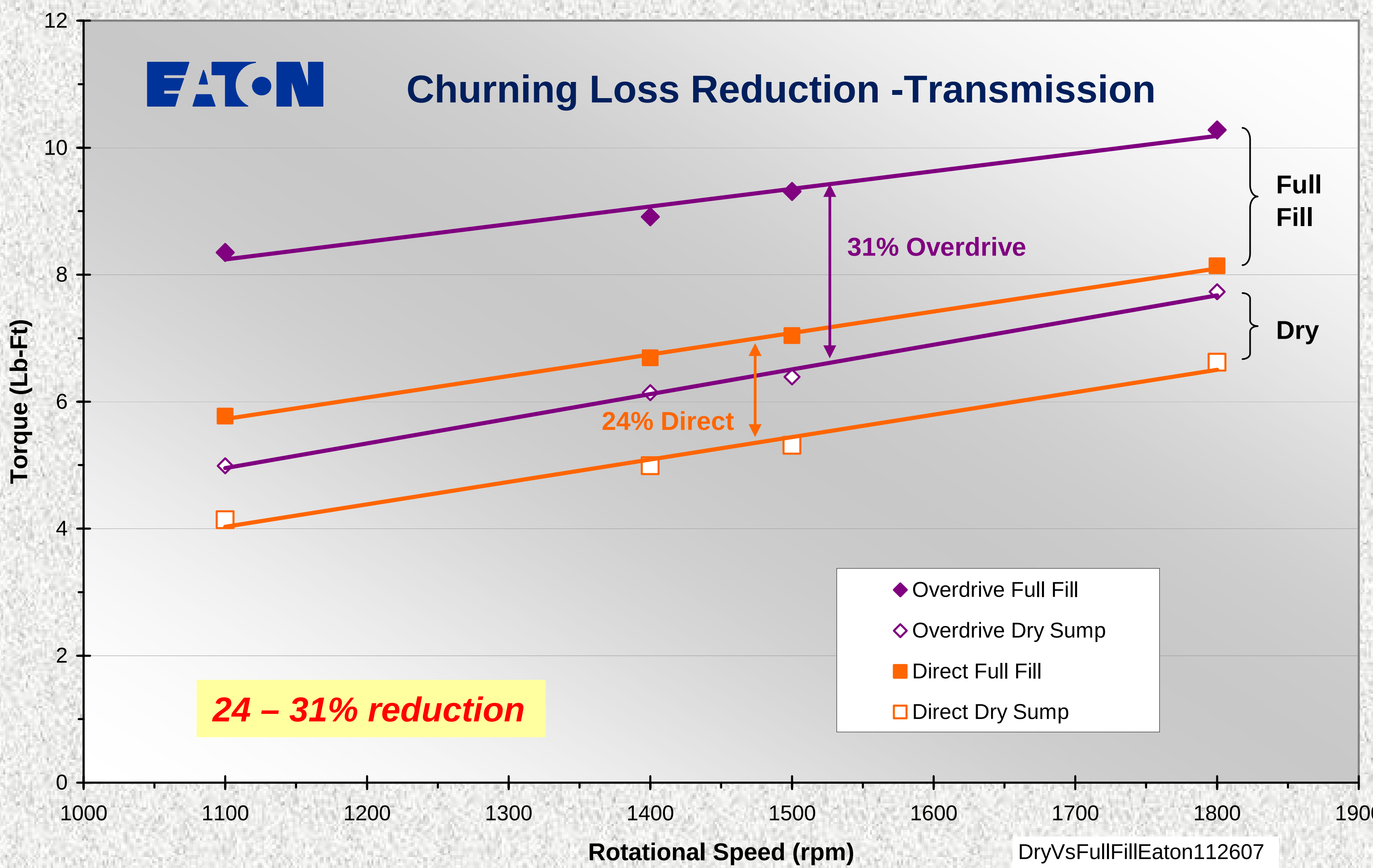
Lubricant additives for friction reduction (24-42%)

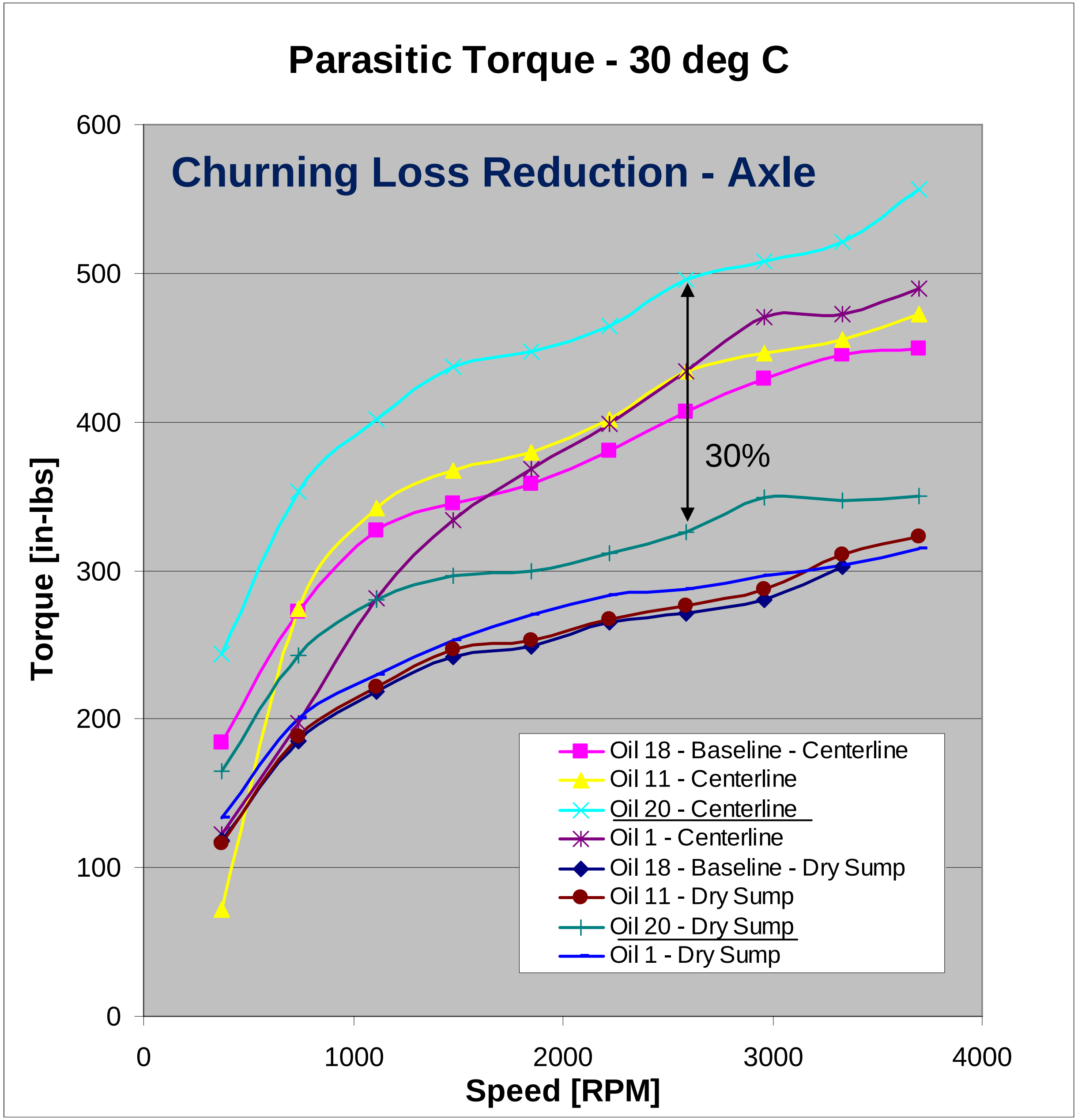
- Additives to bulk oil
- Demand based additive injection
- RISK: gear pitting and wear

Gear coatings for friction reduction (?%)

- PVD diamond like carbon, AlMgB, MoN-Cu
- RISK: coating delamination, disbond, debris

COMPARISON OF DYNAMOMETER TORQUE FOR FULL FILL VERSUS DRY SUMP FOR ROADRANGER SAE 50 REV 7 LUBRICANT



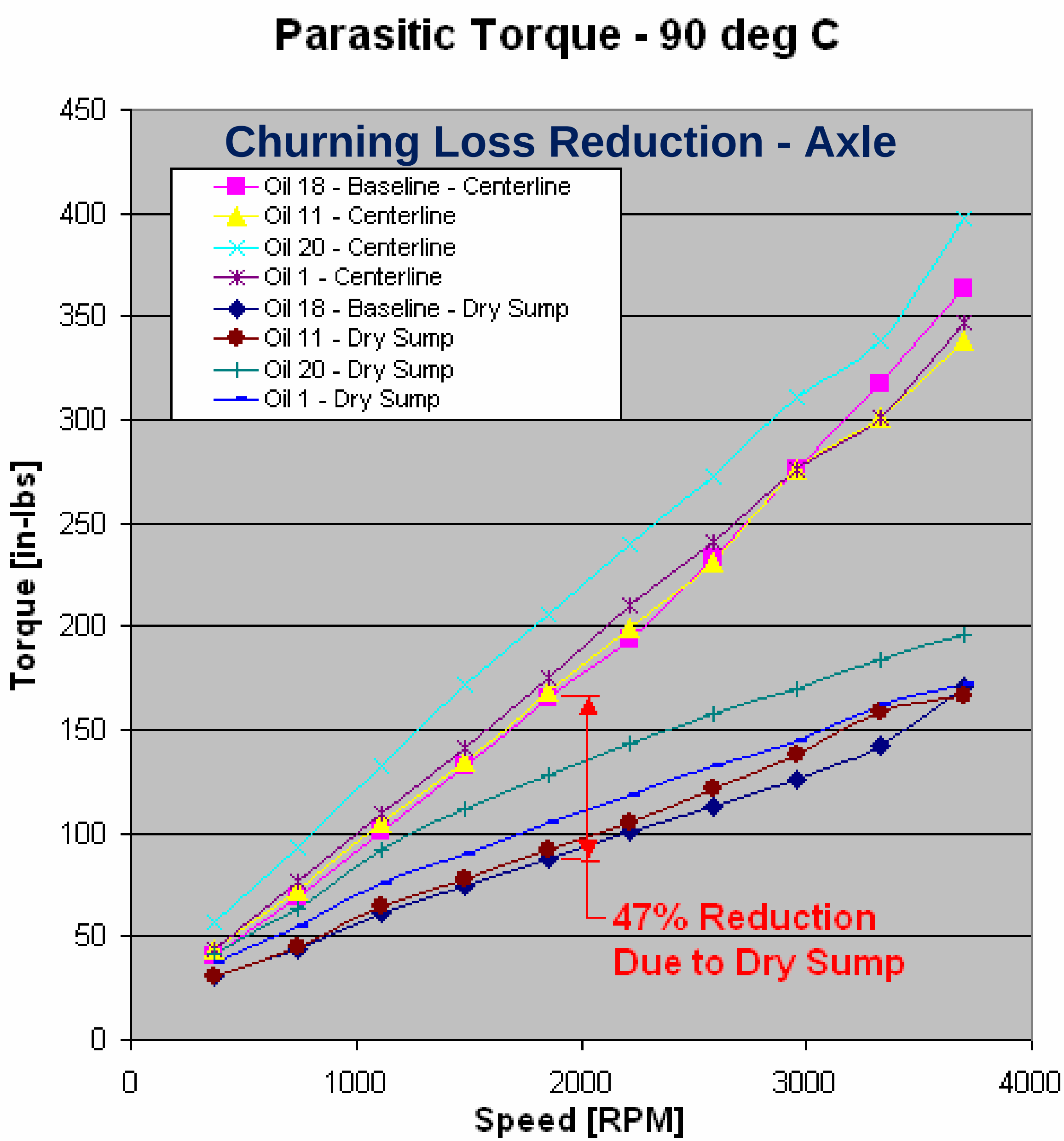


86 deg F

Full sump

Dry sump

Parasitic torque for four Caterpillar oils tested at 30 degrees C (86 degrees F). For high viscosity Oil #20, the reduction in parasitic torque due to the dry sump exceeds 30 percent.



194 deg F

Full sump

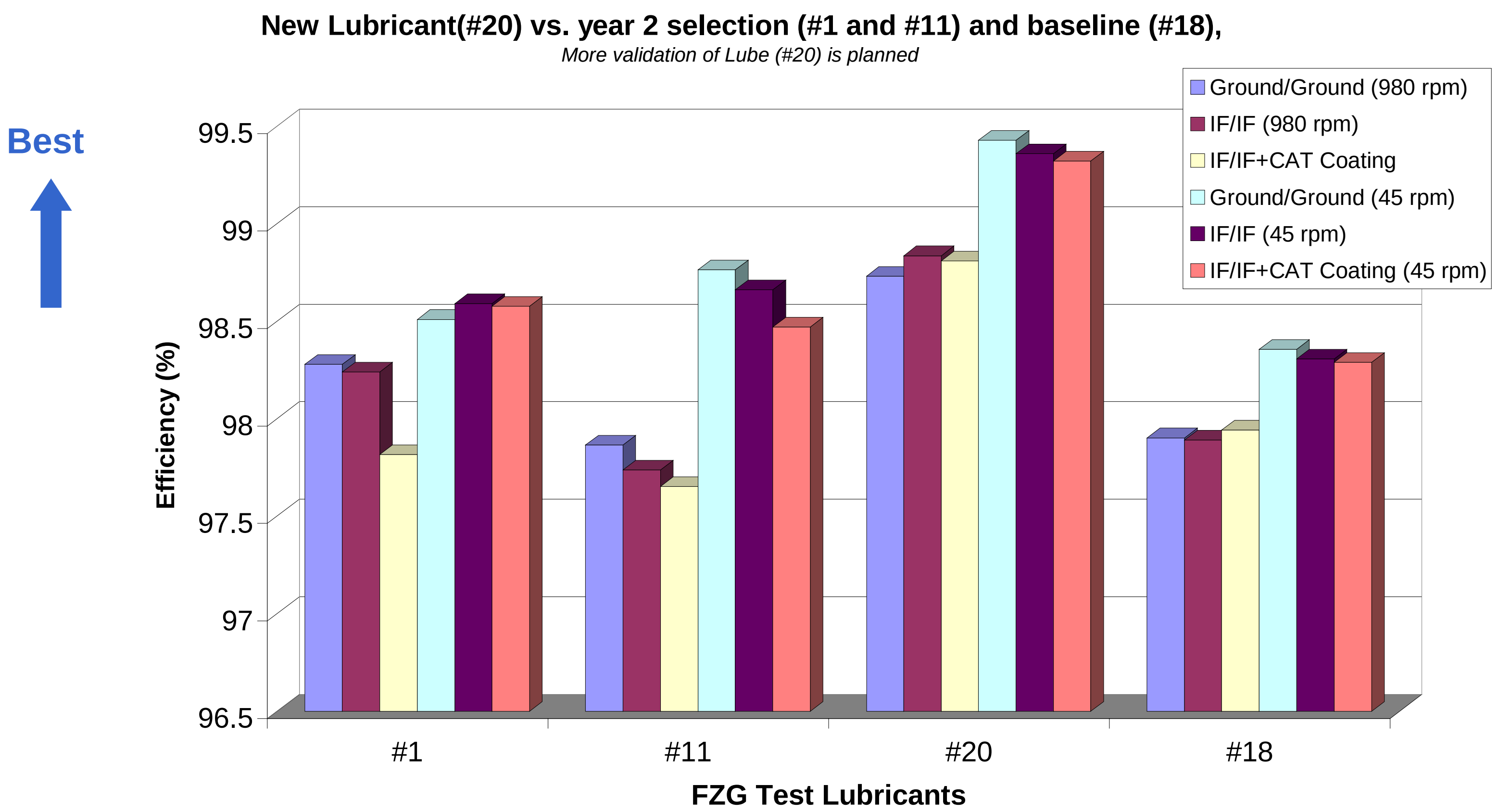
Dry sump

Parasitic torque for four Caterpillar oils tested at 90 degrees C (194 degrees F). For baseline Oil #18, the reduction in parasitic torque due to the dry sump exceeds 47 percent.

CATERPILLAR

CATERPILLAR LUBRICANTS

FZG tested lubricants



CATERPILLAR®

LUBRICANT APPROACHES

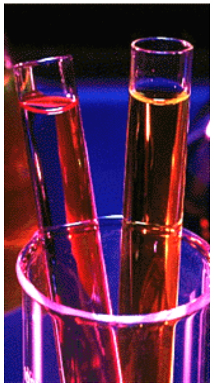
Alternatives to Roadranger Rev 7

- PAO base oil
- Friction modifiers
- Anti-wear additives
- RFY4 oil
- RIM 5 oil; New Castle tester

Reduce friction coefficient for Roadranger Rev 7

- Introduce friction modifiers
- Introduce solid lubricants
- Rev 7 with RJK5 additive blended in oil
- RJK5 dosing additive

EATON ROADRANGER REV 7 HYBRIDS



Ann Arbor Testing & Development, Inc.

FALEX FIXED 4-BALL TEST

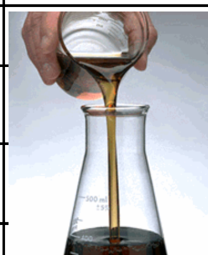
1200 rpm, 40 Kg load, 100 degrees C, 8.0 hours

	TEST NO.	LUBRICANT	FRICTION COEFFICIENT (average)	WEAR SCAR DIAMETER (mm)	
	H142 Baseline	Eaton Roadranger SAE 50 Rev 7	0.066	0.44	COMMERCIAL (August 2006)
Rev 7 modifications	H143	R7L5	0.066	0.44	
Rev 7 modifications	H144	R7L6	0.066	0.43	
Rev 7 modifications	H145	R7L7	0.064	0.43	
Rev 7 modifications	H146	R7H7	0.079	0.45	
Rev 7 modifications	H147	R7H8	0.074	0.44	
	C230	Mobil SHC 50 11/12/02	0.119	0.61	
	H154	Mobil SHC 50	0.123	0.64	COMMERCIAL

High contact stress: >150,000 psi

June 5, 2007

PAO Lube + Additive Formulations*

TEST NUMBER	DESIGN CODE	TEST METHOD CODE	COMPOSITION	FRICTION COEFFICIENT	WEAR SCAR DIAMETER (mm)
H142	RFN4		**Roadranger SAE 50 Rev 7 Baseline**	**0.066**	0.44
H154	RFN4		**Mobil SHC 50 tested 5/25/07**	**0.123**	0.64
H173	RFF3		100-Durasyn 168 PAO	**0.132**	1.57
H204	RFY4		Durasyn 168 + CK3D + RFF2 + RFY2 + H121	**0.038**	0.33
H205	RFY5		Durasyn 168 + CK3D + RFF2 + RFY3 + H121	**0.039**	0.33
H189	RFN5		96-FCB3 Durasyn 168 PAO + 1-CK3D + 2-RFF2 TechGARD 740 + 1-RFN3 Elco 108	**0.039**	0.34
H200	RFV3		96-Durasyn 168 + 1-CK3D + 2-RFF2 +1-RFV2	**0.04**	0.34
H203	RFX3		Durasyn 168 + CK3D + RFF2 + RFV2 + JDF4 + H1.221.3	**0.04**	0.34
H188	RFN4		96-FCB3 Dursyn 168 PAO + 1-CK3D + 2-RFF2 TechGARD 740 + 1 RFN2 Elco 103	**0.040**	0.35
H182	RFH9		94-Durasyn 168 PAO + 2-RFF2 TechGARD 740 + 2 RFH3 Lubrizol 5178 F + 2-CK3D	**0.040**	0.40

-42% (friction coefficient, H142 to H204)

-25% (wear scar diameter, H142 to H204)

*Lubes from Ann Arbor Testing & Development, Inc

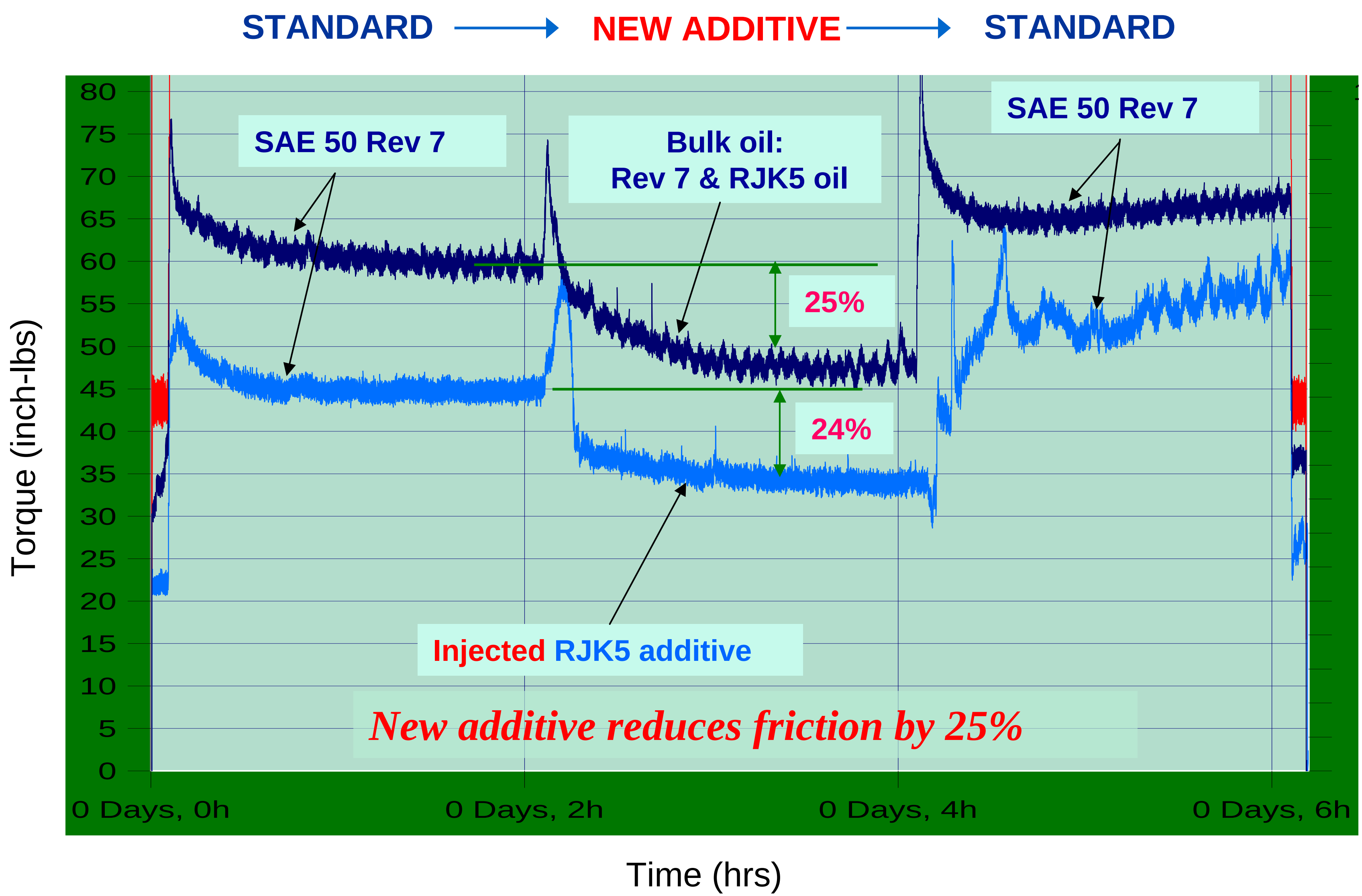
H204 Oil Functional Breakdown

TEST NUMBER	DESIGN CODE	LUBRICANT COMPOSITION	FRICTION COEFFICIENT	WEAR SCAR DIAMETER (mm)
H142	RFN4	**Roadranger SAE 50 Rev 7 Baseline**	**0.066**	0.44
H154	RFN4	**Mobil SHC 50 tested 5/25/07**	**0.123**	0.64
H204	RFY4	PAO + CK3D + RFF2 + RFY2 + H121	**0.038**	0.33

PAO + CK3D + RFF2 + RFY2 + H121

96 PAO Base oil + 1 Friction Modifier + 2 Gear Oil Pkg + 1 Zn Additive

EATON: SWITCHING OIL ON-THE-FLY



PVD COATING CHALLENGES

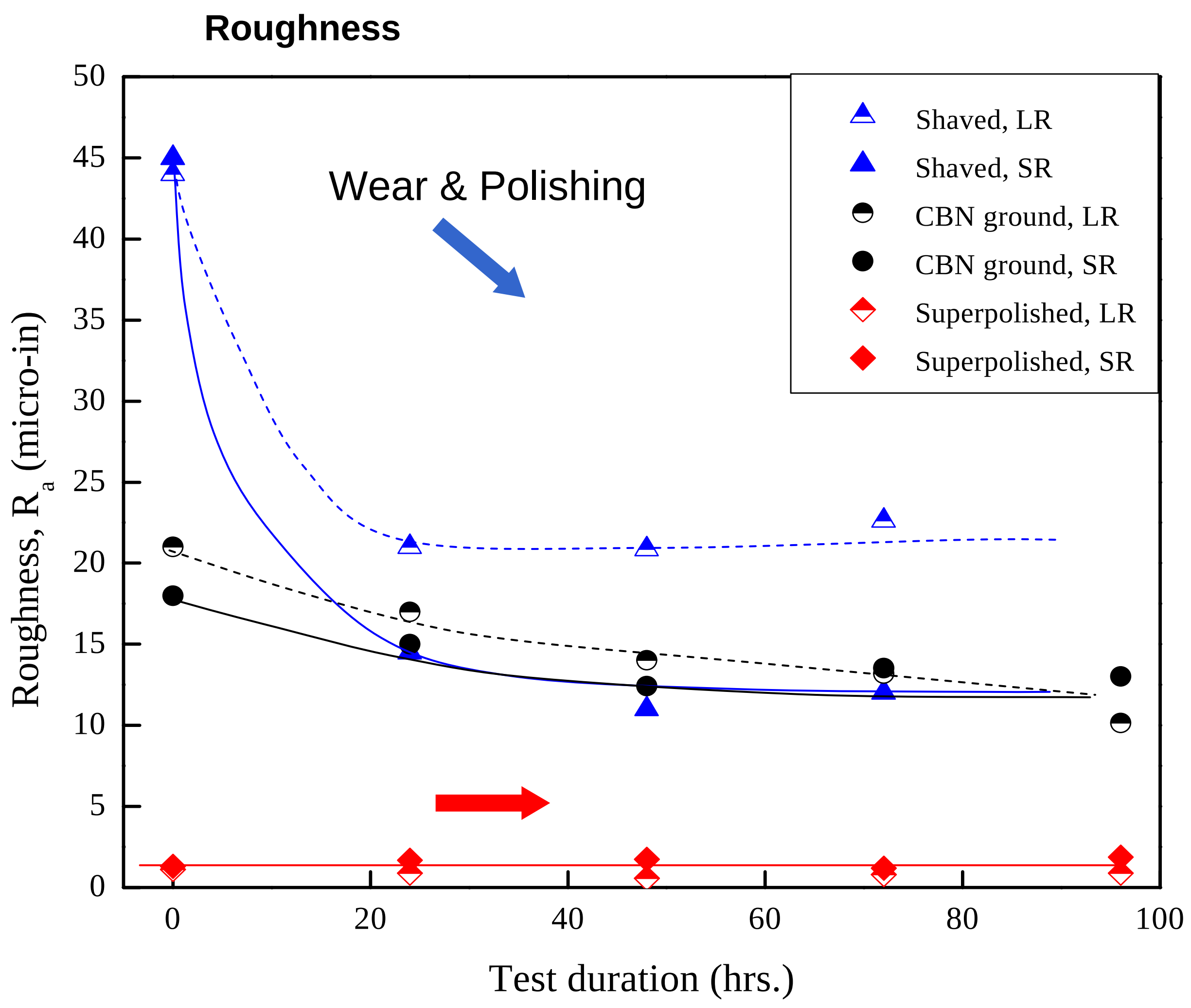
Challenges have been identified when PVD (physical vapor deposition) processing is used for coating gears:

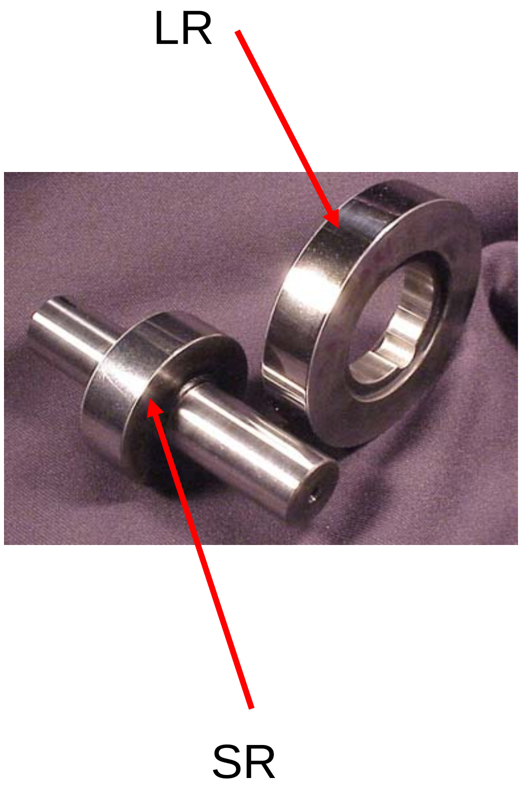
- *Gear geometry*
- *Limited temperature processing*
- *Surface finish*
- *Cost*

PVD GEAR COATING

Eaton spur gear, contact fatigue rollers and Falex ring that have been coated with Diamond-Like Carbon by physical vapor deposition

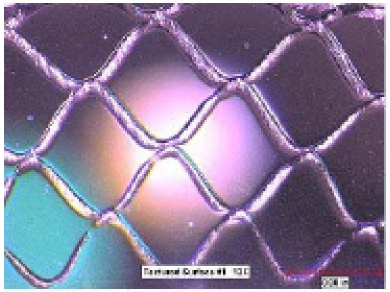
ROLLING CONTACT FATIGUE RESULTS



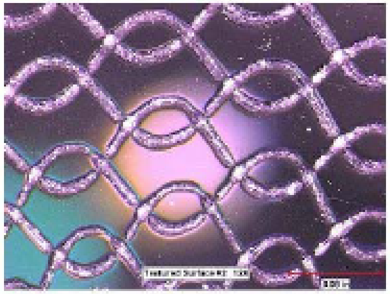


SURFACE TEXTURING

Quarterly Progress Report Q2 2005

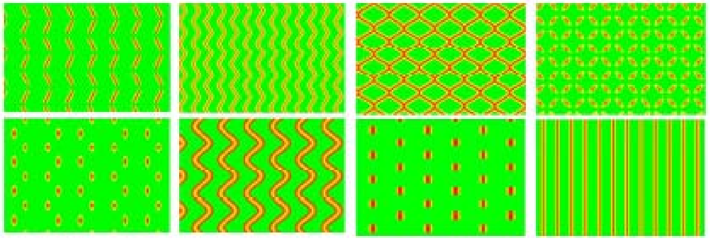


Ring 1

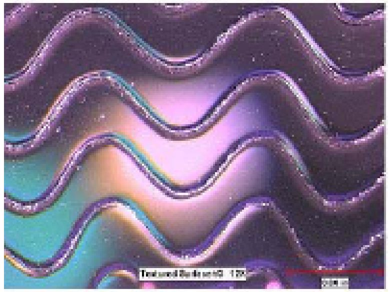


Ring 2

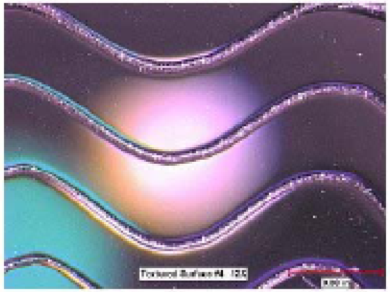
Quarterly Progress Report Q1 2005



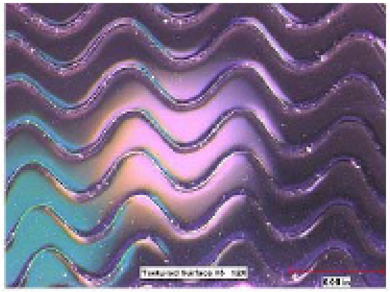
Virtual texturing patterns



Ring 3



Ring 4

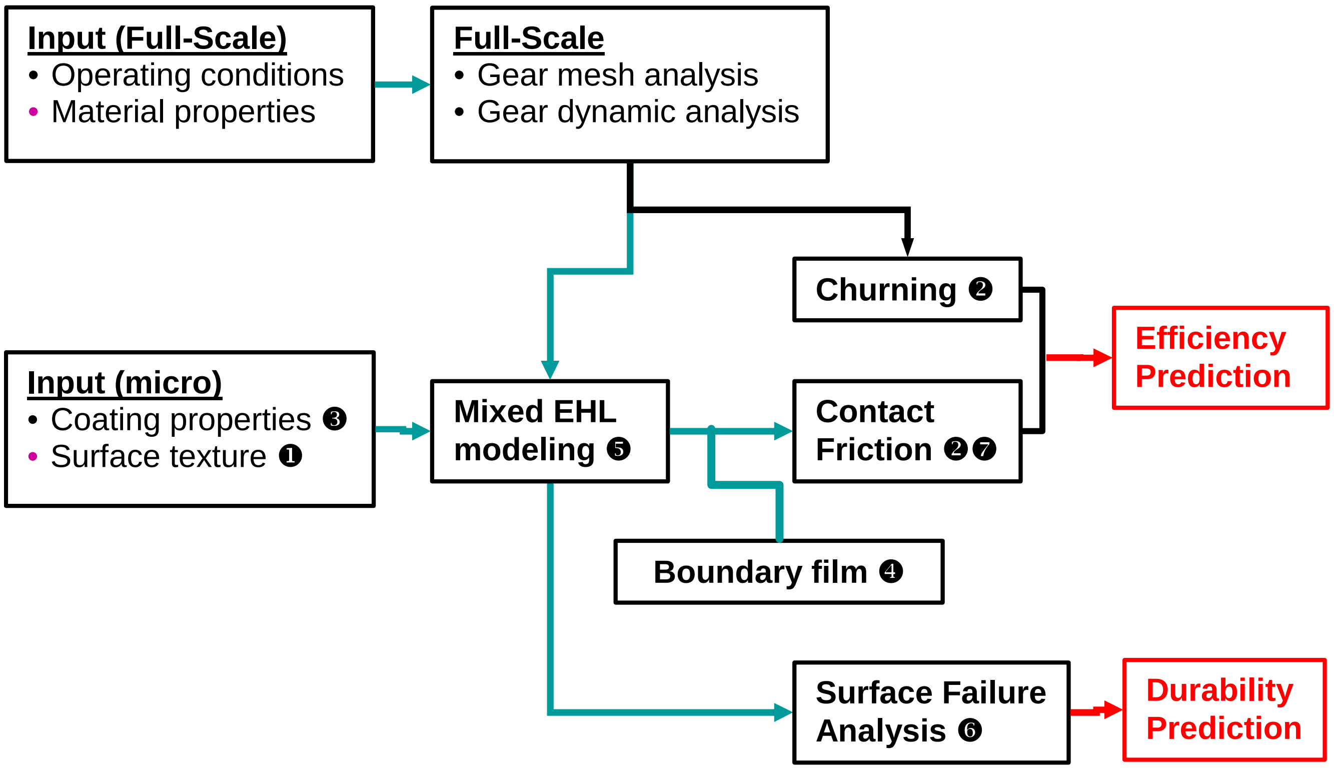


Ring 5

Fricso Vibra-grooved samples. Rings 2 and 4 exhibited lowest coefficient of friction in Falex mailbox pin test. Contact stress: ~13,000 psi.

INTEGRATED GEAR DESIGN MODEL

Deliverables 9, 10 &12 BP2
Coatings, Gear Design, Strategy

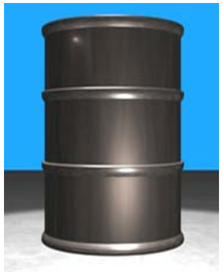


SUMMARY

- Research has enabled an *initial vision of the efficient powertrain* assembly, *whether a transmission or an axle*
- An efficient powertrain assembly includes
  - Advanced low fill sump with precision oil injection to the gear mesh and to bearings
  - Low viscosity synthetic oil, heavily dosed with friction modifiers and anti-wear additives
  - Super finished contact surfaces including gear teeth and rotating elements
  - Coatings applied to super finished surfaces
    - Potential to reduce friction and to reduce operating temperature
    - Durability remains an issue requiring further development and testing

SUMMARY data

- A 2-4% improvement in fuel economy correlates to a savings of $ 1200 to $2400 per vehicle for the fleet
- More importantly a 2-4% improvement in heavy truck miles per gallon yields a savings of 390 to 780 gallons of diesel fuel per vehicle
- Assuming a population of 2.5 million active heavy trucks in the US and saving 500 gallons per vehicle annually, the fuel savings reaches 1.25B gallons of diesel fuel. This amount of diesel fuel comes from 7.5B gallons of crude oil, roughly 180M barrels.
- If only 20% of the trucks were updated, the savings would be 250M gallons of diesel fuel or 1.5B gallons of crude, about 36M barrels.



Courtesy of Wink News

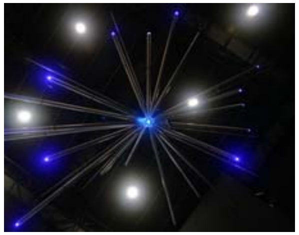
Courtesy of ABC News

END

REFERENCE SLIDES

© 2007 Eaton Corporation. All rights reserved.

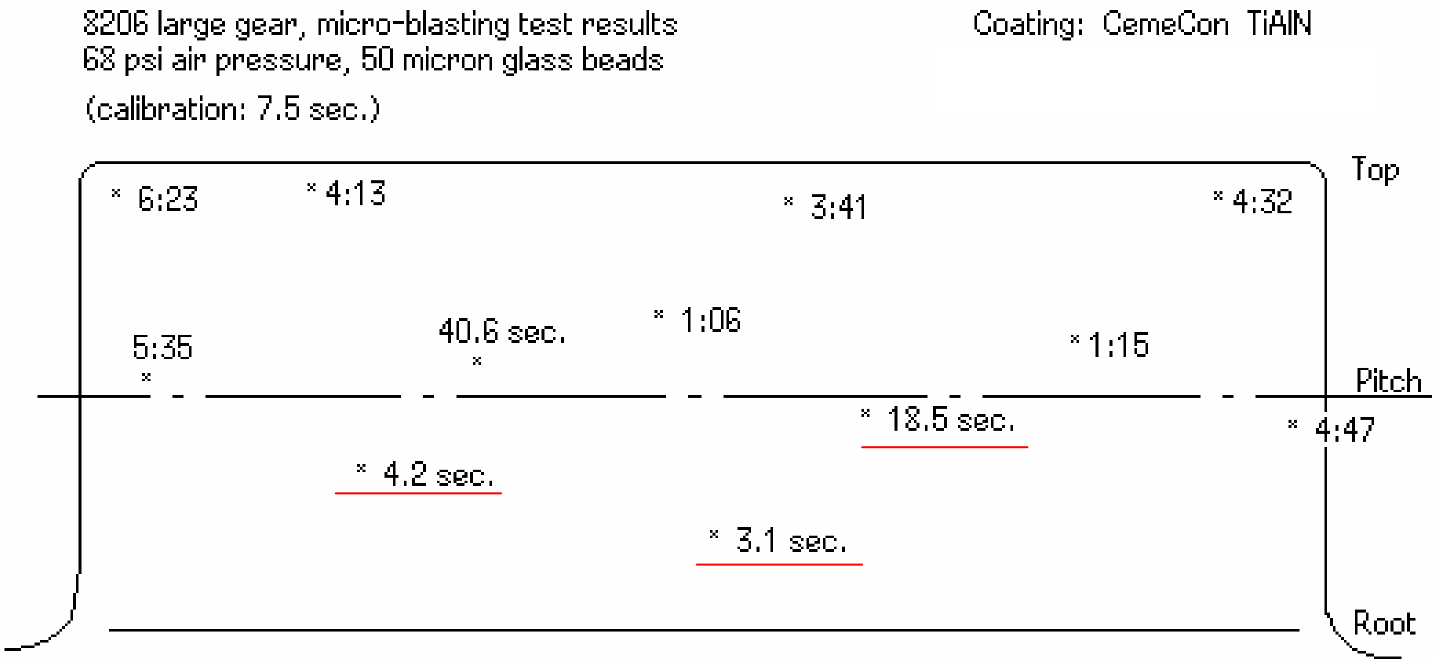
THE BUSINESS OF EFFICIENCY



Fuel Economy: miles per gallon; 120,000 miles annually, at 6 mpg = *20,000 gallons* of fuel; 2.0% improvement target

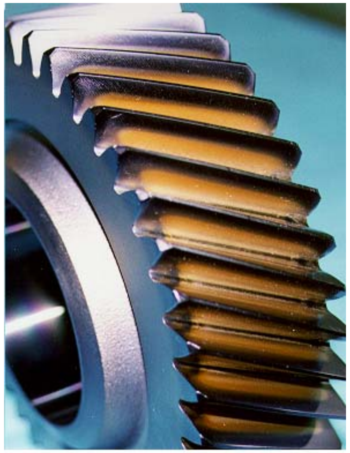
- 2% fuel economy improvement: .02 * 6 mpg = 0.12 better mpg
- Improved mpg = 6.12 mpg
- 120,000 miles / 6.12 mpg = *19,608 gallons*
- *20,000 gallons – 19,608 gallons = 392 gallons saved*
- *392 gallons * $3.00 to $3.50* / gallon = $1,176 to $1,372 savings annually
- 1,000 vehicle fleet * $1,000+ savings = >$1M annually
- Swift Transportation Co., Inc – 18,000 tractors

Coating thickness / adhesion (micro-blasting method)



Gear Tooth – coating thickness distribution

Spur gear – TiN Coated



Helical gear - Ion Etched

POWERTRAIN EFFICIENCY

Business Strategy

- Medium and heavy duty trucks; off-highway equipment
- Eaton dominates NA HD truck market, >90% market share
- MD truck market share is 20%, an opportunity for growth
- Fuel savings for fleet customers; 2% improvement in mpg from transmission; additional 2% from axles; $1200 to $2400 savings per vehicle for fleet