

“A compact, energy-efficient and highly reliable” air revitalization system going into space

Relying on Russia and the United States for air on the International Space Station

Normally, six astronauts live while conducting tests and research on the International Space Station (ISS), which orbits at an altitude of about 400 km. Because there is no air in space, oxygen was transported from the ground when the ISS was initially put into operation. Now, it is also using oxygen generators, developed by Russia and the United States. The carbon dioxide exhaled by astronauts is removed by equipment also manufactured by Russia and the United States, and vented overboard. Presently, the oxygen supply to and carbon dioxide removal from the Japanese experiment module “Kibo”, a part of the ISS, relies on equipment from these two countries.

It has been decided that the ISS will be used at least until 2020. Lunar base construction and manned asteroid exploration are being considered for post-ISS space development through cooperation with various countries. For these missions, an even more compact, energy-efficient and highly reliable air revitalization system will be required.

Developing a Japan-made air revitalization system

The air revitalization system is composed of various equipment such as the “carbon dioxide removal assembly” (which removes carbon dioxide from the air), the “carbon dioxide reduction assembly” (which converts the removed and collected carbon dioxide into water) in addition to the “water electrolysis assembly” (which produces oxygen

from that water). (Fig. 1)

● Carbon dioxide removal assembly

Carbon dioxide is removed using a material called “zeolite”, which has the property of absorbing carbon dioxide. Since zeolites prefer absorbing various other molecules, especially water, they cannot absorb carbon dioxide when the air is damp. Therefore, the air is first dehumidified with a membrane dryer. Since zeolite absorbs carbon dioxide at a normal temperature and desorbs it at a high temperature, two containers filled with granular zeolite (absorption columns) are connected in parallel with operation switching between the two about every 90 minutes for continuous removal of carbon dioxide. For desorption, a heater heats the absorption column to about 300 °C. However, since zeolites have high insulating properties, the key is how to smoothly cool the heated absorption column. In tests using air containing about 0.04% carbon dioxide, we have confirmed that the carbon dioxide can be concentrated to about 95%.

Zeolites are excellent for absorbing and desorbing carbon dioxide; however, we have had the problem of it becoming granulated due to the load of the thermal cycle and it penetrating gaps in the device. In order to prevent this and improve its reliability, we are considering a honeycomb shape so that the zeolite can withstand the thermal cycle.

● Carbon dioxide reduction assembly

The chemical reaction from adding hydrogen to collected carbon dioxide generates water and methane. This

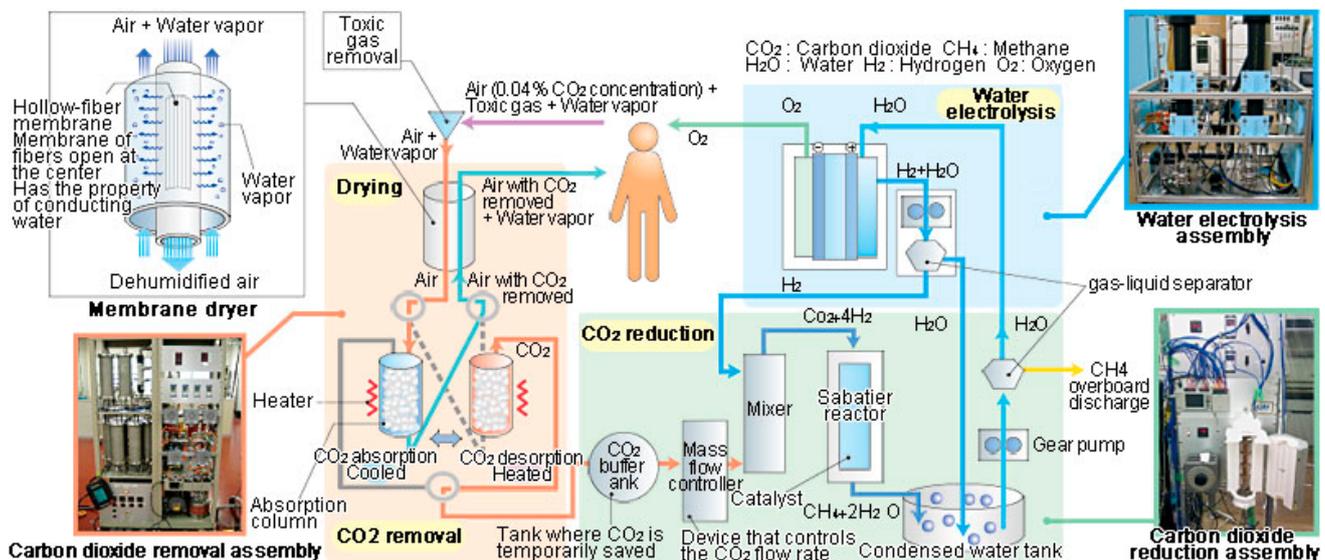


Fig. 1: Air revitalization system (overview)

Research and development of an air revitalization system for ISS demonstration

reaction, called a “Sabatier reaction” , occurs by means of an appropriate catalyst.

The efficiency of the Sabatier reaction is higher at about 350 ° C with a general catalyst. We are researching development of a catalyst with the aim of reducing the catalyst quantity as well as the temperature necessary for a reaction without reducing its efficiency. We have succeeded in reducing the reaction temperature to 250 ° C and halving the catalyst quantity while maintaining the efficiency, but the scale is currently for about one-tenth of a person’s share. If the reaction temperature can be lowered, the power consumption necessary for raising the temperature could also be controlled. In other words, it could become “energy efficient” .

● Water electrolysis assembly

The water created with the Sabatier reaction is electrolyzed to produce oxygen and hydrogen. The problem with electrolysis in a microgravity environment such as space is the separation of water and the generated gas (oxygen and hydrogen). On the ground, gas and water separate naturally through gravitational forces, but this does not happen in space. Therefore, the system is being configured to reduce the water vapor content in the generated oxygen by supplying water from the hydrogen generation side. However, it is necessary to separate the hydrogen and water. The key to that is a “gas-liquid separator” .

Currently three types of gas-liquid separators are being studied and tested for installation into the water electrolysis assembly. (Fig. 2 and 3).

Space demonstration test on “Kibo”

The carbon dioxide removal assembly and water electrolysis assembly are at a size able to handle one adult, and the carbon dioxide reduction assembly is being designed on a larger scale. After a few years, we will link the various component technologies introduced here to construct the entire system and are considering demonstrating it with equipment at the U.S. National Aeronautics and Space Administration (NASA). In addition, the water electrolysis assembly and carbon dioxide reduction assembly, which require space demonstration, will be transported to the ISS by the H-II transfer vehicle “Kounotori” for demonstration testing on the Japanese experiment module “Kibo” . If we can demonstrate, through this testing, the developed technologies for a compact, energy-efficient and highly reliable air revitalization system, we can contribute to future space development.

Manned missions to asteroids or the moon to be conducted in the future-these are the uses that we expect of the life support systems utilizing the environmental technologies that are Japan’s specialty. We are tackling research and development on a daily basis in pursuit of this dream.



A: Rotating gas-liquid separator



B: Hollow-fiber gas-liquid separator



C: Membrane gas-liquid separator

Fig. 2: 3 types of gas-liquid separators



Fig. 3: Test of rotating gas-liquid separator with a test stand in the direction of the gravitational force



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Development of aeroassist technologies for future planetary explorations

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Aeroassist technology

Aeroassist technology is technology that changes the trajectory of spacecraft or the orbit of artificial satellites with the assistance of the atmosphere. Since there is no atmosphere in space, one may wonder if spacecraft can do anything with atmospheric assistance. However, there are quite a few places where an atmosphere exists, even in space. There are planets possessing an atmosphere, such as Venus, Mars, Jupiter, Saturn and Earth, as we all know. By applying aeroassist technologies to explorers for such planets and to spacecraft that re-enter Earth's atmosphere, we can expect significant reduction of fuel for propulsion systems. Moreover, aeroassist technologies allow us to create unique space missions that could not be actualized with conventional technologies.

In order to send a planetary explorer (orbiter) to a target planet, the orbiter must first be accelerated from the ground by a launch vehicle to leave Earth's gravity. Conversely, to insert the orbiter into the circulating orbit after arrival at the target planet, the orbiter must be decelerated so that it can be captured by the gravity of the planet. Deceleration requires a large amount of fuel. For example, to insert an orbiter into a Mars orbit at an altitude of 500 km, more than half its weight must be fuel. In such a situation, there would be a significant limitation in the number of scientific instruments available on board the orbiter. One idea to resolve this problem is to decelerate the orbiter by aerodynamic drag instead of decelerating the orbiter by using fuel. This might be realized by flying the orbiter through the upper atmosphere of the target planet. Flying the orbiter into the atmosphere directly from the interplanetary orbit and instantly inserting it into the circulating orbit after aerodynamic deceleration is a procedure called aerocapture. First inserting the orbiter into a temporal high orbit using a small amount of fuel, then gradually transferring to lower orbits by using aerodynamic drag is a procedure called aerobraking.

Current state of development

Since the aerocapture orbiter suffers significant aerodynamic heating because of an ultra-high speed flight through the planetary atmosphere (at a velocity

of tens of thousands of kilometers per hour), a thermal protection system is necessary for protecting the spacecraft body. In addition, to modify the trajectory of the spacecraft into the desired one, the aerodynamic shape of the spacecraft should be well designed so that the aerodynamic force acting on the spacecraft is appropriate to realize this. The direction of flight should be precisely controlled, as well, with a sophisticated guidance and navigation system so that the spacecraft is not excessively decelerated and dropped to the ground, or insufficiently decelerated and escapes from the gravity of the target planet. To design the thermal protection system, the aerodynamic shape as well as the guidance and navigation system, one must accurately predict the aerodynamic heating rate and the aerodynamic force acting on the spacecraft along the flight trajectory. For the above reasons, we are conducting comprehensive development of individual technologies necessary for the aeroassist technology described above. In order to accurately predict the flight environments, we are developing advanced computational fluid dynamic tools, such as JONATHAN and MOTIF, which cover the effects of molecular dissociation and ionization (real-gas effects) due to an

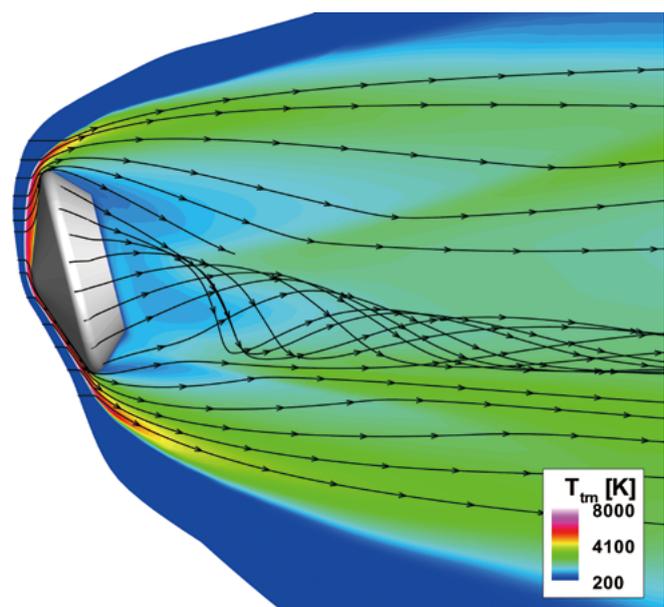


Fig. 1: Distribution of flow temperature around a capsule flying through Martian atmosphere (at 49 km altitude, 5.6 km/s velocity, and -14° angle of attack)

ultra-high-speed flight. These tools have already been applied in many studies of atmospheric entry vehicles.

Figure 1 shows an example of the flow around a capsule in hypersonic flight through the Martian atmosphere, which is computed by the JONATHAN code. Accuracy assessment and improvement of these tools are being conducted with the aid of testing facilities such as the hypersonic rarefied wind tunnel (HRWT) and the hypervelocity shock tube (HVST), which can reproduce on the ground the flight environments of the spacecraft. Once the aerodynamic heating rate and the aerodynamic force are predicted through analyses, an optimal design of the aerodynamic shape and the thermal protection system can be achieved. In this procedure, it is of primary importance to minimize the weight of the thermal protection system as well as the aeroshell covering the spacecraft body for the purpose of increasing the room for scientific instruments on board the spacecraft as much as possible. In order to realize this, an ultra-light-weight aeroshell has been under development in collaboration with the Advanced Composite Research Center and the Wind Tunnel Technology Center. As an example, a schematic view of the reusable aeroshell equipped with a non-ablative light-weight thermal protection system (NALT) is illustrated in figure 2. The heat resistance performance of the thermal protection system has

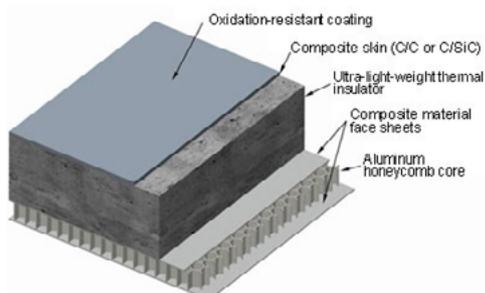


Fig. 2: Schematic view of reusable NALT aeroshell

been validated in the arc-heated wind-tunnel of the Wind tunnel Technology Center, in which test flow temperatures of several thousand degrees can be obtained. The test results are analyzed in detail by the thermal protection system analysis tool, SCMA2, which is also used to design the thermal protection system of the spacecraft in real flight environments.

Future prospects

In addition to development of the component technologies described above, conceptual studies of integrated systems and proposals of unique missions using the aeroassist technology are being performed. As an example, a conceptual view of the Mars Aeroflyby Sample Collection (MASC) system, which collects Martian dust particles suspended in the atmosphere during the Mars aerocapture and returns them to Earth, is illustrated in figure 3. In addition, aerocapture technology demonstrators and landers for Mars Exploration with Lander-Orbiter Synergy (MELOS) are being entertained in collaboration with the JAXA Space Exploration Center (JSPEC). The aerocapture technology is already at the stage of practical use, and we hope to implement aeroassist missions by 2020.

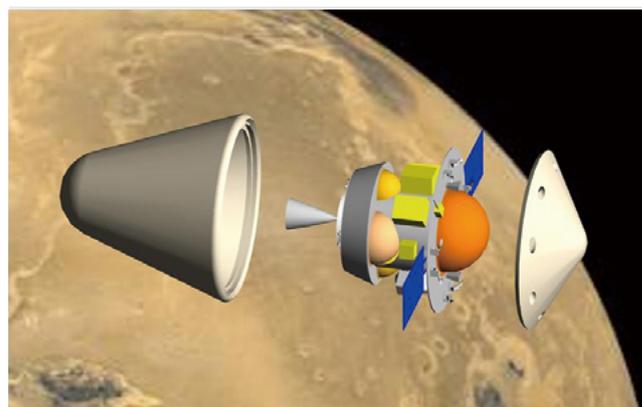


Fig. 3: Conceptual view of the Mars Aeroflyby Sample Collection (MASC) system



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