



DEVELOPMENT OF CORE TECHNOLOGIES FOR HYDROGEN AIRCRAFT

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Abstract

There is an increasing movement to decarbonize all industries around the world to prevent climate change due to the effects of global warming. The goal of CO₂ reduction has also been set for aircraft, and discussions on the development of hydrogen aircraft have become more active in order to achieve this goal. Kawasaki Heavy Industries (KHI) is developing core technologies for hydrogen aircraft with support from NEDO* Green Innovation Fund. In this lecture, I will present about the development of hydrogen combustor, hydrogen supply system and liquefied hydrogen tank, etc., which are the core technologies necessary for the realization of hydrogen aircraft.

*New Energy and Industrial Technology Development Organization

Keywords: hydrogen, aircraft, combustor, tank, pump

1. Introduction

Countries around the world are moving toward decarbonization in order to curb climate change caused by global warming, and the United States, European countries, and Japan have set the goal of achieving carbon neutrality by 2050.

International CO₂ reduction guidelines for aircraft have long existed, but as governments around the world begin to set goals for decarbonization, discussions about hydrogen aircraft as a means of reducing CO₂ emissions have become more concrete.

This article provides an overview of the technological development that KHI is working on as a core technology necessary for the realization of hydrogen aircraft.

2. Background

Regarding environmental regulations for aircraft, the International Civil Aviation Organization (ICAO) In 2022, ICAO has adopted a goal for international aviation to achieve net zero CO₂ emissions by 2050.

Figure 1 shows the aircraft CO₂ reduction scenario when each technology is applied [1].

CORE TECHNOLOGIES FOR H2 AIRCRAFT

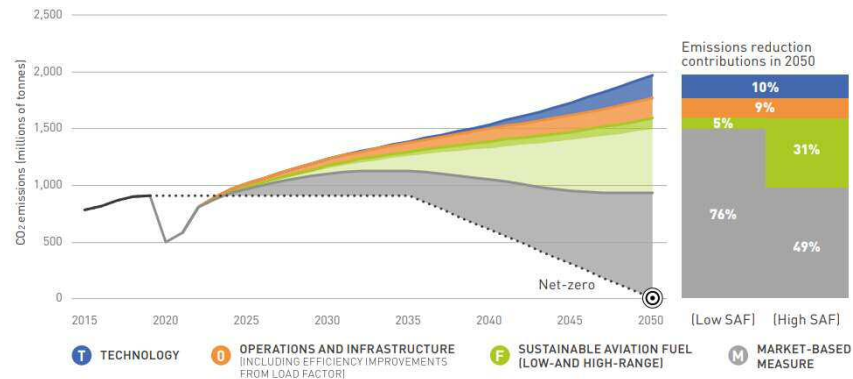


Figure 1 – Aircraft CO₂ reduction scenario.

Airbus announced a long-term plan “ZEROe” to commercialize hydrogen aircraft by 2035, this project plan to develop several sizes aircrafts (80 to 200 seats) with hydrogen turbofan, hydrogen turboprop, and hybrid (engine with fuel cell) propulsion system in response to this international circumstance.

In Japan, the Green Growth Strategy formulated in December 2020 included technology development for hydrogen aircraft as an effort to decarbonize the aircraft industry. And NEDO Green Innovation (GI) Fund project was established to realize the formulated the Green Growth Strategy.

KHI have been conducting "Development of Core Technologies for Hydrogen Aircraft " as a NEDO GI fund project, which technologies necessary to realize hydrogen aircraft. (Figure 2)



Figure 2 –Core Technologies for Hydrogen Aircraft.

3. Development of Hydrogen Related Technologies in Kawasaki Heavy Industries

With an eye on expanding the use of hydrogen as a future energy source in Japan, KHI is promoting technological development toward the realization of a "CO2 free hydrogen chain (Figure 3)" that integrates hydrogen production, liquefaction, transportation/storage, and utilization.



Figure 3 –CO2 free supply chain concept.

The "CO2 free hydrogen chain" is the production of hydrogen at low cost from unused resources and/or surplus/cheap renewable energy in resource countries. That hydrogen is liquefied for transport transportation by liquefied hydrogen carrier ship. The concept is to use it as secondary energy in the country where it is used.

As a method of hydrogen production, KHI is collaborating with the Australian federal government and the Victorian state government to launch a pilot project to produce hydrogen using Australia's abundant brown coal as a raw material and transport it to Japan. The project was being promoted together with members of HySTRA (CO2-free Hydrogen Energy Supply-chain Technology Research Association) as part of the NEDO "Large-Scale Maritime Transportation Supply Chain Construction Demonstration Project for Hydrogen from Unused Brown Coal (2015-2022)".

In February 2022, hydrogen produced in Australia was successfully transported to Japan on a liquefied hydrogen carrier and unloaded at the liquefied hydrogen cargo handling demonstration terminal "Hy touch Kobe".

Figure 4 shows the liquefied hydrogen carrier ship and the liquefied hydrogen tank (tank capacity 1250m³) [2]. This world's first liquefied hydrogen carrier ship was named "Suiso-frontier" and was underwent inspection on structure, engine, fitting, material, etc. in accordance with the requirements for safe transportation of hydrogen by sea and the regulations of the Japan Maritime Association based on the provisional recommendation of the International Maritime Organization and was registered as a ship class in December 2021.

Additionally, in June 2022, KHI successfully demonstrated power generation using this hydrogen as fuel at the Hydrogen CGS (Co-generation system) Demonstration Plant, a hydrogen gas turbine power generation demonstration facility on Port Island, Kobe City.

As mentioned above, KHI has achievement of developing various technologies and products from hydrogen production to transportation storage and utilization, so KHI will utilize this experience and knowledge to develop core technologies for hydrogen aircraft.

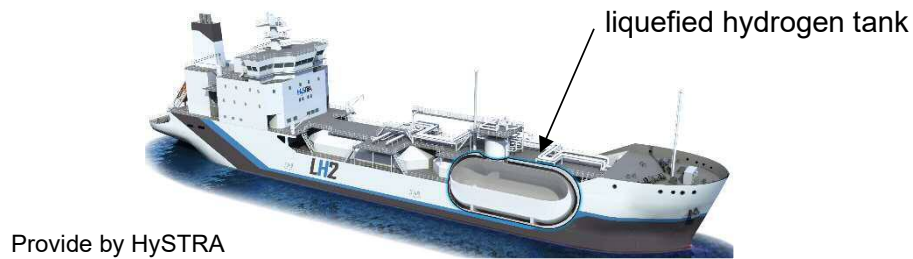


Figure 4 – Liquefied hydrogen carrier ship “Suiso-frontier”

4. DEVELOPMENT OF CORE TECHNOLOGIES

As mentioned above, there are several possible propulsion systems for hydrogen aircraft, but the target of the technology development carried out in this GI Fund project is a hydrogen turbofan type system that has a simpler structure and is suitable for passenger aircraft with a large number of passengers. The size of the aircraft targeted by this technology development is a small passenger aircraft with 80 to 250 seats and a cruising range of up to 2,000 km (Boeing 737, Airbus A320 class) which accounts for approximately 40% of the CO₂ emissions currently emitted by aircraft worldwide. The following three technologies are important for realizing hydrogen aircraft. The first is a hydrogen engine combustor that is capable of stable combustion using hydrogen as fuel and suppresses the generation of air pollutants (NO_x, etc.). The second is a lightweight liquefied hydrogen tank with high heat insulation performance. The third is the liquefied hydrogen supply system, which consists of pump, valve, heat exchanger, etc. that can stably supply cryogenic liquefied hydrogen to the engine.

Furthermore, The aircraft concept will be examined to determine how to arrange and mount various types of equipment that have different operating environments and sizes from those of regular aircraft. The details of each technology development are described below.

4.1 Combustor for hydrogen engine

The regulation values for aircraft are set by CAEP, a working group within ICAO, and a further 54% reduction is planned in 2027 compared to the NO_x regulation value (CAEP/8) established in 2014. For this reason, we have set a NO_x target of “54% reduction from CAEP/8” for the hydrogen engine combustor that we are currently developing.

Since 2010, KHI have been working with AcUAS (Aachen University Applied Science) and B&B-AGEMA in Aachen, Germany, to develop the MicroMix combustion technology as a low NO_x combustion technology for hydrogen gas turbines for power generation.

MicroMix combustion technology has been continuously researched at AcUAS since the 1980s.

Figure 5 shows a closeup view of the MicroMix burner. Hydrogen is injected through tiny hydrogen injection holes less than 1 mm in diameter, and rapidly mixes with orthogonal air jets to form a hydrogen flame. By forming a small hydrogen flame, it is possible to eliminate the generation of localized high-temperature areas, shorten the combustion reaction time, and suppress the generation of NO_x.

A hydrogen gas turbine for power generation incorporating this combustor was tested at Kobe Port Island in 2019-20 as part of NEDO's "Dry Low NO_x Hydrogen Gas Turbine Technology Development and Demonstration Project," and was able to operate with NO_x values below the regulation value.

KHI applied this combustion technology for aero MicroMix combustor which have to operate under a wider range of operating conditions compared to gas turbines for power generation. We are currently developing aero MicroMix burner with numerical analysis and high pressure combustion test in RWTH Aachen university.[3] Figure 6 shows the MicroMix burner test apparatus for high pressure combustion test.

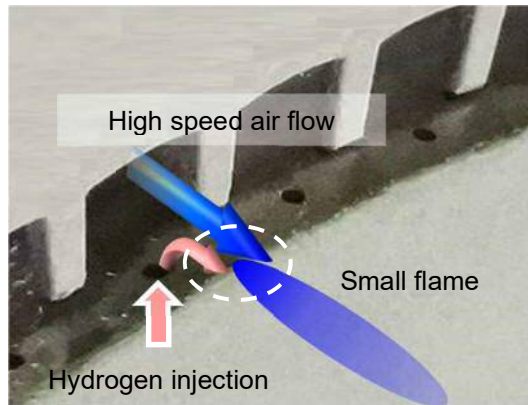


Figure 5 – MicroMix burner

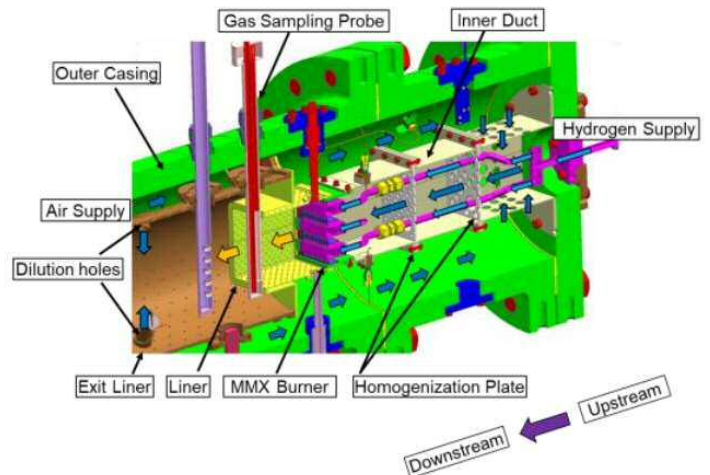


Figure 6 – MicroMix burner test apparatus

4.2 Liquefied hydrogen tank

Hydrogen aircraft loading liquefied hydrogen instead of jet fuel, but liquefied hydrogen has about four times the volume per unit of energy compared to jet fuel. If hydrogen aircraft will be to fly the same distance as a conventionally fueled aircraft, it would need a tank four times the volume of current jet fuel tanks. Additionally, since liquefied hydrogen must be stored at an extremely low temperature of -253°C , a high-performance insulation structure is required to prevent heat from entering the tank from outside.

KHI have the design and manufacturing technology for large liquefied hydrogen tank for ground use at the Tanegashima Space Center and tanks for liquefied hydrogen carrier ship, and in developing liquefied hydrogen tank for aircraft, we utilize these technologies to develop a lightweight liquefied hydrogen tank with high-performance insulation structure. Figure 7 shows the concept of Liquefied hydrogen tank.

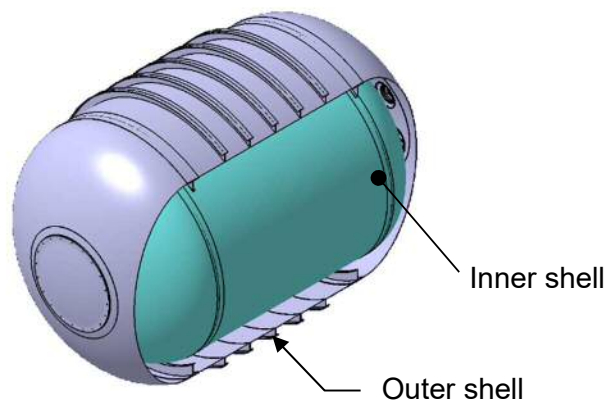


Figure 7 – Concept of Liquefied hydrogen tank

4.3 Liquefied hydrogen supply system

Hydrogen aircraft need to stably supply hydrogen from the tank to the combustor according to the engine output, which requires valve, pump, heat exchanger, etc. that can be used in cryogenic environments. In order to proceed with development efficiently, we are currently conducting joint development with Nikkiso, Kitz, Sumitomo Precision Industries, and JAXA, all of whom have extensive experience with their respective equipment.

Nikkiso successfully tested a liquid hydrogen pump using liquid hydrogen in 2023.[4] Figure 8 shows an overview of the liquefied hydrogen pump and the test equipment.

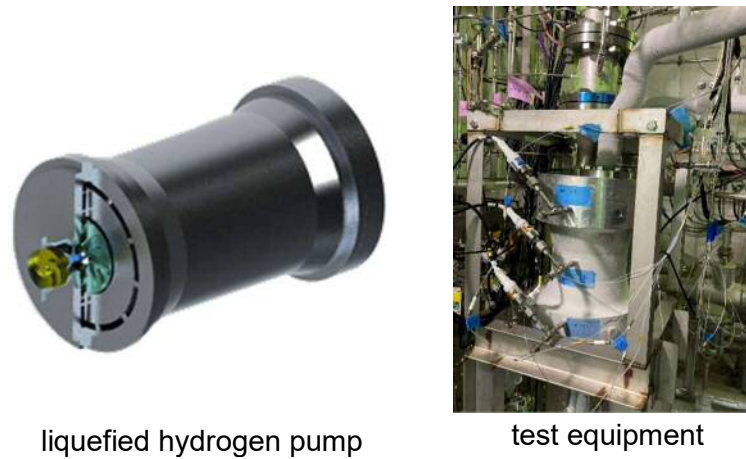


Figure 8 – Liquefied hydrogen pump and the test equipment.

In addition, in the final stage of the technology development period, around 2029-30, We will conduct an integrated ground demonstration test that combines in-house small aircraft engine with a built-in hydrogen combustor, a liquefied hydrogen supply system, and a liquefied hydrogen tank at the JAXA Noshiro Rocket Testing Center.

4.4 Aircraft concept study

In the case of "tube and wing" aircraft, which is common among current passenger aircraft and has wings on the sides of the cylindrical fuselage, jet fuel is stored in a flat space inside the main wing. For hydrogen aircraft, the capacity of the liquefied hydrogen tank is four times that of the jet fuel tank and the tank shape must be spherical or cylindrical to minimize the surface area per volume of the tank in order to store cryogenic liquefied hydrogen. It is necessary to adopt a different mounting method for these tanks. For this reason, we are currently considering the aircraft concept necessary to realize a hydrogen aircraft, such as considering the optimal method of mounting tanks while ensuring cabin space. Figure 9 shows an example of hydrogen aircraft concept.

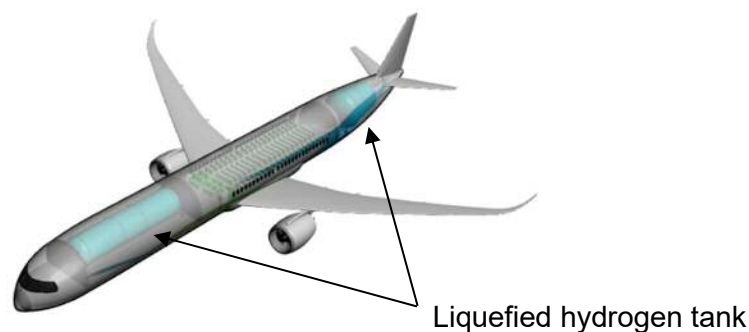


Figure 9 – Example of Hydrogen aircraft concept

5. Conclusion

At Kawasaki Heavy Industries, we are leveraging various hydrogen-related technologies that we have been working on to realize a "CO₂-free hydrogen chain," and developing technologies such as hydrogen engine combustors, liquefied hydrogen supply systems, and liquefied hydrogen tanks as core technologies necessary for hydrogen aircraft. By carrying out this development, we intend to contribute to the decarbonization of aircraft.

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References

- [1] "WAYPOINT2050", https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf
- [2] HySTRA, <https://www.hystra.or.jp/project/>
- [3] Suda Y, Kato D, Tsuru T, Oda T, Ashida Y and Wirsum M, NOx Emission Characteristics of a Low NOx Emission Burner for Hydrogen Aircraft under High Pressure and Temperature, *Proceedings of the International Gas Turbine Congress 2023 Kyoto*, IGTC-2023-185
- [4] NIKKISO press release, <https://www.nikkiso.com/news/files/4ebb31a3237202fc3e8d237dbc02f7b0.pdf>

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