Vapor Compression Refrigeration for Cold Storage on Spacecraft

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Problem Statement

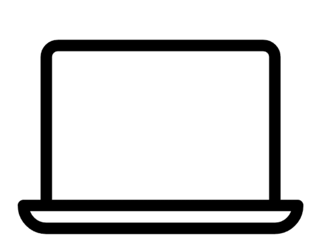
This project aims to employ the vapor compression cycle, commonly used in all household refrigerators and freezers, in complete weightlessness or "zero gravity" conditions. The project poses several challenges:

- Considering weightlessness, both heat exchangers have to be redesigned
- An oil free compressor must be designed because oil behavior in the cycle at weightlessness is an unknown. The pressure ratio imposed by the operating conditions will be $p_r = 10$.
- The system must fulfill strict weight and power limitations, which are a secondary mass penalty of 0.2 kg per kg of stored food and 0.15 W per kg of stored food.

The main demand for the development comes from cold storage on future space exploration. Those will demand astronauts to be on missions without regularly receiving supplies. The quality of stored nutrients decays with time, an effect that can be slowed down by cooling. Hence, efficient and reliable means for cold storage are desirable. Current cooling technology aboard of the ISS relies on the Reversed Brayton Cycle. The vapor compression cycle is pursued because of its higher efficiency.

Potential Impact of Research

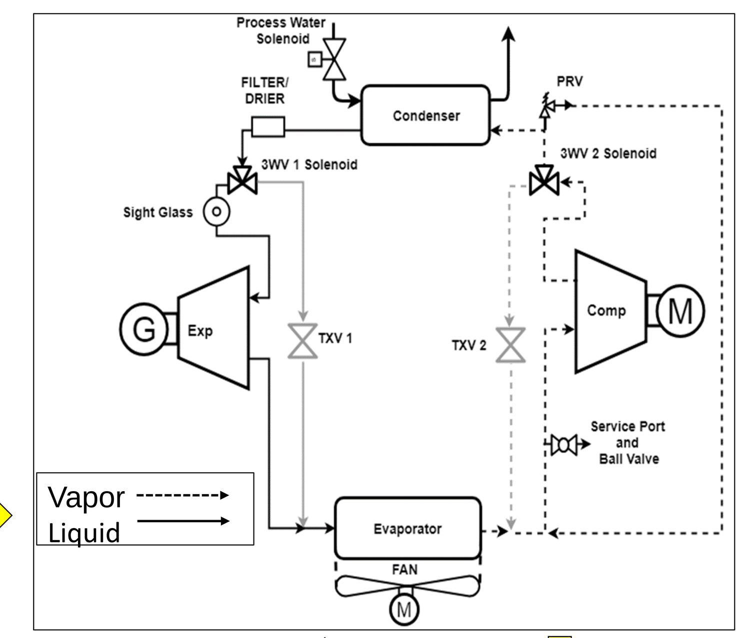
- Efficient and light means of cooling in a microgravity environment will not only improve food storage but can be extended to cooling medicine, electronics and other temperature sensitive items during space exploration.

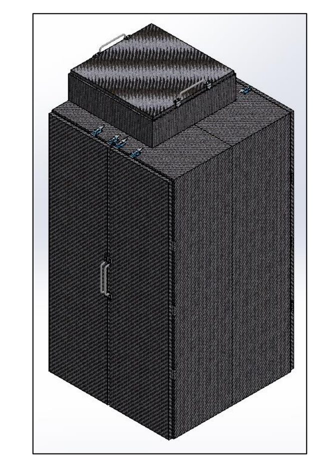


- A vapor compression cycle that can operate at different accelerations can potentially also operate in any orientation. Applications requiring orientation independent cooling like fighter jets or cooling in rotating wind turbines would benefit from this development.

Approach and/or Methodology

1. Reliability and efficiency constraints as well as operating conditions and environment: **Initial cycle design and modeling**

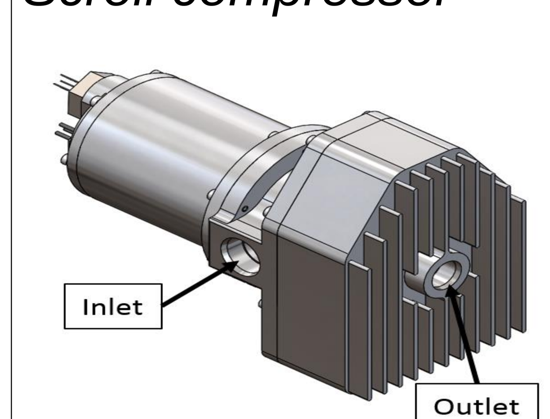




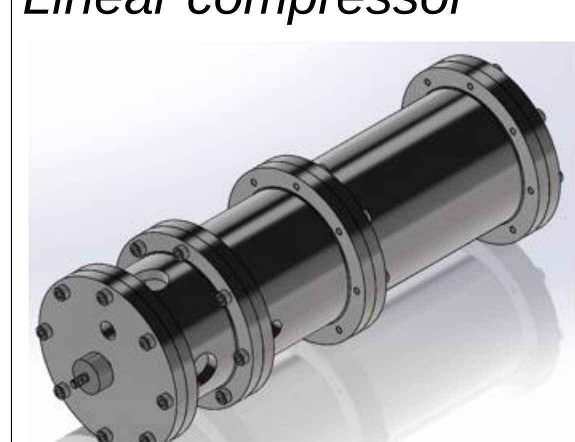
CAD model of final cabinet

2a. **Compressor development for oil free operation**

Scroll compressor

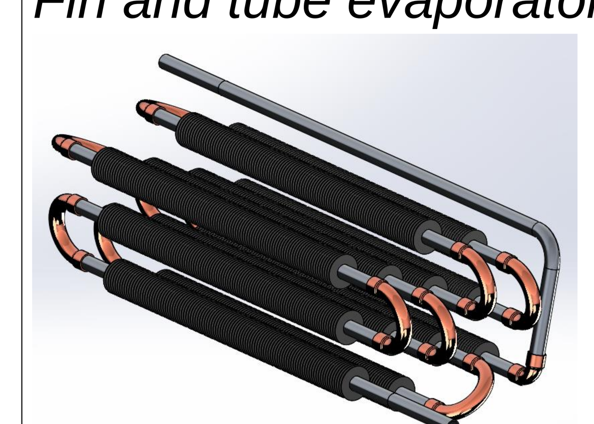


Linear compressor

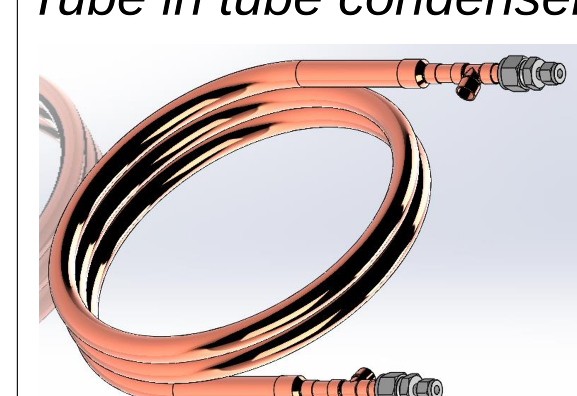


2b. **Heat exchanger design**

Fin and tube evaporator



Tube in tube condenser



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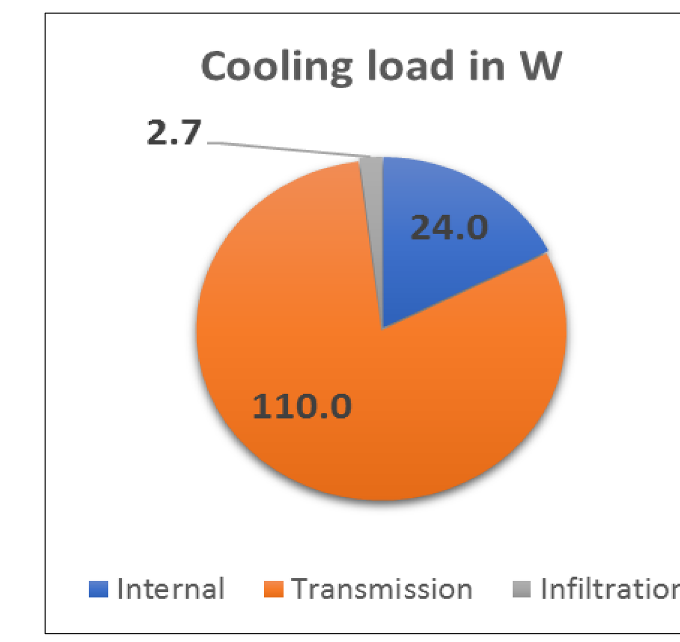
3. Terrestrial testing
Proof fulfillment of performance requirements

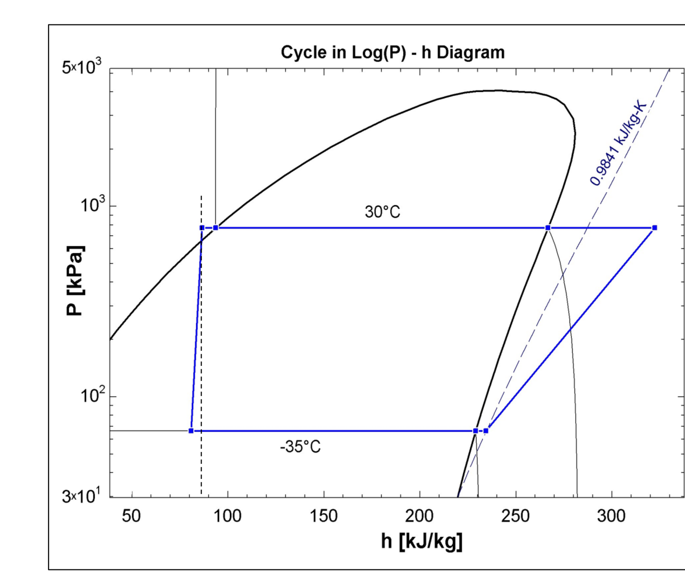
4. Microgravity testing
- Miniature scale test

Results

- The cooling load due to heat transfer into the cabinet is modeled to be 110 W. This low infiltration is achieved by using vacuum insulation panels over the complete surface of the cabinet.
- Other cooling loads due to the door opening (infiltration) or the internal fan are much smaller.



- The diagram shows the Log(P)-h diagram of the cycle at standard operating conditions.
- The effect of the expander on the cycle, work recovery and increase in cooling capacity can be seen from the slope in the line of the expansion process.



- The thermodynamic modeling shows $COP = 1.66$ and $\eta_{2nd} = 0.45$ for a temperature lift from $T_{evap} = -30$ to $T_{cond} = 30$.
- The power consumption per kilogram of food is $0.95\ W/kg_{food}$

Future Work

- Analytical modelling with separate gravity terms shall be utilized to simulate terrestrial, lunar or zero gravity conditions.
- The separate components as well as the complete system shall be tested on earth to validate the modeling efforts.
- Possibilities for micro-gravity testing are explored.