Water Electrical Propulsion System Combined with Manned Space Mission

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Yuichiro Nogawa [1]
Splije L.L.C, Tsukuba, 3050032, Japan

and

Hirokazu Tahara [2]
Osaka Institute of Technology, Osaka, 5358585, Japan

Abstract: Since 2011, we have been studying for new advanced type of electric propulsion system what we call WEPS (Water Electric Propulsion System) by using "waste water" produced in ISS or future manned space vehicles.

Our basic concept for this new advanced electric propulsion system is that modification with existing electric propulsion (DC Arc jet) system by changing its fuel. Regarding "the direct usage of water" as a propellant, we are planning to use the reclaimed waste water from Water Recovery System (WRS) in ISS Environmental Control and Life Support System (ECLSS) currently on orbit.

The first major step of this study is to develop a new gas generator to provide H_2O gas to Arc jet thruster. Per our experiment results so far, we found that our exiting mass flow controller could not produce enough water flow to ignite firing continuously due to H_2O liquid state. Osaka Institute of Technology (OIT) is developing a new type of gas generator which could provide sufficient H_2O gas with high flowrate to Arc jet. Recently, we succeeded in making new gas generator in firing by "H_2O only fuel" for a short period. Optimization for stable firing is still required.

Per the latest our roadmap for WEPS, our final goal is to make a small satellite using WEPS and deploy from ISS. It can be launched to ISS by Visiting Vehicle (HTV, Space-X DRAGON, or Orbital ATK Cygnus is possible candidate) and released by using ISS robotic arm.

Nomenclature

WEPS	=	Water Electric Propulsion System
WRS	=	Water Recovery System
ISS	=	International Space Station
ECLSS	=	Environmental Control and Life Support System
JEM	=	Japanese Experiment Module
JEF	=	JEM Exposed Facility
HTV	=	H2B Transfer Vehicle

I. Introduction

SPLIJE L.L.C and Osaka Institute of Technology have been studying for new advanced type of electric propulsion system what we call WEPS (Water Electric Propulsion System). This propulsion system applies "water" as a fuel because water is green, reusable, and ecological. This green propellant eliminates toxic ones (such as hydrazine and

[1] President/CEO, nogawa.yuichiro@gmail.com
[2] Professor, Advanced Rocket Laboratory, Department of Mechanical Engineering, tahara@med.oit.ac.jp

nitrogen tetroxide often used), and can keep space environment safer and cleaner. WEPS also is expected to resolve difficulty in perspective of re-fuel or cost saving is significantly important for the future manned space mission.

We are seeking a non-complicated design for WEPS with directly using water as a fuel. So we don't use H_2/O_2 produced by water electrolysis that should need to integrate more complicated system. For the thruster, DC Arc jet thruster (a kind of electrostatic propulsion) is the best as a perspective of a light weight and low power consumption. No constraints for its propellant, thus a main modification with existing electric propulsion system by changing its fuel from NH_3 or N_2H_4 to 'water'.

WEPS design and its preliminary test firing experiment is in progress. Per the latest our roadmap for WEPS (See **Fig. 1**), our final goal is to make a small satellite using WEPS and deploy from ISS. By way of Phase1 demonstration on ISS for a test payload with minimized WEPS (Only Fuel Tank and DC Arc jet are implemented), a small satellite with all WEPS will be deployed from ISS in Phase2. These can be transferred to JEF (ISS/JEM Exposed Facility) from exposed pallet from ISS Visiting Vehicle (HTV or Space-X Dragon is possible candidate) by using ISS robotic arm. SPLIJE L.L.C has been studying an orbital analysis to inject transferring orbit and reach some destination (e.g. Moon) after ISS deployment using this WEPS Arc jet.

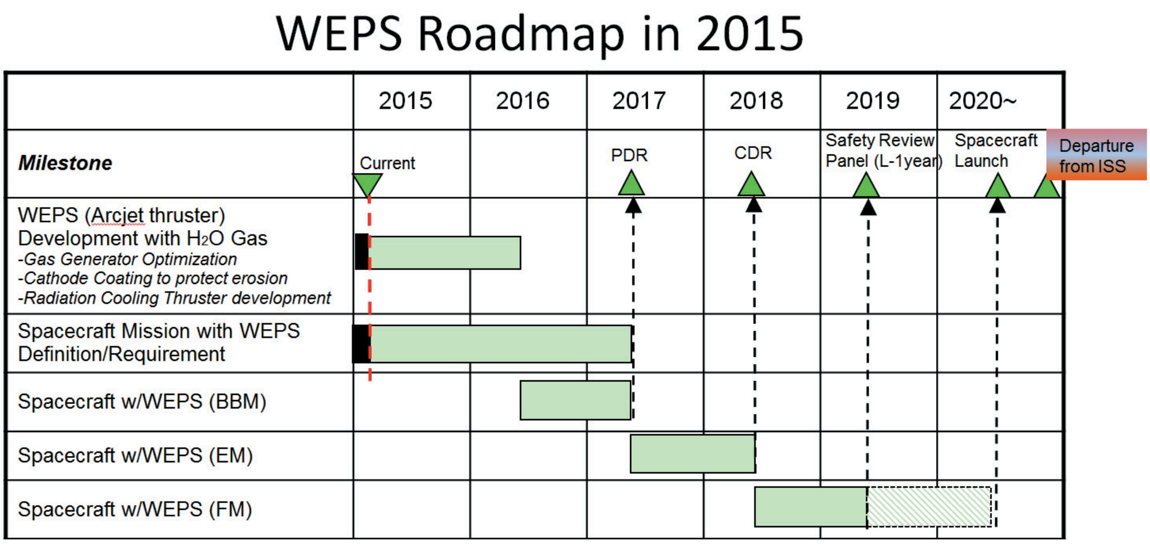

Figure 1. Latest WEPS Road Map

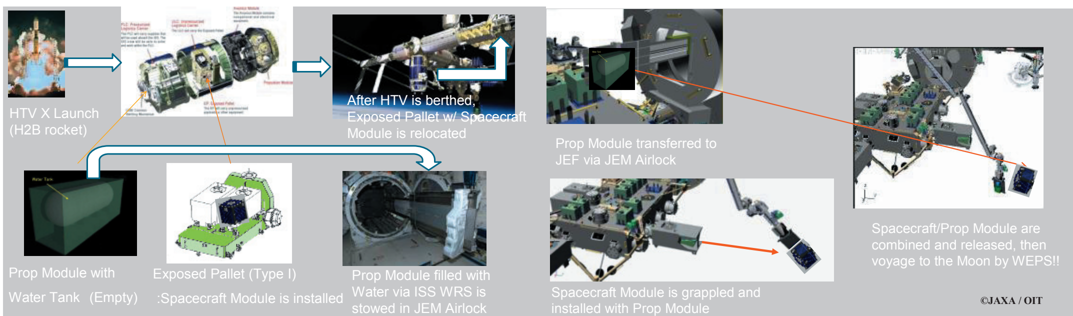

Figure 2. Satellite Assembly and Deployment from ISS/JEM with WEPS; HTV Launch case (will be in 2018~)[5]

II. WEPS design concept and H/W improvement

A. WRS(Water Recovery System) in ISS

WRS is one of ECLSS in ISS. After water is consumed by ISS crew members through drinking and cleaning activities, WRS provides clean portable water by reclaiming waste water, including water from ISS crew member's urine, cabin humidity condensate, and extra vehicular activity (EVA) wastes[2]. For the relationship with other ISS ECLSS System such as condensate water bus or CO_2 Removal or O_2 Generation, please see Figure 3. We are going to use this reclaimed waste water from WRS and ISS crew needs manual filling the water into Prop Module by intra vehicular activity[2].

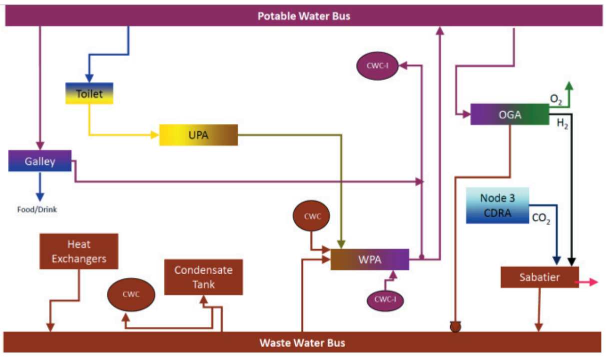

Figure 3. ISS ECLSS WRS overview[1]

B. DC Arc jet design improvement for WEPS

DC Arc jets are a form of electric propulsion for spacecraft, whereby an electrical discharge (arc) is created in a flow of propellant (typically NH_3 or N_2H_4). There many DC Arc jet thrusters currently on orbit and they are working very well, so DC Arc jet is well known as one of the most reliable thrusters. WEPS will apply this typical Arc jet thruster as planned, but Osaka Institute of Technology has designed new version to prevent thruster itself from damaging during firing and to achieve lower power consumption around 1-3kW (See **Fig. 4** and **Fig. 5** in detail).

This new Arc jet consists of a stainless steel (SUS304: 18% Cr/8% Ni) anode/nozzle (change from copper), a pure tungsten cathode, and insulator materials made from Polycarbonate. At first we selected SiC for nozzle but replaced with SUS304 because SiC nozzle dissolved at high temperature due to its difficulty for non-metal part heat radiation and we observed the ignition in a low voltage condition.

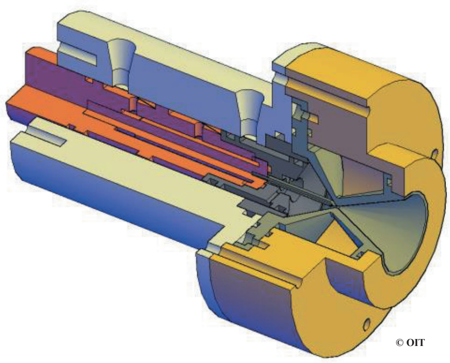

Figure 4. WEPS DC arc jet thruster (3D Cut View)[6,7].

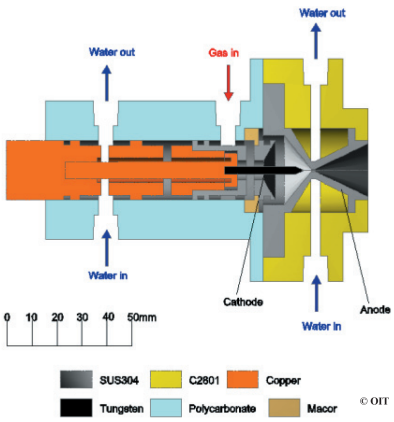

Figure 5. WEPS DC arc jet thruster[7]
(Cross-sectional View).

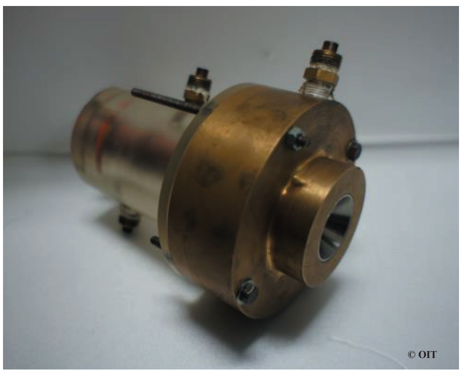

Figure 6. WEPS DC arc jet thruster (Photo)[7]

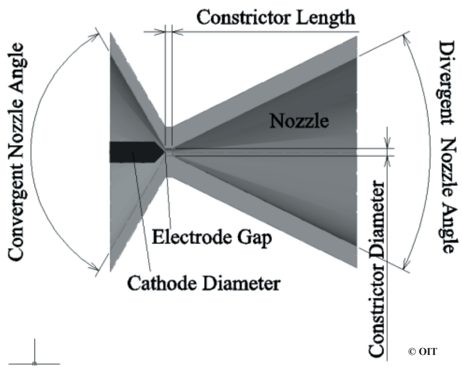

Figure 7. WEPS DC arc jet thruster (Electrode)

A constrictor of a convergent-divergent nozzle throat, as shown in **Fig.** 7, has a diameter of 1.0 mm and a length of 1.0 or 1.5 mm. A divergent nozzle angle is 52 deg and a cylindrical cathode made of pure tungsten has a diameter of 3 mm. The shape of the cathode tip is conical shape. The gap between the electrodes is set to 0 mm[6].

C. Gas Generator

At the firing test in 2011, we found that water flow by a micro tube pump is not high enough to fire by H_2O only. Per our experiment results so far, we found that our exiting mass flow controller could not produce enough water flow to ignite firing continuously due to H_2O liquid state. Recently, we succeeded to make a new gas generator using a heat “glow plug”. Glow plug is one of the car engine igniter for an internal combustion engine.

The new gas generator whose body is made of Copper, as shown in **Fig. 8,** a glow plug is used. Its schematic of experiment equipment with this gas generator is shown in Fig**. 9.** This gas generator is implemented to provide “H_2O gas” to Arc jet.

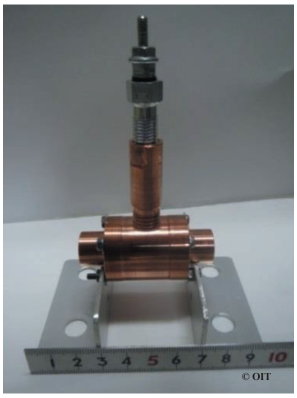

Figure 8. Gas Generator.

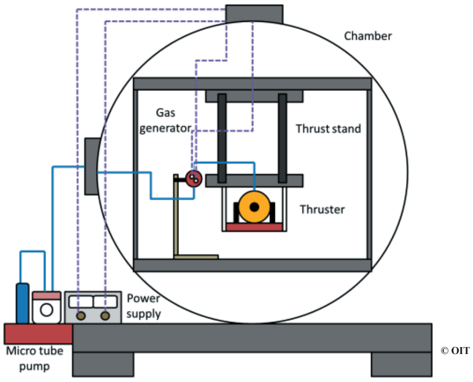

Figure 9. Schematic of experimental equipment. (With Gas generator)

III. Validation test results with new Arc jet thruster

A. Experiment Facility

Osaka Institute of Technology has many kinds of facilities to perform electrical propulsion experiments and others. One of vacuum chambers is used for DC Arc jet firing experiment, and the photo is shown in **Fig. 10** and a simplified schematic is also shown in **Fig. 11**. Since 2012, PWM power supply has been used to perform stable operation with quick response. The vacuum pressure is kept below 1Pa with rotary pump and a mechanical booster (exhaust speed 600m^3/h for both)[6]. Thrust measurement system we use is a thrust stand with plate springs newly developed by OIT.

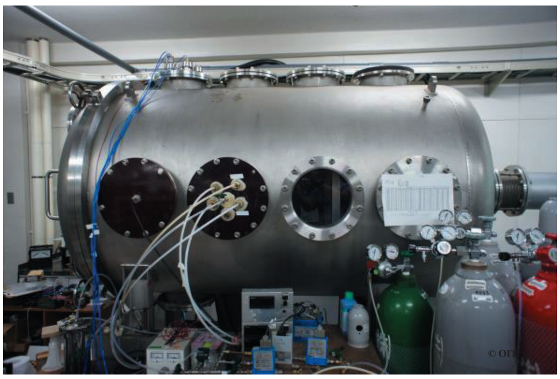

Figure 10. Vacuum chamber (Side View).

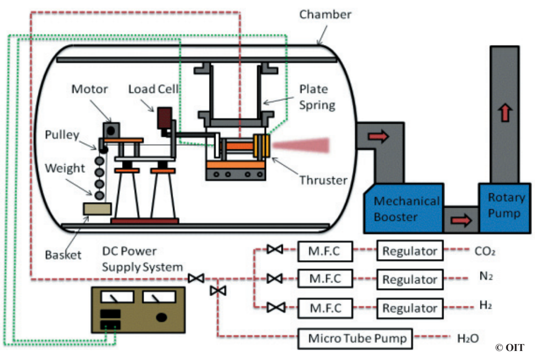

Figure 11. Schematic of experimental equipment. (Except Gas generator)[6,7]

B. Latest validation test for WEPS feasible study

1. Firing test with N_2 Mixture Gas

After making new DC Arc jet thruster, several firing tests were performed. It is important to check a firing characteristic for new Arc jet thruster with this current condition as a first step. The propellant flow rate condition is shown in Table 1. For example, one of the tests starts with flow rate 7.0SLM for N_2 gas only, and then adds H_2O flow starting with 30ml/h until 90ml/h. **Fig. 12** shows the trend graph (Indicator value vs. elapsed firing time) and Table.3 summarizes this test result with calculated Isp and thruster efficiency.

The thruster performance was much less than typical DC Arc jet in each case but we need to consider this Arc jet is smaller type (which means lower power consumption type) than existing ones. One thing we found at this test is that adding H_2O effects in a good manner and that more H_2O flow, more thrust/Isp are.

Table 1.Propellant flow rate

	H_2O (Liquid)	N_2(Gas)
Flow Rate	30-90 [ml/h](distilled)	7.0 [SLM]

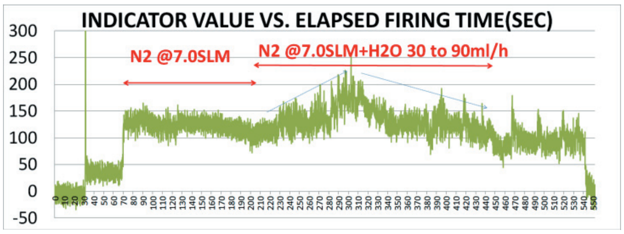

Figure 12. Firing trend profile supplied with combined propellant (H_2O and N_2 gas)

Table.2 Test result summary

*All Values are as of N_2 Gas (7.0SLM)	N_2(Gas) +H_2O(Liquid) (H_2O flow rate :30-90ml/h)	N_2(Gas)
Thrust [mN]	114.6	106.5
Input Power [kW]	1.68	1.26
Isp [sec]	80.2	74.5
Thruster Efficiency[%]	2.7	1.5

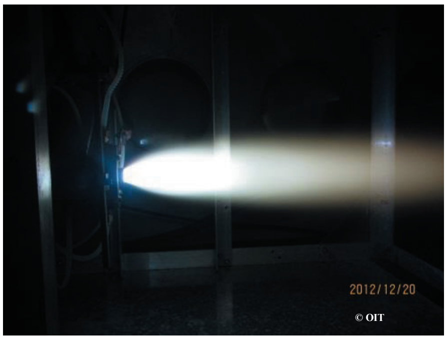

Figure 13. DC Arc jet Firing (N_2@3.5 SLM+H_2O)

2. Firing test with H_2O Gas Only.

As a result of successful making Gas Generator, finally we also got preliminary data for firing with H_2O Gas, shown in **Fig. 14**. This is the only data we have so far and firing duration is so short that we couldn't get thruster performance data. The length of firing time is much shorter than usual(~10secs), but improving supply system from Gas Generator to Arc jet to be more direct, it will be longer and firing itself will be also stable.

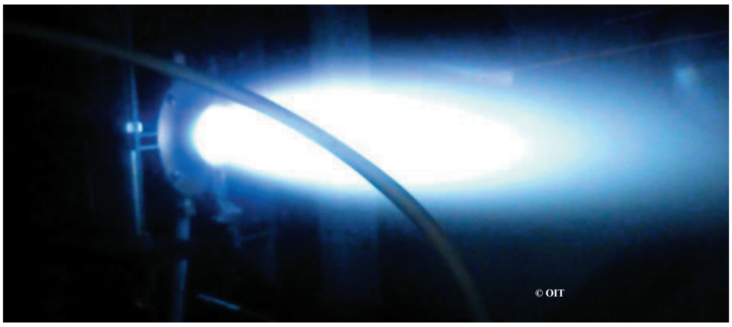

Figure 14. DC Arc jet Firing (H_2O Only)

IV. Forward work

There are three major forward works to resolve. First action to be performed is to check how refined water is required for WEPS because some of ISS reclaimed waste water is ionized. Second action is to pre-coordinate with JAXA/NASA because there a few chances to be an external payload of visiting vehicle. We are sure not to miss it. Secondly, considering commercial usage, we may have to contact with Space-X for visiting vehicle manifest in near future. The last forward work which is most important to design fuel tank volume precisely is that an orbital mission analysis needs to be optimized for transition trajectory using a small satellite and its water tank volume estimation to go to the Moon.

V. Conclusion

Since 2011, WEPS (Water Electric Propulsion System) by using "waste water" produced in a spacecraft has been studied per our basic concept that modification with existing electric propulsion (DC Arc jet) system by changing its fuel to H_2O.

Per the latest our roadmap for WEPS, "2 steps development" will be performed with a plan which develops a WEPS test payload (for technical demonstration in ISS) and develops a small satellite using WEPS next. These can be transferred to JEF (ISS/JEM Exposed Facility) from exposed pallet from Visiting Vehicle (HTV or Space-X DRAGON is possible candidate) by using ISS robotic arm.

Osaka Institute of Technology has completed Arc jet design optimization to prevent thruster itself from damaging during firing and to achieve lower power consumption.

As a resolution to the issue that our exiting mass flow controller could not produce enough water flow to ignite firing continuously, we succeeded in making a thermal Gas Generator. The Gas Generator is developed by glow plug, so quick water evaporation/gas injection to arc jet can be achieved and firing by H_2O only was succeeded for a short period. Optimization for continuous firing is required and seeking best solution.

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