The HERCULES (2004-2018) R&D program on 'green' engines for ships

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HERCULES Coordinator

Presentation to CIMAC Circle at Norshipping 2017
Oslo, Norway, 31st May 2017
HERCULES is developing new technologies for marine engines:

- Reduce emissions
  - gaseous
  - particulate

- Increase engine reliability

- Increase engine efficiency
  - Reduce fuel consumption
  - Reduce CO$_2$ emissions
  - Reduce lifecycle cost
HERCULES Mythology

1998  1999  2000  2001  2002  2003  2004

EC/EAG
Expert Advisory Group
Land Transport & Marine Technologies

EC FP6 (2002-2006)
...Integrated Projects
(New Concept)

HERCULES proposal
• Efficiency
• Emissions
• Reliability

HERCULES-A starts

1998  1999  2000  2001  2002  2003  2004

EC Paper
(...European large Engine Industry...)

@CIMAC Hamburg
Idea:
Marine Engine Project

Talks MAN +
WARTSILA
Talks with EC
100M EUR 10 years

High Efficiency R&D on Combustion with Ultra Low Emissions for Ships

Flipchart page
First MAN – WARTSILA joint Meeting: Helsinki, 4th July 2002

HERCULES
Mythology

High Efficiency R&D on Combustion with Ultra Low Emissions for Ships

Flipchart page
First MAN – WARTSILA joint Meeting: Helsinki, 4th July 2002

HERCULES-A starts

1998  1999  2000  2001  2002  2003  2004
HERCULES TIMELINE

I.P. HERCULES (A)
33 M€ Budget
43 months duration
42 Partners

HERCULES-B
26 M€ Budget
36 months duration
32 Partners

HERCULES-C
17 M€ Budget
36 months duration
32 Partners

HERCULES-2
25 M€ Budget
36 months duration
32 Partners

100 M€ Budget, 14 years duration
HERCULES Programme

From HERCULES-A, B, C to HERCULES-2

Research  Selection & Development  Technology Group Integration  Flexibility & Lifetime optimisation


Combustion modelling  Engine  Advanced Injection, Spray and Combustion
HERCULES TIMELINE


Vision ⇒ R&D Project HERCULES ~100 M€ Budget, 10 years duration

Phase I

I.P. HERCULES (A)
33 M€ Budget
43 months duration
42 Partners

High Efficiency R&D on Combustion
with Ultra Low Emissions for Ships

TIP3-CT-2003-506676

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
H - A: Variable turbocharging

Two-stage turbocharged 4-stroke engine

CIMAC 2007 Congress: Best paper award!
HERCULES TIMELINE

Vision ⇒ R&D Project HERCULES ~100 M€ Budget, 10 years duration

Phase I
I.P. HERCULES (A)
33 M€ Budget
43 months duration
42 Partners

Phase II
HERCULES-B
26 M€ Budget
36 months
32 Partners

Higher-Efficiency Engine with Ultra-Low Emissions for Ships
SCP7-GA-2008-217878
Extreme Engine

Combustion modelling

Combustion visualization

Hot Engine

Multistage turbocharging

Emission Reduction: WIF, HAM, EGR, CGR

After-Treatment Systems, Sensors

Tribology

Engine Control systems

Combustion modelling and experimentation

Combined Cycle

Intelligent Turbocharging

Extreme EGR, SCR, Scrubber

Tribology - Optimization

Advanced sensing and engine control
Optical cylinder covers for 2-stroke
Advanced intelligent turbocharger

PTI / PTO

T/C with variable compressor inlet guide vanes

T/C with variable turbine nozzle vanes
Emission reduction - Exhaust Gas Recirculation and After-treatment

High Pressure Boiler installed on 4T50ME-X
Vision ⇒ R&D Project HERCULES ~100 M€ Budget, 10 years duration

Phase I
I.P. HERCULES (A)
33 M€ Budget
43 months duration
42 Partners

Phase II
HERCULES-B
26 M€ Budget
36 months duration
32 Partners

Phase III
HERCULES-C
17 M€ Budget
36 months duration
22 Partners
Optical investigations

Objective #1: Substantial reduction in fuel consumption (WPG1, WPG2, WPG4)

Optical cylinder head with optical access and viewing range

WP 3: Injection, Spray Formation and Combustion
<table>
<thead>
<tr>
<th>WORK PACKAGE GROUP</th>
<th>ITEM</th>
<th>IFP-C3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPG2 Fuel Injection Models &amp; Experiments</td>
<td>Models for flow and cavitation applicable to large engine injectors</td>
<td>M</td>
</tr>
</tbody>
</table>

Exploitable Results Examples

**TIMESPAN:** SHORT=S, MEDIUM=M, LONG=L

**WPG2**

- Fuel Injection Models & Experiments
  - Models for flow and cavitation applicable to large engine injectors
  - Exploitable Results Examples
    - Nozzle bore eccentricity investigation
    - CFD investigations of the nozzle internal flow
      - dense core spray contour
      - droplet size and velocity
    - Shadow-imaging PDA
    - Nozzle bore eccentricity investigation
    - STAR-CD vs. IFP-C3D (incl. cavitation model)
      - Reference case
      - Eccentric nozzle case
      - IFP-C3D
      - StarCD
## Exploitable Results Examples

(TIMESPAN: SHORT=S, MEDIUM=M, LONG=L)

<table>
<thead>
<tr>
<th>WORK PACKAGE GROUP</th>
<th>ITEM</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPG5</td>
<td>Low friction and wear engine piston rings</td>
<td>S</td>
</tr>
<tr>
<td>New Materials &amp; Tribology</td>
<td>Increased performance main engine bearings</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td><strong>Thermal Barrier Coatings for piston crowns</strong></td>
<td>M</td>
</tr>
</tbody>
</table>

**Thermal Barrier Coatings**
Productivity, HERCULES-A to HERCULES-C

- **Prototypes**
  - HERCULES-A: 22
  - HERCULES-B: 15
  - HERCULES-C: 12

- **Products**
  - HERCULES-A: 2
  - HERCULES-B: 6
  - HERCULES-C: 10

- **Patents**
  - HERCULES-A: 24
  - HERCULES-B: 7
  - HERCULES-C: 7

- **Publications**
  - HERCULES-A: 23
  - HERCULES-B: 38
  - HERCULES-C: 30
HERCULES Timeline

I.P. HERCULES (A)
- 33 M€ Budget
- 43 months duration
- 42 Partners

HERCULES-B
- 26 M€ Budget
- 36 months duration
- 32 Partners

HERCULES-C
- 17 M€ Budget
- 36 months duration
- 32 Partners

HERCULES-2
- 25 M€ Budget
- 36 months duration
- 32 Partners

100 M€ Budget, 14 years duration
HERCULES-2 Objectives

- **Near Zero Emissions**
  - Extreme Engine
  - Combustion modelling
  - Combustion visualization
  - Hot Engine
  - Multistage turbocharging
  - Emission Reduction: WIF, HAM, EGR, CGR
  - After-Treatment Systems, Sensors
  - Tribology
  - Engine Control systems

- **Adaptive for Lifetime**
  - Advanced Materials
  - Combustion modelling and experimentation
  - Combined Cycle
  - Intelligent Turbocharging
  - Extreme EGR, SCR, Scrubber
  - Tribology - Optimization
  - Advanced sensing and engine control

- **Control**
  - Advanced Injection, Spray and Combustion experiments and models
  - Integrated emission technologies
  - Materials and tribology
  - Adaptive engine control

- **Combustion**
  - WPG I: Fuel flexible engine
  - WPG II: New Materials
  - WPG III: Adaptive Powerplant for Lifetime Performance
  - WPG IV: Near-zero Emissions Engine

- **Aftertreatment**
  - Tribology - Optimization
  - Advanced sensing and engine control

- **Advanced Materials**
  - Extreme Engine
  - Combustion modelling
  - Combustion visualization

- **Flexible Fuel**
  - Extreme Engine
  - Combustion modelling
Full scale experimental setup for complete variability of turbocharging system combined with EGR
Fuel flexible engine

engine with fuel flexible injection system

measuring mixture distribution
Engine integrated HP SCR inside exhaust receiver
Percentage allocation of budget into 3 main areas of R&D in the 4 HERCULES Projects (189 subprojects)

% of individual project budget

- **Efficiency**
  - HERCULES-A: 56%
  - HERCULES-B: 61%
  - HERCULES-C: 39%
  - HERCULES-2: 49%
  - Total: 43%

- **Emissions**
  - HERCULES-A: 33%
  - HERCULES-B: 30%
  - HERCULES-C: 37%
  - HERCULES-2: 33%
  - Total: 38%

- **Reliability & Lifetime**
  - HERCULES-A: 11%
  - HERCULES-B: 9%
  - HERCULES-C: 24%
  - HERCULES-2: 18%
  - Total: 19%

**Total 102 M€**
### HERCULES R&D 2002 Estimate and Spending TOTAL

<table>
<thead>
<tr>
<th>Category</th>
<th>2002 allocation estimates for 100 Meur</th>
<th>(merge)</th>
<th>H-A,B,C,2 Results 2016</th>
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</thead>
<tbody>
<tr>
<td>CO₂ (EFFICIENCY)</td>
<td>30%</td>
<td>37%</td>
<td>EFFICIENCY 43%</td>
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<tr>
<td>FUELS</td>
<td>10%</td>
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<tr>
<td>EMISSIONS</td>
<td>35%</td>
<td>40%</td>
<td>EMISSIONS 38%</td>
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<tr>
<td>RELIABILITY LIFETIME CONTROL</td>
<td>10% 5% 5%</td>
<td>23%</td>
<td>RELIABILITY LIFETIME 19%</td>
</tr>
<tr>
<td>METHODS, TOOLS</td>
<td>5%</td>
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</table>

| TOTAL                     | 100%                                  |         |                        |
Greening technologies from the HERCULES programme

Several resulting technologies from the HERCULES programme related to large marine engines are:

1. **Multi-stage Turbocharging** (+Variable Valve Timing), allowing higher performance and improved **economy**.

2. **Power Take In/Out and Flexible Turbocharger** (+Variable Geometry), allowing improved **economy** over the operating range.

3. **Increased maximum cylinder pressure**, BMEP, leading to improved **economy**.

4. **Cylinder auto-tuning** & Injection optimization for improved performance, improved **economy**, reliability and **emissions**.

5. **Water-In-Fuel**, Water injection, for reduced NOx **emissions**.

6. **Selective Catalytic Reduction-SCR** for exhaust NOx **emissions** aftertreatment.

7. **Tribology and Lubrication** improvements and advanced Materials, for improved **economy** and reliability.

8. **Waste Heat Recovery** from Hot Engine, for improved **economy**.

9. **Exhaust Gas Recirculation**, for reduced NOx **emissions**, with scrubbers and high pressure exhaust boiler.
<table>
<thead>
<tr>
<th>TECHNOLOGY AREA</th>
<th>COMBUSTION</th>
<th>TURBO CHARGING</th>
<th>EMISSIONS ATU</th>
<th>MATERIALS FRICTION</th>
<th>MONITOR CONTROL OPTIMIZATION</th>
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<tbody>
<tr>
<td>Multi-Turbo/ VVT</td>
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<td>PTI/PTO</td>
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<td>WHR- Hot Engine</td>
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<td>Cylinder cut-out</td>
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<td>Dual Fuel /Multi Fuel</td>
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</table>
Near future R&D in ship propulsion engines

- Hybrid powertrains
- Exhaust aftertreatment
- Tribology
- Optimum performance over lifetime
- Extreme value engines
- Fuel-flexible engines
- Intelligent engines
Final comments

- The longevity of alliances is often used as proxy of their performance.
- The HERCULES alliance of 14 years has been demonstrably successful.
- Many results of R&D already matured into products.
- Much of the 100M budget was spend towards greening.
- If efficiency increases achieved are applied, the 100 M is soon regained.
- Intelligent monitoring/control/optimization is a clear direction for future development.
End of Presentation

www.hercules-2.com