RESEARCH INTRODUCTION

Heat Rejection Technology

Why Do We Need the Flat Plate Heat Pipe?

Satellites incorporate many electronic components that generate heat when operating. If this heat isn't properly removed, the temperature of the components will rise and the components may fail. Until now, the heat from the onboard components of a satellite has usually been removed via the thermal conduction of satellite panels and heat pipes embedded inside them.

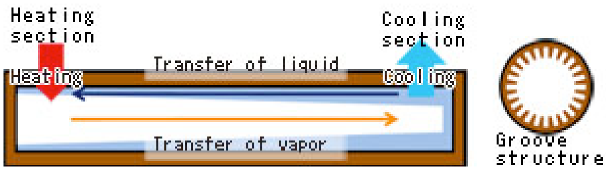
Recently, however, the newer components installed in satellites have higher heat densities than before. In some cases, the component temperatures rise to levels too high to easily remove with the existing thermal management technology.

If these components are to be adopted safely, new technologies to control the heat must be developed. One of the solutions is a flat plate heat pipe (FHP) capable of directly removing the heat from inside components. JAXA began developing a new type of FHP in FY2006.

Developing an FHP for Demonstration on a Small Satellite!

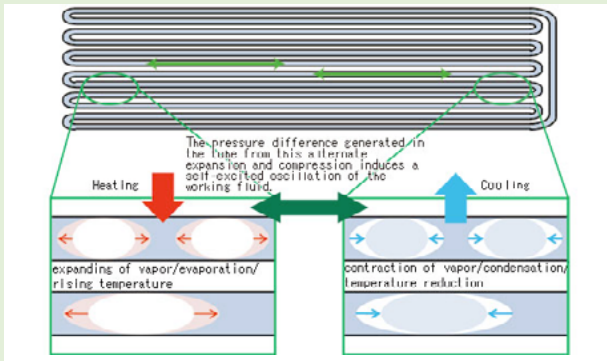
Many approaches are available for the design of flat plate heat pipes for thermal control. For our application, in satellites, we decided to focus on an "oscillating heat pipe (OHP)," a flattened two-phase heat-transfer device with a very simple structure.

The OHP is a closed loop of smooth stainless steel tubing sandwiched between flat aluminum plates and charged with a working fluid inside. The operating principle of the OHP differs from that of a conventional heat pipe. A pressure difference inside the OHP forces the working fluid to circulate and oscillate, and this circulation and oscillation of the fluid transfers both sensible heat and latent heat. The maximum heat-transfer ability per unit weight is smaller than that of the conventional HP, but the effective thermal conductivity can be raised to very high levels by increasing the number of turns of the tube. Another challenge in adopting the OHP, one more difficult to solve, is the tendency of the pipe to lose its heat-transfer function when the heat load to supply the driving force is very low. One



The Heat Pipe (HP) is a tube with "groove structure" on the inside wall and working fluid charged inside. The working fluid inside the pipe is heated into a vapor in the heating section, moves to the cooling section, condenses back into a liquid, and flows back into the heating section along the grooves via a "capillary force." This process, repeated again and again, transfers the latent heat from the heating section to the cooling section.

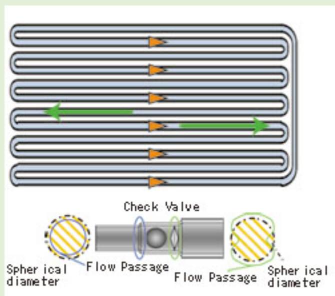
Fig.1 Operating Principle of HP



Operating principle of the oscillating heat pipe

The oscillating Heat Pipe consists of a narrow, unicursal tube and flat plate. Unlike the conventional HP, the OHP has no groove on the inside wall of the tube. The working fluid expands in the heating section and contracts in the cooling section. The pressure difference generated in the tube from this alternate expansion and compression induces a self-excited oscillation of the working fluid. The working fluid flows back and forth between the heating section and cooling section, carrying with it heat from the heating part to the cooling part.

Check Valve



The FHP is also mounted with check valves in the passages of tube where the working fluid moves from the heating section to the cooling section. Each check valve has special flow passage and small ball to restrict the flow of the working fluid in one direction. This one-way circulating flow smoothly transports heat under both high heat and low heat loads.

Fig.2 Oscillating Heat Pipe

way to fix this problem is to install a "check valve.

Our team at JAXA has designed, fabricated, a tested a series of laboratory OHPs (300 mm × 110 mm × 3 mm; 12, 15 and 18 turns; maximum heat-transfer ability of 100 W). In our testing of the these OHPs, we assessed how the number of turns, charge ratio, and check valves affected the heat-transfer characteristics. As a result, we have confirmed that the OHP with check valves can work under a wider range of heat loads than the OHP without check valves. Now that we have finished evaluations test of the bread board model (BBM), we are carrying out a more detailed evaluation of the new OHP using an engineering model (EM).

To confirm the heat-transfer characteristics of the OHP under micro-gravity conditions, we will be designing a space demonstration test on the No. 4 "SDS-4," a small demonstration satellite scheduled to launch in FY 2011..

Collaborative Research with NHK

The Science & Technology Research Laboratories (STRL) of Nippon Hoso Kyokai (Japan Broadcasting Corporation - NHK) are pursuing the realization of a new form of ultra-high-definition television broadcasting through research on a 21GHz-band Broadcasting Satellite with a phased array antenna. JAXA is collaborating with NHK in this project by researching the heat rejection system for the array. The antenna is made up of 188 traveling wave tubes (TWTs), each of which generates abundant heat requiring active cooling.

In this collaborative research, NHK STRL is designing the TWT and JAXA is designing the thermal control system for the antenna. The space for the heat-transfer device between the TWTs is extremely narrow, measuring only 3mm. To work within this tight parameter, we are proposing a heat rejection system using double-type FHPs. Thermal analyses have confirmed the results of our evaluations of the heat-rejection system with the FHP (Fig. 4).

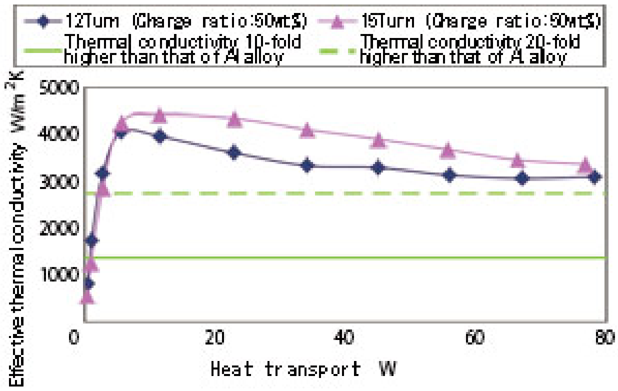


Fig.3 Relation between Number of Turns and Heat Transport

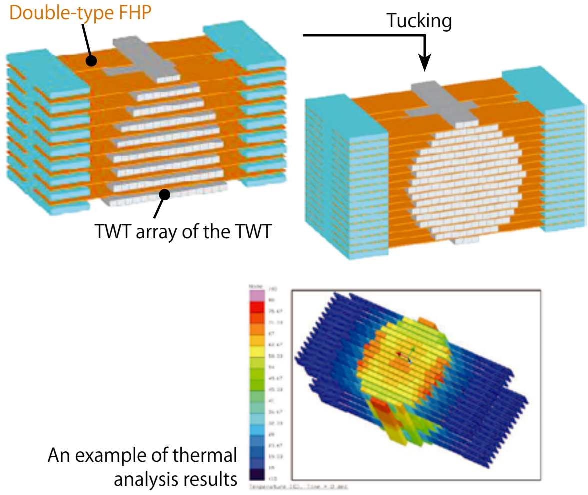
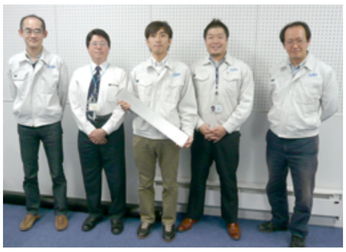


Fig. 4: Thermal Control System with a Double-Type FHP for the Feed Array



[Thermal Systems Group]

(from left) Hiroyuki Sugita, Yasuo Nakamura, Masakatsu Maeda, Atsushi Okamoto, Haruo Kawasaki

R E S E A R C H
INTRODUCTION

Safe Returns for Spacecraft

Returning isn't So Easy.

A spacecraft returns to the earth from cosmic space, a vast environment in vacuum conditions with almost no substance at all. When the spacecraft enters the atmosphere, moving from a vacuum into air, a substance with pressure, the fuselage must withstand a tremendous shock, or aerodynamic force. The temperature of the air in front of the spacecraft climbs to extreme levels from the strong compression force, which intensely heats the spacecraft (aerodynamic heating). This heat exceeds the surface temperature of the Sun (approximately 6000 K) and sometimes even reaches several tens of thousands of degrees. In this environment, the nitrogen and oxygen molecules making up the air can be nearly totally dissociated (Fig. 1). When a spacecraft is designed for reentry, it is crucial to accurately predict the aerodynamic force and aerodynamic heating it will have to withstand.

Flight demonstration tests are the only sure method for understanding spacecraft performance in the special environment in which the spacecraft will travel. Yet tests of this type are challenging and expensive to orchestrate and must certainly be preceded by sufficient validation on the ground. JAXA is promoting research and development of two technologies, a "Flight Environment Evaluation Technology" and "Thermal Protection Technology." More specifically, these can be described as a technology to "Improve the Precision and Reliability of Ground Tests" and a "Numerical Analysis Tool to Reproduce Ground Tests and Predict Flight Environments."

We Want to Know the Flight Environment of Spacecraft

One effective way to precisely understand the environment during a spacecraft reentry is to reproduce the environment on a computer by numerical analysis. The analysis must reproduce the physical processes with extremely high fidelity by accounting for even the molecular processes of dissociation and ionization during the reentry. To do this we are performing an in-depth analysis of the microscopic process of the molecular collision and modeling the rate coefficients of the chemical reaction. More specifically, we have found a way to more precisely model reaction rate coefficients resulting from the collisions between N_2 and N_2, N_2 and N, and CO and O.

One of the most difficult points in developing the atmospheric entry system with ground testing facilities is the inability to reproduce the flight environment a spacecraft encounters at hypersonic speed. To work around this limitation, we have developed a free piston double diaphragm shock tube with 70 × 70 mm cross-section at a test section for use in the development and validation of thermochemical models (refer to page 5).

With the results of our fundamental analyses and our highly precise elementary process model from ground tests, we are proceeding with the development of various computational tools to evaluate the flight environment during reentry. Here we will introduce several examples among them (Figs. 2 and 3).

◇Reactive CFD Code "JONATHAN"

The air around the spacecraft during atmospheric reentry is in "high enthalpy flow," a state of high pressure and high temperature, as well as high energy. We are developing a common analysis tool with sufficient general versatility to analyze various types of high enthalpy flows..

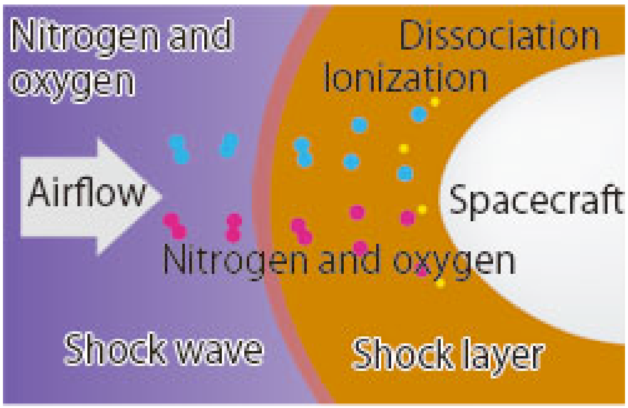


Fig.1 Schematic of Shock Layer around the Spacecraft during Reentry

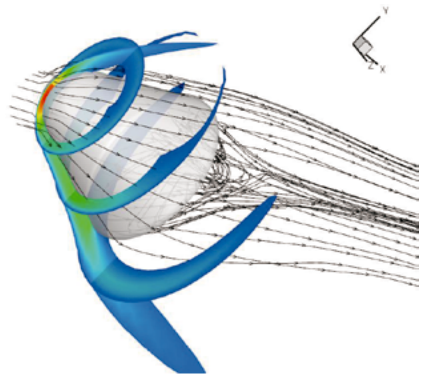


Fig.2 Typical Example of a Converged Solution from the Flowfield around a Mars Aero-flyby Sample Collection (MASC) Vehicle at a High Angle of Attack obtained by JONATHAN

Research and Development on a "Flight Environment Evaluation Technology" and "Thermal Protection Technology" for the Atmospheric Entry System

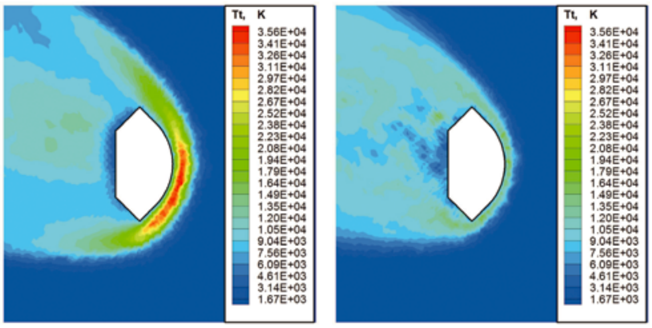


Fig. 3: Analytical Results of Flowfield around Hayabusa Capsule by

◇**Reactive DSMC Code "RARAC3D"**

The atmospheric air is very thin at high altitude where reentry occurs, compared with the air on the ground. Thus, the airflow characteristics around the fuselage also differ from the conditions on the ground. As the atmospheric air is thin, the molecules collide less frequently and the transport phenomenon in the airflow and chemical reaction are slow relative to the time scale of the flow. The interaction between the airflow and the surface of a solid (spacecraft) is very different from that on the ground, where the interaction can be characterized as a continuous fluid. Accordingly, we have developed a an analysis tool with which to evaluate the flight environment in the rarefied flow. We are evaluating the aerodynamic performance for atmospheric reentry and ultra low altitude satellites.

We Need to Protect Spacecraft from Heat

Once you know the aerodynamic heating environment around a spacecraft, the next important step is to find the best thermal protection technology for the environment.

To protect against intense aerodynamic heating, the reusable space plane (space shuttle) operated by the U.S. National Aeronautics and Space Administration (NASA) is made with carbon-based thermal protection materials for the nose, front edge of the wing, and other sections subjected to extreme surfaces temperature during reentry. These carbon-based thermal protection materials have been evaluated mainly against oxidation during reentry.

We have also learned, however, that the nitridation reaction cannot be neglected, as the nitrogen molecule, the main constituent of the air, is also dissociated during reentry. Thus, we are developing and experimentally validating a chemical reaction model which accounts for the nitridation reaction taking place on the surface of the carbon-based thermal protection materials. Fig. 4 shows the scene of an experiment to study the nitriding deterioration characteristics of a carbon-based thermal protection material by heating a graphite material with a high-temperature nitrogen gas flow. Through this experiment, we have developed the world's first nitriding reaction probability model applicable within a wide temperature range.

The results of research and development on our "Flight Environment Evaluation Technology" and "Thermal Protection Technology" apply not only to reusable space planes, but also to landing missions onto an extraterrestrial planet. We will set our sights on these missions as we proceed with research and development in the future.

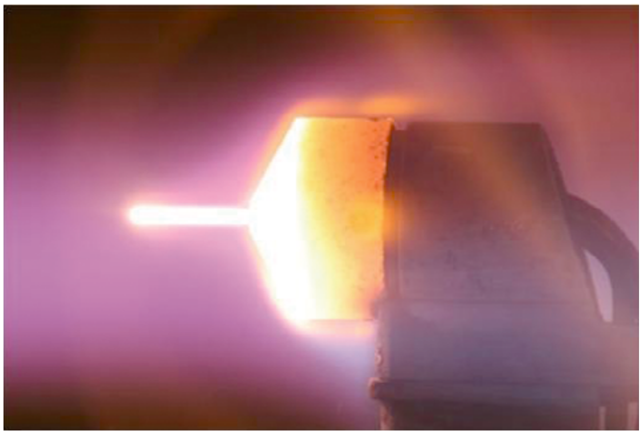


Fig.4 Evaluation of the Probability Value of the Nitridation Reaction by the Heating Test

[Fluid Dynamics Group]

(from left) Hiroki Yanagida,Kazuhisa Fujita,Toshiyuki suzuki
(Front row) Gouji Yamada

Intermission Break

The Heat Environment for Spacecraft

■A spacecraft is heated to extreme temperatures when it returns to Earth

This spacecraft is returning to Earth. The speed during reentry into the atmospheric air is around 1,400 km/hour. This is a tremendous velocity, almost five times faster than the top speed of the Shinkansenur bullet train (around 300 km/hour).

As the fuselage flies through the air at its ultra-fast speed, a "shock wave," a wall of high-pressure air, precedes it in front, and the air around the fuselage, especially the air on the front surface, is strongly compressed and extremely hot. The phenomenon called "aerodynamic heating" is the entry of this extremely hot air into the fuselage. As the travel speed increases, the aerodynamic heating rapidly increases as well. During reentry from the earth orbit, the temperature of the compressed air sometimes reaches several tens of thousands degrees. Robust thermal protection to protect the fuselage from these staggering temperatures is essential.

■A state not solid, liquid, or gas

Because of the ultra-high temperatures, the air in the high-pressure area inside of shock wave reaches a state of either "disassociation" (molecules such as nitrogen (N_2) and oxygen (O_2) break apart into atoms such as nitrogen atom (N) and oxygen atom (O) or a state of "electrolytic dissociation" (the electrons separate from the molecules and atoms, leaving the molecules with positive electrons, or positive electric charges). The substance which causes these states of disassociation and electrolytic dissociation is called "plasma" (refer to page 3).

When a plasma-activated substance collides with a spacecraft, a chemical reaction occurs on the spacecraft surface. This chemical reaction is anticipated during the design of the thermal insulation materials placed on the spacecraft surface..

■A spacecraft receives heat even when it merely floats in space

Cosmic space is a vacuum occupied by almost no substance at all. For this reason, an artificial satellite floating in the Earth orbit is hardly affected by aerodynamic heating. But we must be careful. The sun radiates brilliantly in space. The heat from the sun, infrared ray radiation from the earth, and other sources of heat all affect the artificial satellite (Fig. 2).

The heat generated by the artificial satellite itself is also a problem. The electronic devices installed on the artificial satellite all must operate within specified temperatures ranges in order to function normally. To ensure proper functioning in the severe thermal environment of space, a heat-control system for thermal insulation and heat discharge is indispensable. JAXA is developing two new technologies to create newer and better heat-control systems: first, a multilayer thermal insulating blanket (See issue No.25 of "Sora to Sora"). being developed as part of R&D project on thermal insulation technology; second, a heat-control system with a heat pipe (refer to page 1), radiator, and other components as a "heat discharge technology."

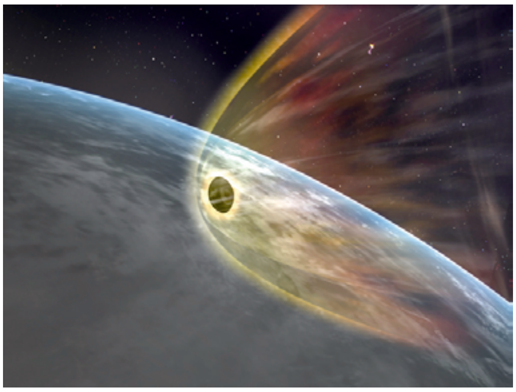


Fig.1 Appearance of the Reentry of the Recoverable Capsule, Hayabusa

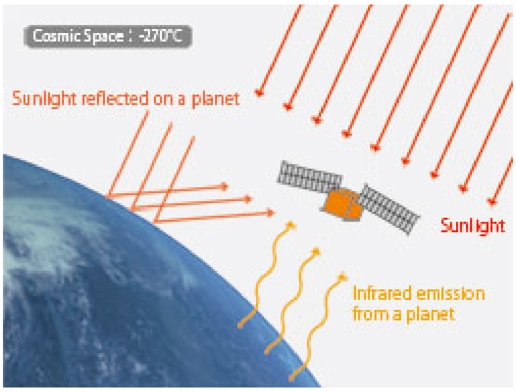


Fig.2 Heat Environment of the Artificial Satellite