36th Annual Small Satellite Conference

SSC22-X-05

Design and Testing of a 100-mN class Water Micropropulsion System using Wire-fed Magnesium Combustion

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Introduction

- **Lage thrust propulsion system** for
  - Orbit insertion
  - Reentry
  - Collision avoidance etc.

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- Requirements for **micropropulsion systems and propellants**
  - Safety ---> HAN, ADN based propellants, H2O2, ABS-GOX, etc.
  - Availability

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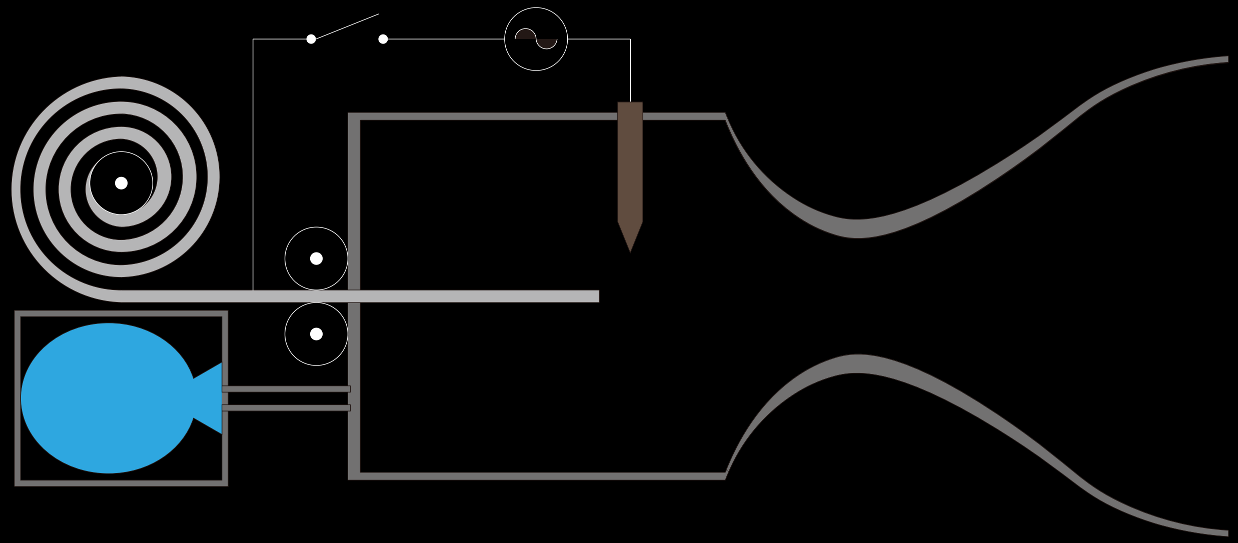
More! → Mg-water micropropulsion system

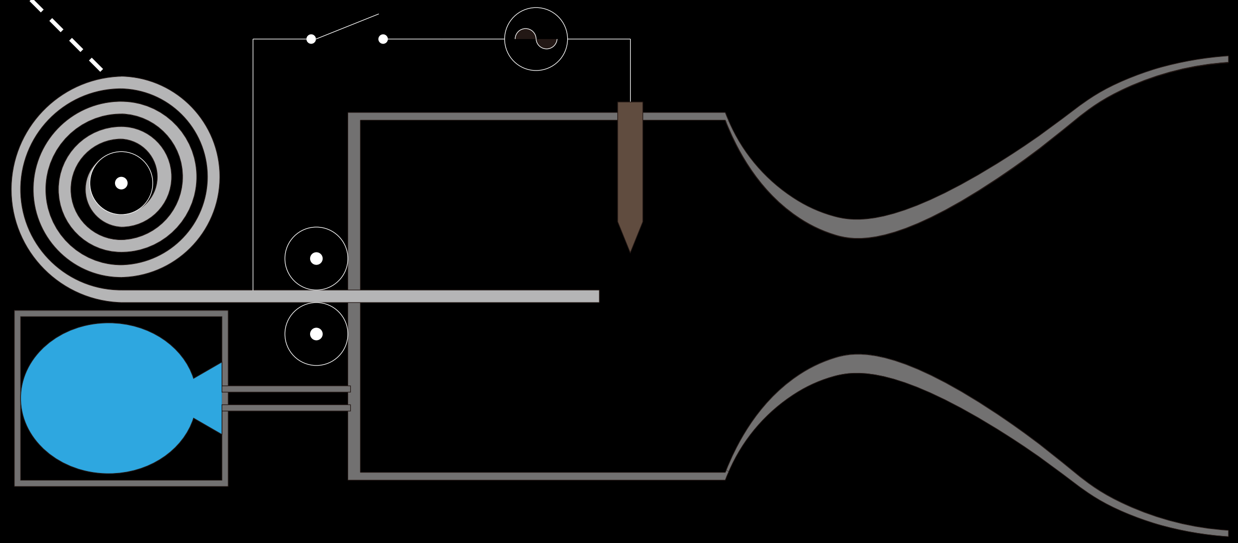
Concept of Magnesium-Water Micropropulsion System



Akiyama, M., et al., *Trans. JSASS*, 2021.

Concept of Magnesium-Water Micropropulsion System

- **Magnesium**: Fuel
  - "Wire shape": ease of supply
  - Installed as a rolled wire
- **Water**: Oxidizer
  - Installed in a liquid phase



Akiyama, M., et al., *Trans. JSASS*, 2021.

Concept of Magnesium-Water Propulsion System

- **Magnesium**: Fuel
  - "Wire shape": ease of supply
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- **Water**: Oxidizer
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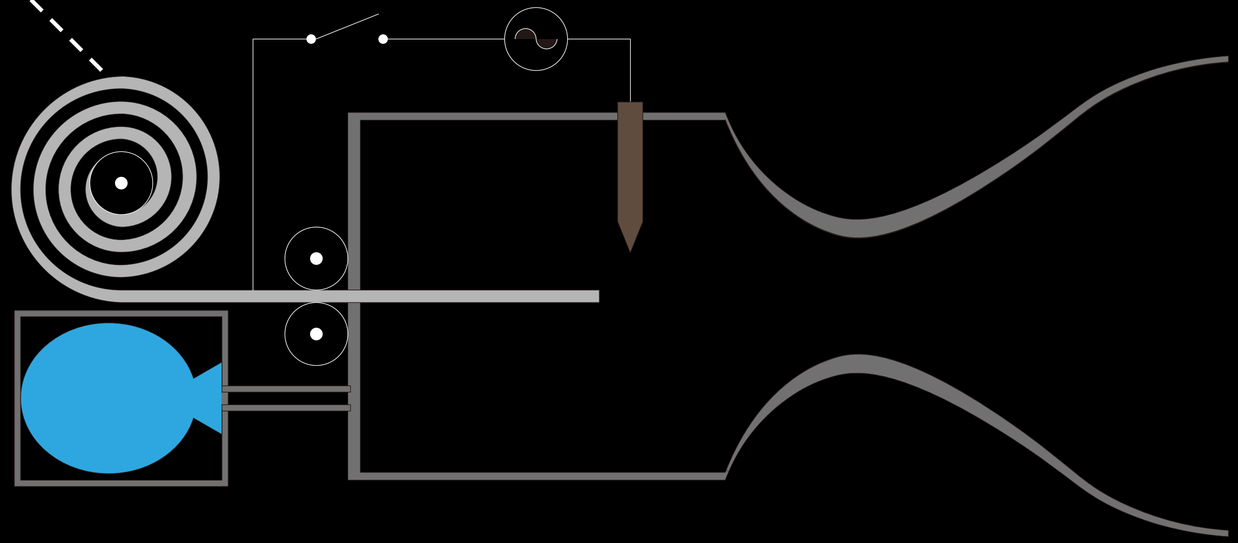
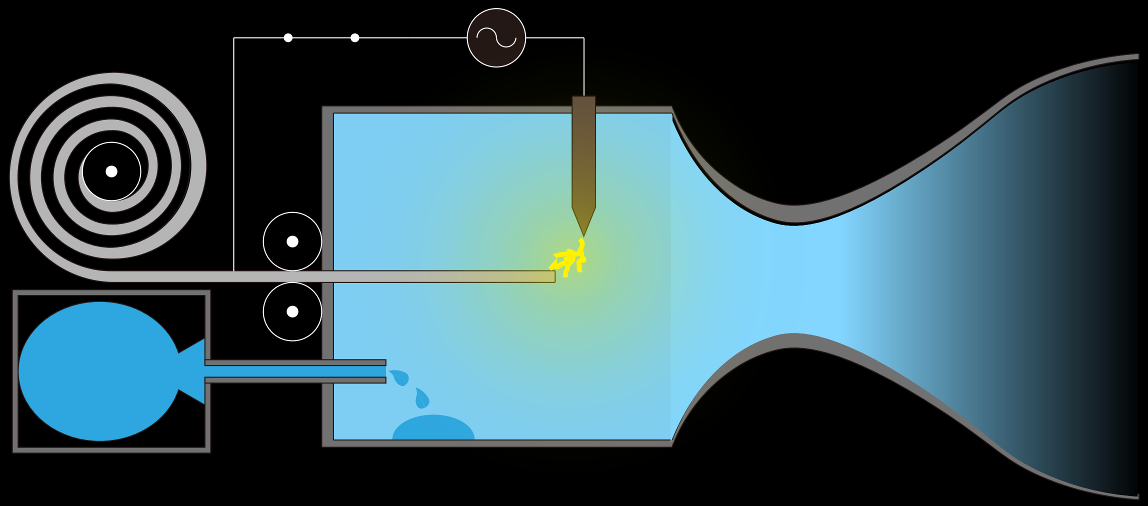
- Propellant features
  - High safety and availability
  - Elimination of gas propellants
    → Reduction of system pressure



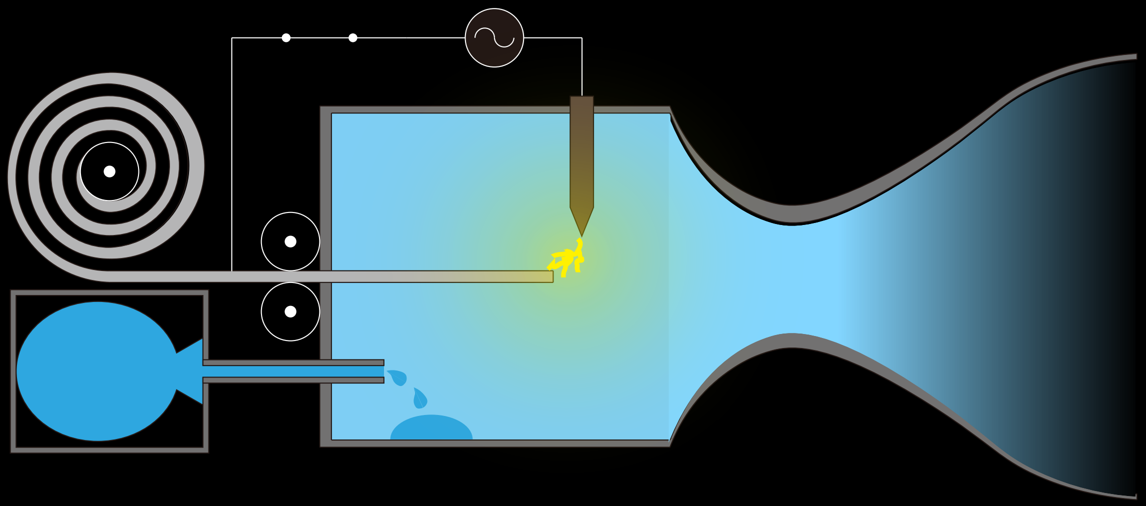
Akiyama, M., et al., *Trans. JSASS*, 2021.

- Operation



- Operation

Discharge of Mg wire with an electrode



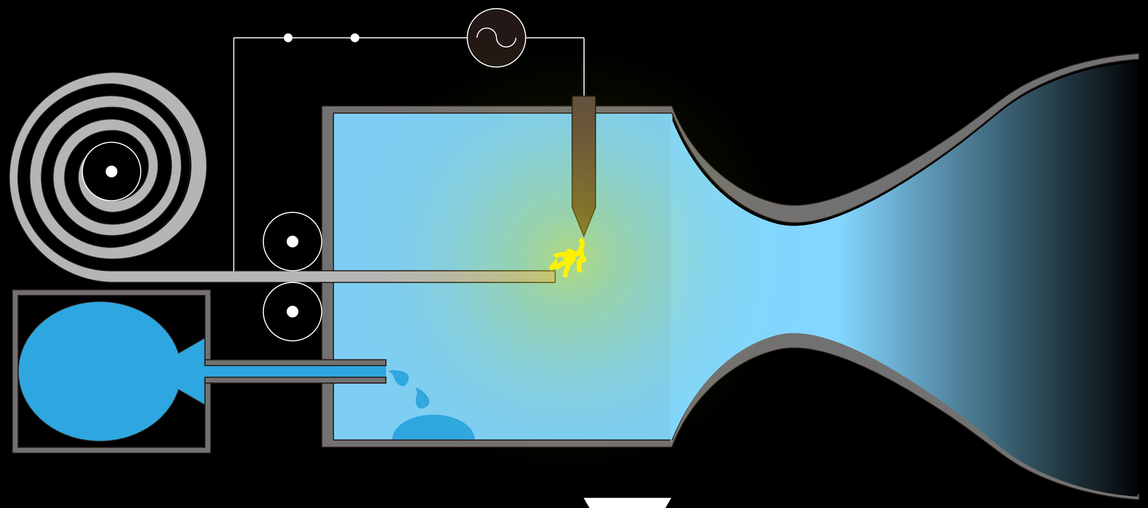
| Concept of Magnesium-Water Propulsion System

- Operation

Discharge of Mg wire with an electrode

▼

Ignition of Mg wire → Discharge stop



▼

- Operation

Discharge of Mg wire with an electrode

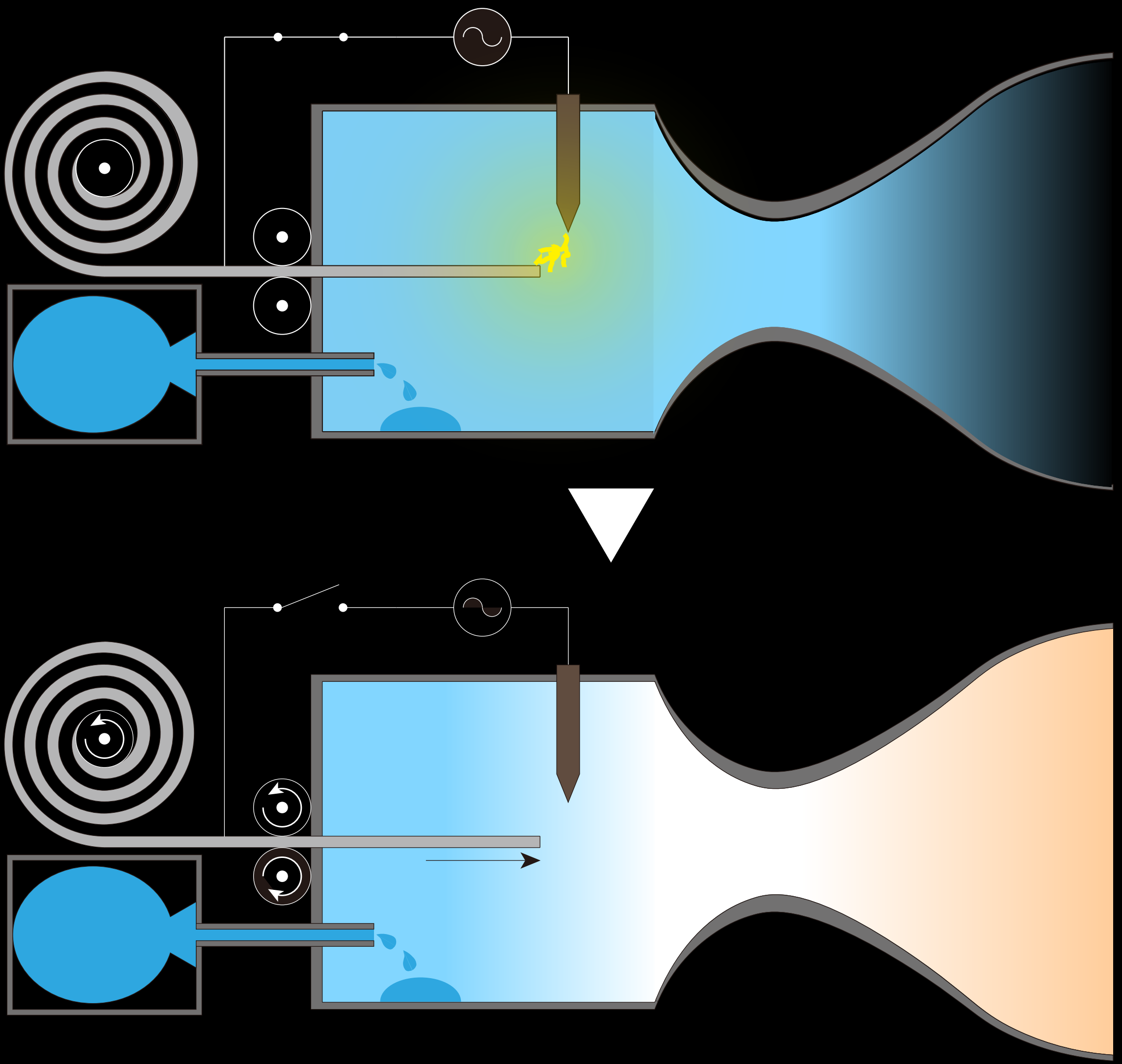
▼

Ignition of Mg wire → Discharge stop

▼

Combustion of Mg wire + Wire supply

$$Mg(s) + H_2O(g) = MgO(s) + H_2(g) + \Delta H_r$$

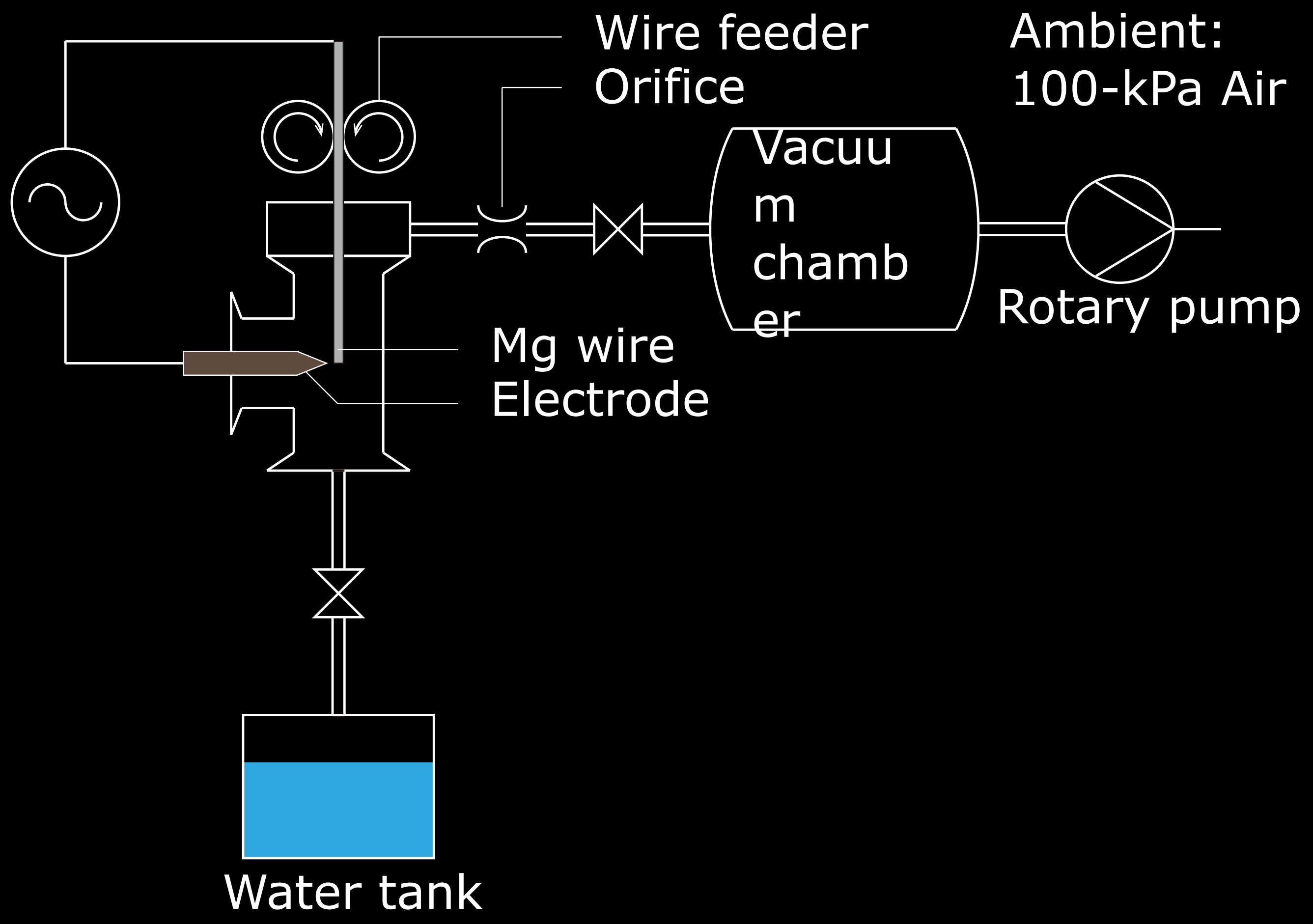


Objectives

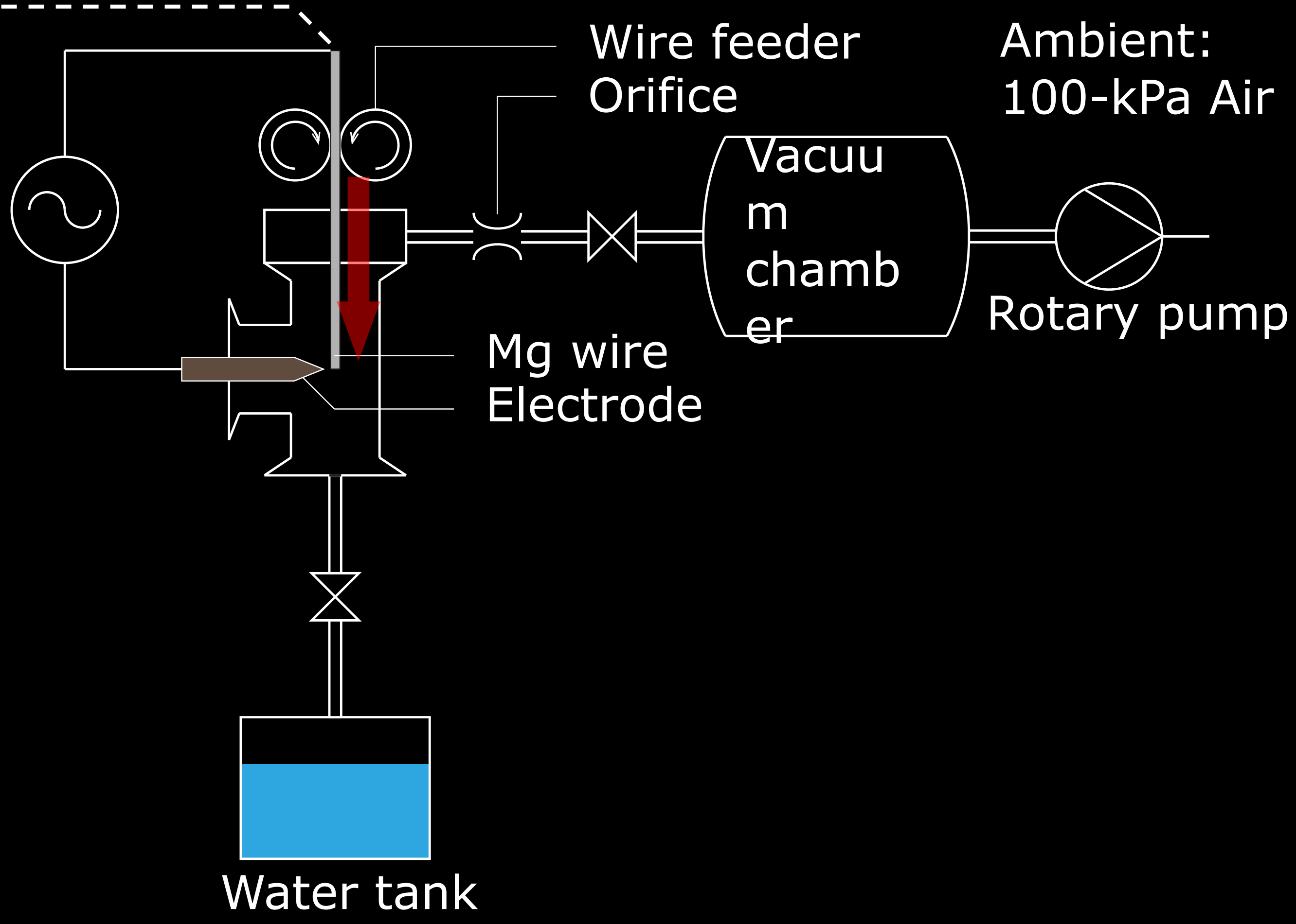
- Verification of Mg-wire combustion in water vapor flow
- Estimation of the thrust performances of the system

Experiment#1
- Verification of the combustion

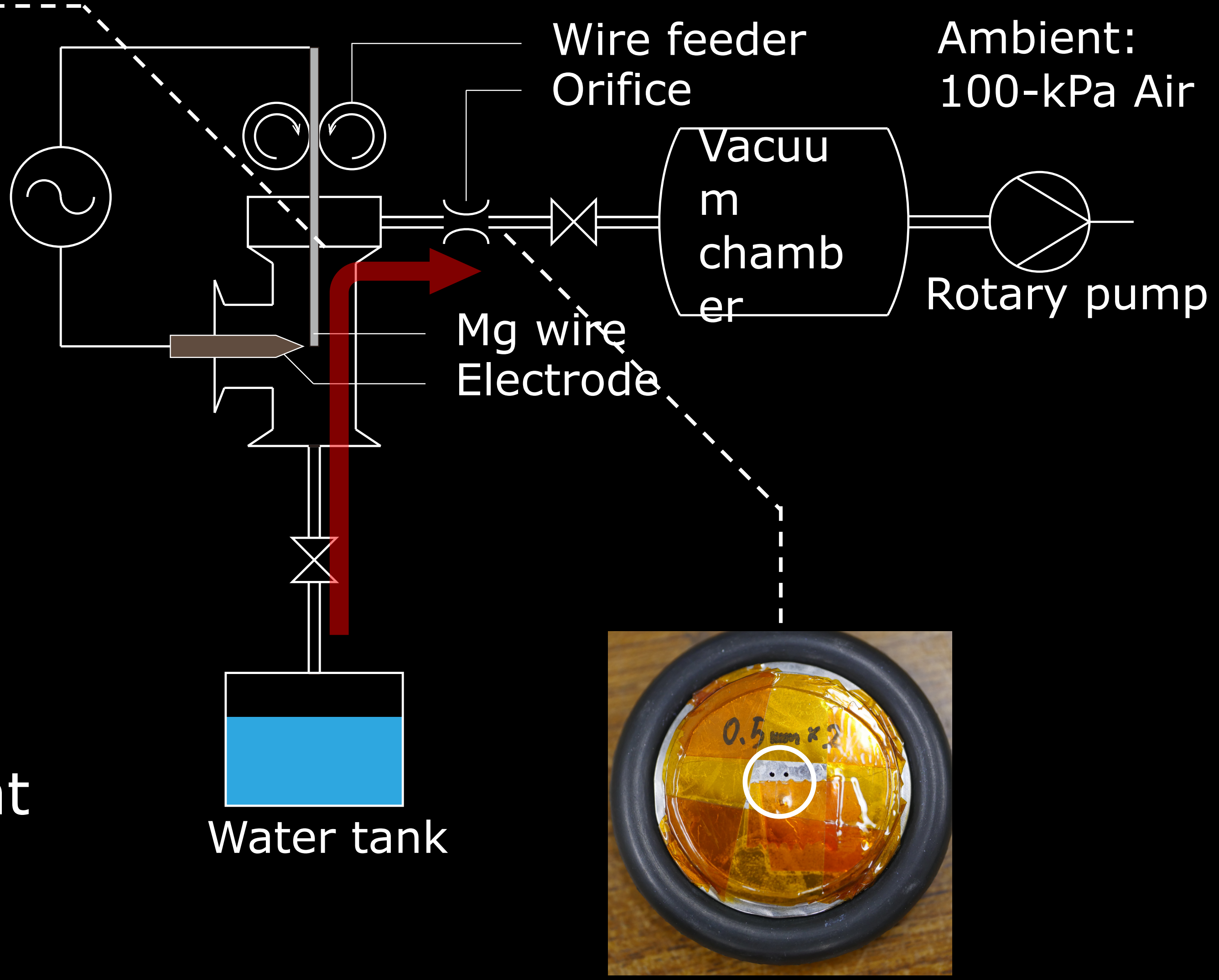
Setup


Wire feeder
Orifice
Ambient:
100-kPa Air
Vacuu
m
chamb
er
Rotary pump
Mg wire
Electrode
Water tank

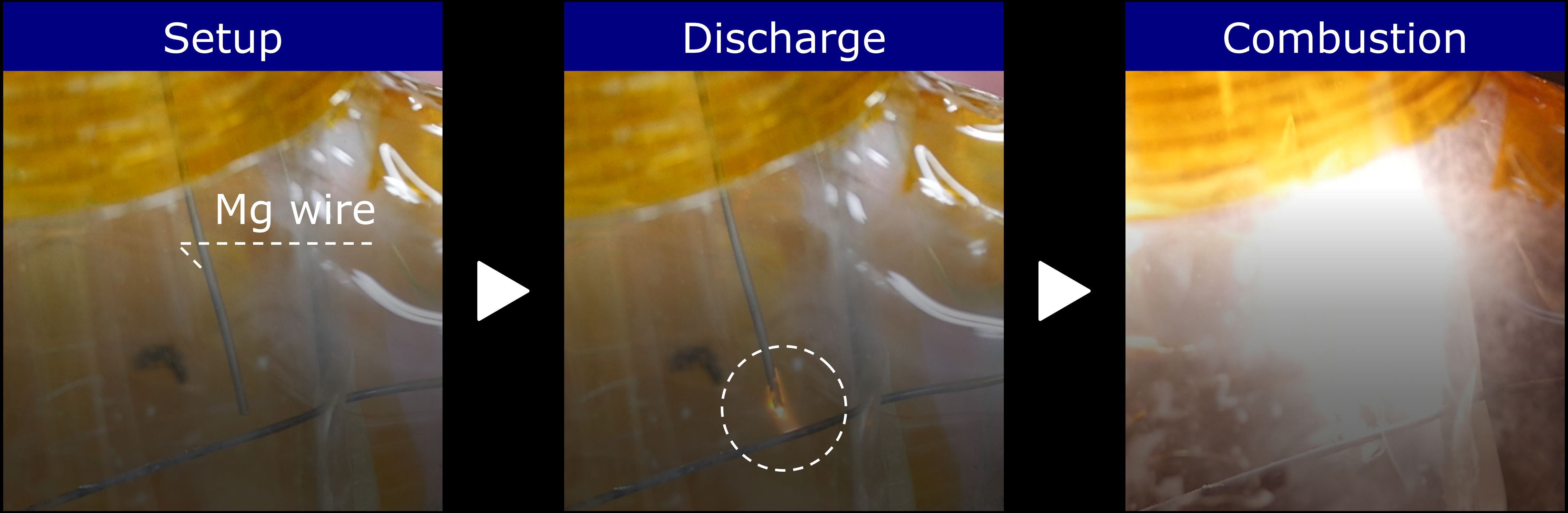
- Fuel wire
  - Made of pure magnesium
  - Φ0.8 mm, L40 mm
  - Supplied by wire feeder
  - Ignited by AC discharge with the other electrode



- Water supply
  - Using deionized water
  - Liquid water heated by a heater
  - Separation of liquid and gas water by gravity
  - Water vapor mass flow rate controlled by orifice plate
  - Combustor and flow path wrapped by heaters to prevent condensation

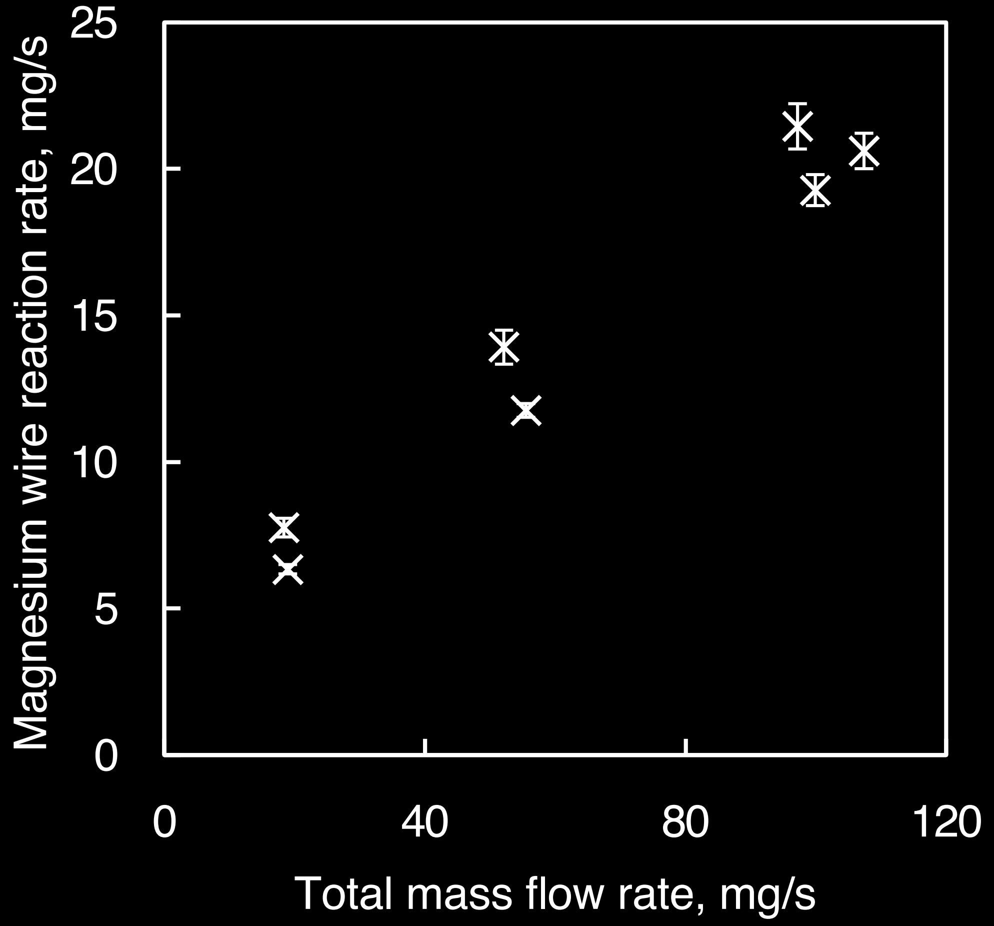


- Water vapor: 68.8 kPa



- Bigger reaction rate as the increase of total mass flow rate
  - Almost linear function

- ✔ Verification of combustion
- ✔ Measurement of Mg-wire reaction rate in water-vapor flow



Experiment#2
- Estimation of the thrust performances

- Using NASA CEA*, the thrust performances are estimated.

Experimentally obtained $\dot{m}_f$, O/F, and P_c

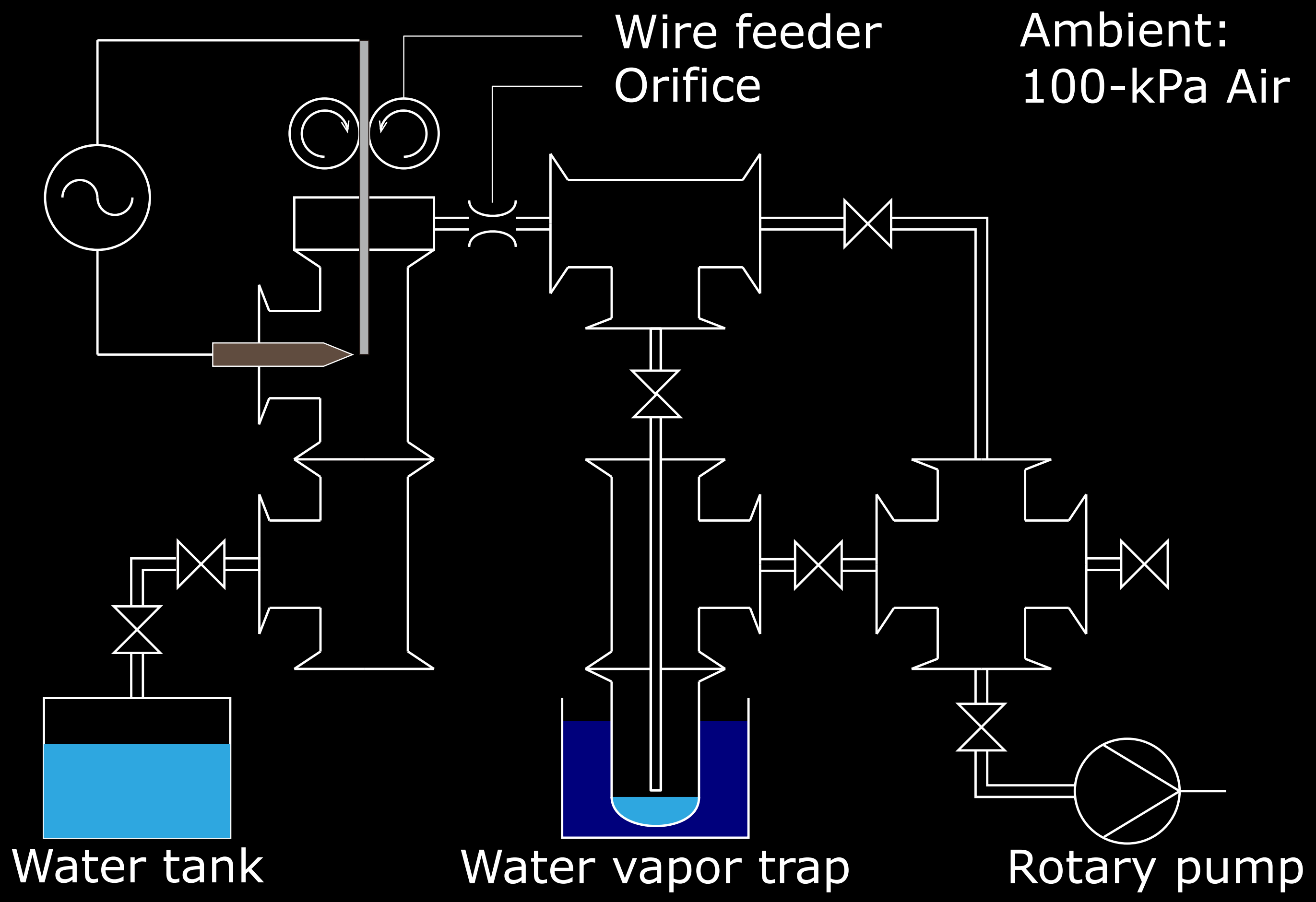
Unknown in Exp.#1

CEA

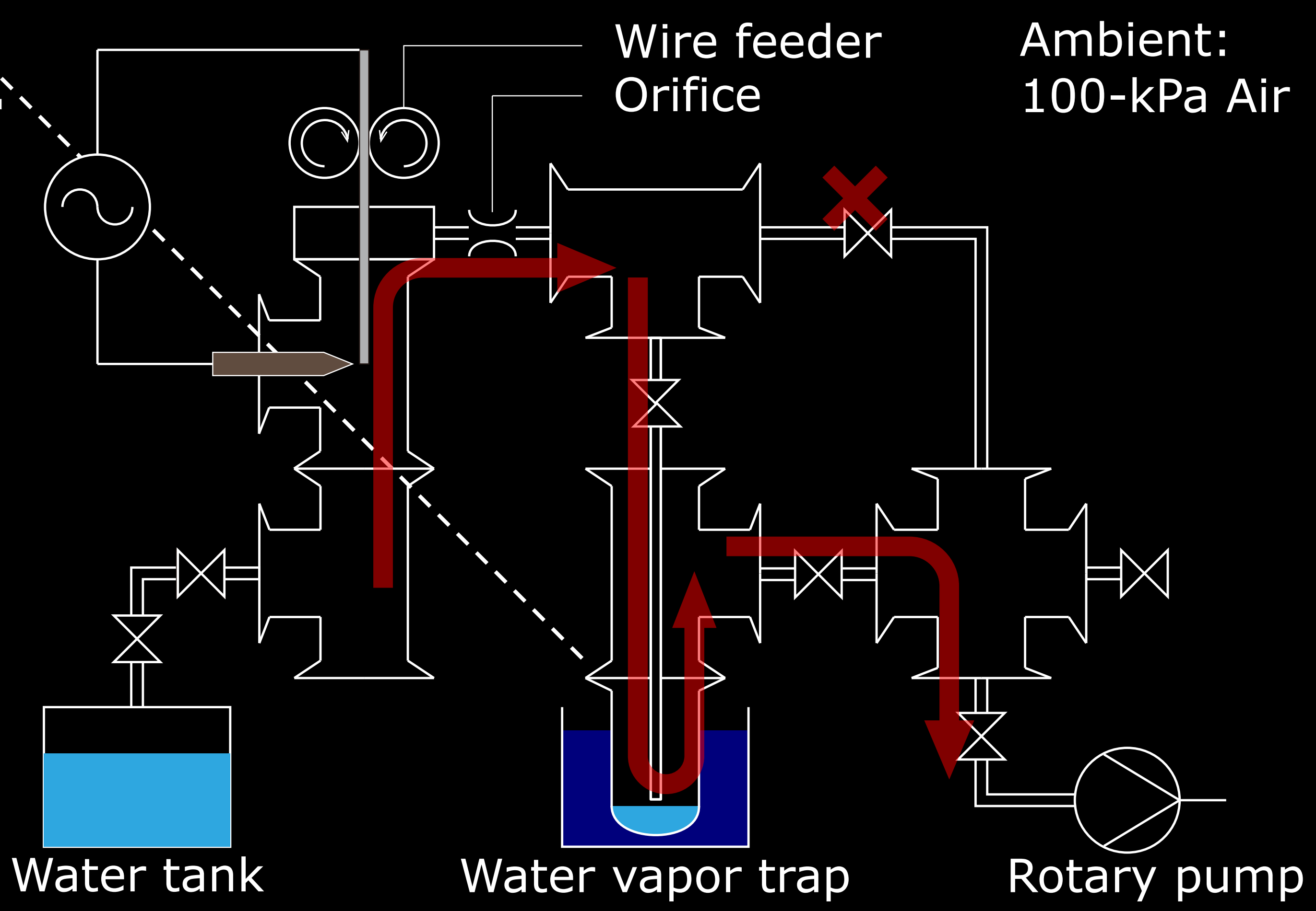
I_{sp}, C^*, C_f → $F = (1 + O/F)\dot{m}_f C^* C_f$

* Gordon, S., et al., NASA-RP-1311,

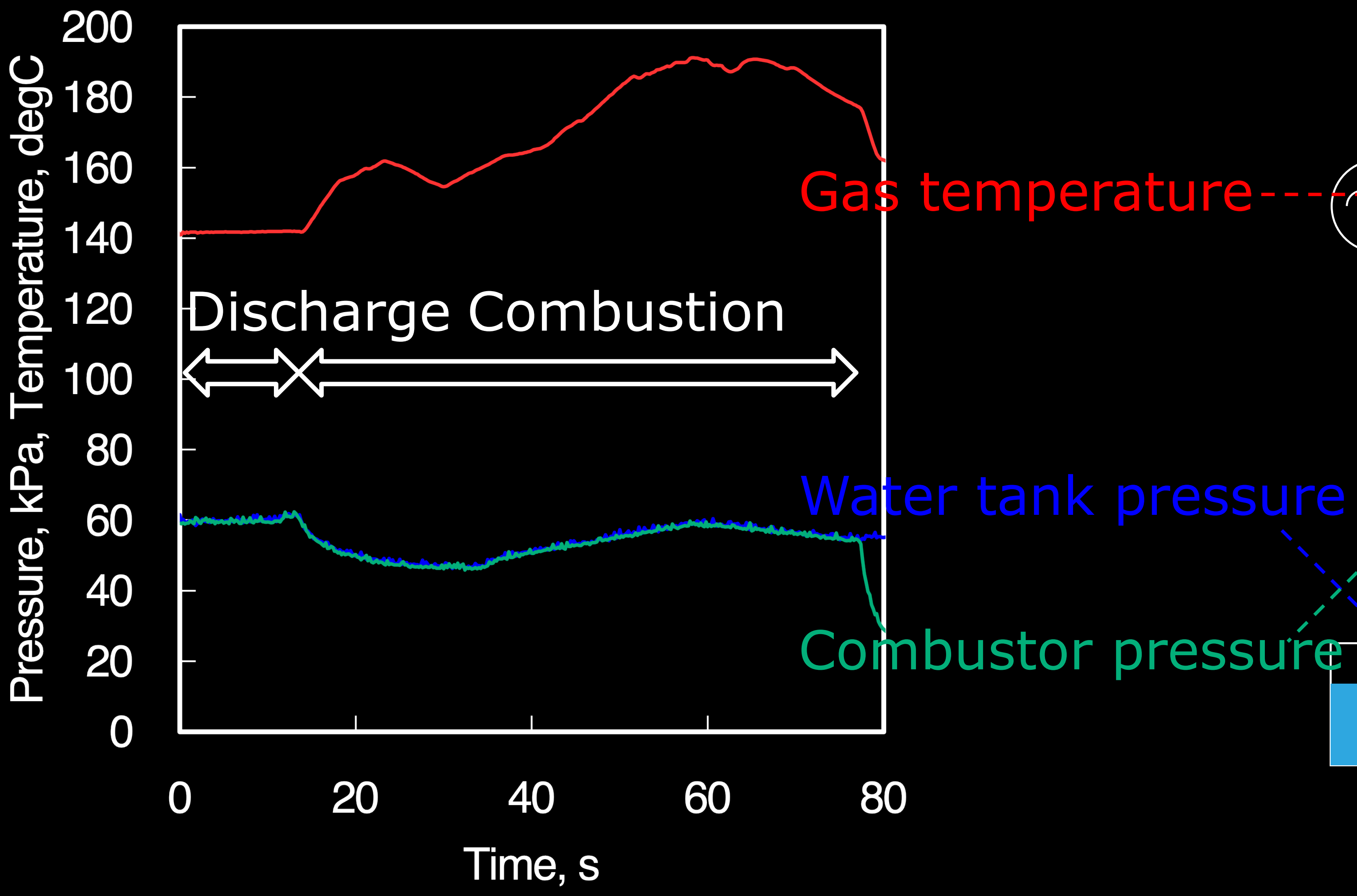
Analysis of Reacted Water Vapor Mass

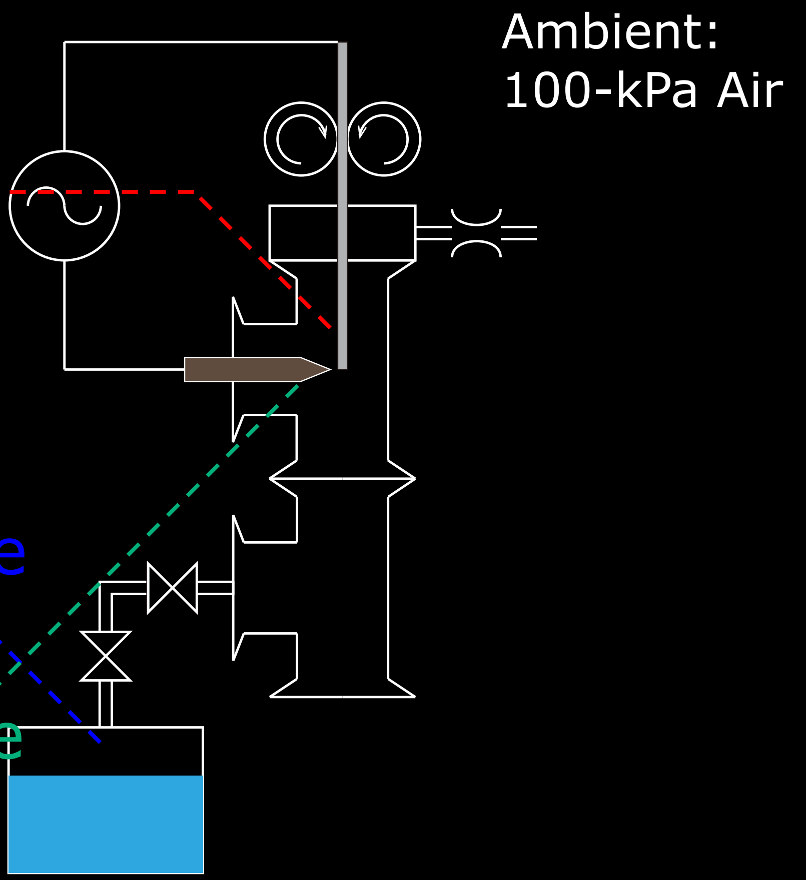


- Water vapor trap
  - Collecting **unreacted water**
  - Cooled to around 5 degC

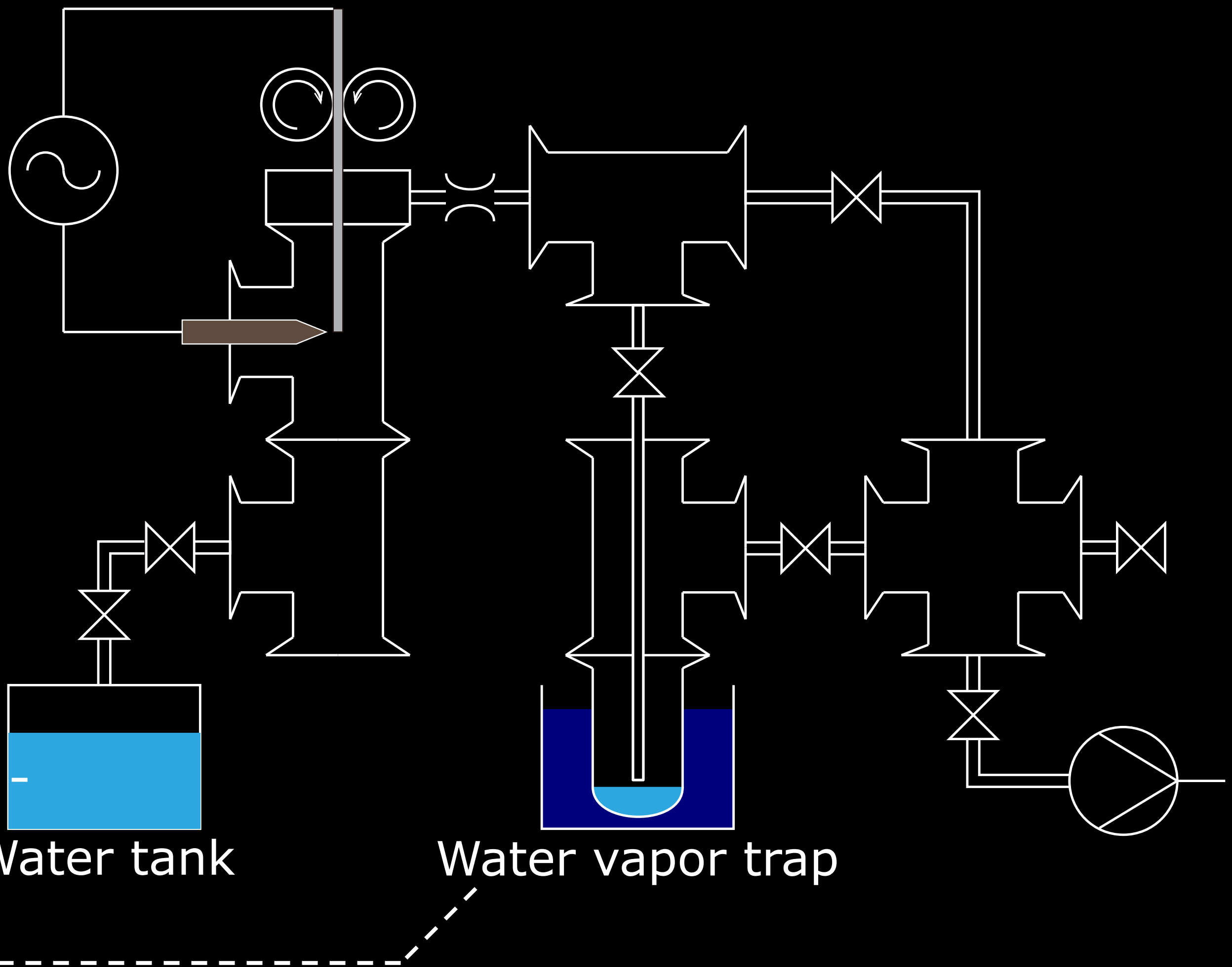


Time Profile of Combustion





Obtaining O/F



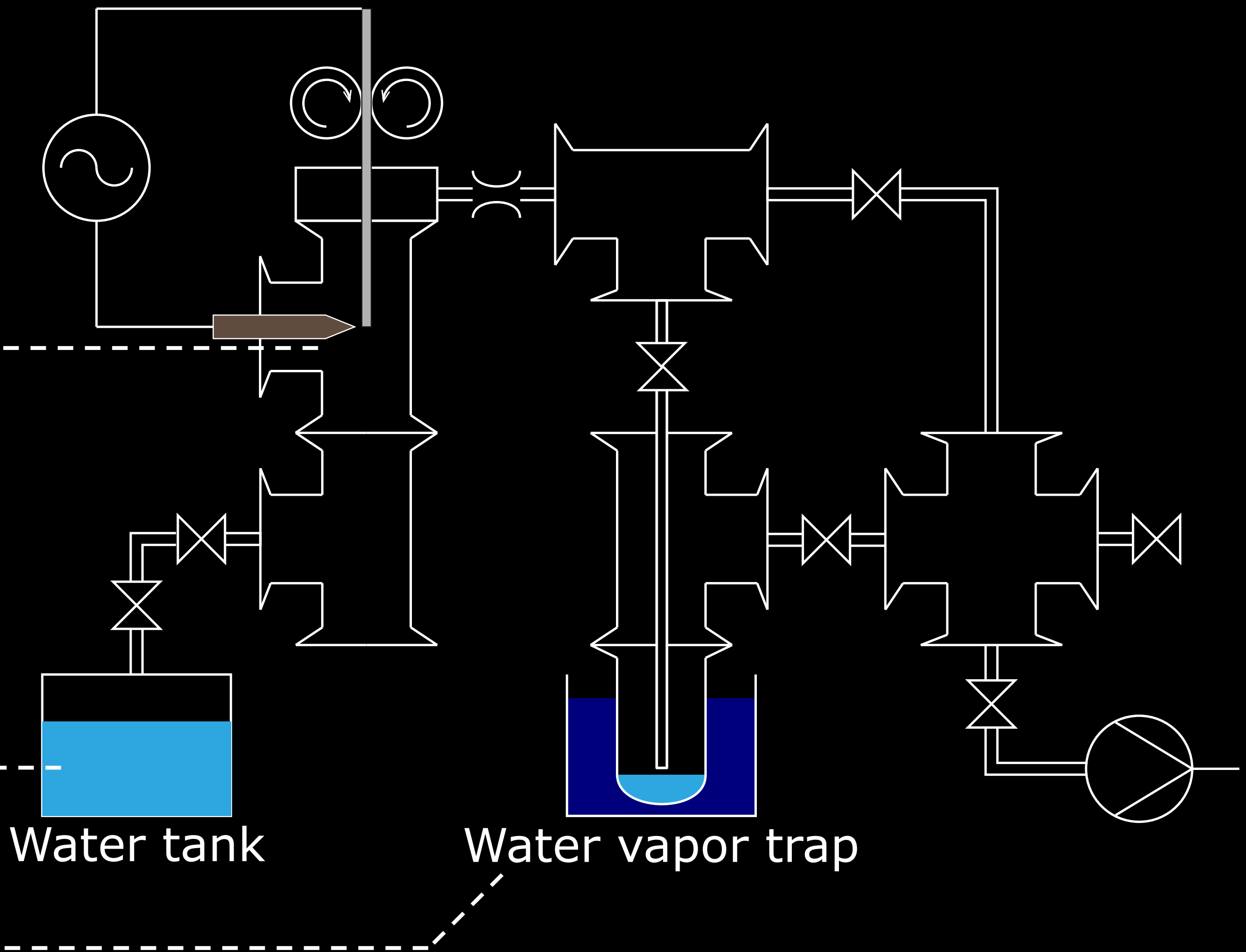
Mass loss: 4.29 g

Mass increase: 3.39 g

Reacted water: 0.90 g

Mass loss: 4.29 g

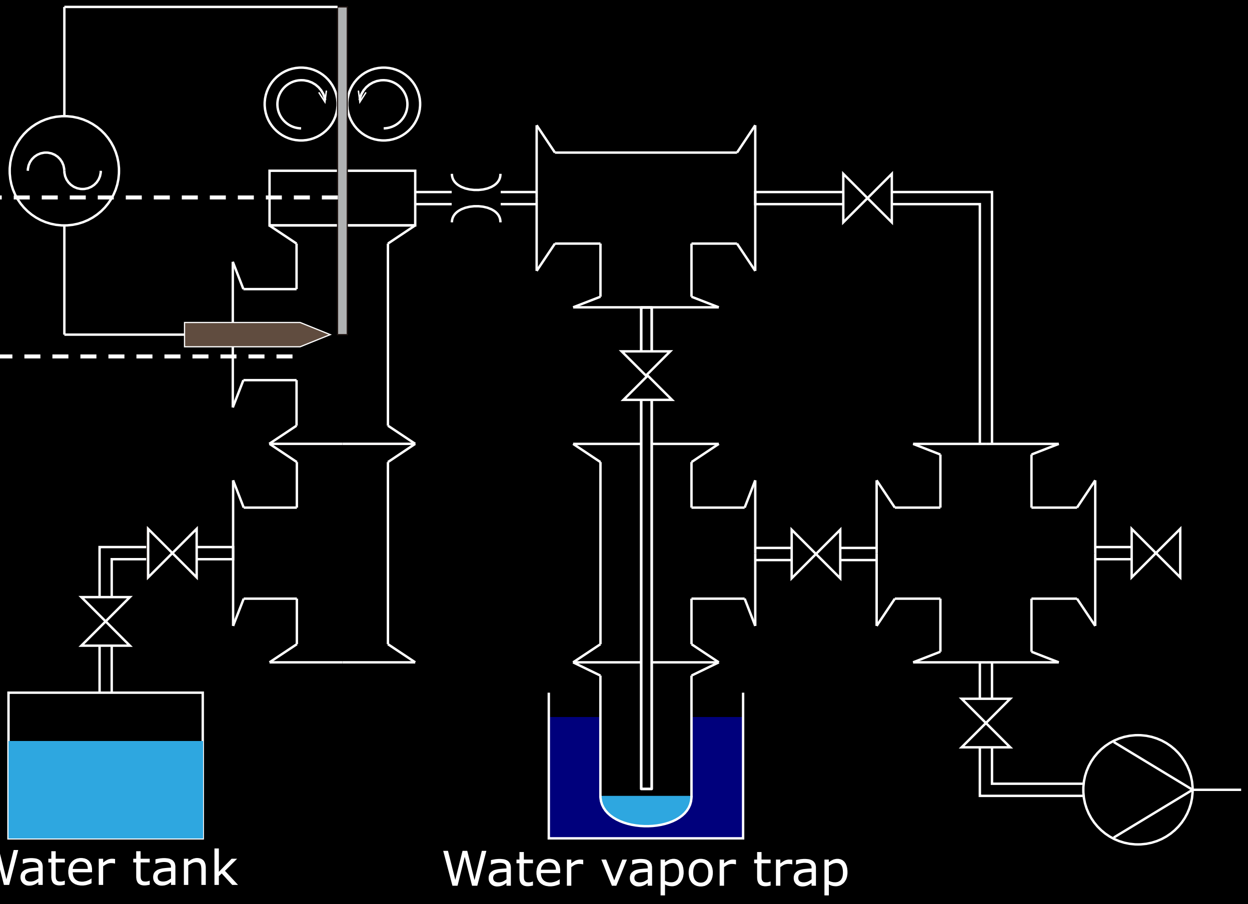
Mass increase: 3.39 g



Obtaining O/F

Reacted Mg: 0.69 g

Reacted water: 0.90 g



Obtaining O/F

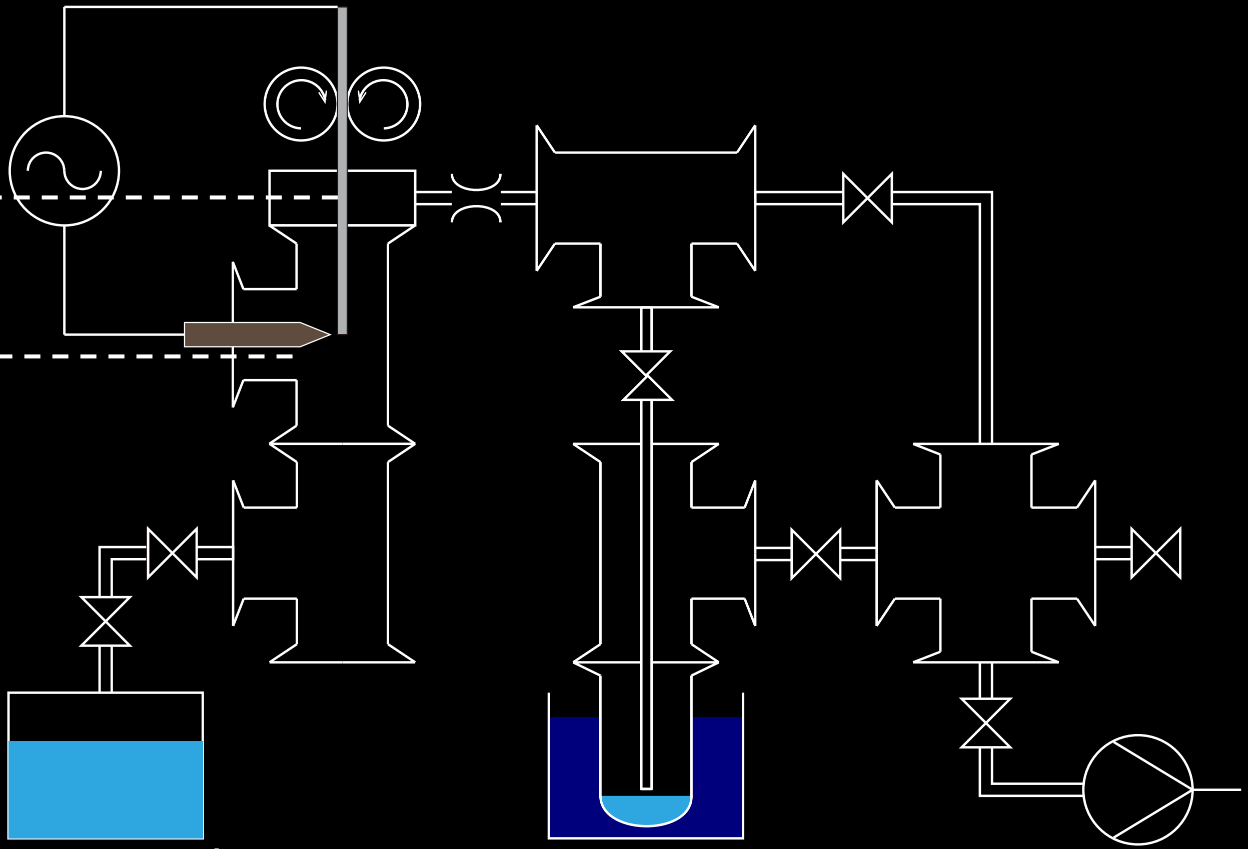
Reacted Mg: 0.69 g

Reacted water: 0.90 g

Combustion period: 62.4 s

$O/F = 1.30$

$\dot{m}_f = 11.0$ mg/s



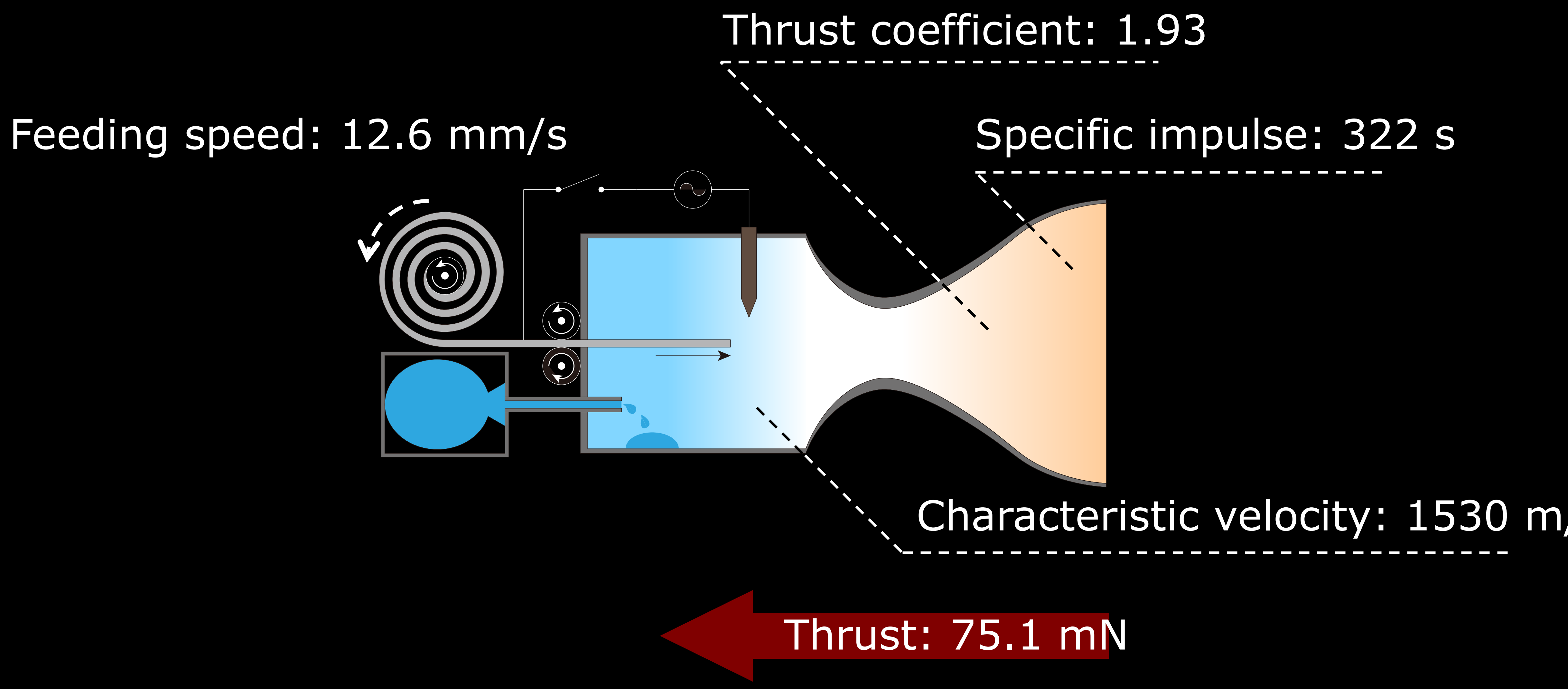
- Analysis using NASA CEA*

Input	
Pressure	53.1 kPa
Fuel	Mg
Fuel temp.	300 K
Oxidizer	H2O
Oxidizer temp.	355 K
O/F	1.30
Nozzle expansion ratio	50
Fuel mass flow rate	11.0 mg/s

Assumption

Experimental results

* Gordon, S., et al., NASA-RP-1311,


Thrust coefficient: 1.93
Feeding speed: 12.6 mm/s
Specific impulse: 322 s
Characteristic velocity: 1530 m/
Thrust: 75.1 mN

Conclusion

- ✔ Suggestion of Mg-water micropropulsion system
- ✔ Verification of combustion, and successful measurement of Mg-wire reaction rate in water-vapor flow
- ✔ Obtainment of O/F, and estimation of thrust performances

Thank you!

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See also…

- Water resistojet thruster P4-14
- Al-water micropropulsion system P4-15
- (Water) hall thruster P4-19, P4-21
- 6DOF thrust measurement system P4-23