Motivation for the MER-LHP development

LHP

Increasing number of locations from where wasted heat shall be picked up

Multiple evaporator and multiple condenser designs

MER-LHP Potential Applications

1. Telecommunication geostationary satellites
2. Other Earth orbits satellites
3. Interplanetary missions
4. Rovers on Mars and Moon
5. ISS experiments
6. Manned vehicles
MER-LHP Advantages and Challenges

**MER-LHP Advantages**

- Optimized functional layout
- Scalability
- Expandability
- Heat load sharing
- Flexibility in components locations
- Coupling between separate radiators
- Minimized mass/volume of spacecraft
- Gravity independence
- Reliability

**MER-LHP Challenges**

- Overcoming expandability limitations
- Overcoming controllability limitations
- Overcoming vapour parasitic heat intolerance of individual EV
MER-LHP Driving requirements

- Temperature: evaporator(s) OT [-20 °C; +60 °C], NOT [-30 °C; +85 °C]; condenser(s) OT [-60 °C; +60 °C], NOT [-60 °C; +60 °C]

- Thermal conductance: $G_{LHP} \leq 0.01 \text{ W/K (OFF-mode)}$; $G_{LHP}$ / Maximum temperature drop = 15 °C, from the largest evaporator at the maximum power level to one active condenser.

- Transport lines length ≥ 4 m

- Evaporator contact surface with heat load: scalable from 23 cm$^2$ to 280 cm$^2$

- Mass minimization

- Fluid lines flexibility shall allow 2 mounting/dismounting cycles

- Lifetime: 5 years on ground + 15 years in orbit

- Proof pressure: $1.5 \times \text{MEP} = P (\text{MNOT}) = 69 \text{ bar}$; burst pressure: $2.5 \times \text{MEP} = P (\text{MOT}) = 115 \text{ bar}$

- Maximum heat transport capability (at MOT): 67 W - 800 W (depending on EV size); 1000 W (system)

- Operation in 1g: evaporators and condensers shall operate in horizontal and vertical position (CC above the evaporator); RCC shall operate at least at 0.5 m below the evaporator at the highest horizontal plane
MER-LHP Trade-off

- Multi-evaporator loop heat pipe (ME-LHP)
- Multi-evaporator capillary pumped loop (ME-CPL)
- Multi-evaporator loop heat pipe with capillary links (ME LHP CL)
- Multi-evaporator capillary pumped loop with capillary links (ME CPL CL)
- Capillary pumped loop with auxiliary mechanical pumping (ME CPL MP)
- Multi-evaporator capillary pumped loop with auxiliary capillary pumping (ME CPL CP)

<table>
<thead>
<tr>
<th>ME CDL concept</th>
<th>Thermal perform.</th>
<th>Size-and-mass</th>
<th>Patent aspects</th>
<th>Manuf. ct. aspects</th>
<th>Recurr. cost</th>
<th>Integration/scalability</th>
<th>Reliability</th>
<th>Expandability</th>
<th>Controllability</th>
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<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>34 (4)</td>
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<td>MER LHP</td>
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<td>5</td>
<td>5</td>
<td>4</td>
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<td>5</td>
<td>5</td>
<td>44 (1)</td>
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MER-LHP Concept Definition

MER-LHP ACL type overcomes the problems of:
1. limited number of evaporators (classical LHP design);
2. instability of operation in transient modes with increased parasitic heat leak through the capillary wick wall (classical CPL design).

SCC together with an advanced control scheme serves to reliably supply the primary wick with a sufficient amount of subcooled liquid in any operational conditions, even in very unfavorable transient ones.

- Unlike ordinary LHP, the MER-LHP is controlled by a RCC.
- Unlike ordinary CPL, the SCC is included as part of each evaporator.
MER-LHP BBM (I)

- Ev1
- Ev2
- Glass
- CN1
- CN2
- Pressure transducer
- Flow meter
- RCC
- Capillary blocker

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MER-LHP BBM (II)

Adverse and horizontal layouts

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**TEST #1:** Thermal performance in horizontal, LHP mode

Tested at $T_{CN} = -40^\circ C$, $T_{CN} = -15^\circ C$ and $T_{CN} = 10^\circ C$. Maximum tested power: 500 W. Power on RCC < 10 W.

**TEST #2:** Thermal performance in horizontal, RCC regulation mode

Tested at $T_{CN} = -40^\circ C$ and $T_{RCC} = +20^\circ C$; and $T_{CN} = -15^\circ C$ and $T_{RCC} = +36^\circ C$. Maximum tested power: 500 W. Power on RCC: 5 - 20 W.

**TEST #3:** Power cycling

**TEST #4:** $T_{SINK}$ cycling

**TEST #5:** Testing at different orientations

Relative position RCC-evaporators:
- Adverse elevation: up to -63º (~0.5 m height)
- Favorable elevation: up to +34º
Glass tubes are implemented for vapour/liquid interface visualization.

The video shows bubbles through the purge line prior to dry-out.
The heater on the RCC was included in the baseline design.
The secondary liquid lines or purge lines were kept as optional and eventually disconnected.
The common 2-way PRV installed in the common vapour line to provide temperature control for the entire system was removed.
No elements to provide additional subcooling to the SCCs were included.
Glass tubes, flow-meters and pressure transducers were not included.
IberEspacio Standard Size Evaporators

XL-size wick evaporator (432 mm length; 22 mm OD)

S-size wick evaporator (57 mm length; 11 mm OD)

M-size wick evaporator (165 mm length; 14 mm OD)
MER-LHP DM (III)

Ambient tests configuration

5 ports Connector (Additive Manufacturing)

Capillary Blocker

TVC tests configuration

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## MER-LHP DM (IV)

### Evaporator Specifications

<table>
<thead>
<tr>
<th>Evaporator</th>
<th>Small (No.3)</th>
<th>Medium (No.1&amp;2)</th>
<th>X-Large (No.4)</th>
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<tbody>
<tr>
<td>envelope material</td>
<td>SS 316</td>
<td></td>
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<tr>
<td>saddle material</td>
<td>Al 6082 – T6</td>
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<tr>
<td>saddle footprint</td>
<td>45x45 mm</td>
<td>152x51 mm</td>
<td>400x75 mm</td>
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<tr>
<td>length</td>
<td>57 mm</td>
<td>165 mm</td>
<td>432 mm</td>
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<tr>
<td>Primary wick OD</td>
<td>11 mm</td>
<td>14 mm</td>
<td>22 mm</td>
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<tr>
<td>Pore size</td>
<td>2.5 μm</td>
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<td>1 μm</td>
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<tr>
<td>Porosity</td>
<td>65 %</td>
<td>65 %</td>
<td>47 %</td>
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<tr>
<td>Permeability</td>
<td>3×10⁻¹³</td>
<td>8×10⁻¹⁴</td>
<td>3×10⁻¹⁴</td>
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<tr>
<td>Wick material</td>
<td>SS316 (fiber)</td>
<td>Nickel</td>
<td>SS316 (powder)</td>
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### Transport Lines

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<th>Value</th>
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<td>Material</td>
<td>SS 316</td>
</tr>
<tr>
<td>Vapour ODxID</td>
<td>6x4 mm</td>
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<td>Vapour total length</td>
<td>4140 mm</td>
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<tr>
<td>Liquid ODxID</td>
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<td>Liquid total length</td>
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### Condenser

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<td>SS 316</td>
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<tr>
<td>ODxID</td>
<td>3x2 mm</td>
</tr>
<tr>
<td>Length</td>
<td>1020 mm</td>
</tr>
<tr>
<td>Plate size Width x Length</td>
<td>70x450 mm</td>
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</table>

### SCC Specifications

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<tr>
<th>SCC</th>
<th>Small (No. 3)</th>
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<th>X-Large (No. 4)</th>
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</thead>
<tbody>
<tr>
<td>material</td>
<td>SS 316</td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume</td>
<td>14 cm³</td>
<td>15cm³</td>
<td>58 cm³</td>
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<tr>
<td>length</td>
<td>57mm</td>
<td>51mm</td>
<td>67mm</td>
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<tr>
<td>ID</td>
<td>20 mm</td>
<td>20 mm</td>
<td>30 mm</td>
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</table>

### System Parameters

- RCC: ID / OD 55.6 / 60.0 mm
- Length 135 mm
- NH3 Charge 270 g

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**MER-LHP DM Testing (I)**

<table>
<thead>
<tr>
<th>TC ID</th>
<th>Position</th>
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<tbody>
<tr>
<td>1 EV1</td>
<td>Evaporator 1</td>
</tr>
<tr>
<td>2 EV2</td>
<td>Evaporator 2</td>
</tr>
<tr>
<td>3 EV3</td>
<td>Evaporator 3</td>
</tr>
<tr>
<td>4 EV4</td>
<td>Evaporator 4</td>
</tr>
<tr>
<td>15 C_1</td>
<td>Condenser line, middle 1</td>
</tr>
<tr>
<td>16 C_2</td>
<td>Condenser line, middle 2</td>
</tr>
<tr>
<td>19 RCC</td>
<td>RCC top, at the middle</td>
</tr>
<tr>
<td>27 SCC1</td>
<td>Evaporator 1 SCC</td>
</tr>
<tr>
<td>28 SCC2</td>
<td>Evaporator 2 SCC</td>
</tr>
<tr>
<td>29 SCC3</td>
<td>Evaporator 3 SCC</td>
</tr>
<tr>
<td>30 SCC4</td>
<td>Evaporator 4 SCC</td>
</tr>
<tr>
<td>39 C1OUT</td>
<td>Condenser 1 line outlet</td>
</tr>
<tr>
<td>40 C2OUT</td>
<td>Condenser 2 line outlet</td>
</tr>
</tbody>
</table>
**TEST #1:** Thermal performance + maximum power, LHP mode

**TEST #2:** Thermal performance + start-up, LHP mode

**Evaporator 1:** > 600 W
**Evaporator 2:** > 360 W
**Evaporator 3:** > 200 W
**Evaporator 4:** > 1200 W

**System:** > 1200 W

**DTc = 10°C**

**TSink = -15°C**

**QRCC ~ 5 W**

**DTc = 3-10°C**

**TSink = +10°C**

**QRCC ~ 5 W**

**QStart-up = 50 W**

**QRCC ~ 5 W**
MER-LHP DM Testing (III)

TEST #3: Thermal performance, RCC regulation mode

TEST #4: Power cycling

TEST #5: Tsink cycling

TEST #6: Testing at different orientations

Tsink = -10 °C

TRCC = 40 °C

QRCC ~ 8-10 W

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MODEL IMPROVEMENTS:
✓ Secondary wick modeling.
✓ Sub-cooled liquid in the compensation chamber (SCC).
✓ Dedicated path to direct the heat leaks (bubbles) from the evaporator core (purge line eventually not needed).
✓ Liquid level in the SCC and the RCC.
✓ Liquid flow through the evaporator.

CORRELATED TESTS:
✓ Maximum Power (all evaporators active).
✓ Cold and hot performance, LHP mode.
✓ Cold and hot performance with RCC control.
✓ Performance at different condenser and RCC elevation.
The novel Advanced Control Loop concept of MER-LHP has been developed. Performance validated via simulation and testing in two stages: with two evaporators and with four evaporators. The MER-LHP operation is driven by the control of the DT between the RCC and the SCC of each evaporator. Such a control can be performed by a heater on the RCC. The subcooling to keep the SCCs at liquid phase has been defined as a critical parameter and the system design has to include the necessary media to obtain a certain level of sub-cooling (i.e. efficient radiator design). The MER-LHP operation can be simulated using EcosimPro TMM. The development of such a model has implied a significant step further in the LHP simulation. All objectives of the project “MER-LHP” have been fulfilled. The MER-LHP thermal architecture implies an autonomous, self-regulated, light weight, highly efficient and adaptable, centralized two-phase heat transport system (thermal bus concept), to be potentially used for the thermal control in space and terrestrial applications.
MER-LHP Further Steps

- Improvement of the MER-LHP TMM to be able to obtain more reliable and accurate predictions, for any power step (including 0W) and particularly for the SCC temperature.
- Consolidation of the Qualification Program, adapted to a particular application.
- Development of a Qualification Model and completion of the Qualification campaign.
- Optimization of the RCC control laws taking into account the specific missions constraints.
Thank you!

Multi-Evaporator-Reservoir Loop Heat Pipe

MER-LHP