Massachusetts Institute of Technology

Low Engine Friction Technology for Advanced Natural Gas Reciprocating Engines

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COOPERATIVE AGREEMENT DE-FC26-02NT41339

Awarded April 1, 2002 (24 Month Duration)

$910,068 Total Contract Value ($ 728,063 DOE)

PROJECT OBJECTIVES

- To reduce parasitic losses of Advanced Natural Gas Reciprocating Engines by reducing piston/ring assembly friction
- To minimize concomitant effects on wear, durability, and oil consumption

via

- *Assessing opportunities and establishing fundamental design and performance relationships via computer modeling and experiments*
- *Validating concepts and strategies and demonstrating system operation in a full-scale engine*

PROJECT SCHEDULE

DoE Form 4600.3

(Low Engine Friction Technology for Advanced Natural Gas Reciprocating Engines)

Program Period: April 1, 2002 - March 31, 2004

Calendar Year 2002: A M J J A S O N D | Calendar Year 2003: J F M A M J J A S O N D | 2004: J F M

#	MAJOR TASKS	Comments
1	**Develop Program Plan**	**Completed**
2	**Assess Opportunities**	**Completed**
	Preliminary analyses & empirical observations	
3	**Design & Perf Analysis**	**Extend 1 mo**
3.1	(a) Modify and adapt lub. models	**Done Early**
3.2	(b) Apply models to study friction	**Extend 3 mo**
	Develop and explore low friction	Extensive analyses
	concepts. Perform parametric studies.	Multiple designs
3.3	(c) Recommend design options	to propose thru Jun
	Request prototype components for tests	**Extend 1 mo**
4	**Demonstrate Design**	**Colorado St U**
4.1	Establish baseline test engine measurements	**Extend 3 mo**
4.1.1	- install engine and make standard measurements	**Extend 3 mo**
4.1.2	- instrument and test engine with special diagnostics	**Extend 3 mo**
4.2	Test components in controlled engine	Accelerate to stay
	experiments to validate design concepts	on schedule
4.3	Demonstrate complete low-friction engine system	To be performed
5	**Analyze Results and Iterate**	To be Performed
5.1	- Analyze more in-depth various design options	To be Performed
5.2	- Refine models and iterate tests as necessary	To be Performed
6	**Program Operation**	**Continuous**
6.1	Conduct/prepare periodic reviews and reports	**2 team reviews**
6.1.1	- Monthly team conferences (involving students)	**Monthly telecfs**
6.1.2	- Deliver semi-annual/annual reports	1 semi-annual report
6.1.3	***- Deliver Final Report***	

Accomplishments

- Initial assessment supports that goal of 30% power cylinder friction loss reduction is possible, but challenging, involving a combination of design parameters.
- Preliminary analyses point to top ring and oil control ring as primary friction contributors. Developed models for ANGRE engines.
- Full-scale test engine operational with basic instrumentations installed, baseline testing is beginning.
- First reduced-friction parts to be recommended and procured May/June 2003

TECHNICAL APPROACH

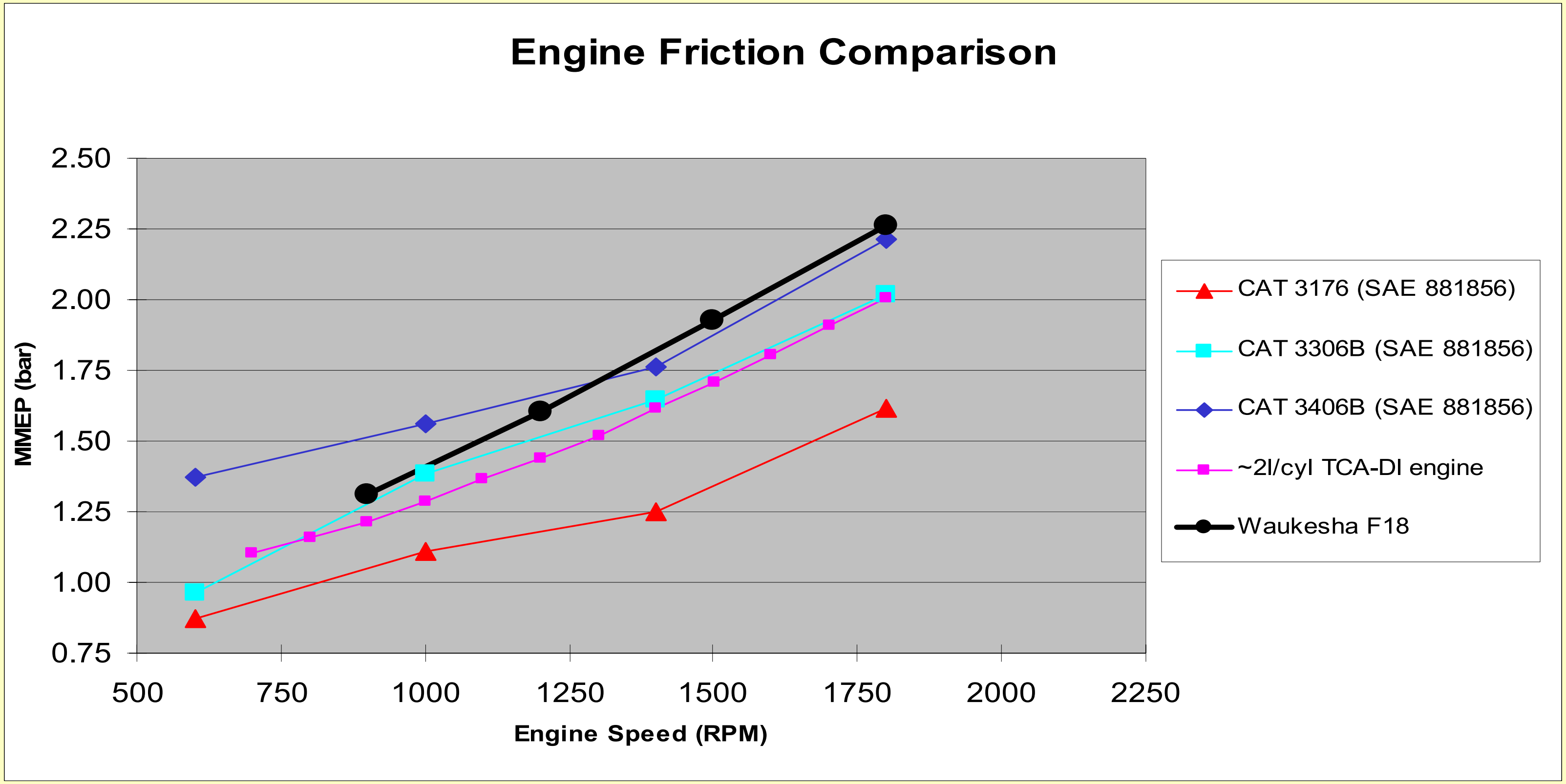
- Assess Piston/Ring-Pack Design Strategies for Minimum Friction Loss
- Establish Fundamental Design and Performance Relationships
- Design and Demonstrate Low Friction Concept

Via:

- Computer Modeling
- Concept Validation
- System Demonstration

Engine Comparisons

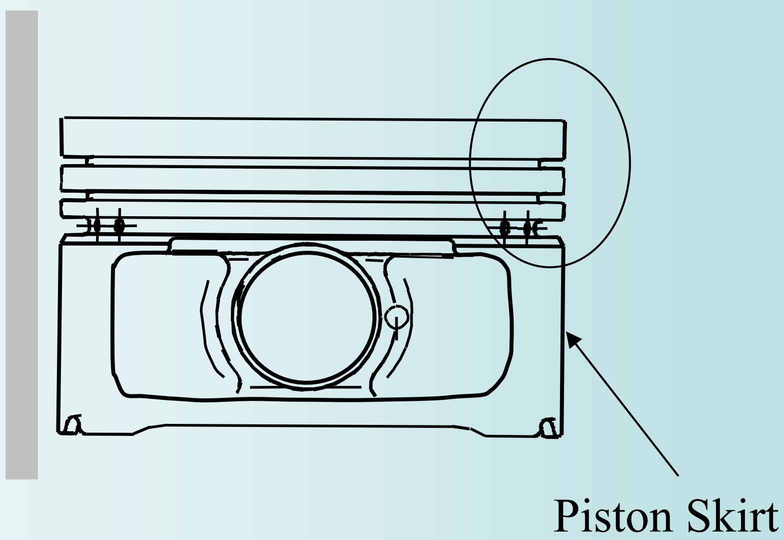
➢Potential for improvement



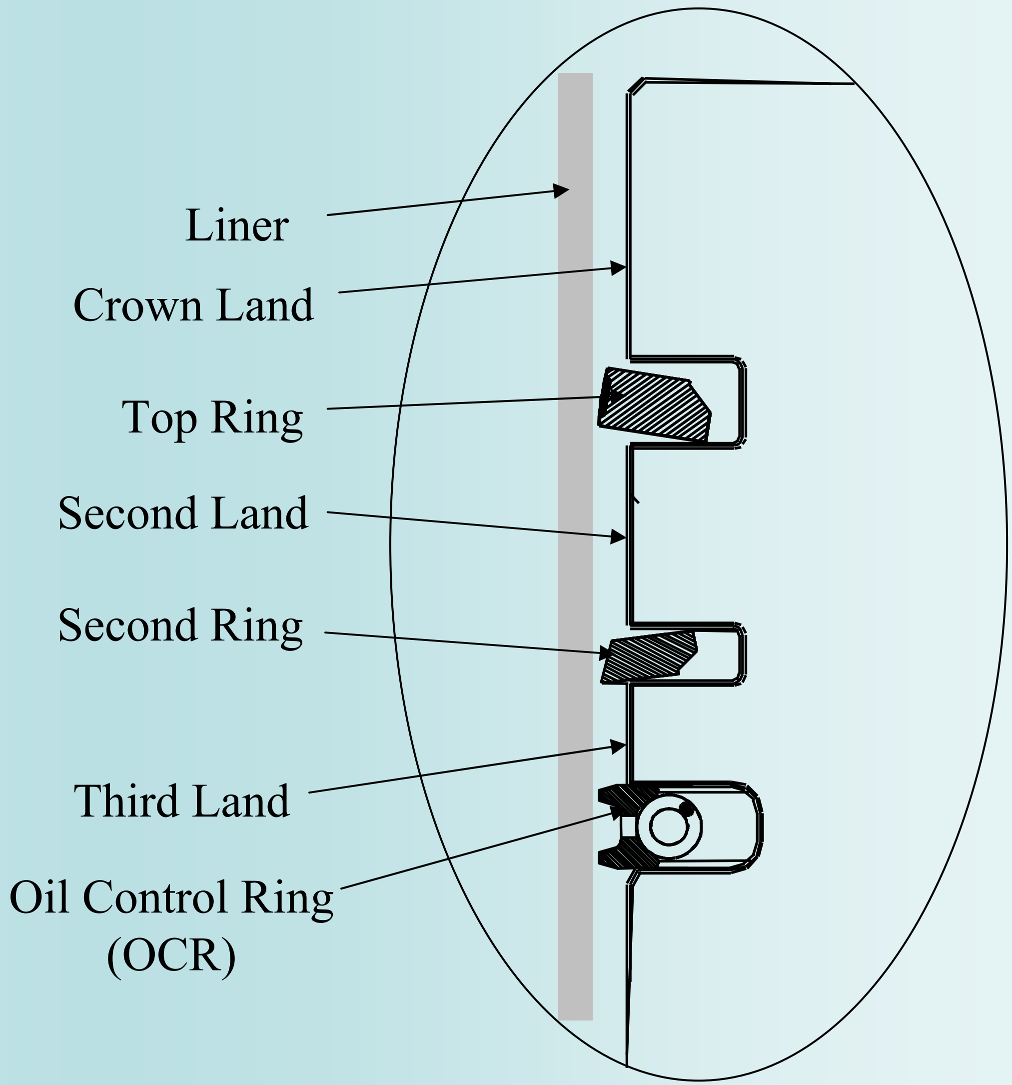
- At 1800 rpm, motoring friction is higher in Waukesha VGF18
- Even higher friction is expected in firing conditions

System Terminology

Skirt-Liner System

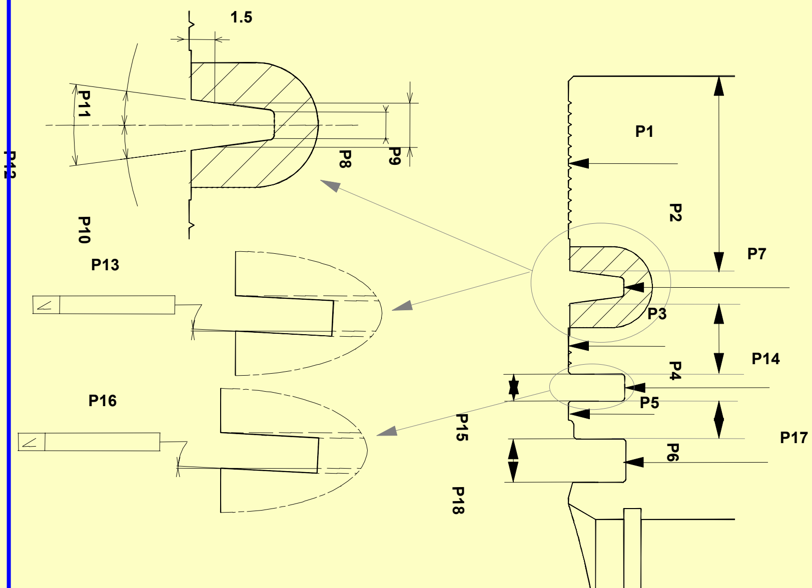


Ring-Liner (or Ring-Pack) System

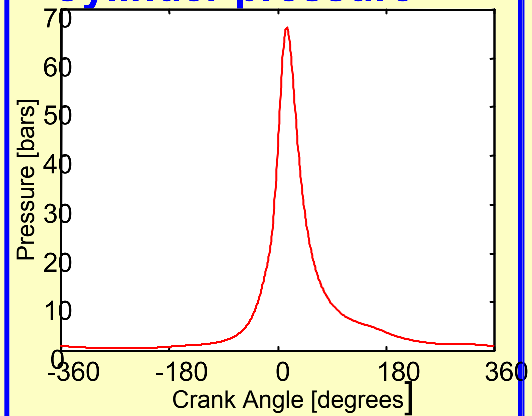


Considering design and operating parameters

Piston Parameters



Cylinder pressure



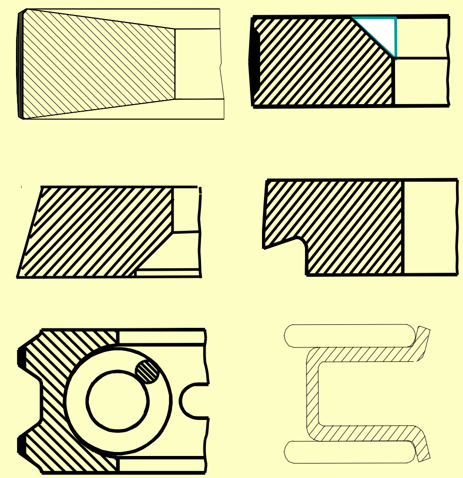
Crankcase pressure

Engine speed

Temperatures

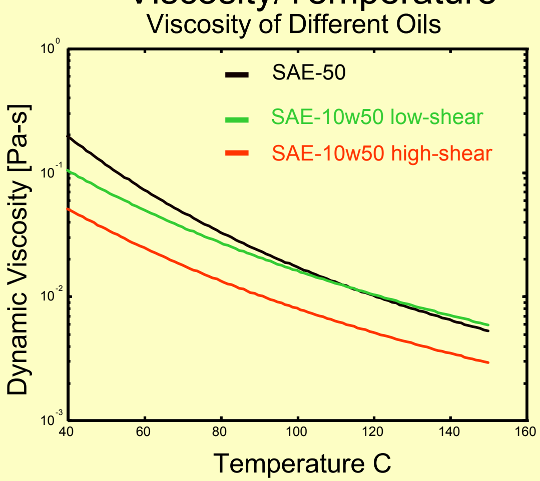
Piston thermal expansion

Ring Parameters



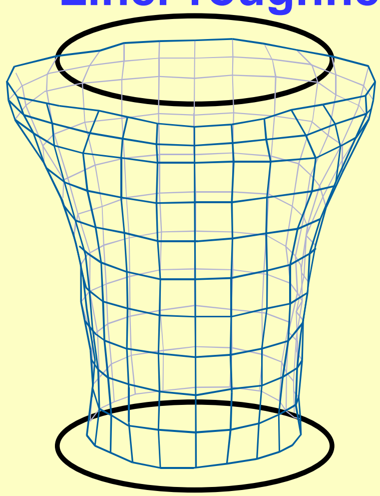
Oil Specifications

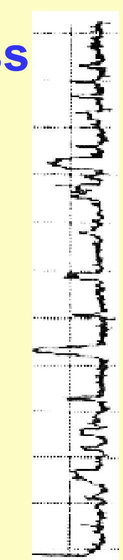
Viscosity/Temperature



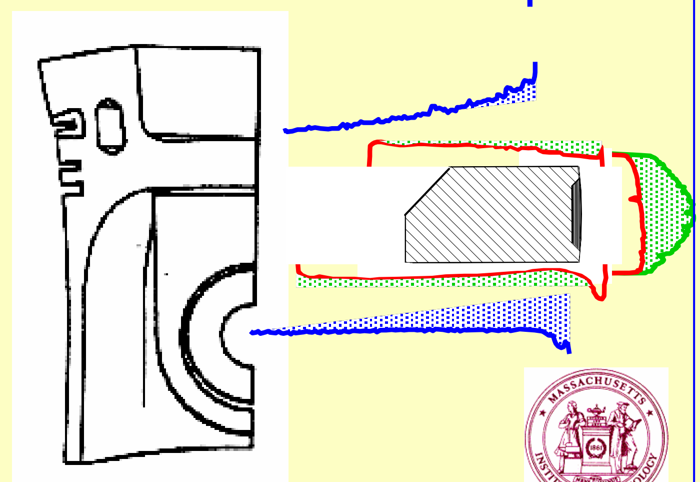
Bore distortion

Liner roughness

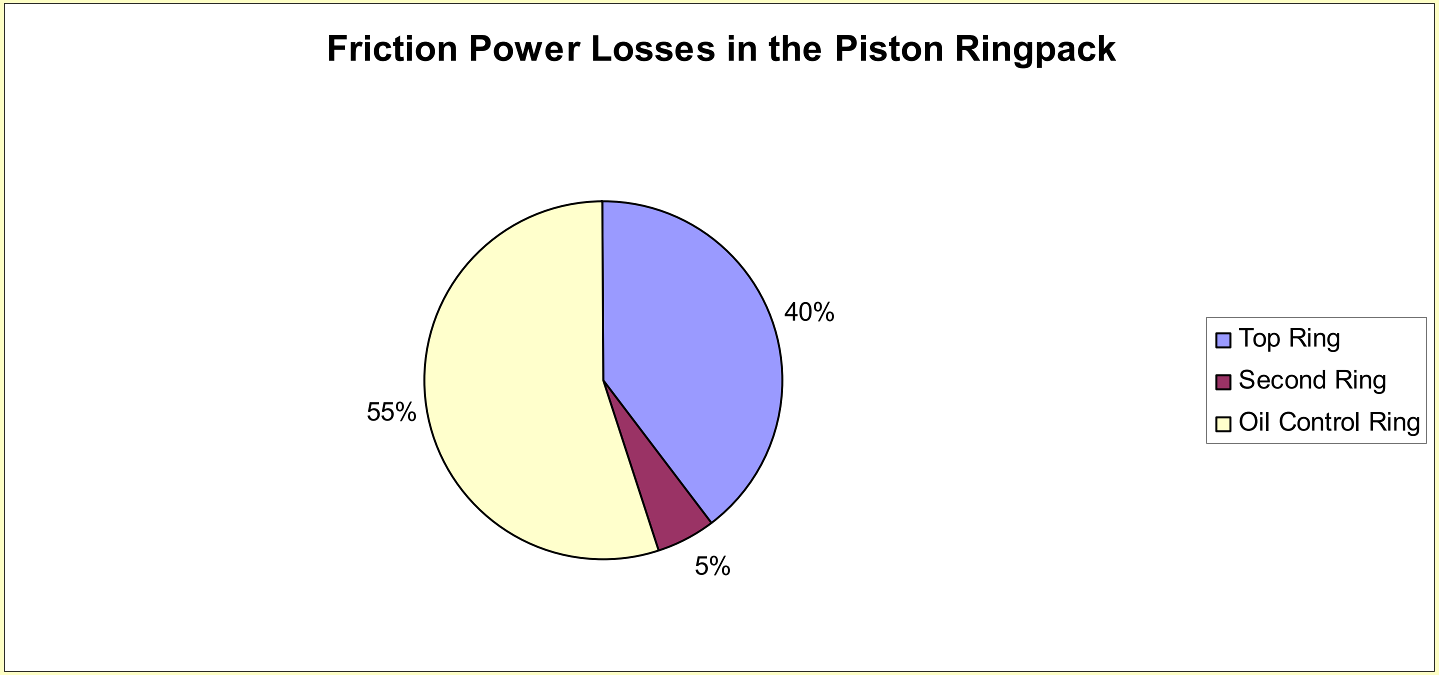




Thermal Distortion and worn patterns



Main Ring-pack Friction Contributors

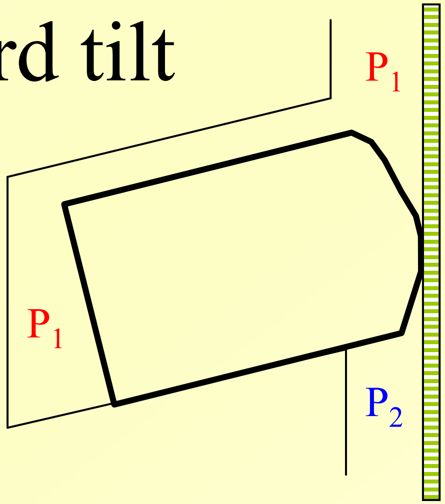


- Top ring and oil control ring are main contributors to friction in ring-pack

Friction Reduction Strategies

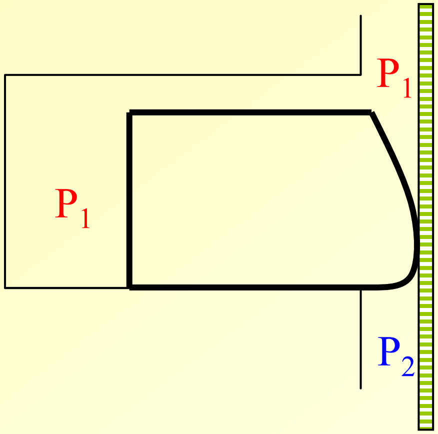
Top Ring

1. Introduce top ring groove upward tilt



• Goal is to minimize area over which high pressure difference acts

2. Manufacture top ring with a skewed barrel profile

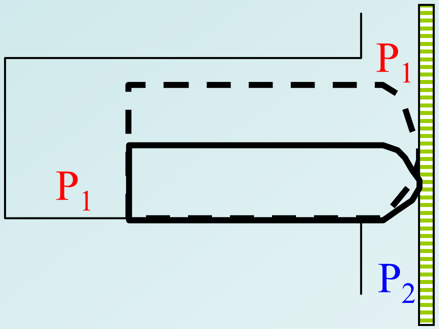


• Goal is to minimize area over which high pressure difference acts

Friction Reduction Strategies

Top Ring

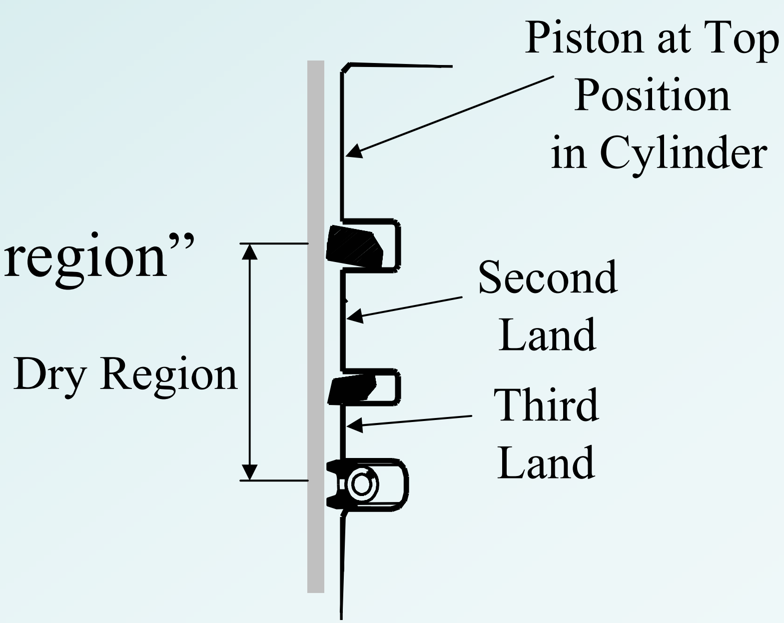
3. Reduce top ring axial height



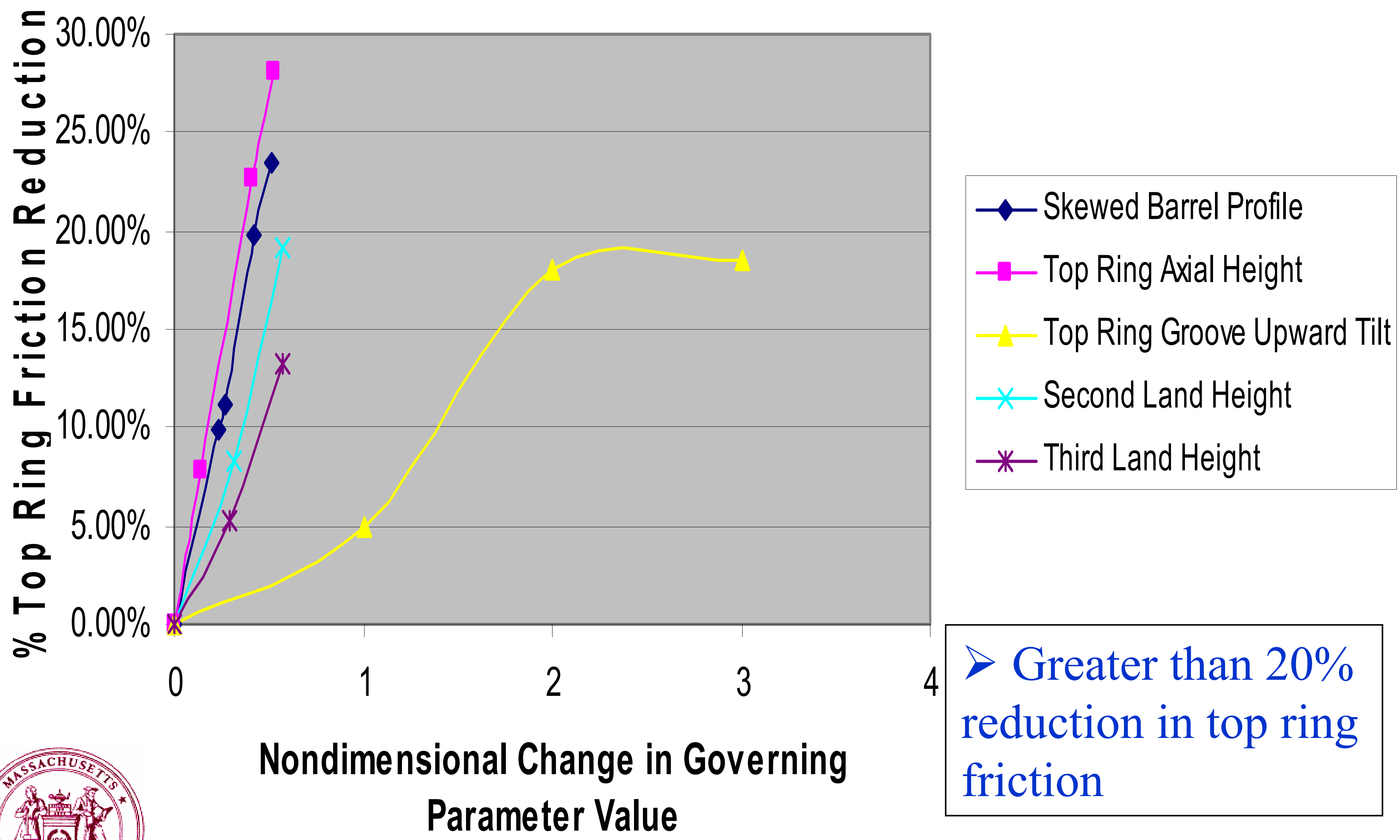
• Goal is to minimize area over which high pressure difference acts

4. Reduce second land and third land heights

• Goal is to minimize length of “dry region” where little oil exists on the liner



Top Ring Friction Reduction

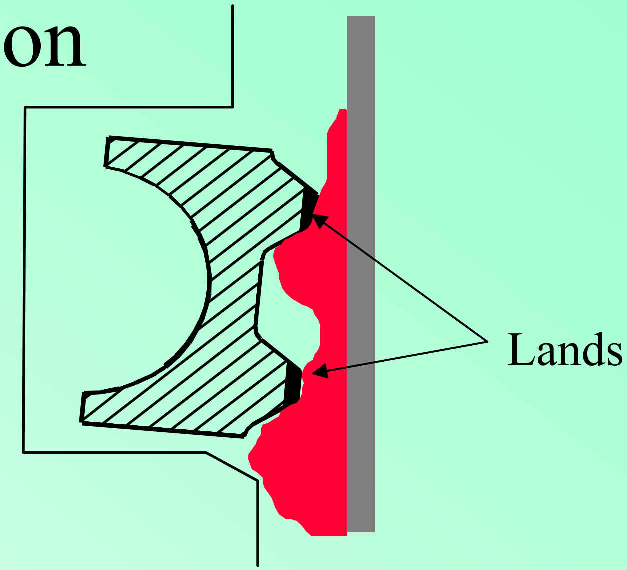


- Greater than 20% reduction in top ring friction

Friction Reduction Strategies

Oil Control Ring

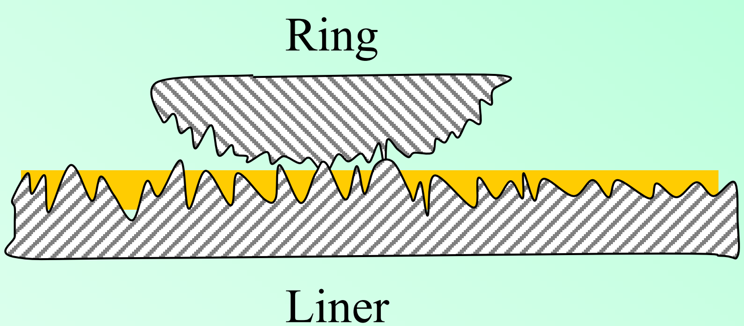
1. Reduce oil control ring tension



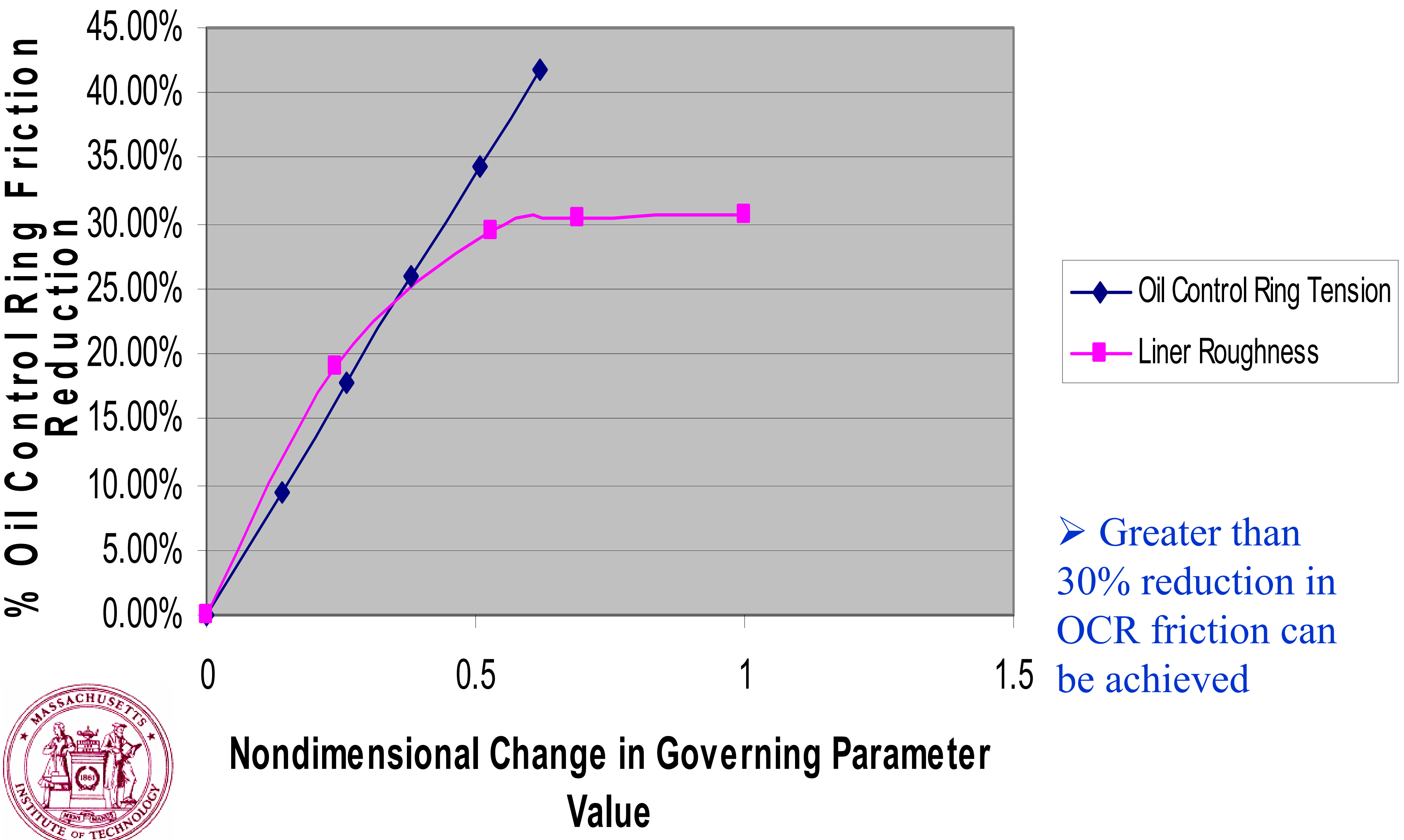
- Goal is to reduce high force acting on small lands, which creates high unit pressure on oil film, reducing oil thickness

2. Reduce liner roughness

- Goal is to reduce friction generated by rough surfaces in contact

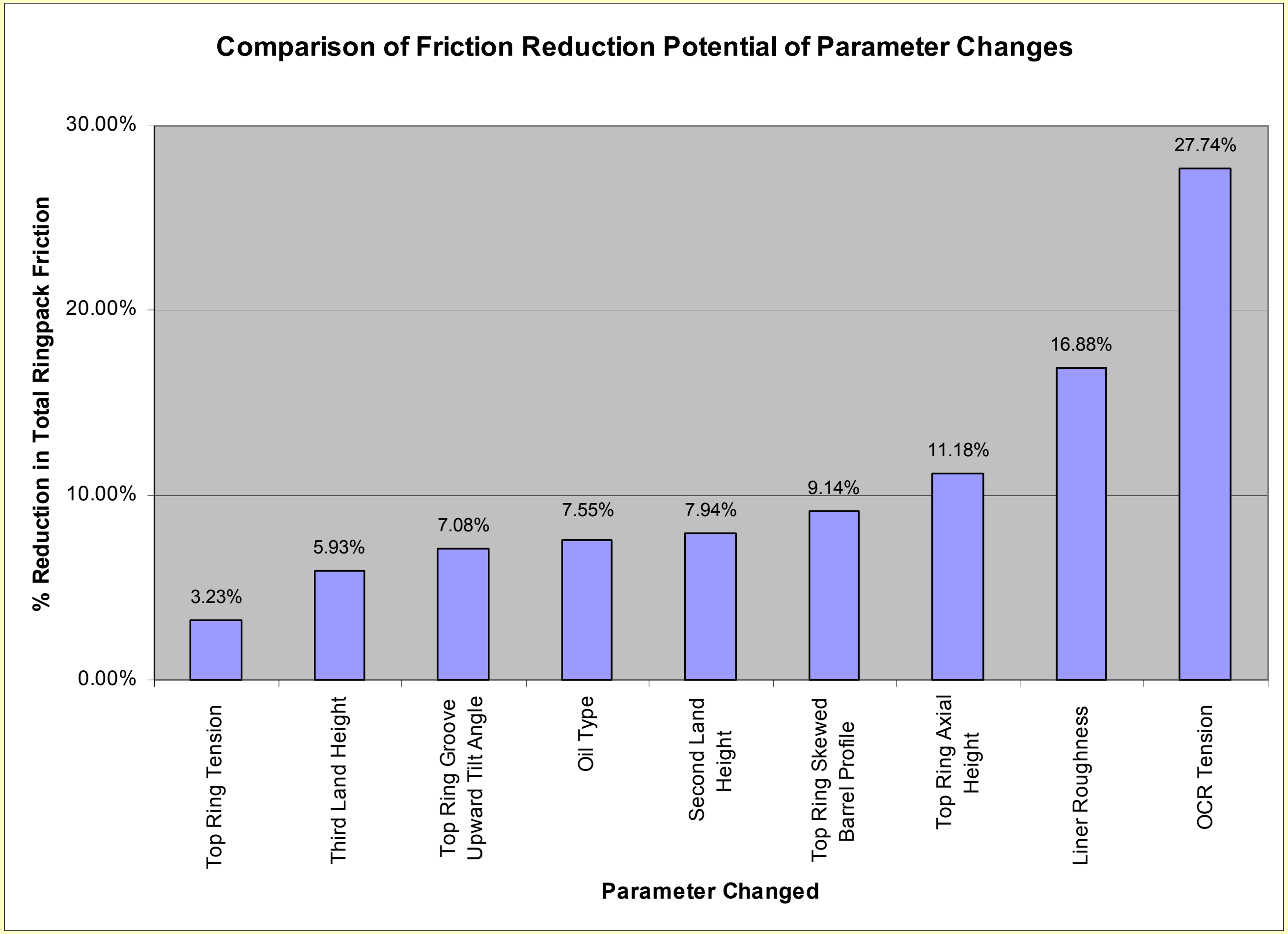


Oil Control Ring Friction Reduction



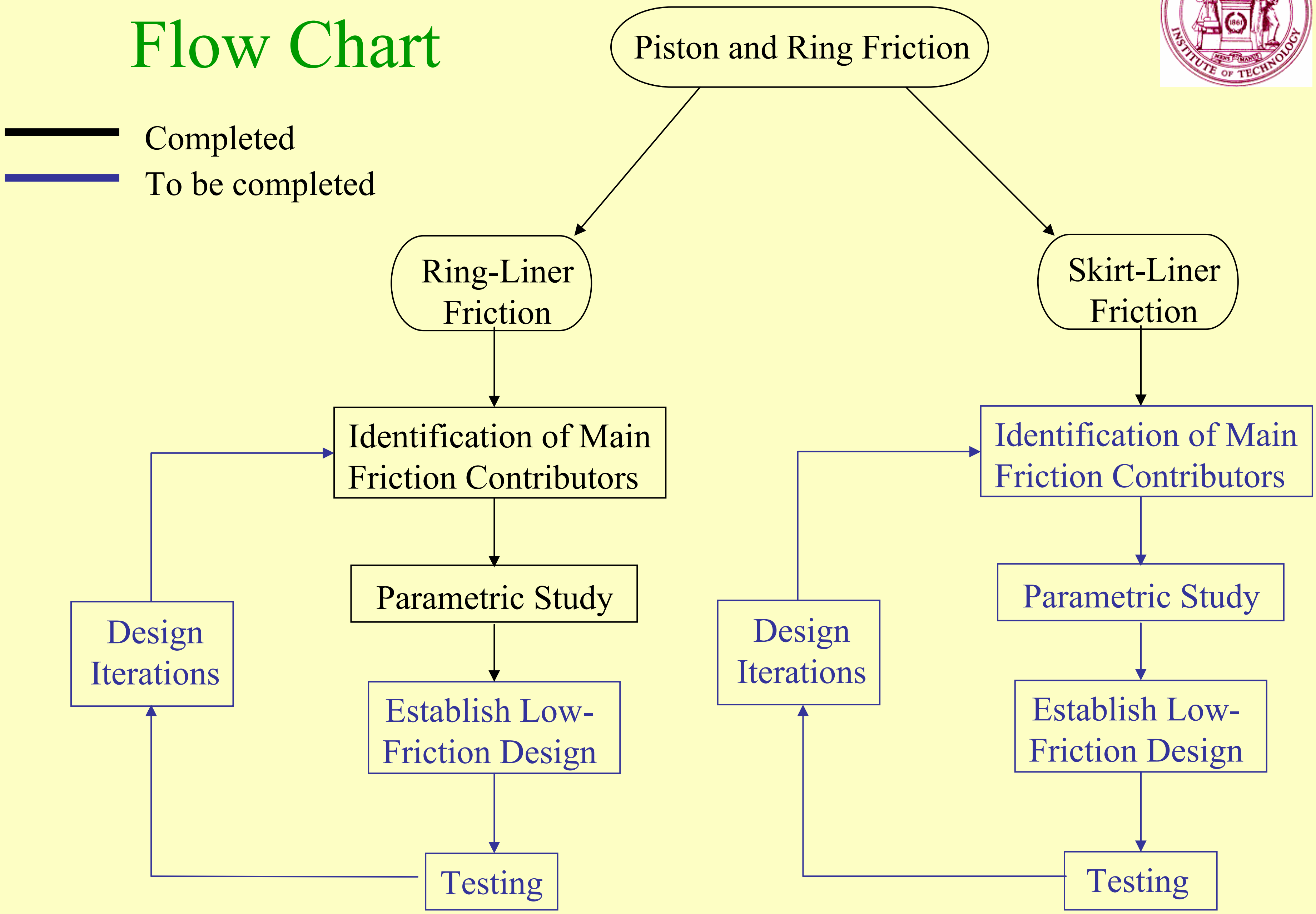
- Greater than 30% reduction in OCR friction can be achieved

Summary of Results



- Application of all parameter changes in combination results in a reduction of total ringpack friction of 50%

Continuing Study Flow Chart



Current Focus Areas

1. Development of low-friction ring-pack design guidelines based on parametric study results

- Identify limitations on changes in ring-pack design parameters (evaluate potential increases in wear, oil consumption, blow-by, etc.)

2. Piston-skirt liner friction study

Engine Instrumentation (1/2)

Fully Instrumented Engine

Pressure Measurement Using Rosemount 3051 Pressure Transmitters

- **Blow-by**
- **Intake Air Pre-Turbo**
- **Intake Air Post-Turbo**
- **Intake Air Intercooler Differential**
- **Intake Manifold**
- **Fuel**
- **Exhaust Manifold**
- **Exhaust Post-Turbo**

Colorado State University

Engine Instrumentation (2/2)

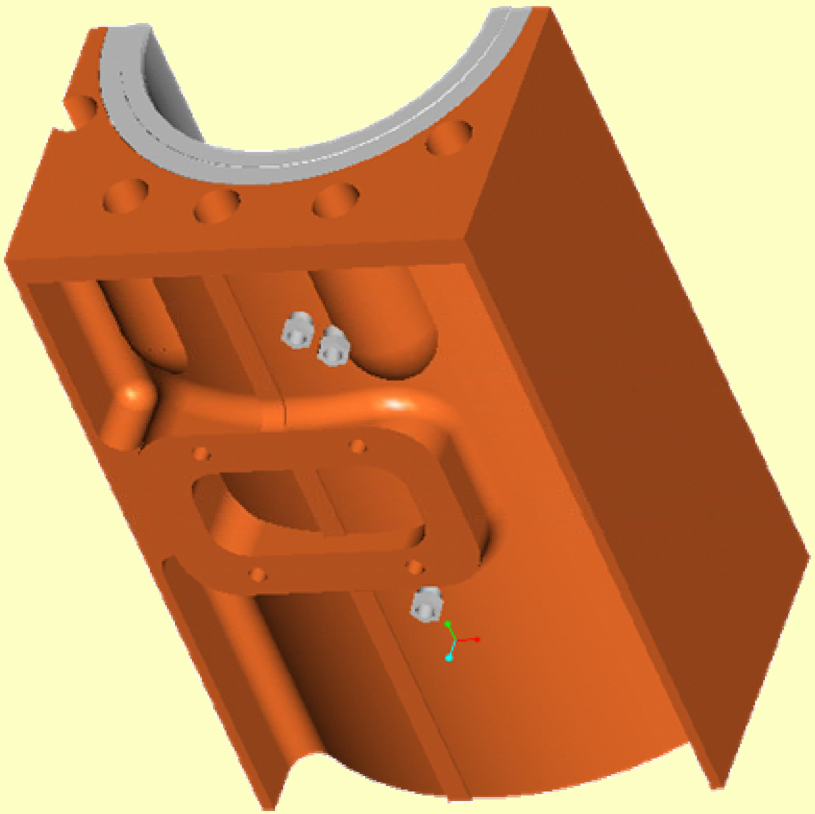
Fully Instrumented Engine

Temperature Measurement Using Omega K-type Thermocouples

- Blow-by
- Intake Air Pre-Turbo
- Intake Air Post-Turbo
- Intake Air Post Intercooler
- Intake Manifold
- Fuel
- Cylinder Exhaust (all 6 cylinders)
- Exhaust Manifold
- Exhaust Post-Turbo
- Jacket Water in and out
- Intercooler Water in and out
- Oil Cooler Oil in and Out
- Oil Cooler Water in and out
- Dyno Cooling Water in and Out

Inter-ring Pressure Transducers

- Pressure Transducers to be Mounted Offset of Cylinder Centerline in order to Miss Head Stud
- Special Mag-Drill Base Plates and Cutting Tools on Order To Facilitate Machining



Testbed Facilities:
Environmental Control

- Used to control temperature & humidity
- Allows for Simulation of a wide Variety of Atmospheric Conditions

Emissions Measurement: 5-Gas Bench for Criteria Pollutants

Hydrocarbons –
  Flame ionization detector

NOx
  Chemiluminescence

Oxygen
  Paramagnetic

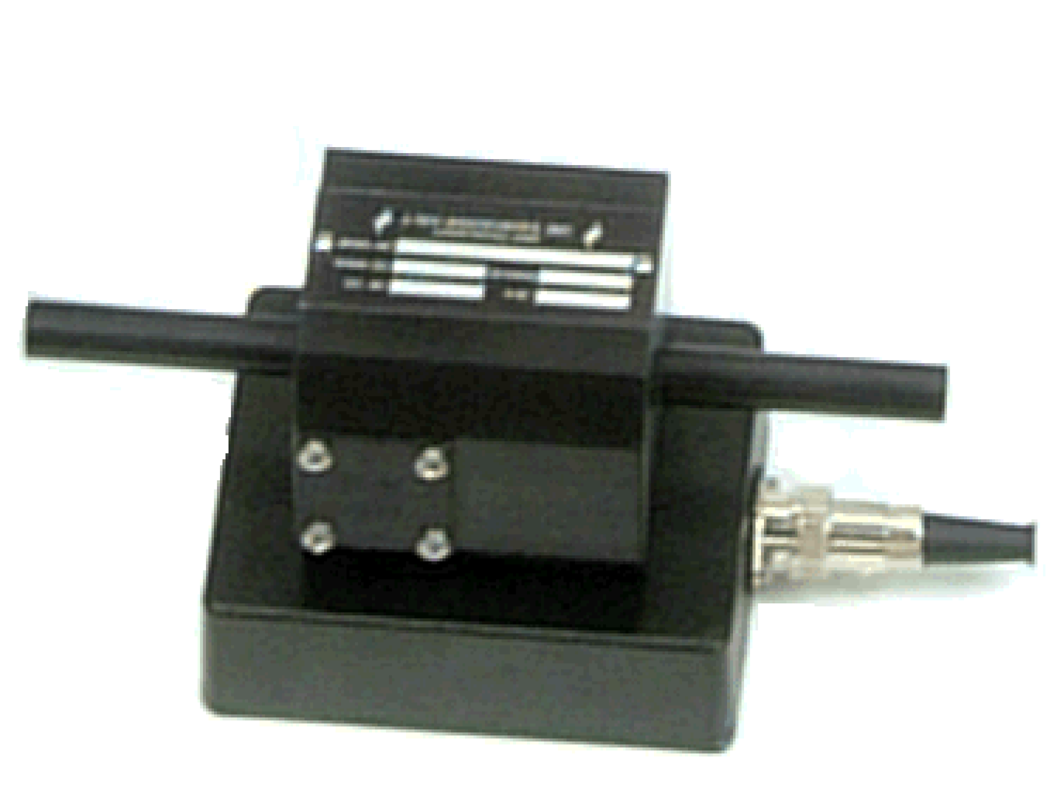
CO & CO_2
  Non-dispersive infrared

FTIR for HAPs

- HAPs measured with Fourier Transform Infrared (FTIR) Spectrometer
- Measures absorption in infrared spectrum
- Measures ≈40 compounds

Blow-by Measurement

- Blow-by Measurement Using J-Tec Associates VF 563B Inline Blow-by Meter
- Accuracy of ± 2% ≈ .32 SCFM
- Repeatability of ± 0.5% of Reading



Oil Consumption Measurement

- Oil Consumption Measurement Using AVL 403S Oil Consumption Meter
- Automatic Refill
- Refill Level Accuracy of 2**m**m
- Refill Quantity Accuracy of ±1gm and ±1% Quantity Refilled

Summary of Tests and Validation

- Waukesha F18GL Engine Installed and Operational
- Blow-by Measurement Device Installed and Operational
- Inter-Ring Pressure Transducer Mounting Design Complete
- Oil Consumption Measurement Strategy Finalized
- Baseline Testing Scheduled for Mid April

Project Team

Project: Low-Engine-Friction Technology for Advanced Natural Gas Reciprocating Engines

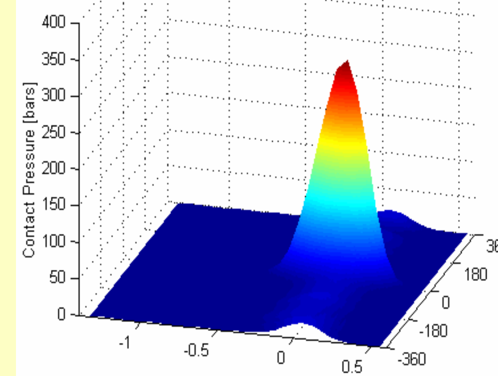
Sloan Automotive Engine Laboratory
Massachusetts Institute of Technology
Faculty/Staff: Victor W. Wong, T. Tian, J. B. Heywood
Graduate Students: Grant Smedley, Ertan Yilmaz

Sub-Contractor:

Engines and Energy Conversion Laboratory
Colorado State University
Faculty/Staff: Bryan Willson, Ted Bestor
Graduate Students: Nathan Lorenz , Tim Bauer
Undergraduate Student: Travis Mathis

With support from
Waukesha Engine Dresser, Inc.
Edward Reinbold, Rick Donahue, Jim Drees

Questions?



Value

Trend

piston/rings
surface finish
oil transport
test results

Knowledge

Project: Low-Engine-Friction Technology for Advanced Natural Gas Reciprocating Engines