Methane Engine Just for Future Space Transportation

Development of methane engine enabling reusable launch vehicle and long-term in-space operations

A methane engine is promising as an engine for reusable launch vehicles and in-space transportation systems, and research and development activities thereof has been started in the world. Ahead of recent those activities, IHI has developed a prototype methane engine and performed its hot firing tests, and is continuing the research and development effort for the engine to production version, as well as new technologies required for future long-term operations in space.

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Spaceplane ©ArianeGroup

Single-shaft turbopump for manned reusable vehicles ©ArianeGroup

Trend of space development

Space development has been implemented as government projects at the initiative of individual countries so far. However, in the fields of space infrastructure for the Internet or, information providing services using satellites, such as positional information and weather information, for traffic, logistics, agriculture, and so on, private companies have been actively participating with commercial programs at present.

Meanwhile, the discussion of space development activities including manned activities, such as Lunar Landing and Mars Exploration, has been started jointly with several countries as next-generation projects of space utilization, looking beyond the completion of activities of the International Space Station (ISS), and private companies are also beginning to think the participation in this field.

In the next-coming space utilization, there is a plan to first simply transport material and equipment from the ground to a space station in Low Earth Orbit (LEO) using a launch vehicle, then manufacture and assemble a satellite in such space-based station, and place the satellite from the station to an orbit for mission.

Space commercialization requires more rigorous reduction of launch cost than before. Thus, the mission of transportation from the earth to the space station in LEO, reusable launch vehicles are thought to be used in terms of reducing launch cost. For instance, the development of reusable launch vehicles such as Falcons of Space X (USA) is being progressed for it.

Propellant	Density (kg/m^3)	Density × specific impulse ($kg \cdot s/m^3$)	Boiling point (°C)	Cost at optimal mixture ratio (Yen/kg)	Soot	Environmentally load	Storability in space
Liquid hydrogen	71	31 950	Approx. −253	Approx. 1 042	None	Combustion gas clean, but a large amount of energy required and CO_2 produced when manufacturing liquid hydrogen.	Evaporation rate 50.8 (%/month)
Liquefied methane	425	157 250	Approx. −161	Approx. 306	None	Combustion gas good, however, energy required for liquefaction.	Evaporation rate 10.6 (%/month)
Kerosene	807	288 906	182 - 268	Approx. 479	Combustion produces a large amount of soot.	Combustion produces large amounts of CO_2 and nitrogen oxide. Energy for purification required.	Requires heater in space (It solidifies at approx. −45°C).

Comparison among propellants for launch vehicle

In addition, the mission of transportation in outer space from the space-based station needs long time operations in space, and therefore an engine appropriate for the long-term mission is required.

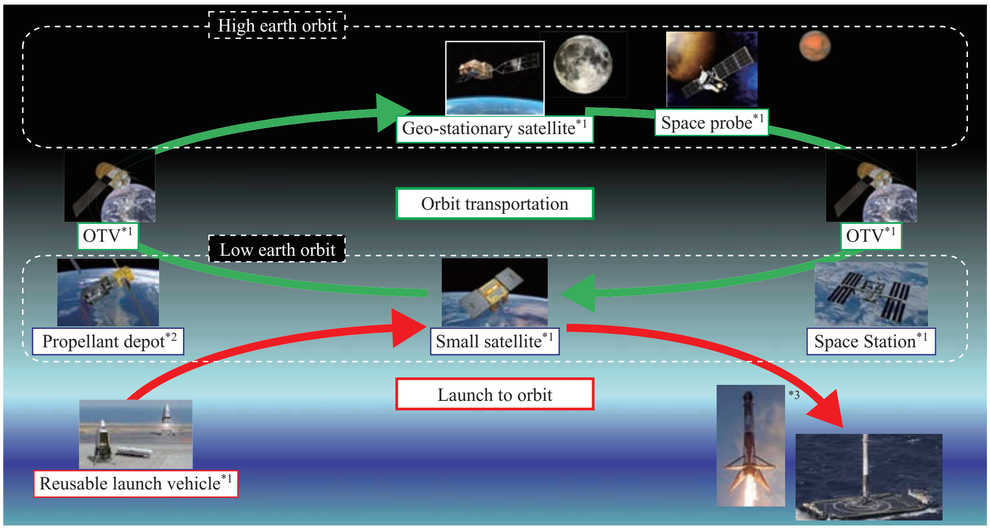
Methane engine promising for reusable launch vehicles and long-term space transportation mission

IHI has continued to research a methane engine for years. The methane engine uses two propellants, liquefied methane as fuel, and liquid oxygen as an oxidizer for combustion.

Liquefied methane has the following advantages as compared with commonly used rocket fuels typified by kerosene and liquid hydrogen.

- Liquefied methane produces higher value of "density × specific impulse" than liquid hydrogen, thus making it possible to downsize a fuel tank and the entire vehicle body as a result.
- Since hydrocarbon fuels such as kerosene produce a large amount of soot, reusable operations may result in the clogging of the flow passage in side an engine by the soot deposited. On the other hand, liquefied methane does not produce soot, so even reusable operations never results in the clogging of a flow passage.
- As compared with liquid hydrogen which also does not produce soot, liquefied methane is less likely to vaporize and capable of being stored for a long time, thus being suitable for long-term operations in space.
- Since liquefied methane has a larger molecular weight than liquid hydrogen, it is less likely to leak and low in explosibility, thus being higher in safety.
- The temperature of liquefied methane (−161°C) is close to that of liquid oxygen (−183°C) as an oxidizer, and the required volume of loaded liquefied methane is comparable with that of oxygen. Accordingly, the design and manufacturing of equipment such as propellant tanks or valves can be standardized between liquefied methane and liquid oxygen, including the aspect of handling process of propellant, thus making it possible to reduce development cost and production cost.

Considering such advantages, a reduction in size, reusability, long-term storability, a reduction in cost, a situation favorable



(Notes) *1 : ©JAXA
*2 : ©MDA
*3 : ©SpaceX

Image of future space transportation

to liquefied methane for future transportation systems obviously appears. Recently, in overseas, the application of a methane propulsion system has been increasingly explored toward the reusable launch vehicle. Also, toward the next-generation space-based space utilization, the methane engine is thought to be promising as the infrastructure transportation service business, considering reusability, a reduction in size, long-term storability, and operability.

Methane engine technology developed so far by IHI

It has been known that liquefied methane has several advantages as rocket fuel. However, rocket engines using conventional kerosene or performance-oriented liquid hydrogen have been mainstream, and no methane engine has been developed.

In 2010, IHI performed a hot firing test of a prototype methane engine with a thrust class of 10 tons first in the world toward the commercialization of the product, and the viability of the methane engine became in sight.

The prototype engine has a regenerative cooling system with liquefied methane to cool the combustion chamber and selects the gas generator cycle engine system, using combustion gas to drive the turbopump for pressurizing the propellant.

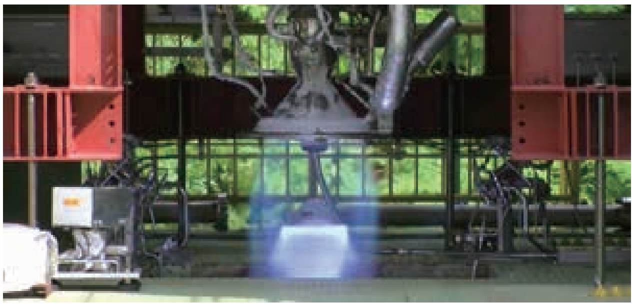
Prior to the prototype methane engine above, IHI developed a gas generator cycle methane engine with a thrust class of 10 tons, using an ablative cooling type combustor configured to cool the wall of the combustion chamber taking the heat from combustion gas by evaporation of the combustion chamber wall surface, under the research and development program of the National Research and Development Agency, Japan Aerospace Exploration Agency (JAXA).

JAXA is subsequently conducting technology research activities for performance enhancement of methane engine, using an expander cycle engine system configured to drive a turbopump with methane used for regenerative cooling, and for its technology verification, planning to perform a hot firing test of an engine with a thrust class of 3 tons in FY 2018.

Besides, IHI developed a prototype model of the single-shaft turbopump to be used for a methane engine with a thrust class of 40 tons for a manned space plane propulsion system under the research program of ArianeGroup (France), and successfully performed an operation test. This turbopump aims to meet safety requirements for a manned reusable system that, even in case of a malfunction, prevents any damage from being propagated on other equipment and system. In the future, we plan to perform an operation test in combination with a gas generator of ArianeGroup.

Technologies necessary for in-space transportation system

IHI has conducted the research for methane engine toward production version. However, considering the application



Hot firing of methane engine with thrust class of 10 tons

Expander cycle methane engine with thrust class of 3 tons ©JAXA

to in-space transportation system, the following new requirements different from those for conventional operation should be added. It is also necessary to develop new innovative technologies for putting the engine into production version.

- Reusability

  Conventional propulsion systems for launch vehicles and satellites are both expendable. In the future transportation system from the earth to an on-orbit space station, reusability is important in terms of resource constraint and cost performance.

- Long-term operation

  In-space operation often spans a long time frame. In case of space exploration, such as Mars Exploration, the mission itself takes several years. Accordingly, the long-term storage of fuel and the long-term stable operation capability of the engine system are important.

  The long-term stable operation capability is also required in case of the reusable launch vehicle with increase of launch frequency.

- Maintenance

  In-space operations require the engine maintenance in orbit.

IHI is studying required functions and performance characteristics needed for the above-described in-space transportation system, and conducting elemental technology research and development with the aim of realizing the in-space transportation system.

Introduced below are some of them.

- Engine control system associated with electric motor-actuated propellant flow control valves

  The propellant flow control valve for the conventional engine is a pneumatic actuated shut-off valve that only turns on/off propellant supply. IHI is currently developing a propellant flow control valve capable of arbitrarily setting the opening position by an electric motor and continuously controlling the propellant flow rate. This makes it possible to, not only simply turn on/off propellant supply, but control the propellant flow rate corresponding to any particular engine operational points during operation. With this flow control capability, it becomes possible to vary the engine thrust level, to conduct propellant consumption management taking account of the residual balance between the fuel and the oxidizer, and other such operations.

- Seal for leakless turbopump

  The rotation system of a turbopump requires seals for containment, and through the seals, turbine gas or propellant leaks. For this reason, the seal system needs additional device to block propellant and the turbine gas from each other by injecting another inert gas to prevent contact therebetween. By developing a seal system characterized by a far smaller leakage amount than before, the long-term operation becomes feasible due to the reduction of the consumption amounts of the contact prevention gas.

- Electric-powered turbopump

  A turbopump mainly consists of a pump and a turbine driven by some means such as combustion gas. Usually to start an engine, turbine start gas different from the combustion gas to increase rotation speed to required rotation speed is needed. However, by introducing an electric motor temporarily connecting to the turbine to increase rotation speed to the required rotation speed, the turbine start gas can be eliminated. This allows not only the engine system to be simple but also the turbopump rotation speed at the start to be easily controlled by the electric motor, thus making it possible to stably ignite a combustor and start the engine.

Motor-actuated propellant valve ©JAXA

- Propellant storage

  To store the propellant in space for a long time, it is necessary to suppress the vaporization of the propellant to the maximum extent possible. By operating the above-described electric-powered turbopump at low rotation speed in order to recirculate the propellant, and cooling the circulating propellant by a heat exchanger, the propellant inside the tank can be suppressed from vaporizing.

- Real-time health monitoring

  To avoid damage to other system by any engine operation malfunctions, IHI is currently developing a real-time health monitoring system of engine for constantly monitoring the operation conditions of each component and system. This system employs the Mahalanobis-Taguchi (MT) method capable of quantitatively grasping, with monitoring data, the deviation of current operating conditions from those of normal operation by “Mahalanobis Distance (MD).” Any variation of operating conditions can be detected by MD as “It is not normal,” which might not mean “A failure happened.” With this monitoring system, the soundness of engine system and devices can be automatically checked and the malfunction quickly detected before becoming failure, during long-term in-space operation or reusable launch operation, for avoiding real malfunctions of total system.

Future image of methane engine

As described above, the methane engine is a promising applicable system as an engine for reusable launch vehicles, reusable manned space planes, and future in-space transportation systems.

IHI continues to research technologies necessary for reusable launch missions, manned missions, and future in-space missions, in addition to putting the engine into practical use.

The engine with a thrust class of 3 tons for technology verification is under consideration for application to the Winged Reusable Sounding Rocket (WIRES). In addition, it is also under consideration for the subsequent international cooperative program following the ISS, such as Lunar Sample Return. Through such application, IHI will achieve the development of the methane engine flight proven and toward production version, and contribute to establishing the transportation system technology in space, so as to utilize the methane engine as an in-space propulsion system. Also, IHI will apply the engine for space planes, and further establish technologies related to manned reusable vehicles.

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