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Improved Engine Design Concepts Using the Second Law of Thermodynamics

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Improved Engine Design Concepts Using the Second Law of Thermodynamics

Presentation Outline

- Purpose of Work
- Previous Comments
- Barriers
- Approach
- Accomplishments
- Technology Transfer/Publications/Patents
- Plans for Next Fiscal Year
- Summary

Improved Engine Design Concepts Using the Second Law of Thermodynamics

Purpose of Work

- ♦ Develop engine cycle simulations
- ♦ Examine engine concepts which will –
  - reduce combustion irreversibilities
  - increase thermal efficiency
  - maintain or lower emissions
- ♦ Develop and use simplified systems
  - isolate combustion processes

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Previous Comments:

Summary Comments:

“An excellent approach to help guide improvements in engine efficiency.”

“A stronger connection with industry should be developed so that the power of this technique is brought to bear on improving the design of new engines.”

New Actions:

Will develop stronger ties to industry –

different ideas for these collaborations

invitation …

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Technical Barriers:

- No generic technical barriers for project

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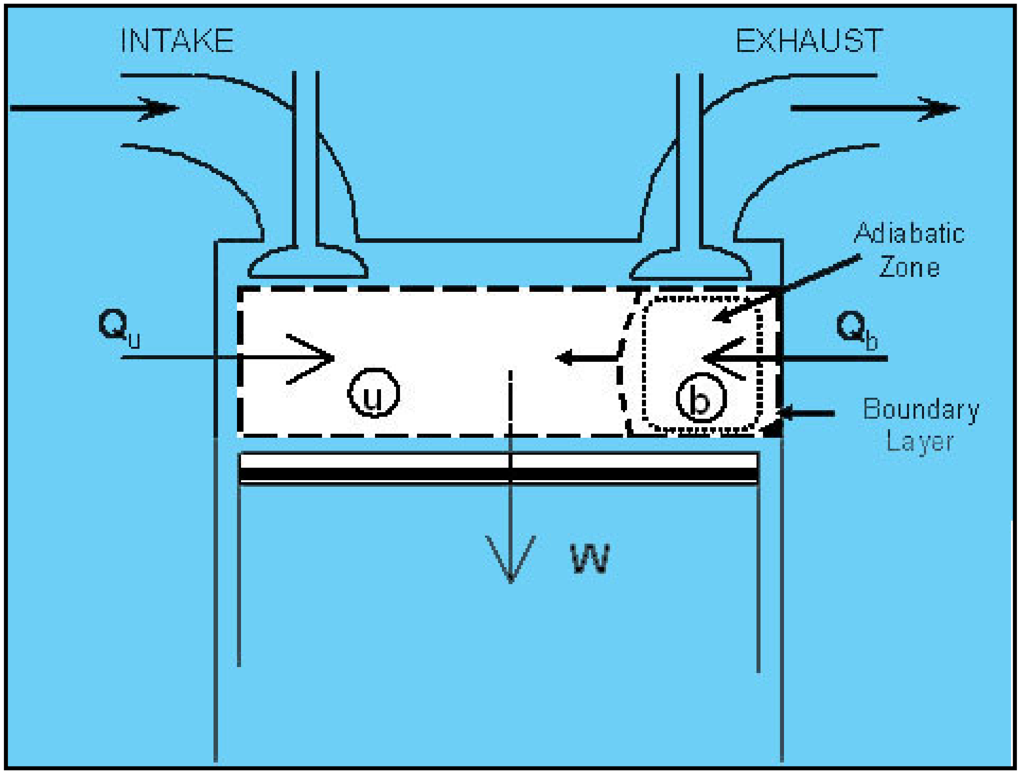
Approach: Thermodynamic System and Analyses Techniques



- An engine cycle simulation based on the first law of thermodynamics is used.
- The analysis is extended to include the second law – availability (exergy)
- Key features include detailed properties, multiple zones for combustion, and availability computations

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Accomplishments

- **Simplified Systems to Isolate Combustion Irreversibilities**
  - **Parametric studies for constant volume and constant pressure systems**
  - **Hypothetical "reversible" combustion processes for reciprocating devices**
- **Spark-Ignition Engines (most recent studies)**
  - **More realistic EGR sub-models**
  - **Effects of compression ratio**
  - **Effects of expansion ratio (over expanded engines)**
- **Diesel Engine Studies (initial results)**

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List of Previous Studies

- ♦ Effects of engine speed and load
- ♦ Effects of equivalence ratio
- ♦ Effects of combustion duration, timing and schedule
- ♦ Effects of the use of EGR
- ♦ Effects of oxygen enrichment of inlet air
- ♦ Effects of the use of hydrogen
- ♦ Effects of compression ratio
- ♦ Effects of expansion ratio (over-expanded engines)

Three Examples of Results from this Work

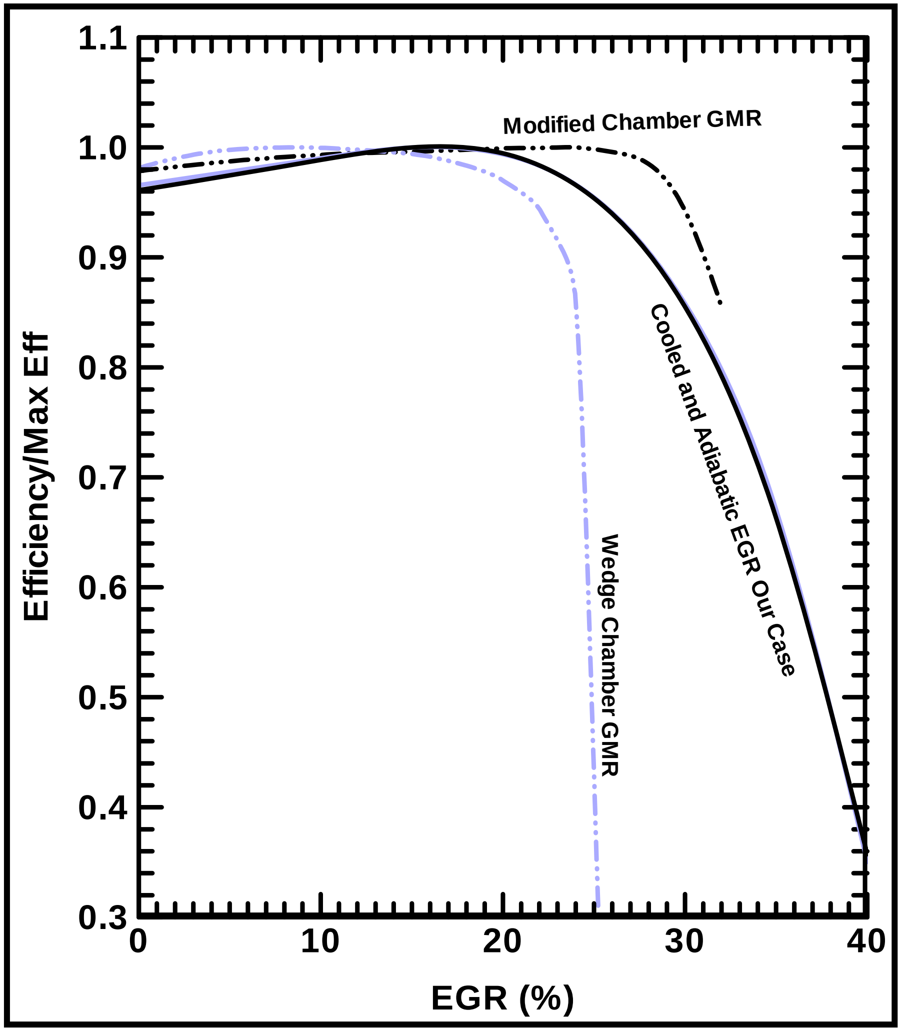
1. SI Engine with EGR
2. Use of Over-Expanded Engines
3. Preliminary Diesel Engine Results

Engine Cycle Simulation:

EGR Sub-Model Improvements

Parametric Study

Engine Cycle Simulation
Improved EGR Model



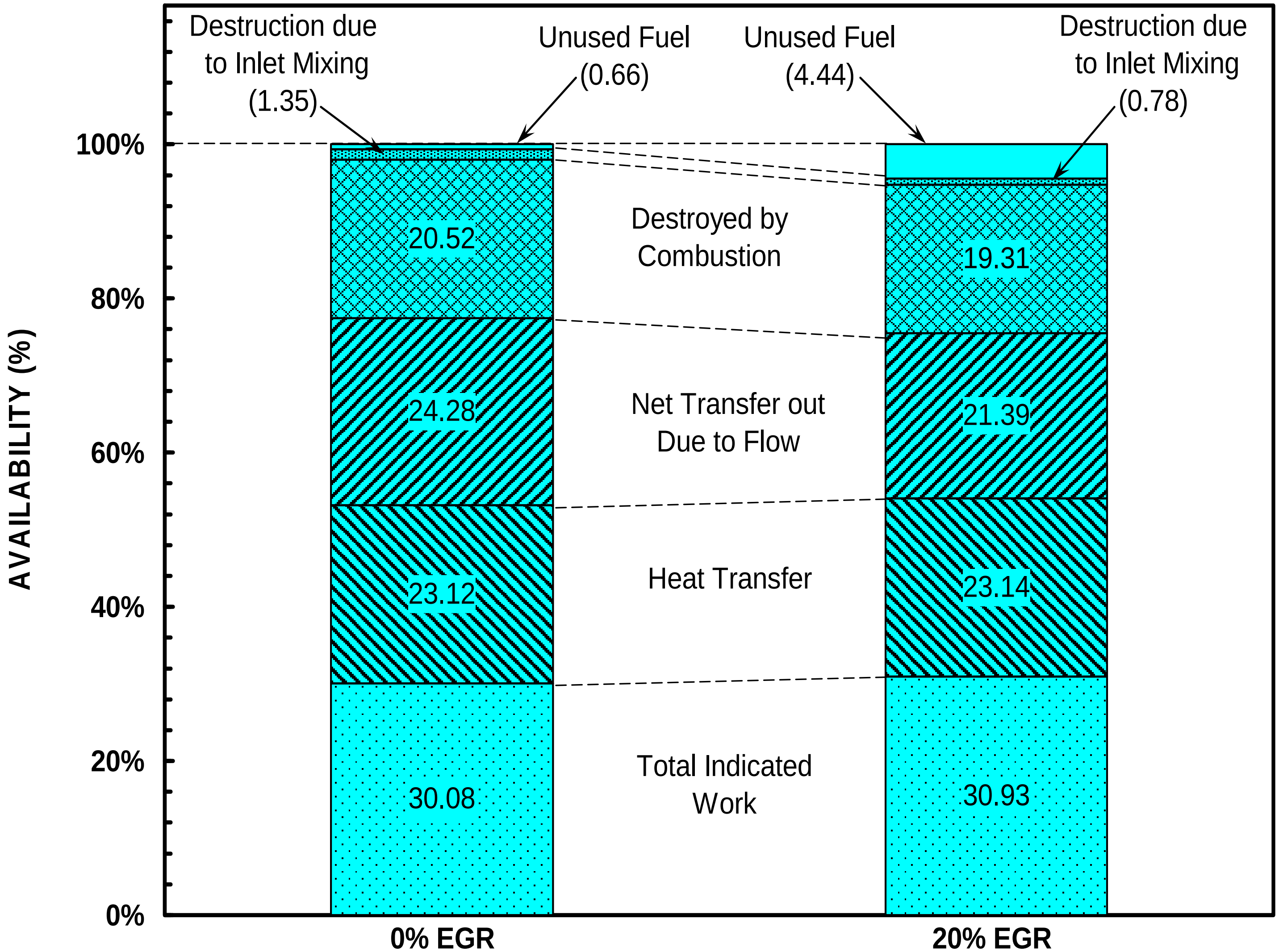
Improved EGR sub-model –

♦ **Combustion "termination" for higher levels of EGR helped match experimental results**

♦ **Longer burn duration (while maintaining optimum timing) for higher levels of EGR not too significant**

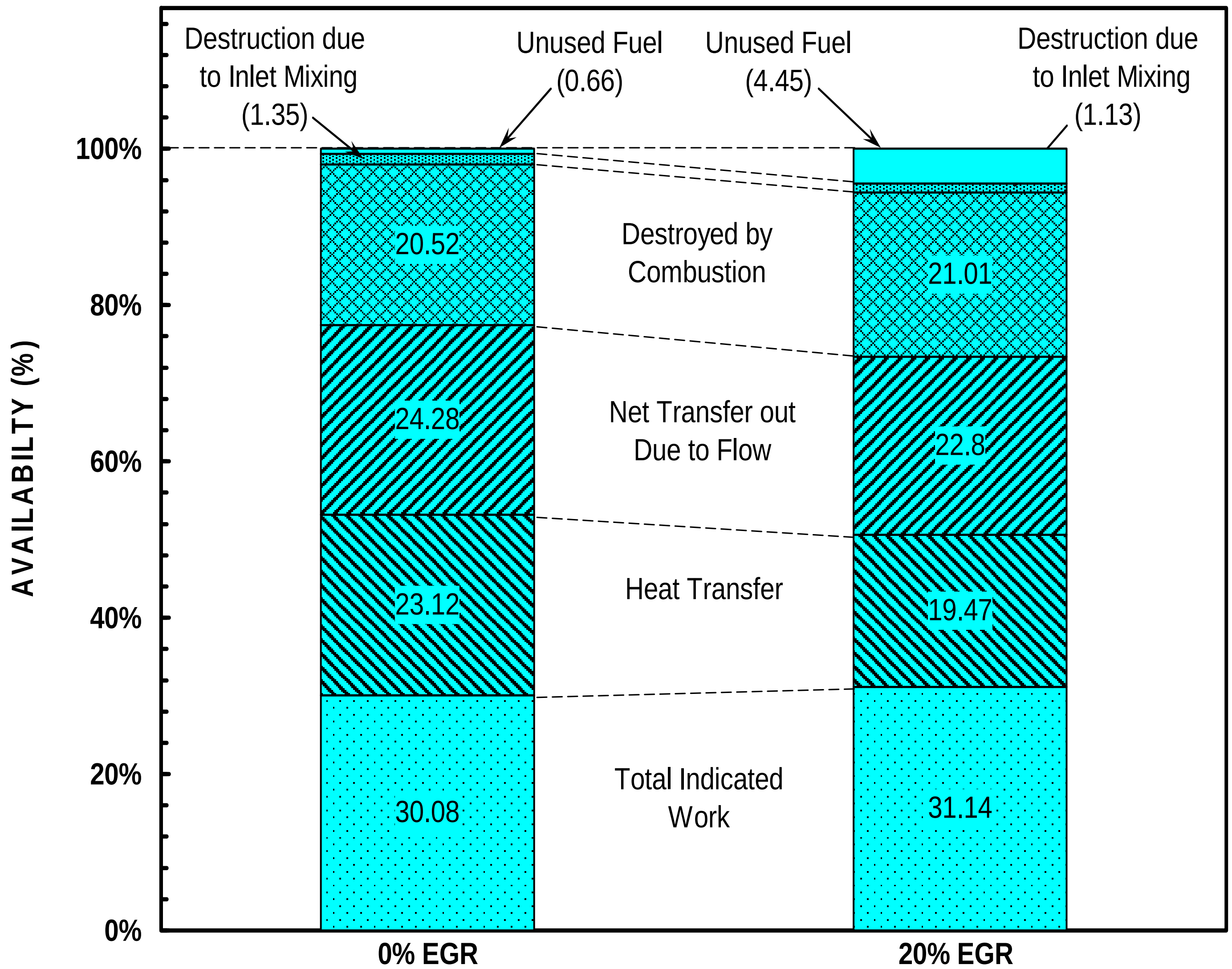
Engine Cycle Simulation: Improved EGR Model

Adiabatic EGR Configuration

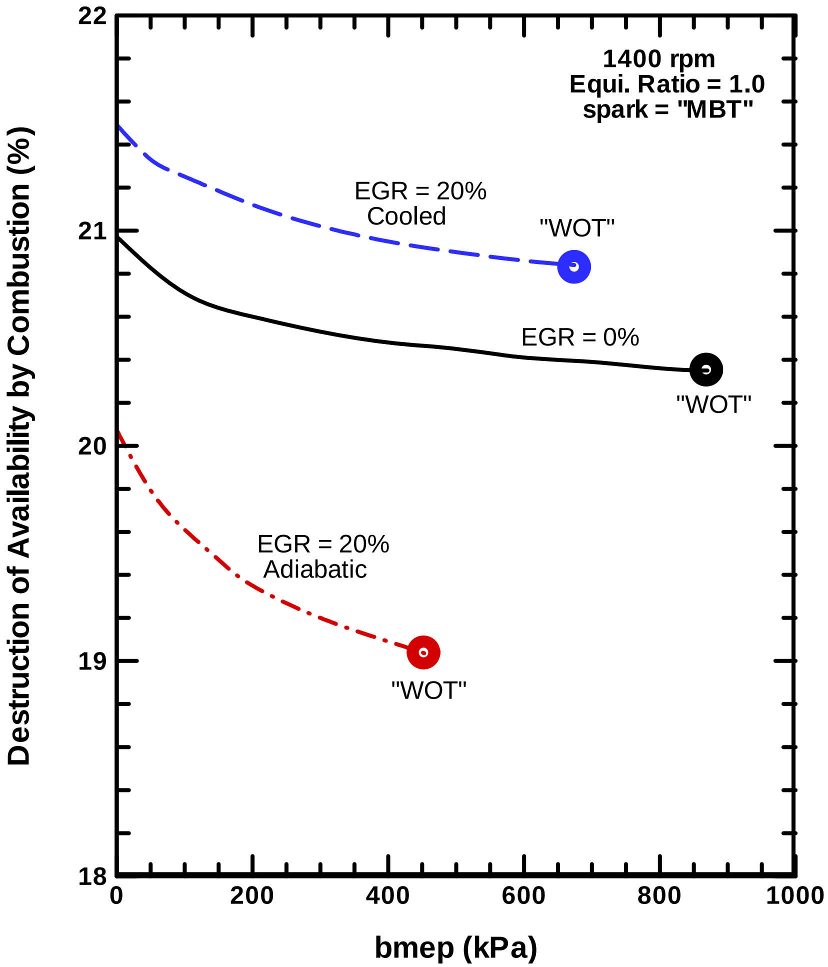


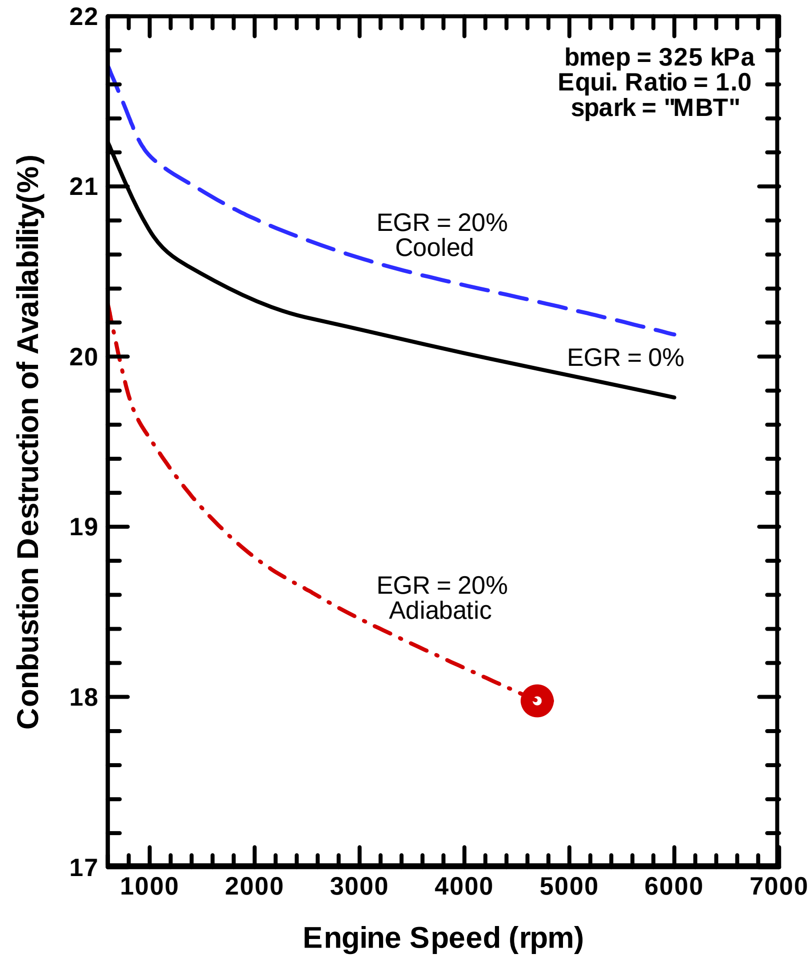
Engine Cycle Simulation: Improved EGR Model

Cooled EGR Configuration



Engine Cycle Simulation
Improved EGR Model
Second Law Results – Load and Speed





Effects of Expansion Ratio

(for a constant compression ratio)

a novel engine mechanism needed

"Atkinson" Cycle Assumptions/Approximations

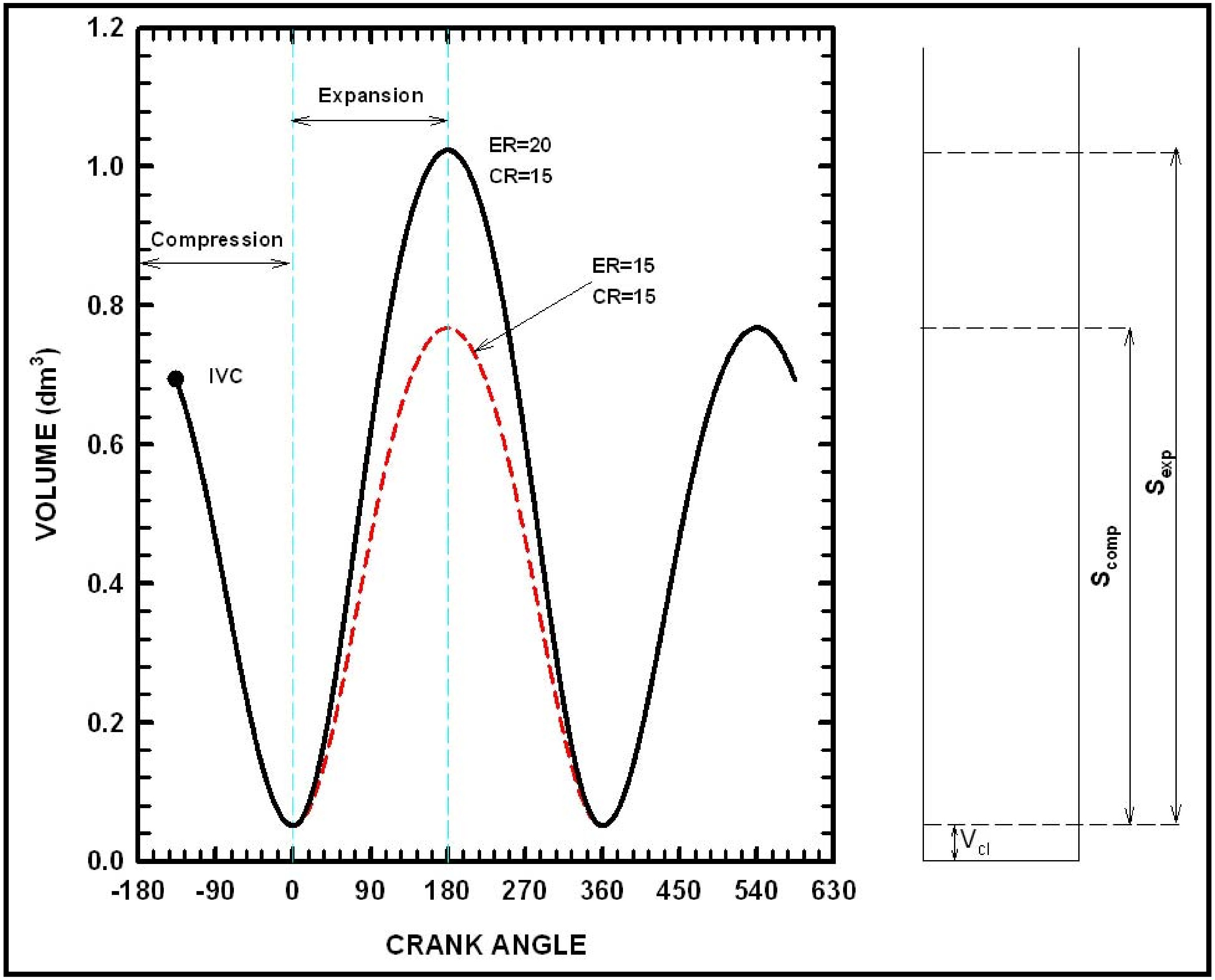
- Piston motion is assumed to be approximated by superimposed motions of the classic "slider-crank" mechanism

- Clearance volume based on compression ratio

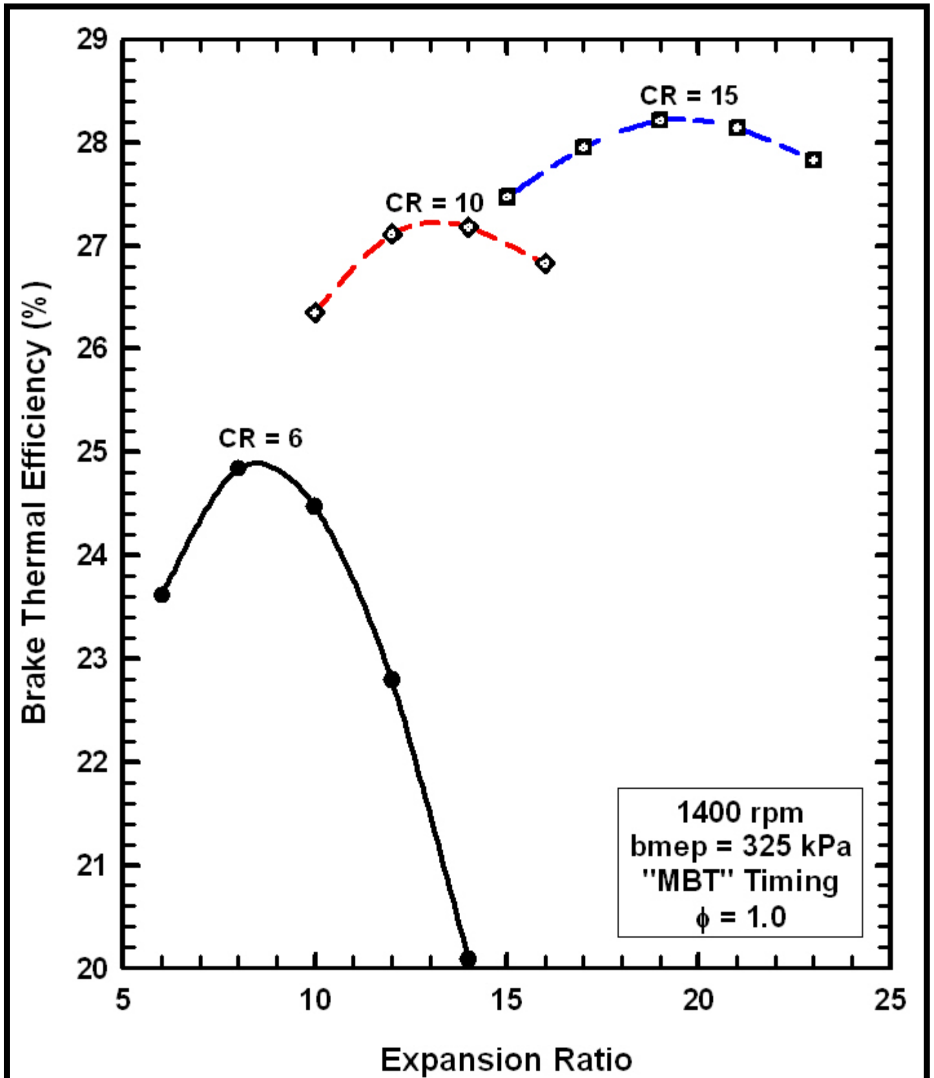
- Mechanical friction based on either compression or expansion ratio (details depend on mechanism)

- Engine performance parameters such as *bmep* based on stroke of the compression process for the displaced volume

Cylinder Volume for "Atkinson" Cycle

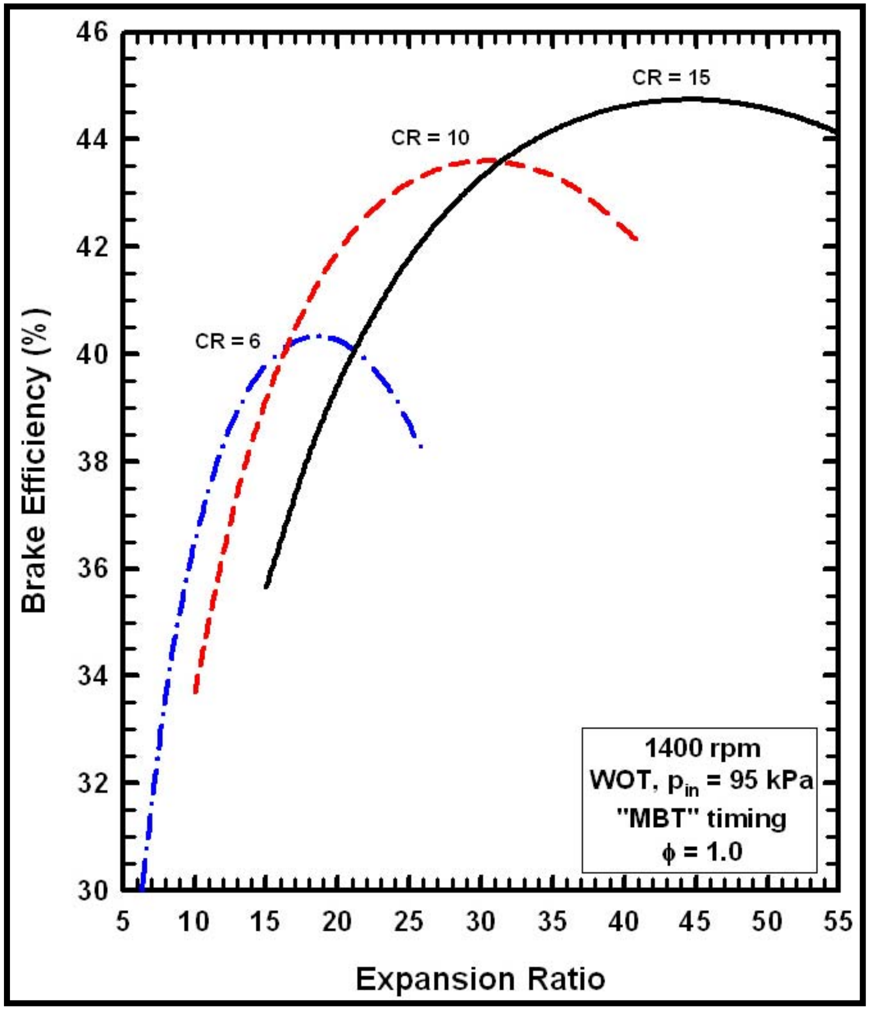


Brake Thermal Efficiency vs Expansion Ratio - Part Load -



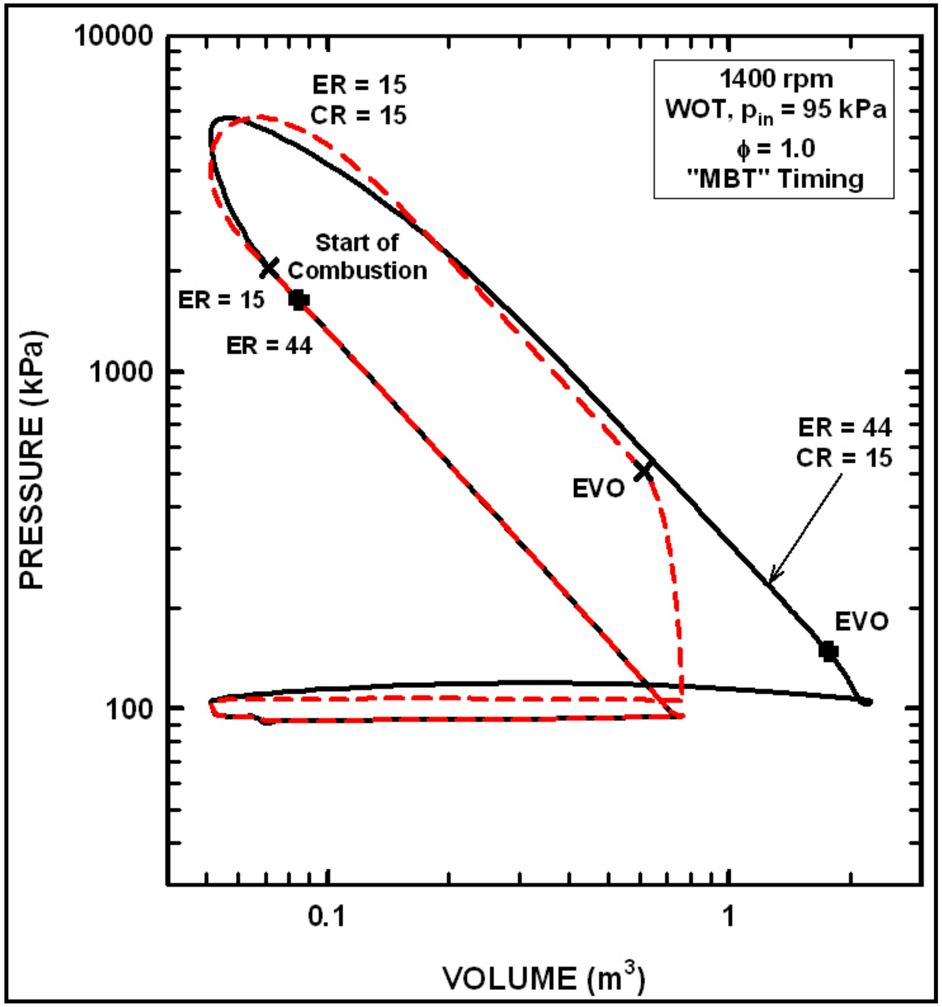
- Note: results for constant part load – must adjust throttle to maintain load
- For these conditions, modest gains of brake thermal efficiency
- For higher than optimum expansion ratio, the efficiency decreased due to increase heat transfer (more surface area) and ineffective exhaust processes

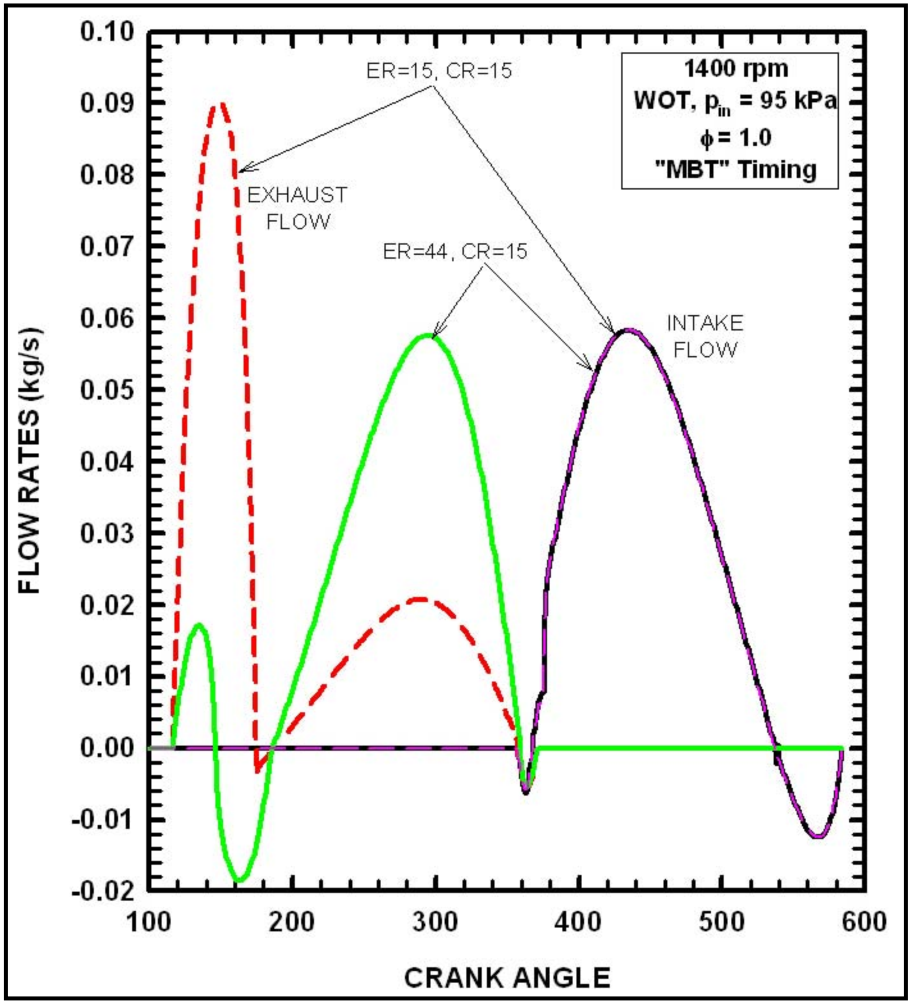
Brake Thermal Efficiency vs Expansion Ratio - Wide Open Throttle (WOT) Cases -

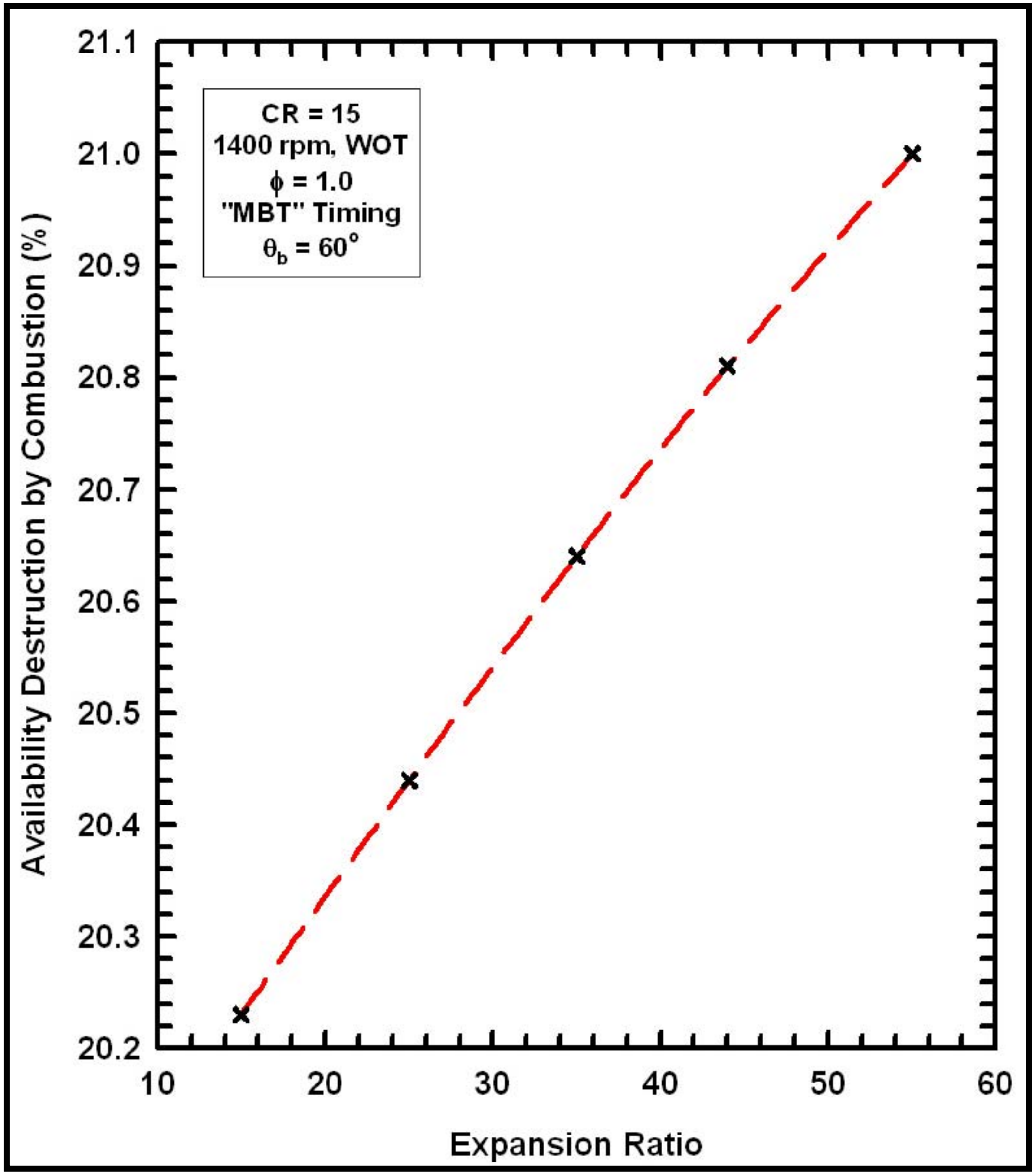


- Compared to the previous part load cases, WOT results in much more improvement as the expansion ratio increases
- The efficiency increases about 10% from no over-expansion (i.e., ER = CR) to the optimum expansion ratio
- Next: Cylinder pressures and flows

Example of WOT Pressures and Flows







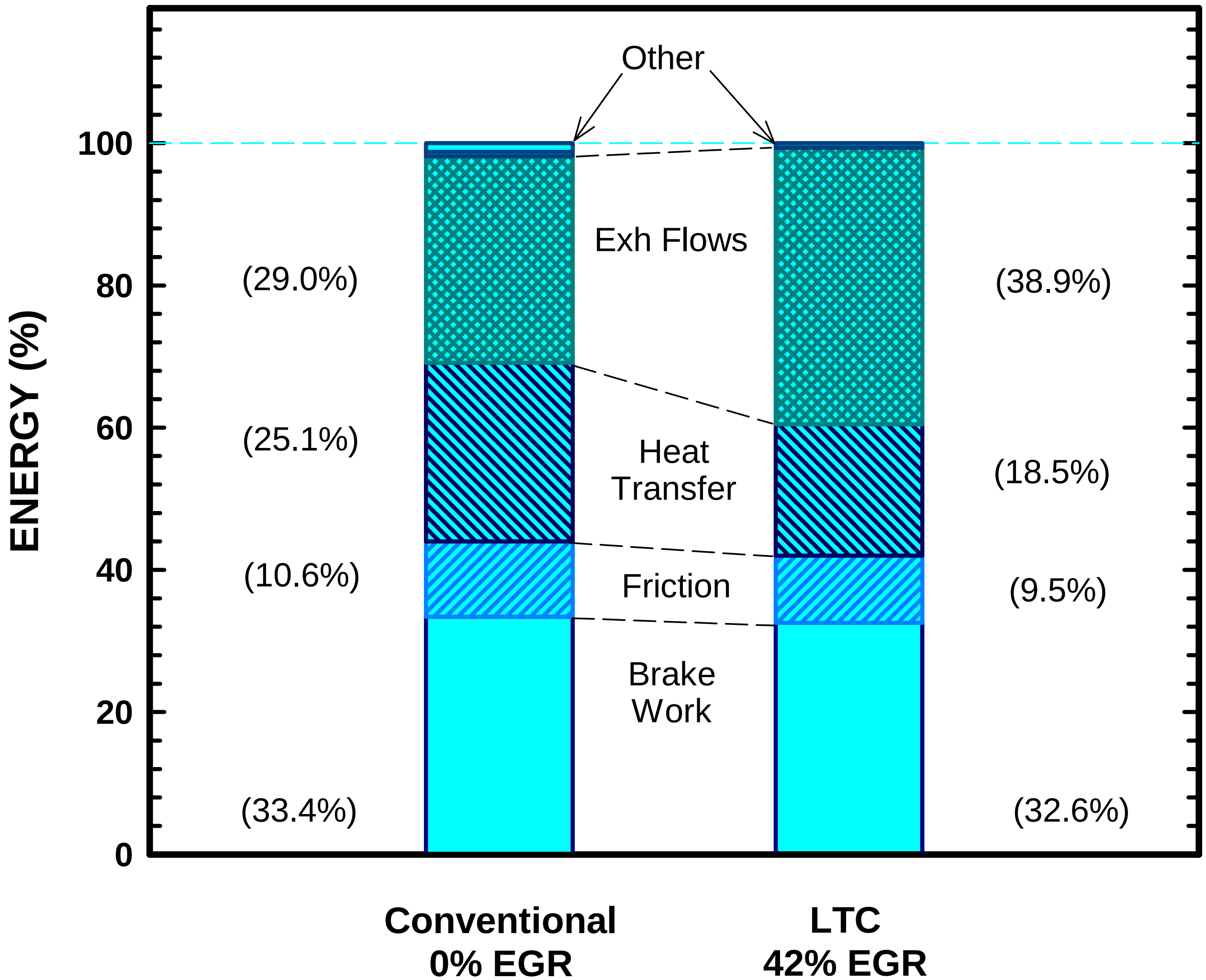
Availability Destruction due to Combustion for WOT Conditions

- Very slight increase in the availability destruction due to combustion – this is largely a result of the modest changes in temperatures
- For part load, the changes were even less – the average destruction was about 21.8% (lower temperatures than for the WOT cases)

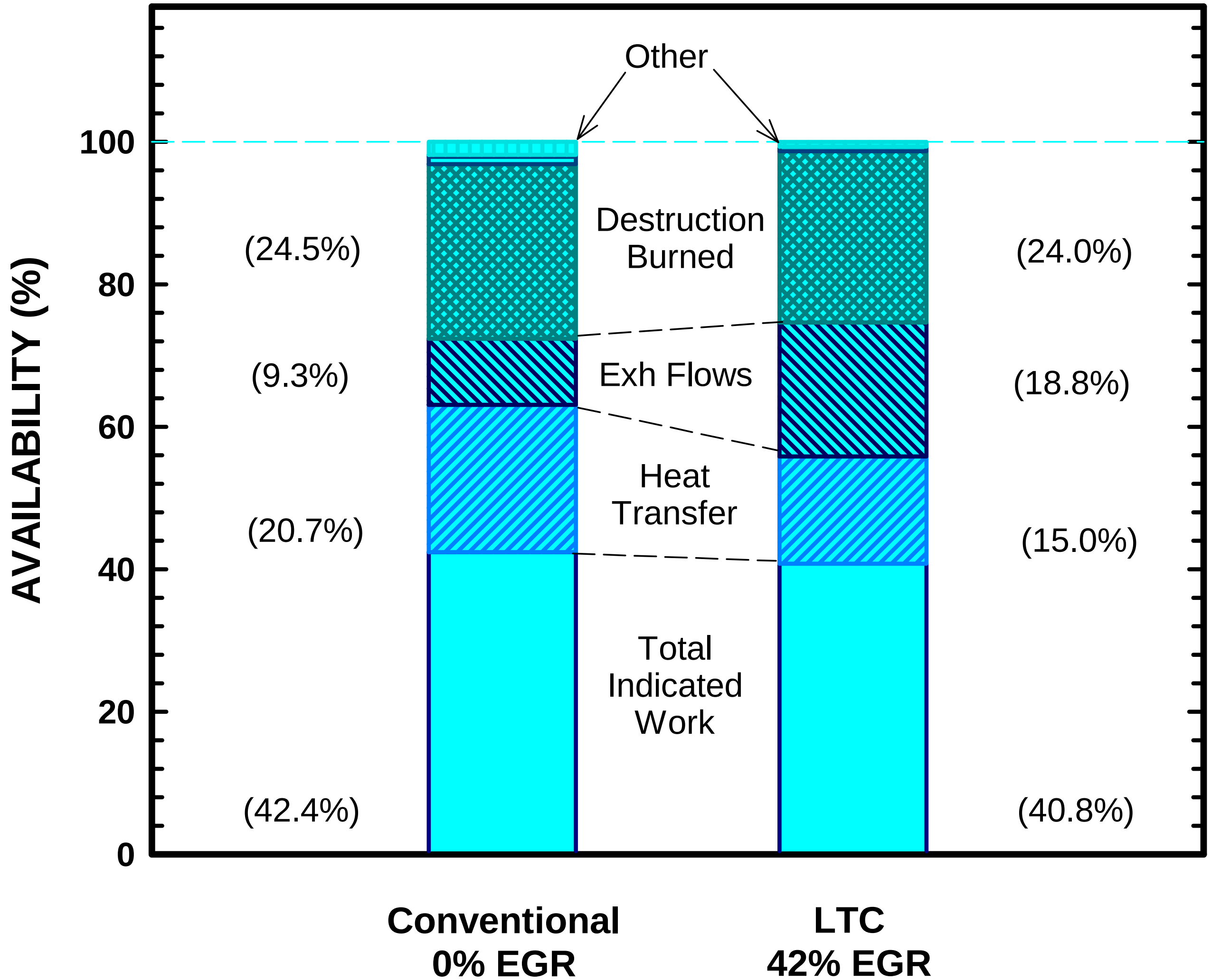
Summary of Diesel Results

Parameter	Conventional Diesel	LTC Diesel
Engine Speed	1500 rpm	1500 rpm
Inlet Pressure	105 kPa	92 kPa
Engine Load, bmep	393 kPa	417 kPa
Equivalence Ratio	0.387	0.843
Exhaust Gas Recirculation	0.0 %	41.9%
Burn Duration (0 – 100%)	24.0°CA	28.0°CA
Start of Combustion Timing	–7.0°aTDC	4.5°aTDC
Peak Pressure	6836 kPa at 9°aTDC	3764 kPa at 22°aTDC
Peak Average Temperature	1678 K at 13°aTDC	1710 K at 28°aTDC
Brake Thermal Efficiency	33.4%	32.6%
EI-NOx	30 g/kg$_f$	0.2 g/kg$_f$
EI-PM	0.17 g/kg$_f$	0.03 g/kg$_f$
HC	220 ppm (C1)	1880 ppm (C1)
CO	240 ppm	4460 ppm

Overall Energy Values



Overall Availability Values



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Technology Transfer/Publications/Patents

1. H. Sivadas and J. A. Caton, “Effects of Exhaust Gas Recirculation on Exergy Destruction due to Isobaric Combustion for a Range of Conditions and Fuels” accepted for publication, *International Journal of Energy Research*, 29 November 2007.
2. J. A. Caton, “Results from an Engine Cycle Simulation of Compression Ratio and Expansion Ratio Effects on Engine Performance,” accepted for publication, *ASME Transactions — Journal of Engineering for Gas Turbines and Power*, 07 November 2007.
3. J. A. Caton, “The Effects of Compression Ratio and Expansion Ratio on Engine Performance Including the Second Law of Thermodynamics: Results from a Cycle Simulation,” in *Proceedings of the 2007 Fall Conference of the ASME Internal Combustion Engine Division*, Charleston, SC, 14–17 October 2007.
4. P. S. Chavannavar, and J. A. Caton, “The Destruction of Availability (Exergy) due to Combustion Processes: A Parametric Study,” *Journal of Power and Energy*, Proceedings of the Institution of Mechanical Engineers, Part A, vol. 220, number 7, pp. 655–669, 2006.
5. J. A. Caton, “Utilizing a Cycle Simulation to Examine the Use of EGR for a Spark-Ignition Engine Including the Second Law of Thermodynamics,” in *Proceedings of the 2006 Fall Conference of the ASME Internal Combustion Engine Division*, Sacramento, CA, 5–8 November 2006.
6. J. A. Caton, “First and Second Law Analyses of a Spark-Ignition Engine Using Either Isooctane or Hydrogen,” in *Proceedings of the 2006 Fall Conference of the ASME Internal Combustion Engine Division*, Sacramento, CA, 5–8 November 2006.
7. J. A. Caton, “The Effects of Exhaust Gas Recirculation (EGR) for a Spark-Ignition Engine: A Second Law Analysis,” in *Proceedings of the 2006 Spring Meeting of the Central States Section of the Combustion Institute*, Cleveland, OH, 21–23 May 2006.
8. P. S. Chavannavar and J. A. Caton, “Irreversibilities Associated with Basic Combustion Processes,” in *Proceedings of the 2006 Spring Meeting of the Central States Section of the Combustion Institute*, Cleveland, OH, 21–23 May 2006.

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Technology Transfer/Publications/Patents

Theses and Dissertations

1. Rajeshkumar Shyani, "An Investigation of the Use of EGR for Spark-Ignition Engines: Using an Engine Cycle Simulation," MSME, expected May 2008.
2. Sushil Oak, "Use of an Engine Cycle Simulation to Study Diesel Engine Combustion," MSME, expected May 2008.
3. Hari Sivadas, "The Effects of EGR, Water/N_2/CO_2 Injection, and Oxygen Enrichment on the Availability Destroyed Due to Combustion for a Range of Conditions and Fuels," MSME, August 2007.
4. Kaushik T. Patrawala, "An Examination of Possible Reversible Combustion at High Temperatures and Pressures for a Reciprocating Engine," MSME, May 2007.
5. Dushyant Pathak, "Use of a Thermodynamic Cycle Simulation to Determine the Difference Between a Propane-Fuelled Engine and an Iso-Octane-Fuelled Engine," MSME, December 2005.
6. Praveen Chavannavar, "Parametric Examination of the Destruction of Availability Due to Combustion for a Range of Conditions and Fuels," MSME, August 2005.

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Plans for Next Fiscal Year

- Complete diesel engine studies using the extended engine cycle simulations
- Use the extended engine cycle simulations to investigate engine performance for a wide range of operating conditions
- Use the extended engine cycle simulations to design engine concepts for reductions of engine irreversibilities

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Summary

♦ Work has been completed for simple systems, SI engines and CI engines.

♦ A new sub-model for EGR for SI engines has been developed and used in a series of parametric studies.

♦ The effects of compression ratio and expansion ratio have been documented. Over expanded engines have modest potential for full load operation, but minimal advantages at part load.

♦ New studies of diesel engines have been initiated. Preliminary results for second law parameters have been obtained.