Experimental Evaluation of the Micro Water Thruster Recovering Waste Heat of a Spacecraft

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Background

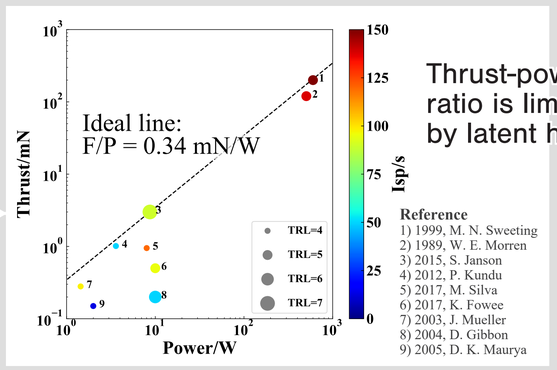
System specific impulse (I_{ssp}) is important for small S/C

$$I_{ssp} = \frac{I_{tot}}{m_{ps}} = \frac{\rho V}{\rho V + m_{st}} I_{sp} g$$

ρ and m_{st} → Vaporizing Propellant

✗ Need high latent heat
- e.g. water: 2.4 kJ/g
- Disadvantage for small S/C

Past studies & ideal value
- Propellant: water
- Ideal: 20 ℃(liquid) → 70 ℃(gas)
  Effective Cf = 1.56

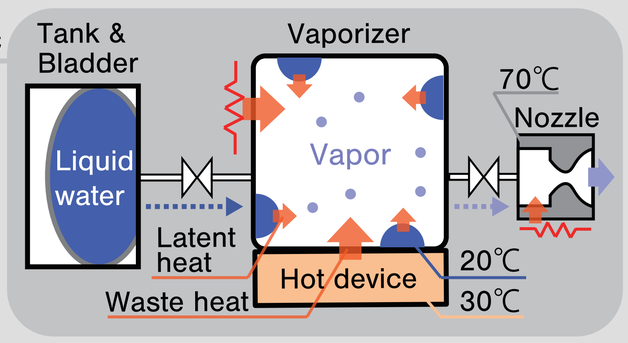


Thrust-power ratio is limited by latent heat

Proposed Concept

Waste heat compensates for latent heat

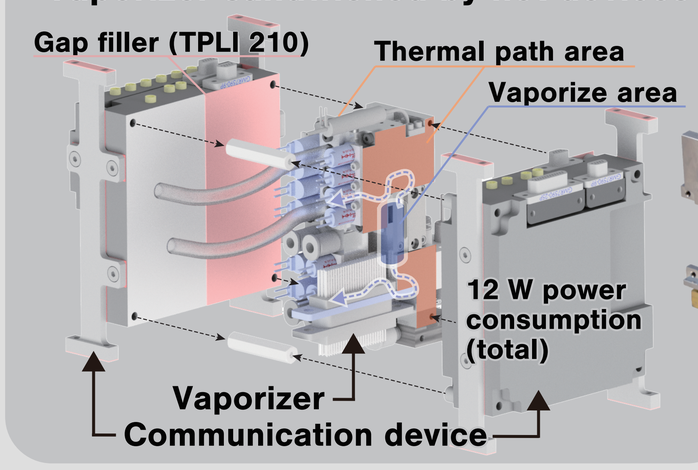
Proposed thruster schematic
- Storing water as liquid
- Vaporizing in vaporizer under normal temperature
- Reusing waste heat to keep vaporizer temperature



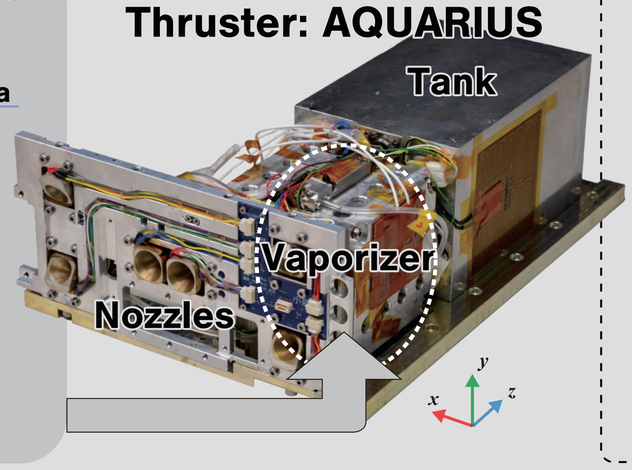
Objectives of this study
- Demonstrating the concept of "Waste heat recovery"
- Evaluating heat transfer by both of simulation and ground experiment

Thruster Assembly and Thermal Vacuum Test

Vaporizer sandwiched by hot devices

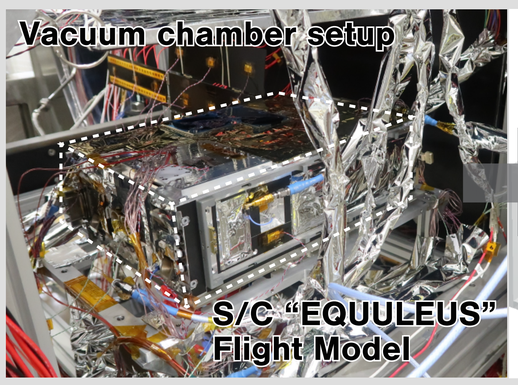


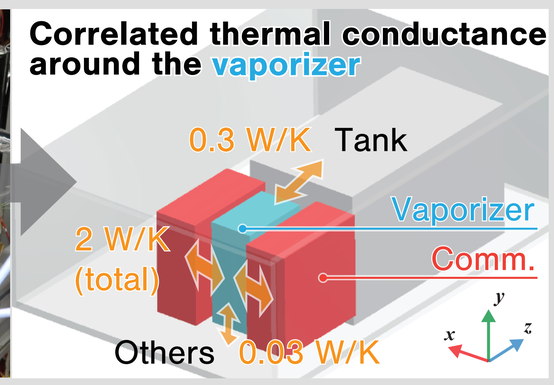
Thruster: AQUARIUS



Thermal vacuum test for thermal model correlation

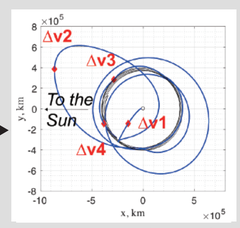
Thermal sensitive thruster → Thermal model correlation is indispensable



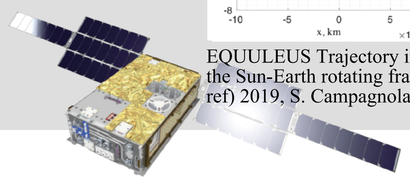


Simulation on Orbit

- By Thermal Desktop®
- EQUULEUS DV trajectory condition (fly Earth to EML2)
- Target: Thrust = 3.85 mN
  - Latent heat = 14.0 W
  - Vap. temp. = 28.0 ℃

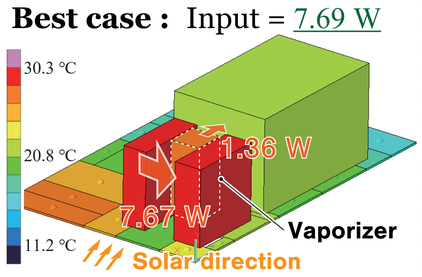


EQUULEUS Trajectory in the Sun-Earth rotating frame ref) 2019, S. Campagnola

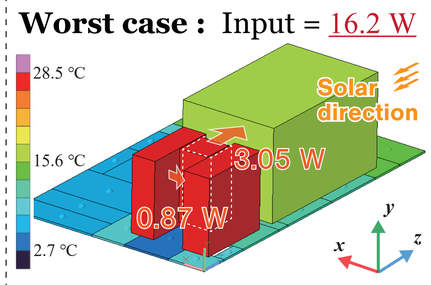


Simulational result
Input heat = Latent heat - Heat transfer

Best case : Input = 7.69 W

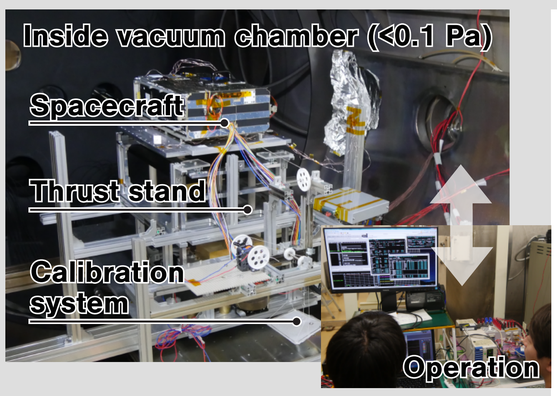


Worst case : Input = 16.2 W



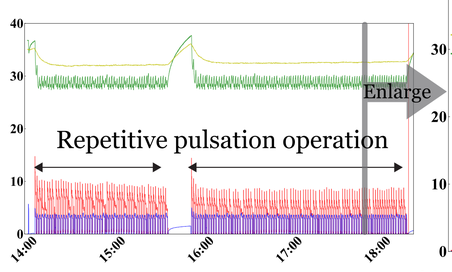
Summary of findings
- Waste heat will be reused at all condition.
- Solar direction highly affects reuse waste of heat.
- Saved power (=heat conduction to vap) is max 6.3 W.

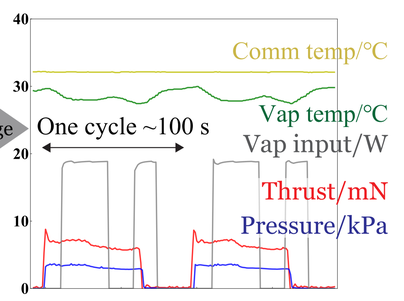
Ground Operation Test



- Target: Ave. Thrust > 3.85 mN
  - Vaporizer was kept ~ 28 ℃
  - Nozzle was kept ~ 70 ℃ by bang-bang heater control
- Steady oparation with installed to spacecraft

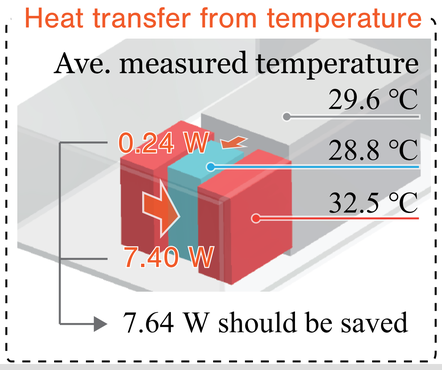
Experimental result





Operation time	14,229 s
Used propellant	79.7 g
Total impulse	56.5 Ns
Ave. thrust	3.92 mN
Specific Impulse	71.1 s
Ave. Latent heat	13.6 W
Vaporizer input	8.58 W
Saved power	5.02 W

Heat transfer from temperature

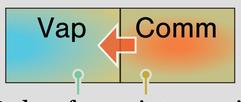


Summary of findings
- Total 4 hours operation was carried out.
- Measured thrust reached target value.
- 5.02 W power saving was demonstrated.
- Waste heat into vap was calculated to 7.64 W.
- Measured thrust-power ratio was 0.41 mN/W and over ideal value in background section.

Discussion

1. Thermal difference between simulation and experiment
   - Simulated result of experimental condition
   - Experimental result ------ ***correlation*** ------ Better thermal mathematical model
2. Lower saved power than thermal conductance-based value at experiment

Reason :
- Thermal correlation error (~20 %)
- Temperature distribution inside components



Conclusion

- For recovering waste of heat, vaporizer was thermally connected to heat consumption device and thermal conductance was checked.
- Concept of recovering waste heat was demonstrated.
- It was simulated that 0.9-7.7 W waste heat will be reused on orbit.
- In actual experiment, 5.0 W was saved compared with latent heat.
- It was proved that this concept broke the limits of the thrust power ratio.

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