Aiming at realizing environment-friendly aviation fuel

Calls for ecology

In December 1997, the Kyoto Protocol was adopted at the third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Kyoto. As a treaty to resolve global environmental problems, such as climate change due to greenhouse gas emissions, the United Nations Framework Convention on Climate Change imposes obligations, mainly on industrialized nations, for implementing policies to reduce greenhouse gases. Under the Kyoto Protocol, the industrialized nations ratifying the treaty have committed to reducing six greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4), as well as emissions of substances with extremely high greenhouse effects, such as Perfluorocarbons (PFC)[*1], by 2012 to a differentiated amount compared to 1990 emission levels.

Why is there a demand for reducing greenhouse gases? The earth absorbs energy from sunlight at surface areas, and the absorbed energy is converted into infrared rays, then irradiated into space. However, some of the irradiated energy is absorbed and re-radiated by greenhouse gases in the atmosphere, causing them to return to the earth's surface (fig. 1). This energy maintains the average temperature of the earth at about 15 ℃. If all of the energy was radiated out, the average temperature of the earth would be -19 ℃, at which the planet would be too cold for most life forms, including mankind, to survive, making greenhouse gases essential. However, in recent years, especially as a result of industrialized nations giving priority to industrial development, greenhouse gases have increased to the extent where they cannot be managed by the natural environment. Therefore, concern about the progression of global warming is spreading all over the world.

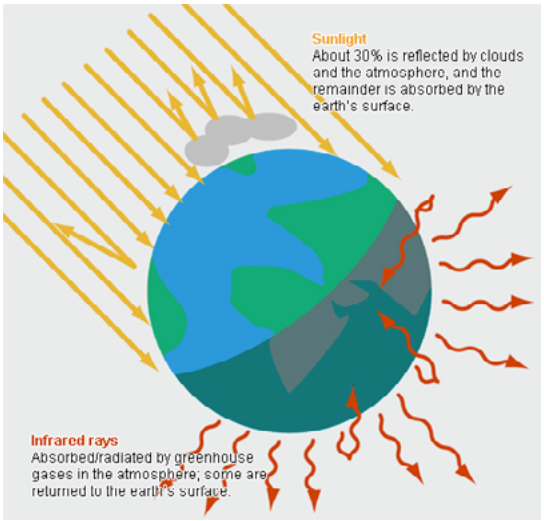


Fig.1 Flow of solar energy on the earth

Eventual depletion of fossil fuels

Many media report that CO_2 is the main cause of global warming. Since large amount of CO_2 is emitted by burning fossil fuels, such as oil and coal, energy supply methods with suppressed CO_2 generation, for example, wind power or atomic energy, are being advocated. In contrast, there is also opposition such as "there must be other causes of global warming" or "warming is not even occurring".

Hearing these comments may cause some people to believe that regulating the use of fossil fuels in order to reduce CO_2 is not necessary. However, the depletion of fuel is another problem that can anyway not be avoided.

There is no exact calculation for when fossil fuel will be depleted. Although there is fuel deep within the earth, which may last for a very long time, there is no doubt that it will eventually be depleted, considering it cannot be artificially produced.

For this reason, there is a demand for sustainable alternative fuels. The sun is what first comes to mind as an undepletable energy source. Commercial facilities, and even some households, have installed solar panels on their roofs and are using power generated by solar energy to provide some of the electricity necessary for living.

If sunlight could be collected in space and sent to the earth, we should be able to use solar energy more efficiently. JAXA is pursuing this idea through research and development of the Space Solar Power System (SSPS) (fig. 2).

Even the aviation world focuses on ecology

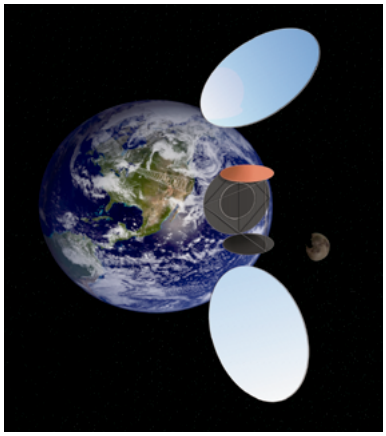


Fig.2 Space Solar Power System (SSPS)

In September 2010, the Environmental Report 2010: Aviation and Climate Change was published by the International Civil Aviation Organization (ICAO; refer to page 6). ICAO, a United Nations agency with over 190 countries participating, fosters development of international civil aviation as well as achieves sound management of international air transportation services. From the environmental aspect, it establishes standards for aircraft engine noise and exhaust. For example, it has certified some substances emitted from aircraft engines as hazardous, such as hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx) and soot.

However, currently there are no regulations on CO_2 emissions with regard to international aviation, and ICAO representatives have only begun discussions toward regulating them. Therefore, engines that use hydrogen or electricity and do not emit CO_2 are drawing attention from a long-term perspective. At JAXA, we are working on research and development of a hypersonic turbojet engine, which does not emit CO_2 during combustion since hydrogen is used as the fuel, as well as fundamental research on engine systems for hybrid aircraft aimed at a flying hybrid vehicle. Our efforts have gained a great deal of interest from the global aviation industry, and an article entitled "Long Term Potential of Hydrogen as Aviation Fuel", written by Dr. Keiichi Okai of the Jet Engine Technology Research Center, appeared in the Environmental Report 2010.

Power of hydrogen

If there were an airplane that could fly to the United States or Europe in 2 hours, wouldn't you want to use it? We are continuing research and development of a hypersonic aircraft, which would be able to cross the Pacific Ocean in 2 hours by flying at Mach 5 (five times the speed of sound). (Fig. 3) This aircraft has a shape significantly different from that of currently familiar airplanes. Actually, it is not only the shape that is different. The engine system and fuel differ greatly from those used in current aircraft. As opposed to current aircraft, which are fueled with kerosene, we are considering using hydrogen as the fuel for the hypersonic aircraft. The aircraft flies by the counterforce to the backward exhaust of combustion gas obtained when liquid hydrogen fuel is mixed with the air introduced into the engine and ignited.

Hydrogen fuel is already being used in rockets. (Fig. 4) Rockets flying into space are loaded with oxygen (liquid oxygen) and fuel (liquid hydrogen). Since the weight of liquid oxygen occupies a large part of the rocket, we can achieve an increase in the payload capacity if the oxygen in the atmosphere could be used during flight within Ethe earth's atmosphere. Therefore, we are conducting research to introduce air into the engine of a rocket flying at hypersonic speeds. This is where the idea of hypersonic aircraft using hydrogen was born.

There are several advantages on using liquid hydrogen

This aircraft, which has a total length of 90 m and seats for 100 people, crosses the Pacific Ocean in 2 hours.

Fig.3 Hypersonic passenger aircraft

Flies into space with energy obtained by burning a mixture of liquid hydrogen and liquid oxygen.

Fig.4 Launch of the Japanese H-IIA launch vehicle

as fuel. The first is its extremely low temperature of −253 ℃. Figure 5 illustrates the concept of a hydrogen jet engine for a hypersonic aircraft. The biggest issue regarding the hydrogen jet engine for a hypersonic aircraft was dealing with the added heat from the air intake. When flying at Mach 5, the temperature of the incoming air reaches about 1000 ℃. A normal jet engine (★) cannot operate in this high-temperature environment. Therefore, we decided to cool the incoming air with liquid hydrogen, thereby making it possible for a jet engine to operate at Mach 5. In addition, due to this cooling, the air density and the volume of the intake air increase. Since the jet engine thrust increases proportionally to the mass flow of the intake air, we can kill two birds with one stone. We previously mentioned that CO_2 is not emitted when hydrogen is used as fuel. In addition, it also holds the potential for suppressing NOx emissions. NOx is generated when nitrogen (N_2) and oxygen (O_2) in air react during high-temperature combustion. However, since hydrogen atoms (H) are easily combined with oxygen atoms (O), there is a possibility of suppressing NOx generation by feeding extra hydrogen into the combustor. We are continuing research into this in collaboration with the University of Tokyo and verifying that the generation of NOx can be suppressed by mixing in extra hydrogen.

The technology of a hydrogen jet engine for a hypersonic aircraft can also be applied to subsonic aircraft. The engine fans (★) of large passenger aircraft are gradually increasing in size for enhanced efficiency; however, by using liquid hydrogen to cool the air before combustion, the thrust of the jet engine can be increased, and there is the possibility that an even larger fan can be turned. In the future, when liquid hydrogen is used as fuel for subsonic aircraft, the technology for the hypersonic aircraft can be used directly. (Fig. 6)

Hybrid aircraft

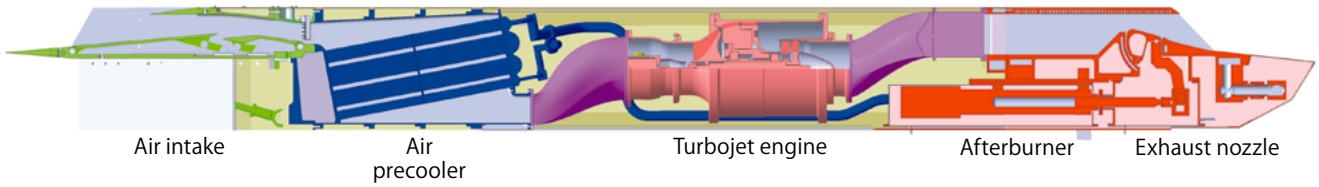
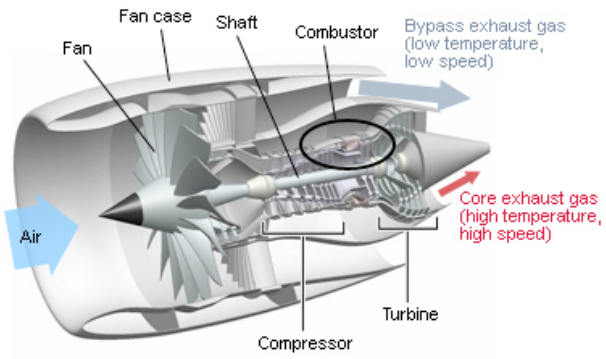


Fig.5 Basic concept of a hydrogen jet engine for hypersonic aircraft

Jet engines and fans

Air entering the jet engine is first compressed in the compressors, resulting in an increase of the pressure, expanded through combustion after mixing with fuel in the combustor, then passes through the turbines to be exhausted toward the downstream. The turbines are connected to the compressors by a shaft, and the compressors are rotated by the drive of the turbines.



The thrust achieved by the jet engine is determined by the product of the amount of exhaust gas per unit time and the exhaust velocity. However, since the exhaust velocity must be close to the flight speed of the aircraft in order to fly efficiently, a jet engine with extremely high exhaust velocity is an engine with poor fuel efficiency for aircraft flying at subsonic speeds. One may wonder what is the best way to achieve both high thrust and high fuel efficiency. This is where a fan is introduced.

The engines of current passenger aircraft are mostly equipped with a large fan at the front of the jet engines (see illustration). Of all air passing through the fan, a large part bypasses the jet engine (core engine) and is exhausted toward the downstream. Since the air passing through the fan is close to the flight speed, the larger the fan is, the better the engine's fuel efficiency becomes. Therefore, most recent highly efficient engines have the ratio of bypassed air to the air passing through the core engine at about 10.

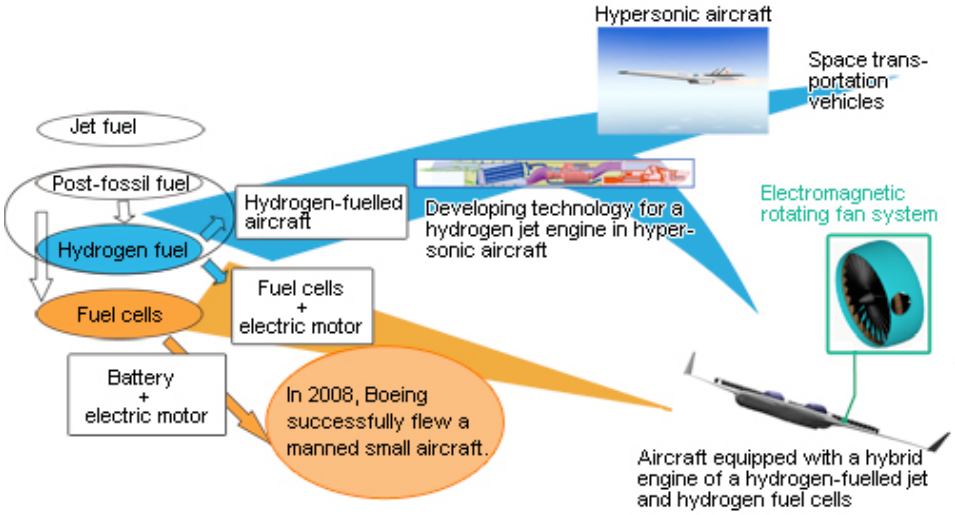


Fig.6 Expanding the technology for the hydrogen jet engine in a hypersonic aircraft into various aircraft required in the future

In April 2008, The Boeing Company (USA) announced that it had succeeded in the world's first manned flight of an aircraft powered by hydrogen fuel cells. The power for this aircraft was supplied by a battery/hydrogen fuel cell hybrid engine(*2). Both operated until the aircraft had ascended to a cruising altitude of 1,000 meters above sea level. After the cruising altitude was reached, the battery was disconnected and the aircraft successfully flew at 100 kilometers per hour for about 20 minutes powered only by the hydrogen fuel cells.

However, this method is not realistic for large aircrafts. Aircrafts should be as light as possible, but, in order to achieve enough thrust to fly a large aircraft, the battery would weigh a great deal, making it difficult for the aircraft to fly. When imagining a large aircraft flying on electrical energy, a hybrid aircraft engine of a hydrogen-fuelled jet engine and fuel cells (fig. 7) is most realistic.

This is a system where air fed into the jet engine is first brought to a high pressure by the compressor. That high-pressure air is supplied to the fuel cell, generating energy through a reaction between the hydrogen fuel and the oxygen in air, and then the exhaust gas passes through the combustor (for further chemical reaction) and turbine to be exhausted backward. We are also studying a reheating mechanism that uses some heat from the exhaust to raise the temperature of the air that flows into the fuel cell. For the fan of this system, we are considering applying an electromagnetic rotating fan system (fig. 6, lower right), driven by electricity.

Standard electrically driven motors are heavy for their output since they use an iron core and permanent magnets, making them unsuitable for large aircrafts, where lighter weight is essential. The electromagnetic rotating fan system utilizes a large-diameter lightweight outer drive motor (fig. 8), resolving this issue. With the time-varying

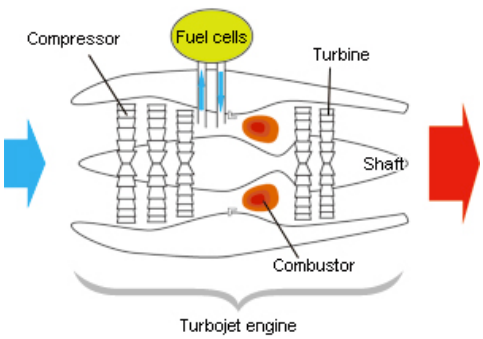


Fig.7 Basic concept of a hybrid aircraft engine

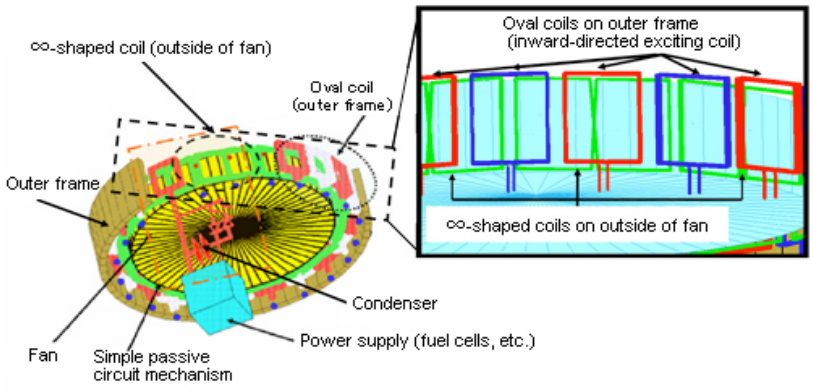
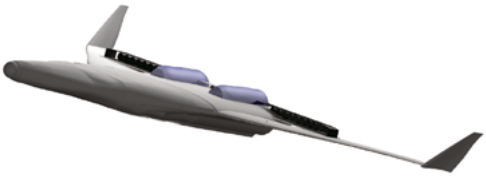


Fig.8 Principle of the large-diameter lightweight outer drive motor



By using a new fuel, namely hydrogen, the aircraft shape may differ greatly from conventional ones. An application for the hybrid engine that we are studying is the Blended Wing Body (BWB), which is designed with the wings and fuselage integrated. Using electromagnetic rotating fans, a distributed arrangement of engines becomes possible.

Fig.9 Hybrid aircraft utilizing the new fan concept

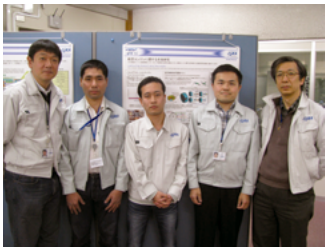
magnetic field generated when current passes through the oval coils arranged on the outer frame, a magnetic field and current are generated in the infiniti8-shaped coils arranged on the outside of the fan, and a rotary drive force is generated by the interaction of the magnetic field and the current. With this approach, the rotating force of the fan is generated with comparatively little power. Efficient use of the energy has been achieved by directly coupling the oval coils with condensers to collect any unused magnetic energy. By passing a large impulsive current from these condensers to the coils on the outer frame, a low-loss motor can be realized, even without an iron core and magnets.

Since this fan system obtains power in the form of electricity, it is not necessary to directly couple it with the jet engine (or the generator) through a shaft, and the fans can be arranged with a very large degree of freedom. Since it is possible to change the direction of the fan or fold it up depending on the flying conditions, various new applications are available, for example, there is even the possibility for a type of variable area engine. (Fig. 9)

Imagine looking up into the sky and seeing an environmentally friendly airplane utilizing our technology! We are seriously researching day and night in the pursuit of this fantastic future.

(*1) Perfluorocarbons (PFC) : Chemical compounds made up of only carbon and fluorine. They are inert and stable, and are used as an alternative to Freon since they have no destructive effects on the ozone layer. However, their potent greenhouse effects have recently become an issue.
(*2)Fuel cells : Batteries that provide electricity by the chemical reaction of oxygen and hydrogen. If hydrogen and oxygen can be supplied, electricity can be produced continuously. This is an environmentally friendly battery since only water is generated from the chemical reaction.

Members conducting the static firing test of the hypersonic turbojet engine



Members of the Electromagnetic Fan System Research Team (Associate senior researcher Keiichi Okai is second from the right.)

Intermission Break

Rules for the global sky

International Civil Aviation Organization (ICAO)

■ Airplanes follow rules in flight

On Oct. 21, 2010, traveling to and from foreign countries became more convenient, beginning with the internationalization of Haneda Airport. Airplanes are an essential means of transportation, connecting the countries of the world. In order for everyone to use them safely and with peace of mind, there must be universal rules. The International Civil Aviation Organization (ICAO), a specialized agency of the United Nations, establishes those rules

With the aim of "developing international civil aviation as well as achieving sound management of international air transport services", ICAO was established in 1947, based on the "Convention on International Civil Aviation (Chicago Convention)". Its headquarters are located in Montreal, Canada, and over 190 countries, including Japan, participate.

■ Civil aviation agreements determined by all of ICAO

ICAO comprises "the Assembly", "the Council" and "the Secretariat". The Assembly, the top decision-making body of ICAO, convenes every three years to elect Council member states and vote on the budget. In the Council, where 33 member states meet three times a year, various reports and debates are carried out.

International rules established by ICAO cover a wide range of issues from those concerning daily operations, such as flight services and maintenance, to environmental protection and counterterrorism.

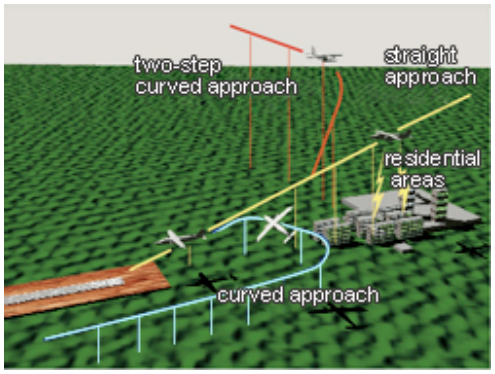
Environmental issues are studied by the Committee on Aviation Environmental Protection (CAEP), established by the ICAO Council in 1983. The various issues covering environmental problems in general, regarding civil aviation, such as "standards on aircraft noise and engine emissions", "policies for reduction of noise around airports" and "global warming countermeasures", are studied by CAEP mainly from a technical perspective.

■ JAXA's environmental efforts

With the international community's growing interest in the environment, ICAO standards concerning the environment are also gradually becoming stricter.

At JAXA, we are continuing research on reducing aircraft noise itself as well as on reducing the sound reaching residential areas around airports by devising other flight paths and flight methods.

We are conducting research on reducing emissions of nitrogen oxides (NOx) by devising new combustion methods. Furthermore, in order to reduce carbon dioxide (CO2), a global warming gas, we are also working on technology for more environmentally friendly fuel. (Refer to page 1 to 5.)



We are conducting research to reduce noise with a curved approach or a two-step approach in order to avoid flying over residential areas.

Fig.1 Approach system for reduced noise

Burning fuel at a high temperature increases the engine efficiency. However, the problem is the increase in CO2 emissions. Therefore, we have set up a facility that simulates the actual combustion environment in order to conduct research for reducing the amount of air pollutants emitted.

Fig.2 High-temperature combustion test facility