INTRODUCTION TO STOCHASTIC PREIGNITION

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Coordinating Research Council
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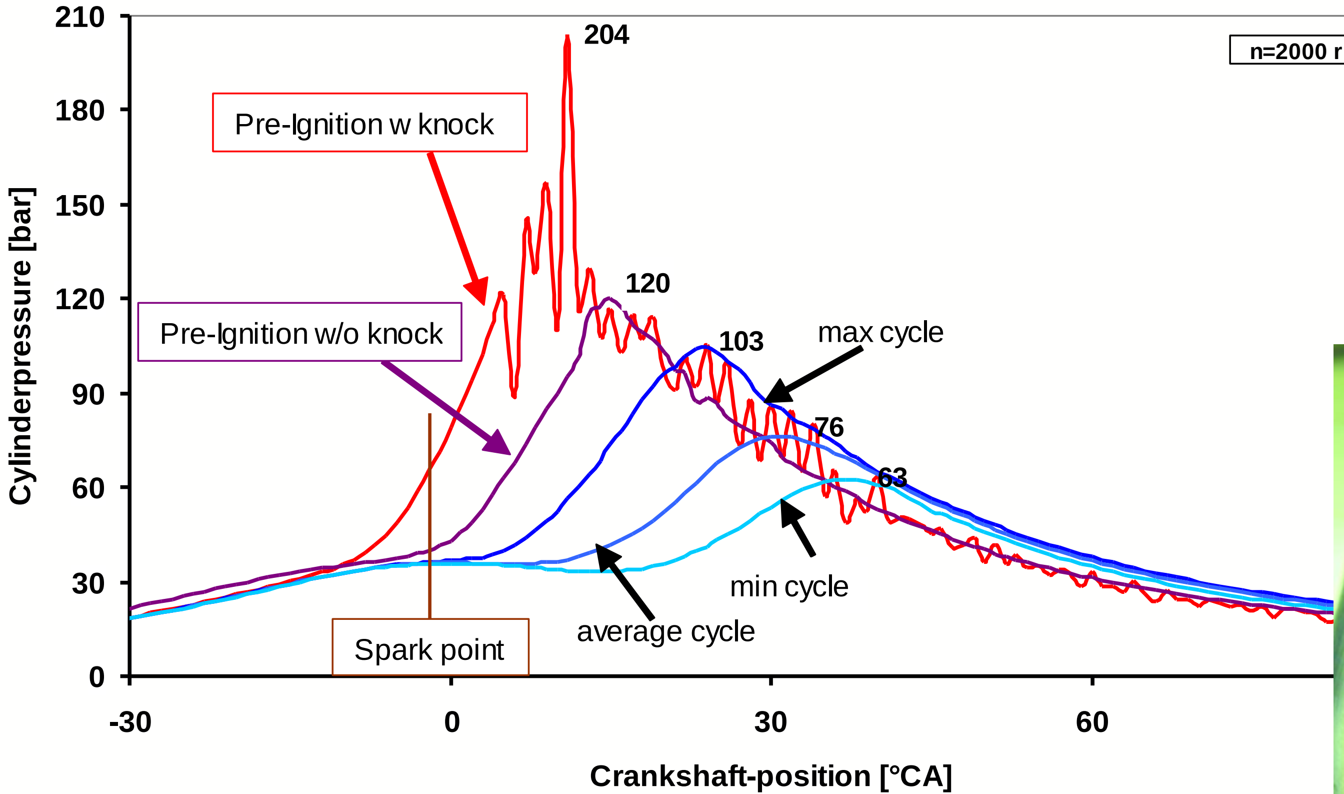
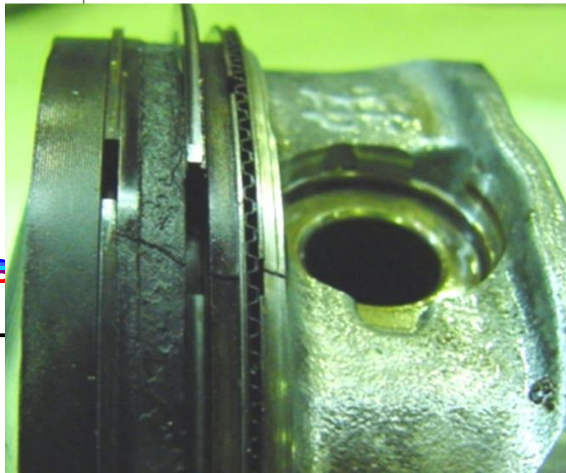
AVFL and Performance Committees

WHAT IS SPI-STOCHASTIC PREIGNITION?

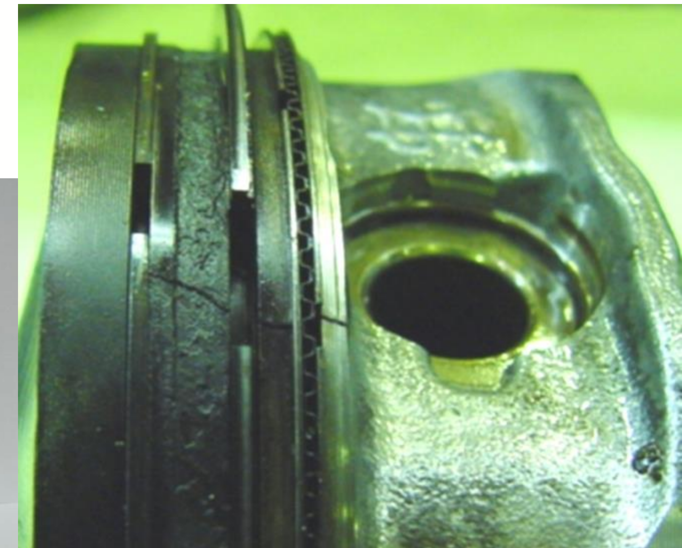
- Early pressure rise in the cylinder, prior to a normal average cycle ignition, which can exhibit damaging high peak cylinder pressures and engine knock.
- Can Occur with and without knock, and before or after the spark point, and with pressure occurring in advance of the normal cycle
- Damaging cycles are those with Peak Pressure above the engine design (sometimes called Superknock)





SIGNIFICANCE OF STOCHASTIC PRE-IGNITION ISSUE:

- OEMS are introducing Turbocharged engines for improved fuel economy
- SPI failures have been found in Turbocharged engines
- Failure modes look like
    - Cracked pistons
    - Broken piston skirts, lands, and rings

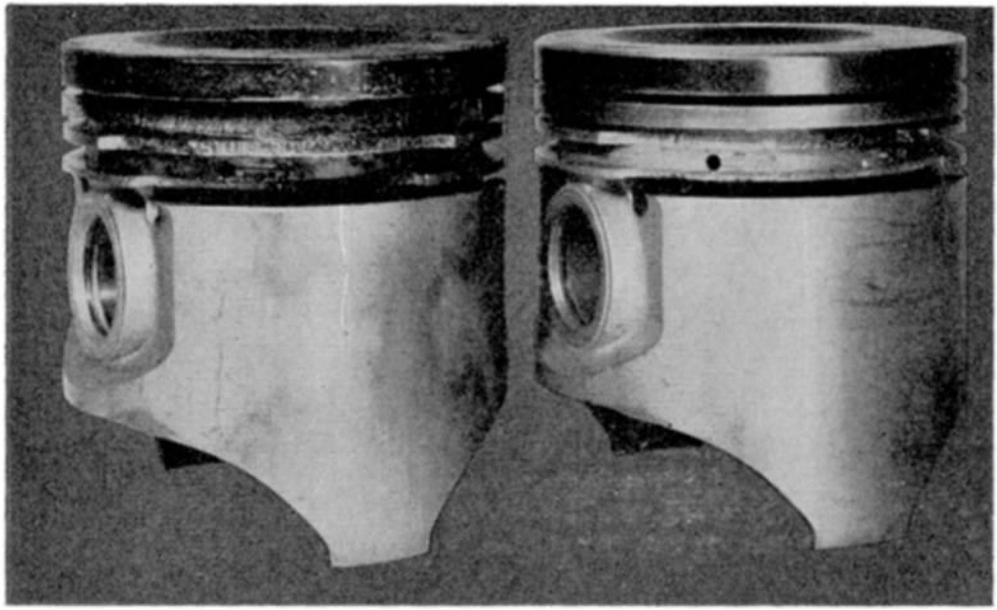


“Lubrication Challenges for TGDI engines”- Briggs, SwRI

WHAT HISTORY TELLS US

20th-century observations

- SAE 2015-01-1869 / JSAE 20159129
- *Originally presented 2015 Fall PFL meeting in Kyoto, Japan*



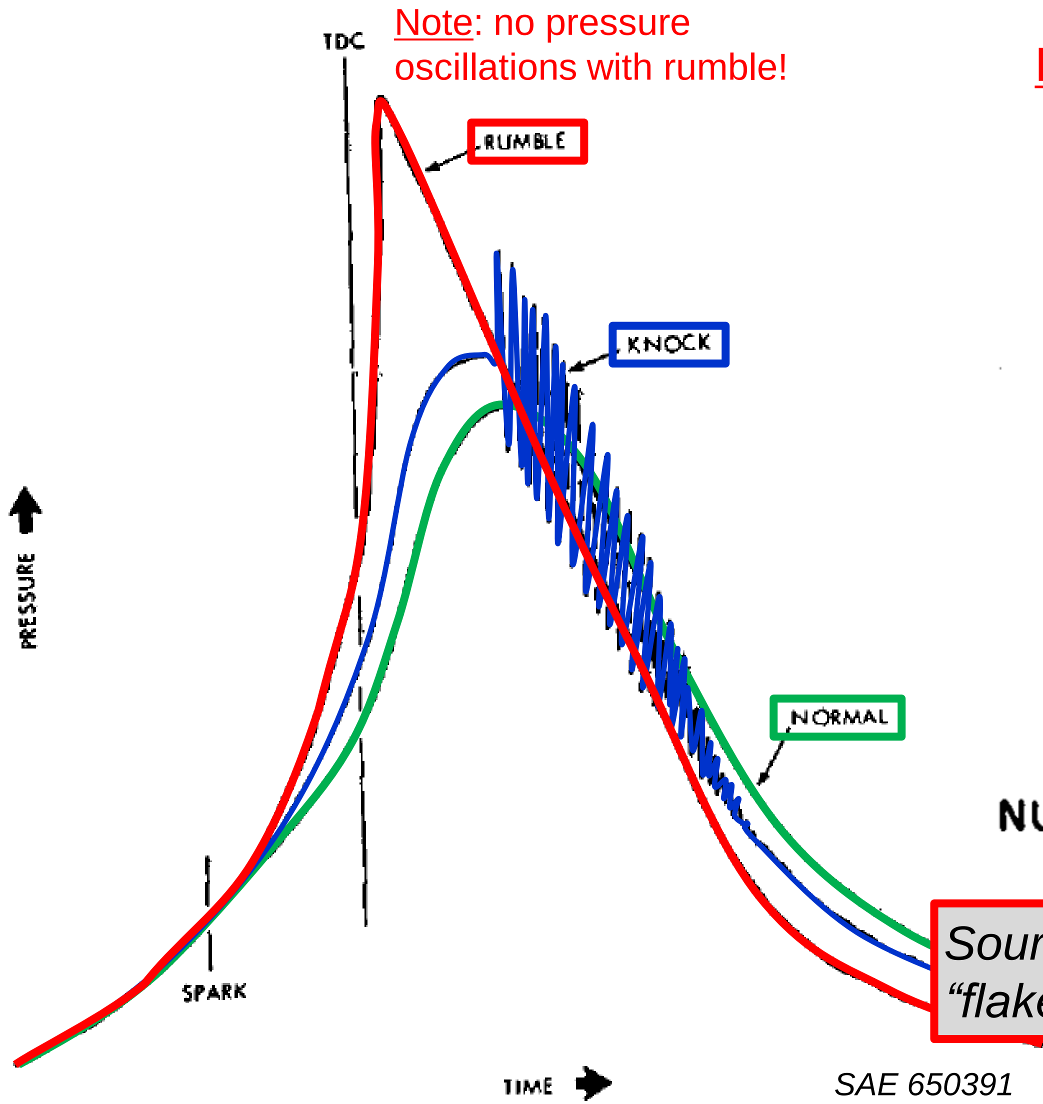
Caris, D., Nelson, E., "a new look at High Compression Engines", Society of Automotive Engineers Technical Paper # 590015 , 1958.

Rumble – *key points*

- Low pitched noise in the ~800 to 1400 Hz range(10)
  – Due to bending vibration of the crankshaft, <u>caused by abnormally high pressure rise rates</u> (11)
- *Distinctly different than end-gas autoignition / knock!*
  – <u>Isooctane</u>: RON = 100, very ***<u>resistant</u>*** to rumble (10)
  – <u>Benzene</u>: RON ~ 103, very ***<u>prone</u>*** to rumble (10)

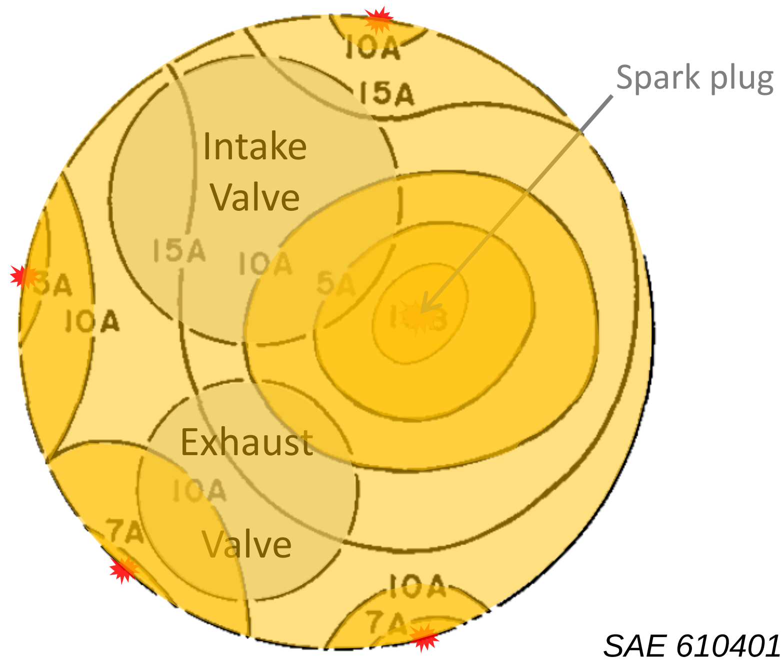
(10) SAE 650391; (11) SAE 610401

RUMBLE – *SAMPLE DATA*



SAE 650391

Flame Propagation During Rumble



SAE 610401

NUMBERS DENOTE CRANK ANGLE

Source of abnormal ignitions was hot "flaked" combustion chamber deposits.[10]

(10) SAE 650391

RUMBLE – *CAUSE*

- Source was abnormal ignition initiated ***at hot "flaked" combustion chamber deposits***[2]
  - Extended operation at light duty schedules tended to produce deposits prone to result in rumble[3]
  - Operation at high load / speed would then result in abnormal ignition from these deposits[3]

(2) SAE 610401; (3) SAE 590018

Wild Ping – *key points*

- “One or more erratic sharp cracks” (9)
- ***The result of loose deposit particles causing significantly advanced preignition***, ultimately resulting in knock (11)
- <u>Short-lived nature</u>: particles either burn up or are exhausted (11)
- Seemingly erratic occurrence over “short” time periods (17)

(9) CRC “Terms for Use in Otto Cycle Engine Combustion”; (10) SAE 650391; (11) SAE 610401; (17) SAE 540221

Summary – Past Observations of Abnormal Ignition

- **Rumble:** not similar to SPI/LSPI
- **Wild Ping:** very similar to SPI/LSPI

- *HOWEVER*, past investigators saw very similar trends with regards to abnormal ignition for both rumble and wild ping.

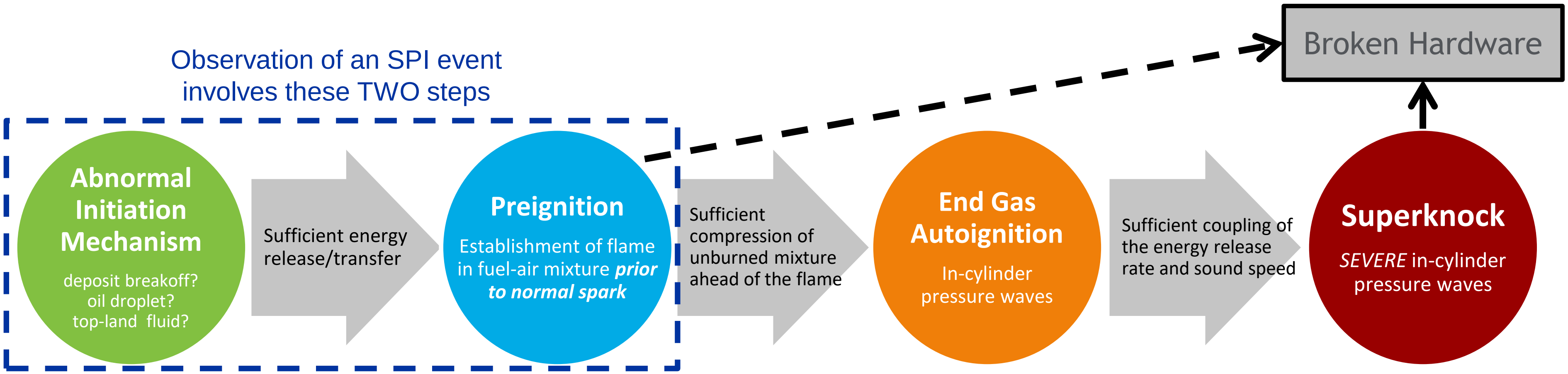
SUMMARY – Historical Effects

Factor	Tendency of fuel/lubricant derivative ignition increased as:
Fuel – base composition	Aromatic content (volume %) ↑ Higher boiling fraction components ↑ *– especially problematic were heavy molecular weight aromatics*
Fuel – additives	Phosphorus, Boron, compounds ↓ *(Lead had no consistent effect, but mostly ↑)*
Oil – base composition	Higher boiling fraction components (use of Bright Stock/ API Grade 1 as blending component) ↑
Oil – additives	Metallic detergent content (% weight) ↑ -- *impact of varying degrees based on the specific metal; calcium had the strongest impact* Viscosity Improver ? Phosphorus, molybdenum, and sulfur content ↓ Presence of zinc inhibitors ↓ *(Total sulfated ash content does not correlate)*
Operating Conditions and Hardware	In general, any factor that promotes combustion (higher temperatures and higher oxygen partial pressures) ↑ Compression ratio ↑, Intake pressure ↑, Intake temperature ↑, Engine speed ↑ Oil consumption rate↑ Soot production (due to specific operating conditions) ↑ Low Speed operation to generate deposits in the engine, followed by a transient acceleration↑
Deposit Properties	Size of particles ↑ Temperature at which the deposit ignites ↓ Temperature at which the deposit melts ↑

RECENT UNDERSTANDING

A Sequence of Events, Not a Singular Phenomenon

- Engine failure is the net result of a sequence of necessary, but not sufficient, steps

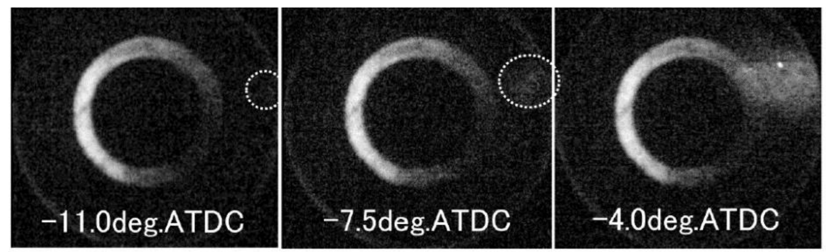


- Each step is affected by engine hardware, operating parameters, fuel properties, and lubricant properties. (!)

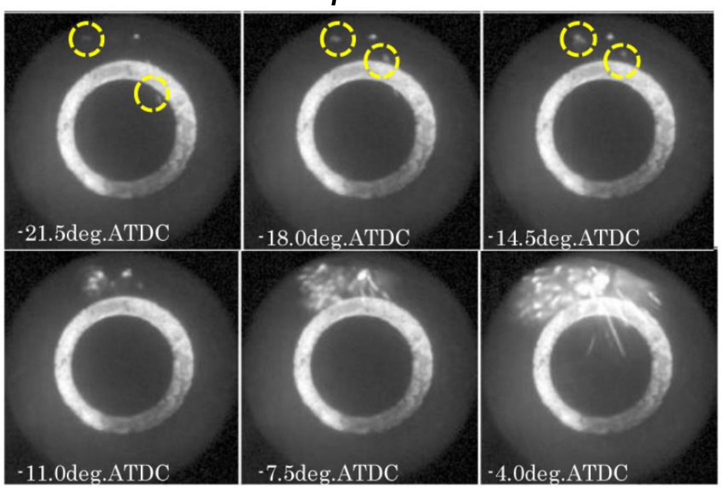
Initiation Mechanisms

- Abnormal preignition initiates from (6*):
  - Deposit particles
  - Oil droplets
  - Top land fluids

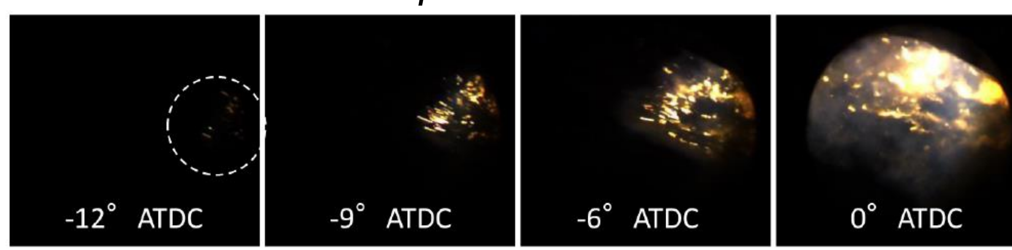
Oil Droplets



Deposits



Top-land Fluids



(6*) SAE 2015-01-0761

All images from SAE 2015-01-0761

Comparison to Historical E

Legend
✓ – same trend as in the past
? – insufficient data
X – contradictory trend as in the past

Factor	↓	Tendency of fuel/lubricant derivative ignition increased as:
Fuel – base composition	? ✓ ?	Aromatic content (volume %) ↑ Higher boiling fraction components ↑ *Especially problematic were heavy molecular weight aromatics*
Fuel – additives	?	Phosphorus, Boron, compounds ↓
Oil – base composit		
Oil – additives		
Operating Condition and Hardware	? ✓ ?	Oil consumption rate ↑ Soot production (due to specific operating conditions) ↑ Low Speed operation to generate deposits in the engine, followed by a transient acceleration ↑
Deposit Properties	✓ ? ?	Size of particles ↑ Temperature at which the deposit ignites ↓ Temperature at which the deposit melts ↑

<u>It is not clear</u> that modern abnormal ignition phenomena are the **exact** same as past phenomena.

HOWEVER,

<u>It is clear</u> that many of the *trends* observed in recent history are **very similar** to those observed in the past.

WHAT’S MISSING?

SUGGESTED AREAS OF FURTHER INVESTIGATION

Suggestions made in 2016 SAE World Congress Oral Presentation

Factor	*Further Research Questions*
Fuel – base composition	• Are all aromatics problematic for all abnormal fuel/lubricant derivative ignition?
Fuel – additives	• Is there an opportunity to mitigate modern problems with a fuel additive?
Oil – base composition	• What properties of oil base stocks affect modern problems? • Do viscosity improvers increase the rate of modern problems?
Oil – additives	• Low ash or ashless additives: is there a solution that works for modern engines? (Do ashless additives "solve this problem" in modern engines?) And can ashless oils meet performance requirements of modern engines? • Does elimination of calcium "solve" the modern problem? • Is there a balanced formulation approach to "solve" the modern problem?
Operating Conditions and Hardware	• Can careful management of liner and piston temperatures eliminate modern problems? • Can piston and ring designs to manage deposits, oil and residual liquid fuel in the crevice reduce modern problems? • To what extent do in-cylinder turbulence and mixture homogeneity affect modern problems?
Deposit Properties	• Can deposit morphology and/or physical properties be affected in a way to reduce modern problems (if deposits are the root cause)?
Fundamental Root Cause	• Do trends hold if there are causes other than deposits, like oil droplets and top land fluids? • What is the impact of oil consumption rate? • Why is the modern problem sometimes worse in clean engines? • Is soot formation a root cause or a correlated observation?

WHAT'S NEXT?

GOAL OF THIS EVENT

- Technical exchange focused on role of:
  - Hardware
  - Operating conditions / operating pattern
  - Fuel
  - Lubricant

  on stochastic preignition and associated failures.

- **Identify next steps and opportunities for possible collaborative studies**