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Status of Nanosatellite Development for Mothership Daughtership Space Experiment by Japanese Universities

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Abstract

We have begun the feasibility study to build a small satellite in the 3kg mass range and in the power range less than 30W since October in 1998, sponsored by National Space Development Agency of Japan (NASDA). This satellite installs three reaction wheels for an attitude control and camera which will demonstrate optical navigation experiment by using image processing. The BBM design status is described in this paper. The components such as a small reaction wheel, electric flash and onboard computer were built. Mothership - daughtership technology and formation flying experiments are planned. New electric propulsion is being developed for small satellite.

1. Introduction

Recently, small satellites of between 50 to 100kg mass range have been developed and planned for launch by several universities. International projects for smaller satellites organized by graduate students are also begun recently. Potential users for smaller and drastically less cost satellites become to increase in the world. We began to study the feasibility to build a small satellite (so called nanosatellite) in the 3kg mass range and in the power range less than 30W and design the space experiment since October in 1998, sponsored by National Space Development Agency of Japan (NASDA). This scale of the satellite is a challenging target for the nanosatellite development. We propose the space experiment using the nanosatellite with an onboard camera to develop several actuators as key technologies and to demonstrate them in space. The experimental module comprises three nanosatellites as daughterships and a control unit of the space experiment as a mothership. In this study, we plan to establish the following technologies:
(1) small reaction wheels,
(2) actuators and software for a three axis attitude control system,
(3) small electric propulsion,
(4) rendezvous docking mechanism for the nanosatellite,
(5) optical navigation experiment in the night,
(6) recharging device.
For future mission design and for future satellite architecture as a prior demonstration in space, we propose the following experiments:
(7) maneuver technology whose attitude information is obtained by video images of the onboard camera,

(8) demonstration of the formation flying between the mothership and the daughtership,
(9) mothership - daughtership technology experiment.

2. Design of nanosatellite

Design philosophy

At first the philosophy for development of the nanosatellite is mentioned. The nanosatellite is not a miniature of large satellite but it is one of new technology which can provide low cost and order made technical service. So, we decided to have two way of thinking. First one is to equip necessary minimum functions. So we have selected important items which must be developed as soon as possible. Second one is to install commercial off the shelf device to provide fast and cheap service, which will not only increase the number of researcher engaging with the space technology but also enlighten children, students and supporters.

The daughtership is designed to be about 30cm in length and diameter. Fig. 1 and Fig.2 show the BBM of the nanosatellite. The nanosatellite consists of onboard computer, reaction wheels, CCD camera, wireless modem, electric flash, gyro sensors, acceleration sensors, thrusters and gas tank.

Figure 3 represents the block diagram of the electric circuit of the daughtership. Conventionally large satellite, is popular a central concentration design which a single CPU controls every subsystem and all signals are concentrated to the CPU. In this satellite, fundamentally, each subsystem is designed to have a modular structure with an individual function. This method makes an interface connecting with other subsystems be easy. It is done with the serial communication for the information exchange with the main controller (CPU) and each module. The serial communication method was adopted in this satellite CPU of Hitachi H8, including the function of the multi-processor communication method that can control several H8s at a time.

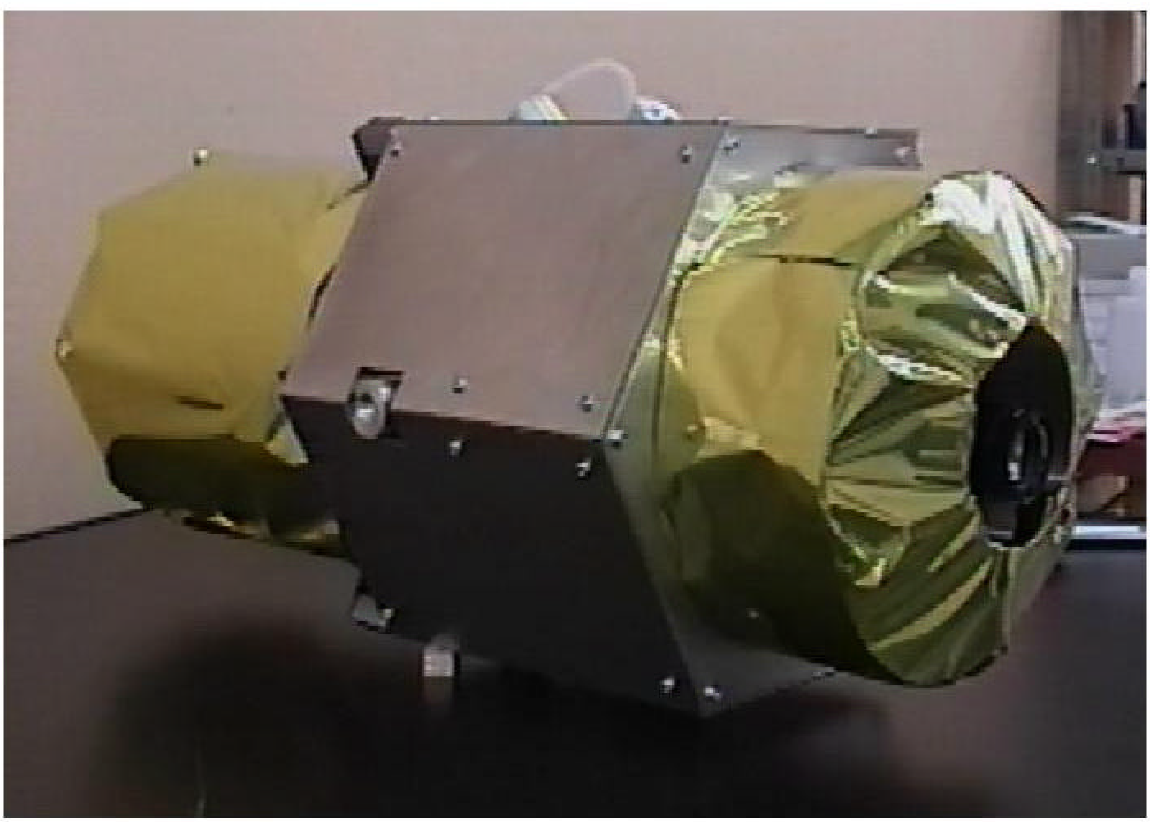

Fig.1 Breadboard model of nanosatellite (1)

Fig.2 Breadboard model of nanosatellite (2)

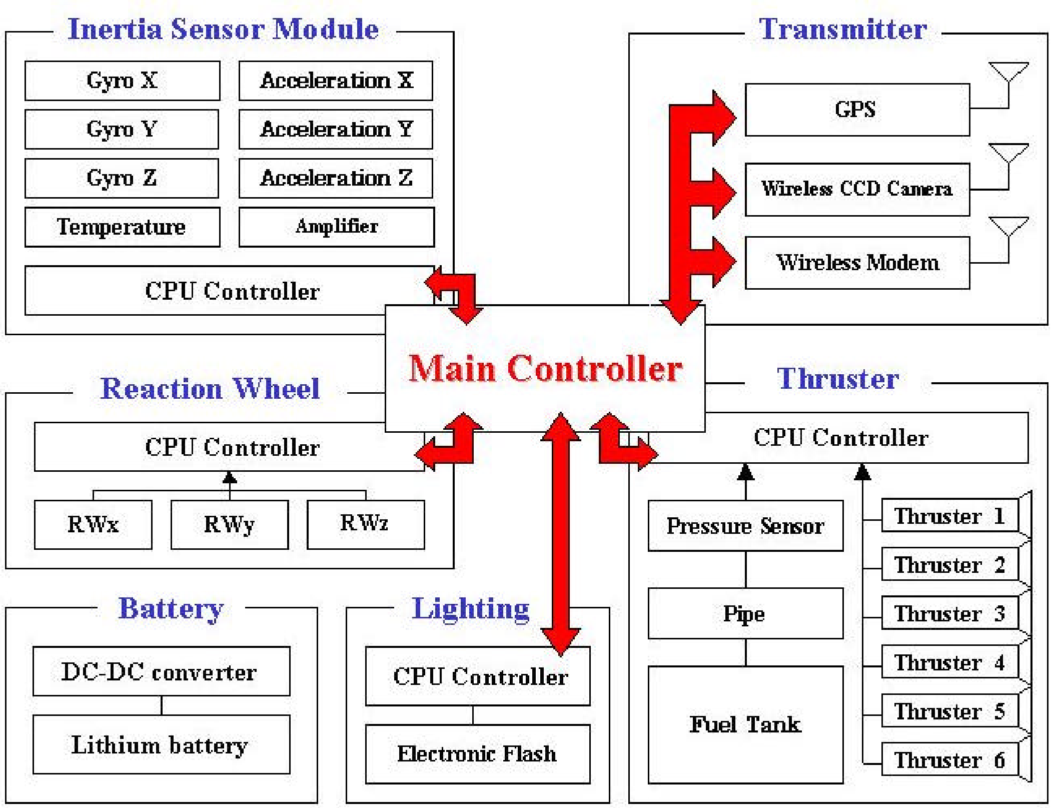

Fig.3 Block diagram of electric circuit of daughtership

Onboard computer

H8/3048 manufactured by Hitachi is used for the onboard computer of the daughtership.

This CPU has a clock frequency of16MHz, A-D / D-A ports of 8ch, timer ITU of 5ch and serial ports of 2ch. The device is selected because of the tolerance in the space radiation environment. The radiation test was conducted at NASDA using Californium as a radiation source. The cross-section of SEL is roughly estimated at 9E-3 cm2, resulting in one SEL accident per 46 months in low earth orbit. The onboard computer consists of master CPU and slave CPU, and two CPUs watch their condition each other by means of a watch dog function of H8.

Wireless camera

Since the daughtership moves around within neighborhood 200 m of the mothership, the maximum image transfer distance of 200 meters is estimated. PRO-5 manufactured by RF-SYSTEM company was selected. Unnecessary components (built-in battery, microphone, cover) are removed. The electrolytic condenser which is poor at the vacuum condition, is substituted for tantalum condenser.

Wireless modem

Making a range for the maximum transmission of 200m in the same way as the previous wireless camera, YSM-321 manufactured by Yaesu Musen was selected. A communication form is RS232C.

Gas jet thruster

Six gas jet thrusters are installed on the daughtership. It operates two thrusters at the same time when it moves to the front and back directions, and it operates one thruster and it moves the right and left directions.

Electrical flash

The electrical flash is deal with as the mission device boarded on the daughtership. The following specifications and the function are required by the electric flash:

(1) usable range of from 0.3 to 50 meters,
(2) luminous timing control by the onboard computer,
(3) electric control that the fixed amount of light may be irradiated at any distance (automatic irradiation control),
(4) interval of two seconds or long (interval being variable dependent on the mission requirement),
(5) synchronism with the video signal can be taken when the video image is captured by the CCD camera.

The laboratory model of the electric flash circuit was built in 1999 and the vacuum environmental test was also conducted.

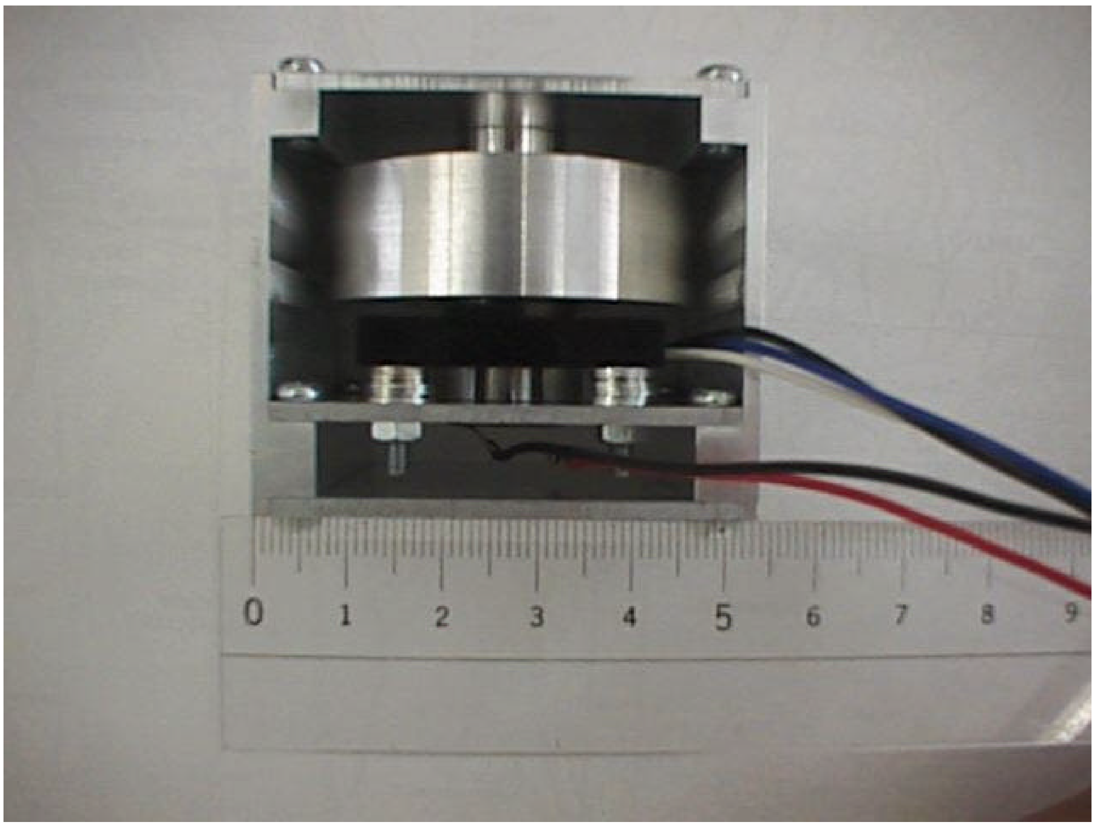

Fig.4 Small reaction wheel developed by HIT

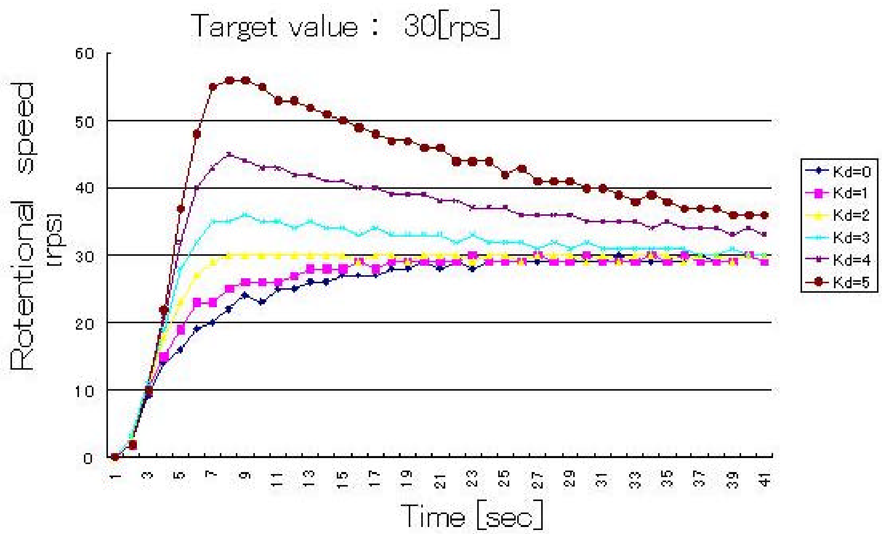

Fig.5 PD control of small reaction wheel

Small reaction wheel

The reaction wheel is used as an actuator for the attitude control and is one of important key technologies of this nanosatellite. Hokkaido Institute of Technology (HIT) has been developed the small reaction wheel which is about 150 grams in weight and 0.015 Nms in maximum storable angular momentum. The motor which can be used in vacuum is 30 grams in weight and has a torque of 28gcm/2W. The wheel mass balance is adjusted precisely and the vibrational level is restricted as low as possible.

The control logic of the reaction wheel is conducted by combining both the classical PD control and PWM(Pulse Width Modulation). The control signal of PWM is sent to the motor drive IC from the CPU installed in the reaction wheel module. The gain parameters are selected so as to realize the critical damping condition. Fig.5 shows an example of the PD control of the rotation.

The endurance test of the prototype reaction wheel has started under the vacuum environment since January in 2000. In the endurance test, the reaction wheel is installed in vacuum chamber evacuated at 1.0E-6 Torr by an oil diffusion pump and applied a constant bias voltage of 12 volt. The rotation of the reaction wheel is kept between 8300 and 8400 r.p.m. The rotation number and the temperature of motor and bearing are monitored during the endurance test, and these data were automatically stored by the personal computer. The endurance test had been conducted for about 2000 hours at 25th May in 2000 since the beginning of January in 2000 without any troubles, and it will be reached over 3000 hours by August.

Fig.6 Endurance test of reaction wheel in vacuum chamber

Table 1 Power and weight breakdowns

Component	Weight [g]	Power [W]
CPU	70	0.27
Wireless CCD camera	170	1.55
Wireless Modem	150	0.85
Cold gas jet +controller	150	2.00
RW + controller	450	2.00
Sensors	100	0.62
Electrical flash	200	0.60
Battery	420	0
Power supply circuit	50	1.62
Gas tank	1100	0
Structure	600	0
Total	3460	9.51

Battery and power supply circuit

The capacity of the battery is estimated assuming a mission time to be ten revolutions on the sun synchronous orbit with the altitude of 1000 km, whose revolution time is estimated at 105 minutes. The energy to be stored is 8.11[W] x17.5 [hour]=142[Wh]. The weight of the battery becomes 142/383=370g when a lithium ion battery (383Wh/kg) manufactured by Yardney is assumed. We must take conversion efficiency into consideration to depend on the drive voltage of devises owing to use a DC-DC converter. The weight of the battery including some margins is estimated at 420g. The device voltage is decided with 5V and 12V, and tip type DC-DC converters are installed as power supply circuits. The conversion efficiency of the DC-DC converters is assumed at 80% to estimate the total consumption power. Table 1 shows the power and weight breakdowns of the nanosatellite.

Docking mechanism

The docking mechanism is under development. As a preliminary experiment, the demonstration of the ejection of the nanosatellite from the mothership was conducted under the microgravity environment in 1999 at Japan Microgravity Center (JAMIC).

New electric propulsion for small satellite application

Hokkaido Institute of Technology has developed a new electrostatic thruster which can be operated very efficiently at low power. The thrust generation mechanism is unique and deferent from the conventional electrostatic propulsions such as ion thruster (DC /Microwave), hall thruster and FEEP. The operation characteristics of this new thruster resembles that of the hall thruster. The main plasma is generated by 1.5 GHz microwave discharge whose frequency is same as that of commercial portable telephones.

Historically speaking, high power electric propulsion such as MPD and large ion engine has been investigated and developed aiming to utilize as main engines for future interplanetary missions. In spite of long development history of electric propulsion, low power electric propulsion have become rather a new technology except for micro PPT and FEEP. If we target a small satellite of about 100 kg in mass range, its electric power being restricted within 50 watts or less, conventional MPD and DC arcjet can be never operated. Ion thruster and SPT can be barely operated but their thrust efficiencies drastically decrease less than a few percents in accordance with power reduction, practical use in space being desperate. These low efficiencies at low power operation attribute to the difficulty of stable plasma generation. However, the microwave discharge plasma is stable at low power. In case of conventional ion thruster such as Kaufmann type, primary electron confinement becomes worse as its size being smaller, resulting in low thrust efficiency. The ion thruster is rather a complicated system even if the plasma is produced effectively by the microwave discharge, so that authors have developed a new electrostatic thruster as represented in Fig.7. The following characteristics of this new thruster are there. This thruster comprises an ion acceleration chamber and electron emission heater as neutralizer, requiring only three power supplies. Propellant gas is xenon. The plasma is generated using microwave discharge enhanced by electron cyclotron resonance (ECR). The generated electrons are confined by magnets which form a ring cusp magnetic field and realize ECR condition. Applying acceleration voltage between the upstream electrode and the neutralizer, an electrostatic field gradient is formed in the plasma, accelerating ions to generate thrust.

The plasma is generated by 5W microwave input at maximum and the power for the thrust generation is several watts dependent on throttling range, the neutralizer power being approximately 2 watts, respectively. The total power required for the thruster system is about 25 watts at maximum. The power distribution and thruster performance are described as follows. The ion production cost of this thruster is 150 volt and propellant utilization efficiency is 90 %. The thrust level ranges between 200 to 500 micro newtons, and the specific impulse between 600 to 1300 seconds. The thrust efficiency is estimated at 10 - 15 %. Figure 8 represents the photograph of the new electrostatic thruster operation.

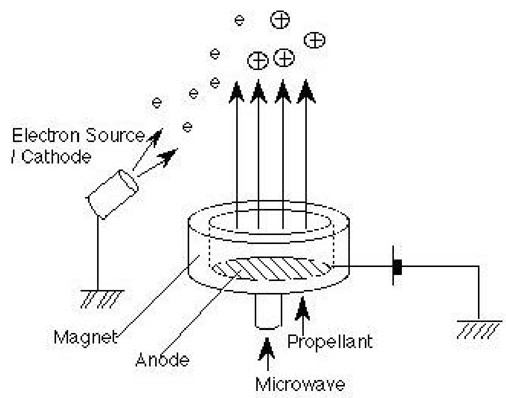

Fig.7 Concept of new electrostatic thruster for small satellite application

Fig.8 Operation of new electrostatic thruster

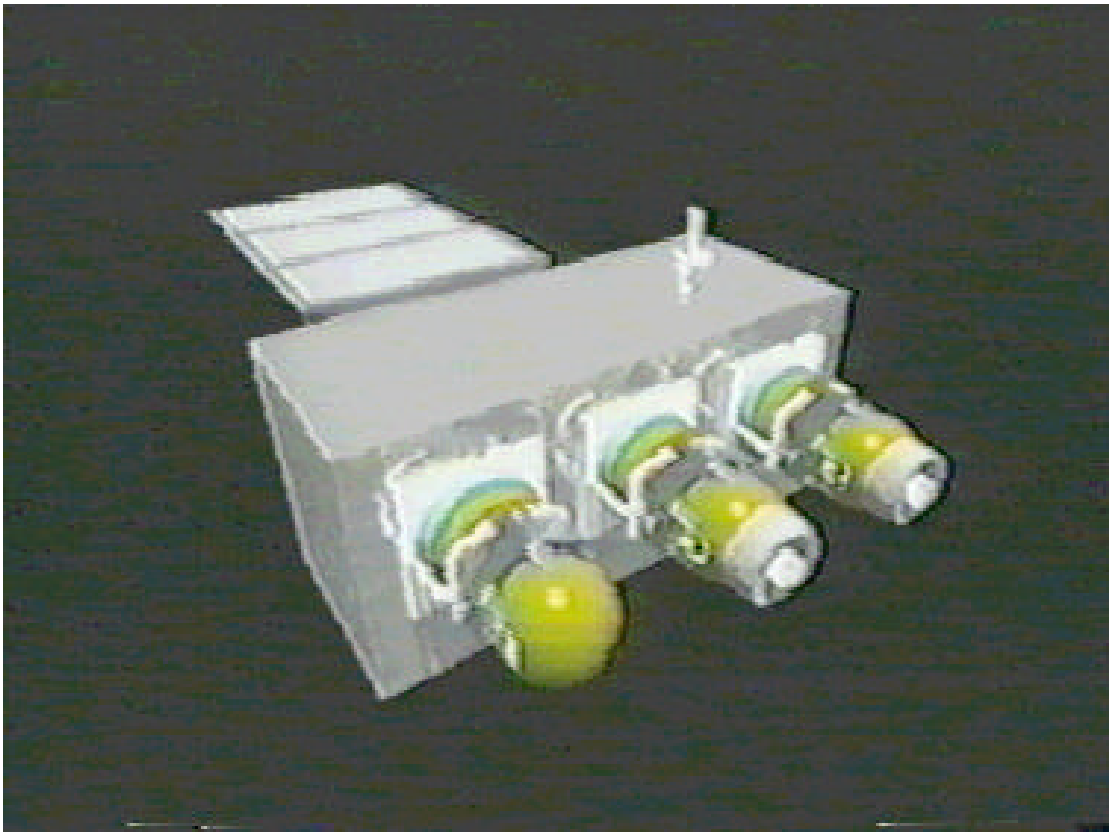

Fig.9 Space experiment

3. Space experiment

The space experiment of proposing this research is composed by the MDS loading experiment module which is named Mothership and three nanosatellites (It is named Daughtership). Mothership has three docking mechanisms. Three Daughterships come and go through each docking port. The operation of the Daughtership is done fundamentally by the command transmission from the Mothership. The space experiment is schematically depicted in Fig.9.

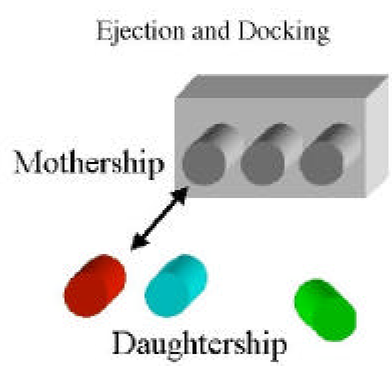

Fig.10 Mothership daughtership experiment

Mothership-Daughtership experiment (Fig.10)
(1) A network function experiment between several satellites.
(2) The rewriting the program of daughtership's CPU via mothership computer.

Formation flying experiment
(1) The formation flight of daughterships controlled by the mothership computer.
(2) The formation flight of daughterships controlled by the daughterships' computer.

Camera satellite experiment (Fig.11)
(1) Demonstration of optical navigation by image procession of onboard camera.
(2) Rendezvous docking experiment guided by mothership.
(3) Autonomous rendezvous docking experiment of daughtership.
(4) Experiment of power recharging.

(5) Three axis attitude stabilization using image processing.
(6) Electronic flash irradiation experiment in night.
(7) Experiment of orbital and attitude control using image processing in night.

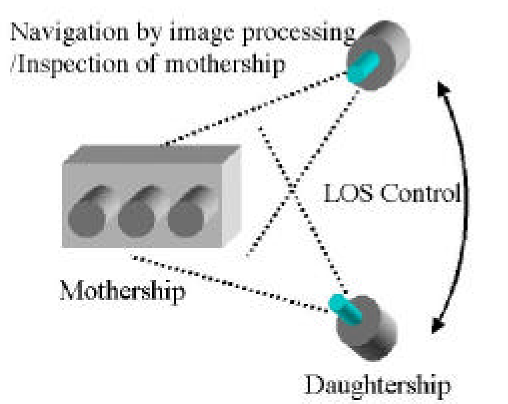

Fig.11 Camera satellite experiment

4. Application of nanosatellite

As a development type of the nanosatellite, the satellite of the new form that it should be as it were called with the "network satellite" should be made possible. The function of the usual large satellite, it disperses in some blocks, the function which is equal to the large satellite is realized by employing more than one nanosatellite from the viewpoint of network. For example, it decentralizes various functions such as communication and mission devises, and each is functioned as a satellite which is independent. A function to add newly to operate each as a separate satellite comes out, too. But, supposing that they are taken into consideration, it considers that the new advantage of the risk dispersion and the future function expansion is bigger. Using this network satellite, only the module which a necessary function is kept in is shot up, and a mutual circuit connection is only changed at the time of the operation of the satellite. The same idea as this is thought in the plan of the "virtual spacecraft bus" of the center of the NASA Goddard space center as well. To extend the space use really, it is necessary to make the tight data link which connects a satellite with the ground station at the same time with the miniaturization and lower price of the satellite. The band of the amateur radio is used as a communication circuit, and the form that each ground office is connected on the internet begins to be made recently in universities in America. The ground stations were also built in University of Tokyo, Tokyo Institute of technology and Kyushu university in Japan.

If the portable telephone which a stationary satellite is used for in near future is realized, it will be possible to use a telephone circuit as a communication circuit which connects between the satellite and the ground. The problem, related

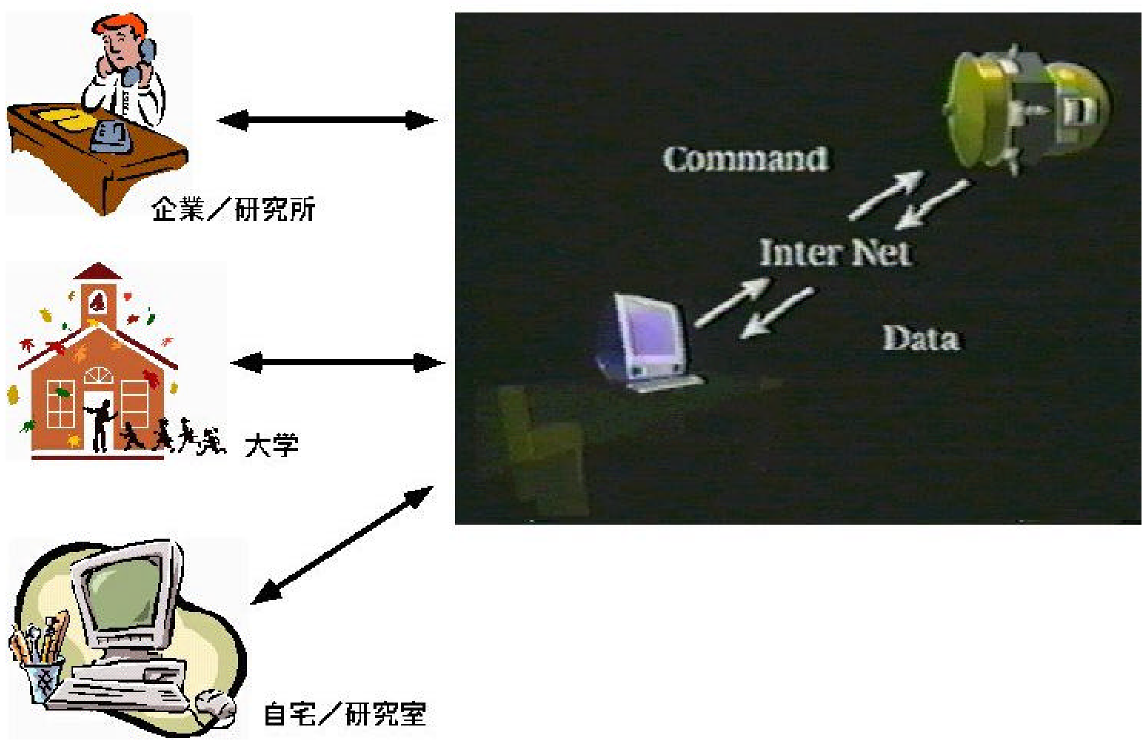

Fig.12 Concept of micro space laboratory for every researcher

to security, of course, will come out. The telephone service by the satellite can realize the new research environment and the control system of the nanosatellite where one can operate by using a personal computer from the laboratory or home (Fig.12). Such a new research environment (in other words, it is a convenient "micro space laboratory”) is supposed to stimulate much creativity of students with many researchers. It will begin to create the new industry seeds that a venture enterprise is promoted from the research. It can be expected to spread the potentiality of the development of the space technology greatly.

5. Conclusion

The feasibility study of the nanosatellite and space experiment has started as a collaboration of three universities, a venture company and NASDA. The breadboard model of the nanosatellite was designed in 1999 and BBM is now under construction. The laboratory model of the small reaction was developed and its endurance test has been continued over 2000 hours in the vacuum chamber. Three space experiments (mothership - daughtership experiment, formation flying experiment and camera satellite experiment) were proposed.

Acknowledgment
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