Development of a Two-Phase Mechanically Pumped Loop (2ΦMPL) for the Thermal Control of Telecommunication Satellites

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Presentation plan

- Background
- Architecture/thermal hypothesis and requirements
- 2ΦMPL hydraulic scheme
- 2ΦMPL components
- Mathematical modeling
- 2ΦMPL overall mass budget
- 2ΦMPL ground prototype
- 2008 perspectives
The future large and powerful telecommunication satellites could need the use of large deployable radiators (DPR) and efficient thermal loop to transport large amount of heat on long distances

**Main original need**: @bus Extended Range

**Other potential applications**: very dissipative units like active antennas
About Mechanically Pumped Loops

- **2ΦMPL Scheme**
  - Control Valves
  - Pump
  - Accumulator (HCA)
  - Condenser
  - Evaporator
  - ByPass
  - Three-Way Valves
  - Vapor or Liquid/Vapor

Main 2ΦMPL advantages wrt to SPL:
- isothermality
- mass
- pump power consumption
- temperature control with HCA

- **Single Phase Loop (SPL) Scheme**
  - Control Valves
  - Pump
  - Reservoir
  - Liquid
  - ByPass
  - Radiator Heat Exchanger (Cold Sink)
  - Payload Heat Exchangers (Cold Plates) to Cool Units
  - Liquid
  - Three-Way Valves
A two-phase TCS was developed in the 90’s for ISS Russian Segment.

In 2002, Russian/Ukrainian experience on both products has been investigated by ThAS through a Trade-Off study with mass as the main criterion: 30% mass saving with a two-phase system was demonstrated.

In 2005, ThAS/CNES, through a R&T program, started a development phase with the first step consisting in the evaluation of an Ukrainian NH$_3$ 2ΦMPL prototype to be designed, manufactured and tested by the Kharkov Aviation Institute according to ThAS requirements.
Platform with shelves
Units layout on shelves

TWT and HP I units layout and dimensions on an horizontal panel
(± /-Z symmetric layout)
### Units thermal characteristics

<table>
<thead>
<tr>
<th>Number of Active Components</th>
<th>Dissipation per Unit (W)</th>
<th>Total Dissipation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWT 1st Floor TWTA</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>TWT 2nd Floor TWTB</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>OMUX Lower Shearwall Part OMUXA</td>
<td>30</td>
<td>22</td>
</tr>
<tr>
<td>OMUX Upper Shearwall Part OMUXB</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total Heat Load (W)</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Operating Temperature (°C)</th>
<th>Non Operating Temperature (°C)</th>
<th>Cold Start Up (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>TWT</td>
<td>+10</td>
<td>+70</td>
<td>-20</td>
</tr>
<tr>
<td>OMUX</td>
<td>+35</td>
<td>+75</td>
<td>-20</td>
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</table>

<table>
<thead>
<tr>
<th>m (kg)</th>
<th>mCp (JK)</th>
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</thead>
<tbody>
<tr>
<td>TWTA</td>
<td>OMUXA</td>
</tr>
<tr>
<td>0.80</td>
<td>0.90</td>
</tr>
<tr>
<td>720</td>
<td>810</td>
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</tbody>
</table>

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Environmental conditions (1/2)

- **Hot environmental condition**
  - Solstice Case
  - East Panel Illuminated
  - Sun Incidence at 06h00
  - Sun Direction at $23.44^\circ$

- **Cold environmental condition**
  - Equinoxe Case
  - No illumination of East and West Panels
  - Sun Direction parallel to Z axis

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South Panel

East Panel

West Panel

Earth Panel

South/West DR

South/East DR
Environmental conditions (2/2)

\[
\left(1 + F_{rad-space}\right) \varepsilon_{OSR} \sigma S_{rad} \left(T_{rad+X}^4 - T_{env+X}^4\right) = Q_{MPL+X}
\]

\[
\left(1 + F_{rad-space}\right) \varepsilon_{OSR} \sigma S_{rad} \left(T_{rad-X}^4 - T_{env-X}^4\right) = Q_{MPL-X}
\]

\[
Q_{MPL_{tot}} = Q_{MPL+X} + Q_{MPL-X}
\]

<table>
<thead>
<tr>
<th>$S_{rad}$ (m²)</th>
<th>$F_{rad-space}$</th>
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<tr>
<td>5</td>
<td>0.86</td>
</tr>
<tr>
<td>4.5</td>
<td>0.85</td>
</tr>
<tr>
<td>4</td>
<td>0.83</td>
</tr>
<tr>
<td>3.5</td>
<td>0.82</td>
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<tr>
<td>3</td>
<td>0.80</td>
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<tr>
<td>2.5</td>
<td>0.77</td>
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</table>

Environmental temperatures variation the deployable radiators for different orbital positions in winter solstice $S_{rad}=5$ m²
2φ MPL Hydraulic Scheme (1/2)

- **TWTB and HPI units.**
  - Number of Active Components: 60.
  - Dissipation per Unit: 30 W.
  - Total Dissipation: 1800 W.

- **OMUXB units (Lower Shearwall Part).**
  - Number of Active Components: 30.
  - Dissipation per Unit: 18 W.
  - Total Dissipation: 540 W.

- **OMUXA units (Upper Shearwall Part).**
  - Number of Active Components: 30.
  - Dissipation per Unit: 22 W.
  - Total Dissipation: 660 W.

- **TWTA and HPI units.**
  - Number of Active Components: 60.
  - Dissipation per Unit: 50 W.
  - Total Dissipation: 3000 W.

**Regulation laws to control the minimal acceptable temperature of units (centralized heating).**

- **Heaters for the saturation temperature control.**

**Temperature sensors + Heating zones**
Configuration within the Platform
• Evaporator tubing
• Pump
• Heat-controlled accumulator (HCA)
• Radiators with embedded heat pipes
• Condenser/subcooler components
• Throttles
• Heaters

Optimization of the components design to minimize the overall system mass:

$$M_{MPL} = (M_{tube} + M_{fluid} + M_{pump} + M_{power} + M_{rad}) \rightarrow \text{min}$$
Evaporators tubing
Condenser/subcooler components in the radiators
NACPA II Pump Opportunity (1/2)

✅ In 2005-2006, ThAS has been invited by ESA to follow NACPA project that has consisted in Realtechnologie AG review of the NACPA centrifugal pump package (documentation + hardware, performance tests included) developed by ESA/ETEL in the 90’s

✅ Between 2006 and 2008, ThAS collaborates for the ESA/Realtechnologie AG development of a new NH₃ pump/motor engineering model and of a prototype of the associated driver motor electronic unit (NACPA II project)
NACPA II Pump Opportunity (2/2)

- ThAS is responsible for the thermal analysis of the NACPA II pump
- Cavitation issue in the pump can be critical at low temperature

Pressure reserve: maximum allowable local pressure drop inside the pump (only 0.44 bar at –10°C)

Temperature reserve: maximum allowable local temperature increase in the pump
Mathematical Modeling (1/2)

Nodalisation of flight 2\(\Phi\)MPL

- control volume;
- branch (junction);
- convective heat conductor;
- conductive heat conductor;
- radiative heat conductor.
Mathematical Modeling (2/2)

<table>
<thead>
<tr>
<th></th>
<th>P, MPa</th>
<th>T, °C</th>
<th>x</th>
<th>m, g/s</th>
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### Overall Mass Budget

<table>
<thead>
<tr>
<th>MPL components</th>
<th>Mass, kg</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Mass of radiators + tubes + HCA | 104     | Surface area of one side of radiator is equal to **4.3 m²** calculated based on conservative hot heat removal conditions corresponding to 270° with the same environmental conditions of both radiators. Thermal gradient of MPL between TWT unit and radiator skin is equal to **22.2 K : 9.5K** between TWT and evaporator fluid (two-phase thermal exchange calculation) and **12.7K** between condenser fluid and radiator  
=> Global conductance>**120W/K** and Heat Rejection Capacity>**650W/m²** |
| Ammonia                         | 8       | Operating point of pump corresponds to 1.17 bar and 44×10⁻⁶ m³/s at 50°C temperature of ammonia. Required power of pump is less than 50 W.     |
| Pump unit (redunded, with electronics) | 8       | **20 kg/kW** but without the shielding against micrometeorits  
=>**25kg/kW** is nevertheless reachable (P=0.998 for 15 years)                                                 |
| **Total**                       | 120     |                                                                                                                                 |

**Note:** The mass of the system is 120 kg, but without the shielding against micrometeorits, **25kg/kW** is nevertheless reachable (P=0.998 for 15 years).
General view of the prototype
Condenser and cooling fluid circulation
Payload simulation means

Positions of heat transfer surface between unit and tube
The prototype partly assembled
2008 perspectives

- **MPL Prototype Functional Testing**
  - The proof, leak and filling phases are foreseen for the end of May
  - During the second semester of 2008
    - Both steady-state (hot and cold cases) and transient (hot to cold and cold to hot) will be tested
    - The regulation concept using HCA heating and centralized heating will be investigated
    - Start-up issue of the system will be investigated too

- **NACPA Pump**
  - The pump BBM shall be successfully tested for performances (including cavitation test) for the end of May
  - The pump+motor DM and the DME BBM shall be assembled/tested for the end of 2008