**CRYOGENIC FUEL TANKS FOR THE CLIP-AIR PROJECT**

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**Thermal Analysis**

**Fuel lost by vaporization**

Heat sinks into the tank causing part of the LH₂ to vaporize during flight.

- Non negligible fuel loss
- Dangerous pressure build-up on the long term
- Additional heat source

**Aim of the study:**
- Define appropriate insulation thickness
- Set characteristics of the cooling system

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**Analysis results**

<table>
<thead>
<tr>
<th>Conf. 1</th>
<th>Conf. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation thickness [cm]</td>
<td>20</td>
</tr>
<tr>
<td>Cooling system</td>
<td>On ground</td>
</tr>
</tbody>
</table>

Due to relatively low H₂ vaporization and small weight margins, the cooling system is not carried on board.

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**Cooling system**

The cooling system consists of liquefying the vaporized hydrogen. The liquefaction process is based on the reverse Brayton cycle:

- **Necessary equipment:**
  - Compressor
  - Turbine
  - Heat exchangers
  - Joule-Thomson valve

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**Project Overview: Modularity and cryogenic fuels**

Clip-Air is a state-of-the-art passenger aircraft project based on a single wing and multiple fuselage design. Its main advantage consists of high modularity due to its detachable load units which can be changed according to demand. The plane is being designed to fly on cryogenic fuels to reduce carbon emissions and the aim of this project is to study the feasibility of a cryogenic fuel tank system capable of operating at temperatures reaching -253 °C. Two vessel configurations were modeled, for which stress and thermal analyses were conducted.

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**Finite element analysis**

**Mechanical and thermal loads**

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Internal pressure (1.4 bar)</td>
<td>- Equivalent von Mises stress</td>
</tr>
<tr>
<td>- Temperature distribution through tank wall</td>
<td>- Displacement</td>
</tr>
</tbody>
</table>

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**Support system**

**Configuration 1: Half-ring support**

**Configuration 2: Rail support for fast loading**

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**Tank and wall design concept**

**Tank wall**
- 2004 aluminum (3 mm)
- 2219 aluminum (1.5 mm)

**Insulation layers**
- Flexible open-cell polyurethane foam (4-7 cm)
- Rigid closed-cell polyurethane foam (0-13 cm)

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**Design configurations**

<table>
<thead>
<tr>
<th>Configuration 1</th>
<th>Configuration 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tanks</td>
<td>3</td>
</tr>
<tr>
<td>Tank length [m]</td>
<td>9.3</td>
</tr>
<tr>
<td>Tank radius [m]</td>
<td>1.765</td>
</tr>
<tr>
<td>Tank weight (incl. fuel) [kg]</td>
<td>8100</td>
</tr>
<tr>
<td>Fuel tank capacity [l]</td>
<td>60</td>
</tr>
</tbody>
</table>

Referring to the first configuration which represents the primary candidate, the second design has the following properties:

- **Advantages**
  - Higher modularity: Lower flight range (2000 km)
  - Higher safety: Greater weight per total fuel volume

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**Conclusion**

Liquid hydrogen was selected as the preferred fuel candidate following this preliminary study. Fuel tanks were designed and underwent analysis to examine stress due to the large temperature gradient. The tanks validate initial design criteria.

For the cooling system, the Brayton process was selected to maintain liquid hydrogen’s thermal state. The studies conducted provided the scale of the system’s elements.

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**Next Steps**

- Finalize material selection for tank wall with experimental tests at cryogenic temperatures.
- Conduct safety tests on fuel tanks.
- Find the appropriate components of the cooling system (compressor, heat exchanger, pumps and piping).
- Expanded flight range design (Transatlantic flight).
- Total cost calculations of the fuel tank designs.