I will introduce Mr. Kozaburo Inoue. Mr. Inoue entered Institute of Industrial Science, University of Tokyo in 1963. Although the name of the institute was changed afterwards to Institute of Space and Aeronautical Science, University of Tokyo, and then to Institute of Space and Astronautical Science (ISAS), he has been engaged in a study of development of satellite communication equipment and communication system of scientific satellite since the initial stage of Japanese scientific satellite development. He was engaged in more than 20 satellite missions of scientific satellite. In particular, Halley's comet which can be observed from the earth every period of 76 years is a subject of concern of the whole world. As an engineering chief of "Exploration mission for Halley's comet" whose satellite was launched to the orbit around the sun, he poured all his energy into developing an explorer that has never been experienced deep space communication of 2 AU (300 million km) in the satellite side under the limitation of 140 kg of weight and less than 100 W of power consumption and constructing a 64 m diameter antenna at Usuda, operational station of deep space communications and communication system. The full text below has splendid contents as a record about Mr. Inoue's hard work at that time. He was retired from his job in 2003, but he is still active as an adviser and a reviewer as a collaborative researcher of ISAS. He enjoys playing tennis and go other than watching sports games and listening to music in his spare time.

(Bv Tomoki Obuchi. SJR Editorial Member)

Exploration Mission to Halley's Comet

Kozaburo Inoue
Collaborative Researcher, Institute of Space and Astronautical Science,
Japan Aerospace Exploration Agency

[Brief Biography]

Mr. Inoue joined Institute of Industrial Science, University of Tokyo. Passing through the institute was reorganized to Institute of Space and Aeronautical Science, University of Tokyo and then to Institute of Space and Astronautical Science (ISAS), he retired at the age limit in 2003. He continues to engage in the satellite launch afterwards. He engaged in research and development of rockets and scientific satellites and explorers from the beginning of Japanese space development for 40 several years. He participated many rockets and launches of scientific satellites and explorers including the Japanese first satellite "Ohsumi". He is now a collaborative researcher at ISAS, Japan Aerospace Development Agency (JAXA) and a part-time lecturer of private university department of science and engineering.

Last year (2010) was the year that should be commemorated for Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA). First, February 11, 1970 is the 40th year after the Japanese first satellite "Ohsumi" was launched. Second, the asteroid explorer "Hayabusa" that was launched on May 9, 2003 returned successfully to the earth on June 13, 2010 after seven years from launching and landed at asteroid "Itokawa", and its capsule was successful collected at Woomera Desert in Australia. The splendid achievement of "Hayabusa" seems to have given in particular Japanese people a big impression.

By the way, the number of scientific satellites and/or space explorers of ISAS that I was engaged in so far amounts to 29. Among them, I would like to talk briefly about Halley's comet exploration mission that is especially impressive. This mission was the PLANET-A program that the ISAS (former Institute of Space and Aeronautical Science, University of Tokyo) gave all power in order to observe Halley's comet that returned to

the sun after 76 years in 1986 25 years ago.

Although ISAS launched more than 10 scientific satellites so far, it was the first time to launch an explorer that escaped from a gravitational field of the earth and performed interplanetary navigation. Two explorers "Sakigake" and "Suisei" were developed by collaborating science and engineering, and they were launched to Halley's comet. In order to observe the Halley's comet, each country developed explorer and let them gather to meet with the comet: the Soviet Union developed 2 explorers "Vega 1" and "Vega 2", the European alliance developed explorer "Giotto", and the U.S. changed orbit of International Sun-Earth Explorer "ISEE-3" which observed solar wind, and changed its name to International Cometary Explorer "ICE".

O Four Development Items

The PLANET-A program to explore Halley's comet started in 1980, and it was necessary to develop 4 items at the same time under limited conditions in short term as follows:

(1) Development of a M-3SII rocket
(2) Development of an explorer for interplanetary navigation
(3) Construction of a large antenna and development of a deep space station
(4) Development of software for the interplanetary navigation

Launch of Halley's Comet Explorer "Suisei" by M-3SII-2 Rocket

(1) Development of M-3SII Rocket

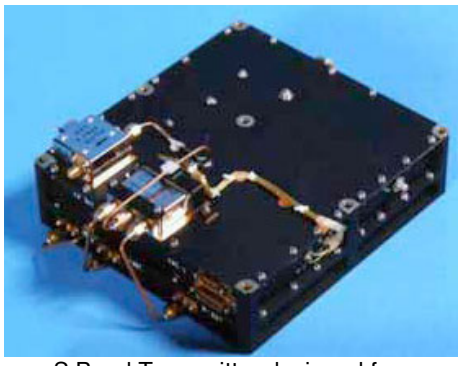
I cannot describe process of rocket development in detail, but the development was started in 1981 by making the development organization clear with putting the program chief as a top management. Under severe time constraints, rocket performance improvement from M-3S type to M-3SII type was achieved by improvement of quality of upper stage motor and increasing its size based on technology accumulation of conventional solid rocket so far, in accordance of basic policy of development to take advantage of the existing motor.

However, a kick motor was necessary as the fourth stage for No. 1 and 2 explorers, because three stages type rocket was lack of ability to put an explorer of 140kg into interplanetary space. Because the direct injection method was planned not to use a parking orbit from the beginning, its size was chosen to get the maximum ability for injection in a combination with the third stage. In addition, from the safety point of view, consideration was paid so that the third stage was in earth surroundings orbit. Meanwhile, serious efforts by the person concerned were paid including eight ground combustion experiments and flight experiments by ST-735-1 rocket at Noshiro test site.

The basic configuration of M-3SII rocket is a three stage rocket which is consisted of M-13, M-23, and M-3B motors. As for No. 1 and 2 rocket, a kick motor (KM-P) was equipped with as the fourth stage.

(2) Development of Explorer

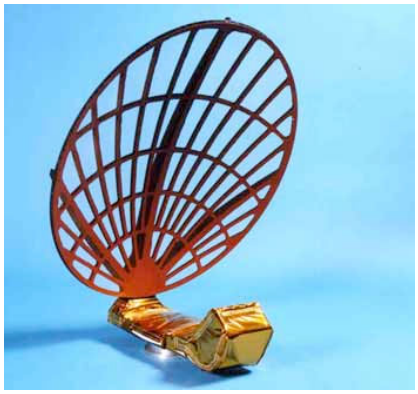
An explorer is the first one in Japan which navigates the interplanetary space, and there are many points different from the earth orbiting satellite. There was a serious effort of persons concerned for the development. Items including ultra long distance communication, orbit and attitude control, orbit generation, orbit determination, attitude determination and thermal control are the first experience, while the weight of the explorer was limited to 140 kg due to performance of a rocket. As a result of repeated examination by a satellite group of the persons concerned, the explorer was determined as followed: the shape of explorer is cylindrical, its attitude is stabilized by spin stabilization method, and its size is with a diameter of 1.4 m and a height of 70 cm from the viewpoint of area of a solar battery and jets for attitude control. An offset antenna of 80 cm diameter with slow speed mechanical de-spun structure developed for ultra long distance communication and control jets with hydrazine fuel are equipped on the top surface of the explorer. The aperture of this antenna is made by mesh knitted with gold-plated Nichrome wire taking into consideration of the weight of



S Band Transmitter designed for Ultra Long Distance Communication.

antenna, vibration proof and thermal resistivity. As an attitude detection device, a sun sensor and a star scanner which looks downward in a thrust tube are installed on the side. In addition, as for an onboard transmitter, an S band transmitter is used, which is newly-designed and high power with 5 W output. Two receivers are embarked onboard for redundancy.

The structure of explorers "Sakigake" and "Suisei" is basically the same. It is consisted of a platform of 1.34 m diameter made of Aluminum-honeycomb, a cylindrical thrust tube made of CFRP, and 8 struts made of CFRP which connects thrust tube bottom end and the platform outskirts. In this way, Aluminum honeycomb and CFRP are used for making weight light. A solar battery is installed on a cylinder panel of 70 cm height, and about 100 W electricity is available. Each equipment including communication system, attitude system and power supply system is mainly installed in the top surface of a platform or a thrust tube.



Offset Antenna of 80 cm Diameter With Slow Speed De-spun Mechanism Developed for Ultra Long Distance Communication.

(3) Construction of 64 m Diameter Antenna and Development of Deep Space Operation Station and Operation System

64 m Diameter Antenna at Usuda used for Ultra Long Distance Communication.

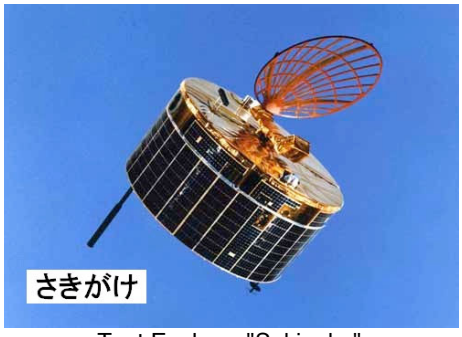
"A large-sized antenna is necessary to enable long distance communication for Halley's comet exploration program." was argued with the person concerned in 1978-1979. Then an investigating group was organized by researchers and engineers of Mitsubishi Electric and NEC Corporation, and large antenna field survey was conducted around the world in March, 1980. Examination of antenna construction site in Japan was begun sequentially. The required conditions of site are as follows: ①Surrounded by mountains to avoid downtown area noise in order to receive very weak radio wave, ②Isolated from air line course and public telecommunication line, ③Located near Tokyo in consideration of data transmission and ④Able to get agreement with local people. Considering these conditions, candidates of site were narrowed down to ten. As a result, the present place at Usuda Town, Nagano Prefecture was decided as the most suitable site. The large-scale antenna was completed without any accident, while not long breath work was continued such as road construction, land creation, import of antenna material, assembling and adjustment. The performance confirmation test for a ground hardware device, including developed and manufactured deep space transmitter and receiver and an operation system, was continued day and night and was completed with this antenna construction. And tracking of "Sakigake" was admirably fulfilled the goals in January of the next year. It is a gift of dedicated efforts of government offices and companies concerned that this large antenna came out in short time. I remember well that the opening ceremony of Usuda Deep Space Center took place in cold wind under this antenna on October 31, 1984.

(4) Development of Interplanetary Orbit Determination Program

The orbit determination program which is indispensable for interplanetary flight was developed over 5 years in cooperation of Company F under Prof. N's leadership, who engaged in orbit determination of explorer Mariner in JPL, NASA, U.S.A. I think that the development of such a large-scale software by small number of people might be a hard work. When I met Prof. F near the ISAS at Komaba, Tokyo, he said, "There were more than 20 number of staff for development of this scale of software in the U.S.A." Since the orbit determination work that was performed by small number of people was a very tight schedule, I brought futon to make orbit software all night at the time of launching. It was just precarious day-to-day management. The construction of the ground system was serious so that a computer and a high-speed line was used to connect to Usuda station for the first time, but Miss N of Company F told his memory about Prof. N who paid attention to all the details in serious work, "Prof. N led to make both the work and manufacturers smooth".

○Test Explorer "Sakigake" and Halley's Comet Explorer "Suisei"

(1) "Sakigake"

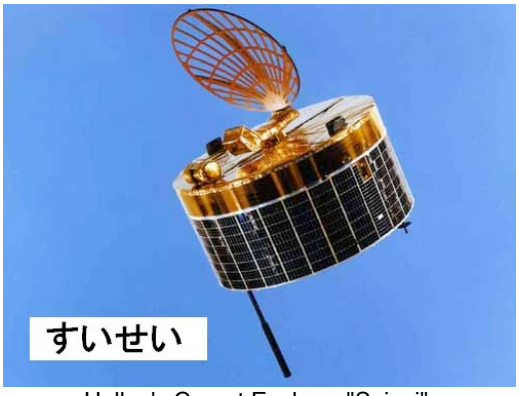


Test Explorer "Sakigake".

Test explorer MS-T5 was launched by M-3SII-1 rocket that was improved M-3S type at 4:26 JST (Japan Standard Time) on January 8, 1985. A flight of the rocket was normal and showed expected performance, and it was cast into planned interplanetary orbit by a perfect flight, and it was named "Sakigake". The achieved orbit was perihelion: $121.7X10^6$ km, aphelion: $151.4X10^6$ km, period: 318.6 day. All members of the experiment team prepared for launch in the biennial at Uchinoura. Although the launching due date was January 5, the initial date was postponed due to weather defectiveness. On January 6, the malfunction was occurred that a power supply ON-OFF circuit of an oil pressure drive motor of an auxiliary booster mobile nozzle did not close just before launching at one time. In addition, because a problem of ground equipment was confirmed, the launching was led on January 8. This success was achieved by all power of ISAS, I seemed to have watched the real ability of an experiment team. It was a memorialized year, namely, 15 years after the Japanese first satellite "Ohsumi" was launched. The new rocket, M - 3SII rocket, which included four kinds of new development motors, made the flight test succeed at a stretch, and it was the time when there was a message via contact broadcast with "Success of 120%" from the A experiment chief.

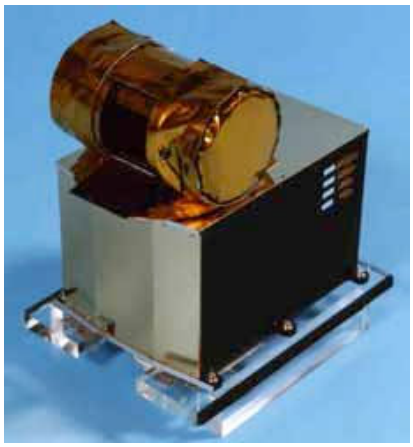
As scientific observations, three kinds of observation device including solar wind ion observation device (SOW), plasma wave observation device (PWP) and solar wind/interplanetary space magnetic field observation device (IMF) were equipped to observe solar wind plasma and a interplanetary magnetic field.

(2) "Suisei"



Halley's Comet Explorer "Suisei".

Explorer "PLANET-A", whose purpose was Halley's comet exploration, was launched by M-3SII-2 rocket at 08:33 JST on August 19, 1985, two days later than initial plan after setting a launcher at a sunny moment despite drizzle. It was a very exciting launching. "PLANET-A" entered the planned interplanetary orbit by a perfect flight of rocket, and it was named as "Suisei". The radio wave of the first path was received in sequence by the tracking stations of NASA in the U.S. and Katsuura, Uchinoura and Usuda in Japan. Based on data provided by Usuda deep space station and NASA deep space communication network, the calculated orbital element was ①perigee altitude: 217 km, ②inclination for earth: 31.25 degs, ③hyperbolic excess velocity: 2.985 km/s, ④aphelion distance: $151.42X10^6$ km, ⑤perihelion distance: $100.50X10^6$ km, ⑥inclination: 0.888 degs, and ⑦period: 282 days.


Ultra-Violet Imager (UVI).

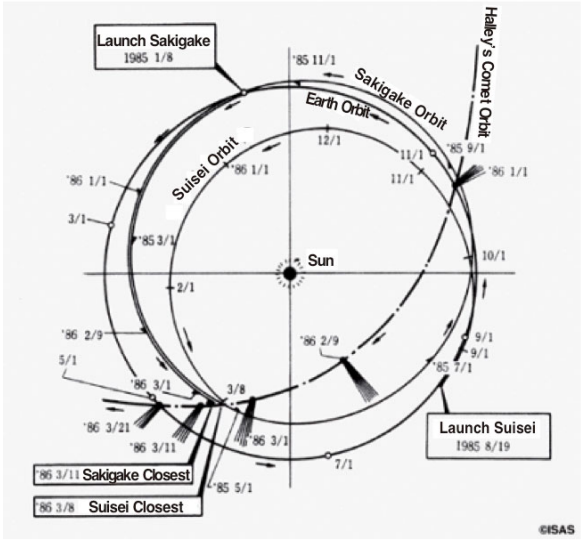
From the received telemetry data, the operating condition of "Suisei" was normal, and it was confirmed that the spin rate was 25.35 rpm, and the angle between sun direction and spin axis was 89 degs. According to the ISAS's calculation, the explorer would be closest to Halley's comet at 22:00 JST, March 8, 1986 and the distance would be 210,000 km. In the international conference that Halley's comet observation-related organizations gathered afterwards, it was shown that spread of dust in the neighborhood of Halley's comet center nucleus is narrower than conventional consideration, and it was expected that the better result by a solar wind observation device was provided the closer to center nucleus. So an orbit adjustment was made to approach Halley's comet on November 14. As a result, the closest distance to Halley's comet became 145,000 km.

The "Suisei" was carrying two observation devices. One is Ultra-Violet Imager (UVI) for imaging a hydrogen coma of Halley's comet by ultraviolet rays such as hydrogen Lyman alpha line (1216Å) and another is solar wind observation instrument (ESP) for observation of charged particle (ion and electron) in the solar wind. A core of a comet is regarded as a lump of a diameter of several km formed in fine particles and ice of a solar system inception material. As this approaches the sun, this is evaporated and forms a huge coma and tail. The observation purpose of UVI is to elucidate mechanism of generation/extinction of coma by imaging this hydrogen coma at

each point on orbit of Halley's comet. On the other hand, ESP is to elucidate existence of a shock wave side formed by interaction through studying interaction of solar wind with the ionization atmosphere of comet. "Suisei" was launched for the purpose of approaching within 1 million km of a nucleus of Halley's comet in order to observe these items mentioned above.

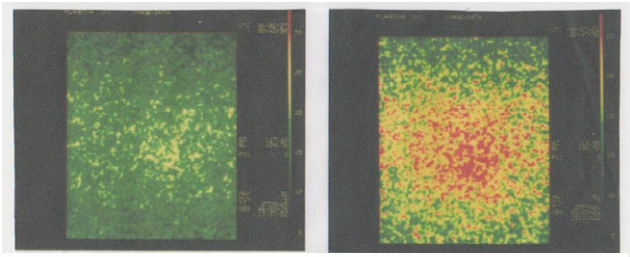
○Results of Sakigake and Suisei

The satellite chief reported "'Sakigake' passed just the opposite side of the sun from the earth in about 3 years later from launching, after it passed Halley's comet at most approach distance 7 million km on schedule. A study about the influence that is given by the Halley's comet to solar wind and about the solar wind itself brought great results, contributing further study about characteristic of sun plasma of the sun neighborhood from a characteristic of an electromagnetic wave in so-called solar-occultation. In addition, many fundamental experiments about deep space exploration were succeeded engineeringly." In any event, it was a great confidence for us that "Sakigake" became the first man-made planet, it approached to Halley's comet as a test explorer, and it continued to send observation data over ultra long distance from about 2 AU (1AU =150 million km).



Orbit of Sakigake and Suisei.

"Suisei" was in the observation state from the middle of September 1985. A solar wind observation device began observation in the end of September, and the ultra-violet imaging device started taking ultra-violet images of Halley's comet successively from the middle of November. Then it passed a point of about 150,000 km sun side of Halley's comet at 22:06 JST on March 8, 1986. "Suisei" was out of a reception range of Usuda station at 13:16 JST on March 8, and observation with UVI was conducted by using program control from 13:34 JST. In addition, one with ESP was conducted until 6:10 JST on March 9 from 21:31 JST on March 8, 1986.


Hydrogen Coma Image of Halley's Comet by UVI,
Right: Light phase image taken on March 1, 1986.
Left: Dark phase image taken on February 27, 1986.

According to observation data, the purple outside Lyman alpha light imaging device caught an image of Halley's comet for the first time on November 14. It clarified that there was repetition of the light and shade in Lyman alpha image. The rotation period of the Halley's comet nucleus, which there were various opinions so far, is found to be 2.2±0.1days by observing a phenomenon with this light and shade systematically. These results were collated and contributed to Nature magazine. Sun observation device acquired very valuable data about interaction of Halley's comet and solar wind on the occasion of closest to Halley's comet during period of March 8 to 9. In this way, the Halley's comet mission progressed successfully by an effort and cooperation of many people, and got many valuable observation results. But we met with a scene to feel nervous about in the integration test and operation before reaching such results. I will try to pick up some impressive matters among them.

○Hard Integration Test at Sagamihara Test Facilities

The integration test of "Sakigake" was performed at the environment test facilities built in the new campus of Sagamihara as a result of reorganization. It was a hard work for us that the newly built clean room had unstable condition in temperature, humidity and cleanliness. In addition, traffic between Komaba and Sagamihara was not convenient in those days, and we had hard days to commute on duty from Komaba to Sagamihara campus for the test.

○Risky Malfunction of De-spun Motor of Antenna

It was an event in the integration test that entered the finish for August launching of PLANET-A ("Suisei"). The final check before transportation to launch site was finished without any problem on July 1, but malfunction that motor did not work at all occurred on July 2 when we were going to work the de-spun motor with the load setting same as battery characteristic test. This de-spun motor is used for the ultra long distance communication

to earth and for imaging Halley's comet. If it does not work, the mission could not be performed. So the persons concerned were hard to discover its cause. The check was performed repeatedly until July 11 by by changing 1 revolution of 360 degrees little by little. As a result, the cause was found that initial start torque was not generated in the very narrow area between antenna and satellite by the circuit which processed a tacho pulse and a position pulse to detect relative velocity and position between antenna and satellite, respectively. I think that the cause was discovered miraculously thanks to Mr. K's passion of Company N concerning its study. As a result of examination, it was concluded that there was no problem for operation and launching was executed. The whole mission worked without any problem at all. I was scared to happenings when I thought that it was late for launch due to the malfunction that unexplained cause took time for restoration.

Snapshot of Integration Test for Installing Antenna to Explorer.

O Acquisition of Observation Data at Closest Approach that cannot be Failed

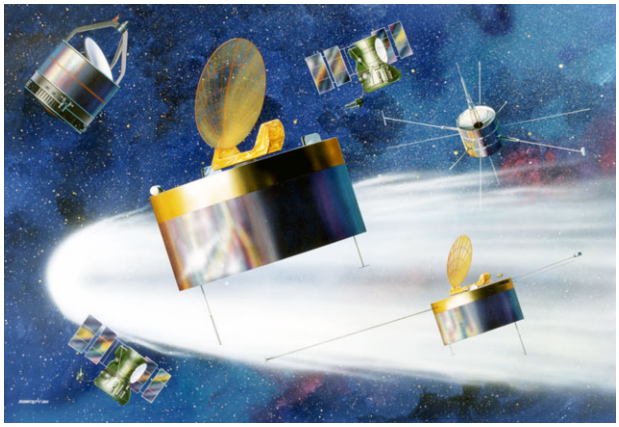
Each country competed to transfer an explorer to Halley's comet that approached the sun after 76 years and acquired observation data by various methods. "Suisei" embarked two observation devices, and acquired data at the time of the most approach, too. We must wait for 76 years if we failed it. Mr. K of Company N in charge of the system of "Suisei" told his memory of those days, "The most nervous matter in the operation of 'Suisei' was making an operation command program of ESP at the time of the comet most approach, neither launching nor orbit adjustment. We must record observation control data of ESP and the data acquired from information of direction of Halley's comet at the most approach and time to a data recorder. We painted operation images of ESP and data recorder and simulated it many times. We worked in the best strain state to be unable to make mistake absolutely, when I thought that result prepared for many years depended on this moment. When observation data on schedule were provided, I relieved honestly."

O World Smallest Deep Space Operation Control Room and Story of Popular Professor

Operation of "Suisei" was performed at the control room built in the clean room of the Komaba campus where was used for test of satellite so far. Prof. N in charge of orbit of explorer had often come to this control room, and he conducted orbit operation. The professor was famous as a heavy smoker, and number of cigarettes increased more and more, because he concerned for orbit determination in the first deep space mission of "Sakigake" and "Suisei". Miss N of Company F in charge of orbit determination told an episode, "I often accompanied the professor with an ashtray." In addition, I remember that Prof. U in charge of operation visited this control room with VIP from foreign country, and he explained this room as the world smallest deep space control one. In any events, I think that this small control room could operate two explorers by small people well.

O International Cooperation

There was new progress at the international cooperation in this mission. Space research organizations gathered, and formed IACG (Inter-Agency Consultative Group). The orbit of Halley's comet passed ecliptic plane (descending node) on March 10, 1986. Around this date, six explorers including "Sakigake", "Suisei", GIOTTO of Europa, VEGA-1 and VEGA-2 of the Soviet Union, and ICE of the U.S.A. approached Halley's comet, and conducted various observation. These observation results were reported to each country through an international consultative organization (IACG) and contributed to result of a joint study. I still remember impressively in particular the scene



Halley Fleet (Explorer of Each Country Approached to Halley's comet for Various Observation)

continued sending image data, while GIOTTO and VEGA plunged into a nucleus of Halley's comet under cooperation of each country.

○ Conclusions

The PLANET-A program had the hard one which must have performed four development items at the same time. People of a journalist said, "The development items are all too many to succeed." Although there were many barriers, it was a wonderful project that exceeded splendidly over them when it finished.

According to the study report on Halley's comet of ISAS, "The Halley's Comet explorer of our country was able to achieve remarkable result in spite of a small one. This was the result of combining excellent outlook and effort for achievement by researchers on space science (science and engineering) who gathered to ISAS as the core, effort by technology groups of the excellent companies in our country that supported this program, and people concerned who supported such a big program both financially and administratively, in particular support by administrative people of both Ministry of Education and ISAS."

(Photographs courtesy of ISAS, JAXA)

(Translated into English by Takashi Iida, Editorial Advisor)