Improved Engine Design Concepts Using the Second Law of Thermodynamics

Contract No. DE-FC26-05NT42633 (NT42633)

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26 February 2008

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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
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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
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)
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Three Examples of Results from this Work

1. SI Engine with EGR
2. Use of Over-Expanded Engines
3. Preliminary Diesel Engine Results
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Engine Cycle Simulation:
EGR Sub-Model Improvements
Parametric Study
Engine Cycle Simulation
Improved EGR 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

- Improved EGR sub-model –
Engine Cycle Simulation: Improved EGR Model

Adiabatic EGR Configuration

-igsaw diagram showing:
  - Destruction due to Inlet Mixing
  - Unused Fuel
  - Used Fuel
  - Destruction due to Inlet Mixing

- 0% EGR:
  - 20.52% Destroyed by Combustion
  - 24.28% Net Transfer out Due to Flow
  - 23.12% Heat Transfer
  - 30.08% Total Indicated Work

- 20% EGR:
  - 19.31% Destroyed by Combustion
  - 21.39% Net Transfer out Due to Flow
  - 23.14% Heat Transfer
  - 30.93% Total Indicated Work

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Engine Cycle Simulation: Improved EGR Model

Cooled EGR Configuration

<table>
<thead>
<tr>
<th>AVAILABILITY (%)</th>
<th>0% EGR</th>
<th>20% EGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unused Fuel</td>
<td>20.52</td>
<td></td>
</tr>
<tr>
<td>Unused Fuel</td>
<td>24.28</td>
<td>21.01</td>
</tr>
<tr>
<td>Destruction due</td>
<td>23.12</td>
<td>22.8</td>
</tr>
<tr>
<td>to Inlet Mixing</td>
<td>30.08</td>
<td>19.47</td>
</tr>
<tr>
<td>(1.35)</td>
<td></td>
<td>(1.13)</td>
</tr>
<tr>
<td>Unused Fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destruction due</td>
<td></td>
<td>31.14</td>
</tr>
<tr>
<td>to Inlet Mixing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4.45)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Expenses due to Inlet Mixing

- Unused Fuel
- Destroyed by
  Combustion
- Net Transfer out
  Due to Flow
- Heat Transfer
- Total Indicated
  Work

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

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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 $b_{mep}$ based on stroke of the compression process for the displaced volume
Cylinder Volume for “Atkinson” Cycle
Brake Thermal Efficiency vs Expansion Ratio  
- Part Load -
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

1400 rpm
WOT, \( p_i = 95 \text{ kPa} \)
\( \phi = 1.0 \)
"MBT" Timing

Pressures vs. Volume

Flow Rates vs. Crank Angle
Availabilty 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

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

![Energy Distribution Diagram]

- **Conventional 0% EGR**
  - Exh Flows: (29.0%)
  - Heat Transfer: (25.1%)
  - Friction: (10.6%)
  - Brake Work: (33.4%)

- **LTC 42% EGR**
  - Exh Flows: (38.9%)
  - Heat Transfer: (18.5%)
  - Friction: (9.5%)
  - Brake Work: (32.6%)

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Theses and Dissertations


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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
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.