

CREW WASTE WATER ELECTRIC PROPULSION SYSTEM DEVELOPMENT AND SMALL SATELLITE DEPLOYMENT FROM ISS WITH ITS ARCJET THRUSTER

IEPC-2013-192

*Presented at the 33rd International Electric Propulsion Conference,
The George Washington University • Washington, D.C. • USA
October 6 – 10, 2013*

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Abstract: Since 2011, Earth-Track Corporation and Osaka Institute of Technology 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 a spacecraft. 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 “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 H₂O gas to Arc jet. 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 H₂O liquid state. Recently, we succeeded in making new gas generator using heat “glow plug” and in firing by H₂O only for a short period. Optimization for continuous firing will be required. Per the latest our roadmap for WEPS, our final goal is to make a small satellite using WEPS and deploy from ISS. By way of demonstration on ISS for a test payload with minimized WEPS (Only Fuel Tank, DC Arc jet are implemented), a small satellite with all WEPS will be deployed from ISS. 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. We also have been studying an orbital analysis to inject transferring orbit and reach some destination (e.g. Moon) after ISS deployment using this WEPS Arc jet.

Nomenclature

<i>WEPS</i>	=	Water Electric Propulsion System
<i>WRS</i>	=	Water Recovery System
<i>ISS</i>	=	International Space Station
<i>ECLSS</i>	=	Environmental Control and Life Support System
<i>JEM</i>	=	Japanese Experiment Module
<i>JEF</i>	=	JEM Exposed Facility

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HTV = H2B Transfer Vehicle
 PM1 = Prop Module 1 for test payload on ISS
 PM2 = Prop Module 2 for final mission to deploy from ISS
 SM1 = Spacecraft Module 1 for final mission to deploy from ISS

I. Introduction

EARTH-Track Corporation 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 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. Considering our status, we revised our roadmap (See Figure 1.). Basically, our target still is not only to inject transfer orbit but also to reach some destination like Moon, but we have decided that pre-test in space is necessary to acquire important data, information, feedbacks to complete our goal. So, we will produce PM (Prop Module) 1/2 and Spacecraft Module 1(SM). PM1 will be launched in FY2016 (by HTV or Space-X DRAGON), and we will conduct Arc jet firing test in PM1 attached to ISS/JEM Exposed Facility (JEF). Furthermore, we will launch PM2/SM1 around next year (2018-), then they will be combined as a “complete” satellite and depart from ISS to Moon or somewhere else.

For the detailed module delivery/assembly plan, HTV or DRAGON can deliver the small satellite placing on the exposed pallet in it. After combining PM2 (released via JEM Airlock) with SM1, the ‘completed’ satellite goes to the Moon (See Fig. 1 and Fig. 2). We aim the first small satellite in the world, using this water electric propulsion system produced by a private company and an institute.

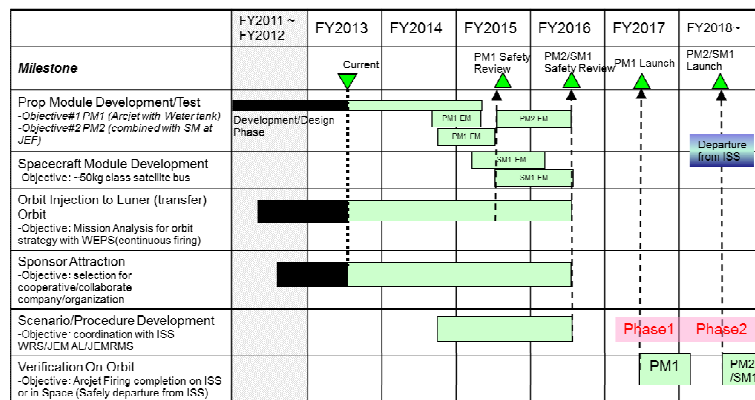


Figure 1. Latest WEPS Road Map

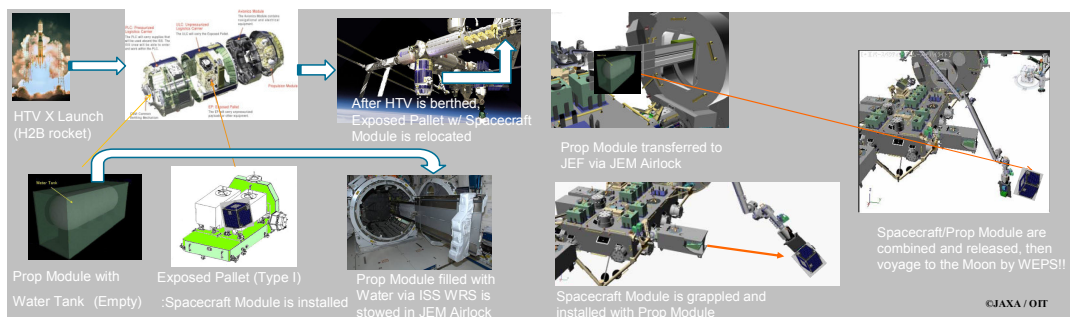


Figure 2. Satellite Assembly and Deployment from ISS/JEM with WEPS; HTV Launch case (will be in 2018~)

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) wastes². For the relationship with other ISS ECLSS System such as condensate water bus or CO₂ Removal or O₂ 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 activity².

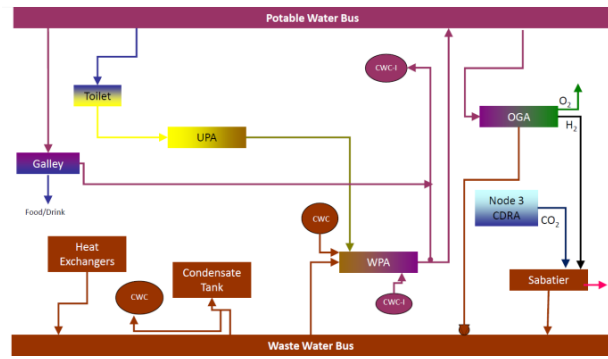


Figure 3. ISS ECLSS WRS overview¹

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 NH₃ or N₂H₄). 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.

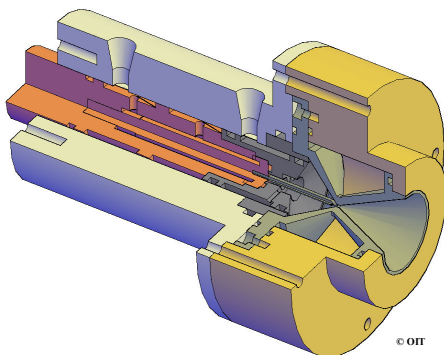


Figure 4. WEPS DC arc jet thruster (3D Cut View)^{6,7}

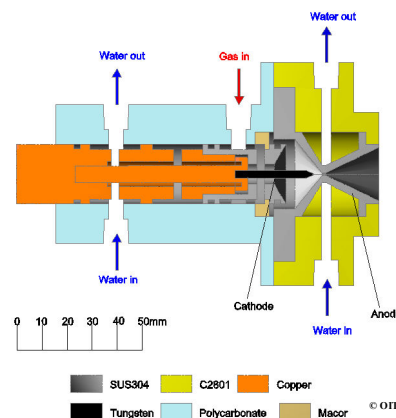


Figure 5. WEPS DC arc jet thruster⁷
(Cross-sectional View).



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

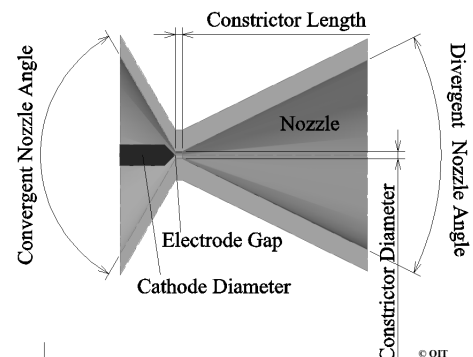


Figure 7. WEPS DC arc jet thruster (Electrode)

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 mm⁶.

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 H₂O 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 H₂O 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**, is consisted of 5 glow plugs (left and right side) and upward and downward line are water (liquid) inlet and water (gas) outlet. Its schematic of experiment equipment with this gas generator is shown in **Fig. 9**. This gas generator is implemented to provide “H₂O gas” to Arc jet.

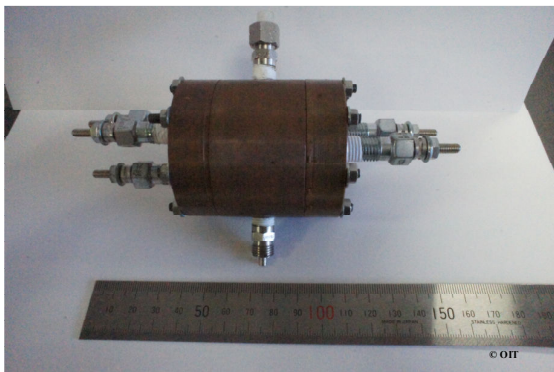


Figure 8. Gas Generator.

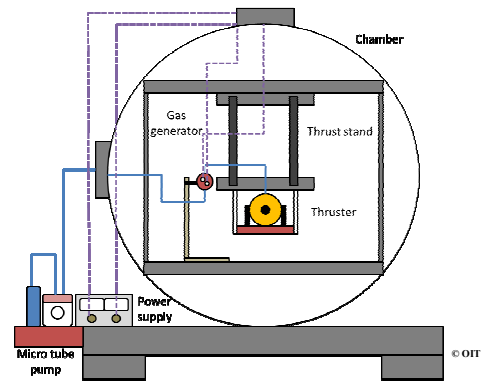


Figure 9. Schematic of experimental equipment. (With Gas generator)

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 600m³/h for both)⁶. Thrust measurement system we use is a thrust stand with plate springs newly developed by OIT.

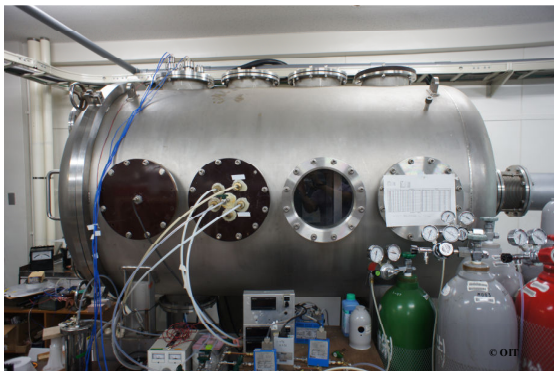


Figure 10. Vacuum chamber (Side View).

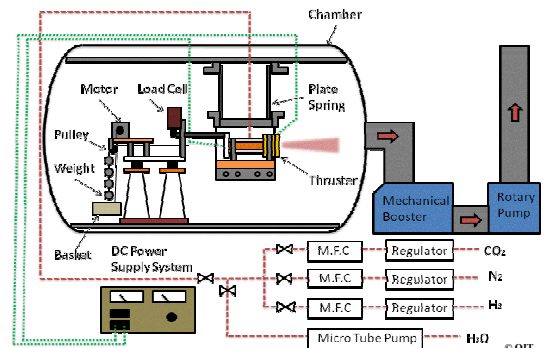


Figure 11. Schematic of experimental equipment. (Except Gas generator)^{6,7}

B. Latest validation test for WEPS feasible study

1. Firing test with N₂ 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 N₂ gas only, and then adds H₂O 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 H₂O effects in a good manner and that more H₂O flow, more thrust/Isp are.

Table 1. Propellant flow rate

	H ₂ O (Liquid)	N ₂ (Gas)
Flow Rate	30-90 [ml/h](distilled)	7.0 [SLM]

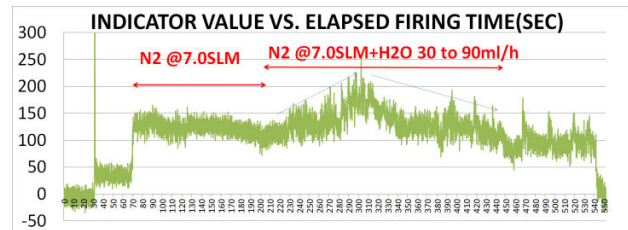


Figure 12. Firing trend profile supplied with combined propellant (H₂O and N₂ gas)

Table.2 Test result summary

*All Values are as of N ₂ Gas (7.0SLM)	N ₂ (Gas) +H ₂ O(Liquid) (H ₂ O 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 (N₂@3.5 SLM+H₂O)

2. Firing test with H₂O Gas Only.

As a result of successful making Gas Generator, finally we also got preliminary data for firing with H₂O 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 plume is much shorter than usual, 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.

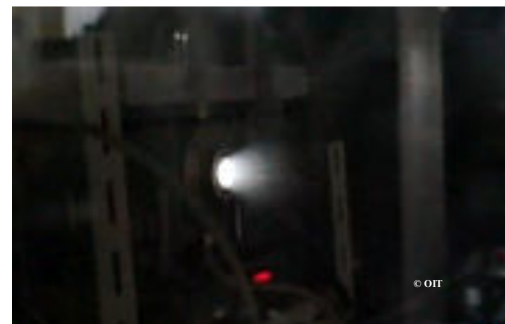


Figure 14. DC Arc jet Firing (H₂O Only)

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 are 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 H₂O.

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 H₂O only was succeeded for a short period. Optimization for continuous firing is required.

We also have been studying an orbital mission analysis for transition trajectory using a small satellite and its water tank volume estimation to go to the Moon.

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