DEVELOPMENT OF CHUBUSAT-1 SMALL SATELLITE

Yasutaka NARUSAWA[1)], Hiroyasu TAJIMA[1)], Masanobu MIZOGUCHI[2)],
Isao MATSUBARA[3)], Hirotaka KOSAKA[4)]

[1)] *Nagoya University, Japan*
[2)] *Daido University, Japan*
[3)] *HIKARI Manufacture Co., Ltd., Japan*
[4)] *KOSAKA Co., Ltd., Japan*
yasutaka_narusawa@mhi.co.jp

ChubuSat-1 is a 50-kg class small satellite jointly developed by a consortium of universities and aerospace companies in the Chubu region of central Japan which is the core region of Japan's aerospace industries. ChubuSat-1 is developed to expand the satellite business by significantly reducing the cost of space utilizations and applications, and also to demonstrate the advanced technology level of the small aerospace businesses in this region. We named the satellite "ChubuSat-1" with a nickname of "Kin-Shachi 1st" to promote the Chubu region as the center of Japan's aerospace industries. ("Kin-Shachi" means golden grampus which is the roof monument of Nagoya Castle, the symbol of Chubu region.)

ChubuSat-1 has an optical camera and an infrared camera to observe the earth surface. Resolution of the optical camera is approximately 10 m. The infrared camera is sensitive in the wavelength from 7.5 to 13.5 microns and enables observation of the ground temperature profile. We also plan to observe space debris using the infrared camera. When a major disaster occurs, ChubuSat-1 may provide pictures and temperature profiles of inaccessible regions to help figure out what is happening in those regions. ChubuSat-1 will also provide the worldwide message relay service using the onboard transceiver of amateur radio band.

In this paper, we describe the present assembly status of ChubuSat-1 flight hardware, and tests and preparation of the launch site operation and on-orbit operation.

Key Words: ChubuSat-1, Satellite, Collaboration

1. Introduction

In this decade, the space industries market of Japan stays about two thirds of the peak time, and most of that depends on the domestic demand. Japan's budget of space is less than 10% of United States or half of Europe.

However, Japan domestic market concerning space directly or indirectly is more than 20 times of space industries market. Future space market will be led by such space use market, especially satellite user market such as communication, broadcasting, weather forecasting, agriculture and forestry. Actually, satellite using service business is rapidly growing up in this several years, and this increases the market of space industries. Requirement to space industries for these increasing demands is cost reduction. Cost reduction of space industries will lower the threshold of entering the space use business.

One of the solutions of satellite cost reduction is the satellite miniaturization. The miniaturization not only reduces manufacturing cost. It will be possible to inject many small satellites with equivalent cost of one large satellite development and launch. Thus, small satellite can explores quite new space use fields which cannot be done by single large satellite. Moreover, the shift of satellite manufacturing from order made of large satellite to mass production of small satellites may revolute the business model of space industries.

Chubu region of Japan, as the core region of Japan's aerospace industries has participated with aircraft, rocket and space station program. To establish new space industries in Chubu region where many aerospace companies have advanced manufacturing techniques, universities and aerospace companies in Chubu region organized the consortium for the development of small satellite in 2011. The project and satellite is named "ChubuSat-1" meaning satellite from Chubu region and nickname "Kin-Shachi". (Kin-Shachi means golden grampus which is the roof monument of Nagoya Castle, the symbol of Chubu region, suitable name of this project.)

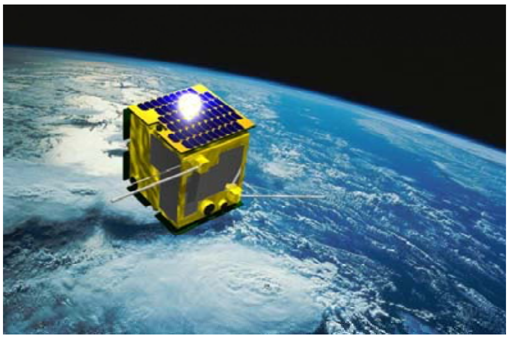


Fig. 1. On-orbit image of ChubuSat-1

ChubuSat-1 has standardized design in anticipation of future low-cost mass production. Furthermore, it is expected that ChubuSat-1 increases the study field of universities through the space use and revitalizes the many companies in Chubu region.

This paper describes the outline of ChubuSat-1 satellite with design features and development status.

2. Development Team of ChubuSat-1

Nagoya University, Daido University, and MASTT (Meiyu Aerospace Support Technology Team) that is a union of aerospace companies in Chubu region of Japan organized the ChubuSat-1 project team. Prof. Tajima of Nagoya University is a project manager. Prof. Mizoguchi of Daido University is a project sub-manager. In this project, Nagoya Univ. and Daido Univ. take charge of ChubuSat-1 satellite system design, procurement of satellite components, satellite assembly, system testing and evaluation. Nagoya Univ. also takes charge of construction of ground station systems and processing and evaluation of observed images. MASTT takes charge of manufacturing most of satellite mechanical or electrical parts except for purchased components.

3. Outline of ChubuSat-1 Satellite

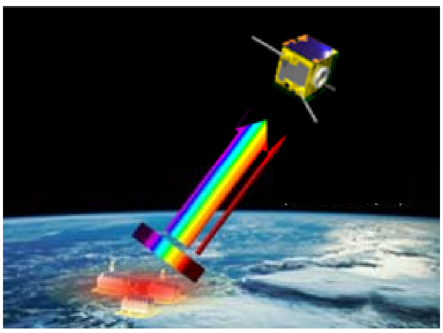
3.1. Mission of ChubuSat-1

ChubuSat-1 has three missions. (See Fig. 2.)

(1) Earth remote sensing;
Two pictures taken by optical camera and infrared camera gives us both information of optical image and temperature distribution of the target. This information contributes to understanding global warming and monitoring disasters around the world.

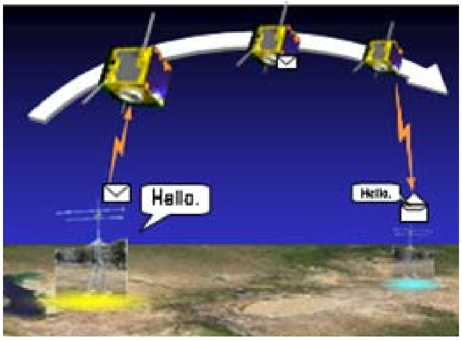
(2) Observation of space debris;
ChubuSat-1 tries to observe the space debris with infrared camera. If this trial succeeds, ChubuSat-1 will be a pioneer of on-orbit observation of space debris with a small satellite and contribute to constructing Japan's original database of space debris.

(3) Relaying of amateur communication;
Using on-board amateur radio transceiver, ChubuSat-1 provides the message transfer service to worldwide amateur radio users. Moreover, ChubuSat-1 distributes some image data of on-board optical camera to them. We expect that these services will contribute to expanding the field of amateur radio use.



(1) Earth remote sensing

(2) Observation of space debris



(3) Relaying of amateur communication

Fig. 2. Mission image of ChubuSat-1

Table 1 lists the specification of ChubuSat-1 optical camera and infrared camera.

Table 1. Specification of ChubuSat-1 optical/infrared camera

Optical Camera	
Imaging device	CMOS
Pixel number	2,048 x 1,536
Field of view	2.15deg. x 1.61deg.
Resolution of ground object	10m
Infrared Camera	
Imaging device	Uncooled bolometer
Pixel number	320 x 240
Field of view	4.6deg. x 3.7deg.
Resolution of ground object	130m

3.2. Outline of ChubuSat-1 Satellite System

Figure 3 shows the overview of ChubuSat-1 satellite. ChubuSat-1 satellite is a 50kg-class satellite with about 50cm x 50cm x 50cm size.

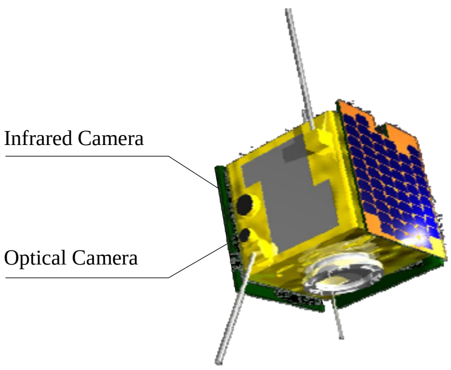


Fig. 3. Overview of ChubuSat-1 satellite

ChubuSat-1 is planned to be launched by Russian DNEPR rocket in December 2012 as one of four piggyback satellites and injected into sun-synchronous orbit of about 500km altitude. Designed life of ChubuSat-1 is 6 months.

Figure 4 shows the system block diagram of ChubuSat-1. Mission component is optical camera, infrared camera and amateur radio transceiver (used both as mission component and bus system component). An on-board computer (OBC) is the main computer of this satellite, and processes satellite sequence control, attitude control, and data handling of house-keeping data and mission data. Attitude control subsystem applies zero-momentum 3-axis control. All function concerning electrical power, current/voltage control, power distribution, battery charging/discharging, heater control are integrated into an power control unit (PCU). This integration achieved miniaturization of the satellite and low cost development of power control subsystem component. Three solar array panels and an Ni-MH secondary battery are equipped for power supply. Communication subsystem uses amateur radio frequencies. One of the frequency and command/reply format will be open to the public for amateur radio users to exchange messages or download disclosed images taken by ChubuSat-1. Propulsion subsystem is not equipped.

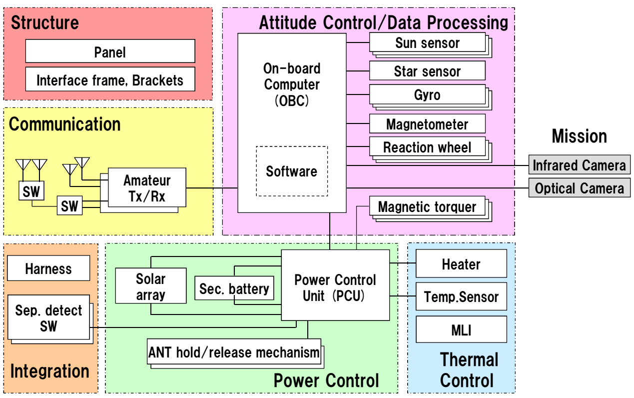


Fig. 4. System block diagram of ChubuSat-1 satellite

3.3. Data Processing Subsystem

ChubuSat-1 OBC consists of three type module, core module with CPU and memory, extended interface module which has interface to other components, and power control module. Core modules and extended interface modules are connected each other with SpaceWire interface. This enables future extension of OBC function by addition of core module or extended interface module. ChubuSat-1 OBC has two core module and three extended interface module. It should be noted that an SOI-SOC (Silicon On Insulator, System On Chip) chip is load on the core module, saves power consumption, endure high temperature and high radiation environment (See Fig. 5).

To changes of peripheral component, OBC can be modified easily by changing and modifying interface circuits and software. This gives us flexibility of adopting future satellite/component. Moreover, OBC is integrated component from attitude and orbital control unit (AOCU), data handling unit (DHU), data recorder (DR), and command decoder (CMD). This integration reduces testing cost, wire harness, and assembly workload.

OBC has following functions;

(1) Boot control: self-check, memory initialization, and watchdog timer clear.
(2) Operation control: on-board software control, external interface control, satellite time control
(3) Attitude control: calculate torque command to each actuator using attitude output from each sensor.
(4) Data processing: command decoding, telemetry gathering, editing and encoding, and communication between peripheral components.
(5) Mission component control.
(6) Prevention of overcurrent failure propagation: when overcurrent is detected, failure module is shut down so that overcurrent would not propagate to other module any more.
(7) Failure detection, isolation and reconfiguration (FDIR) function:
(8) Re-programmable: ChubuSat-1 OBC is re-programmable on orbit.

Table 3 shows the main specification of ChubuSat-1 OBC.

In the development of ChubuSat-1 OBC, engineering model (EM) was manufactured and tested for functional test and compatibility test between peripheral components. After EM, flight model (FM) has been manufactured (See Fig. 5), and already tested electrically between other flight components.

Table 3. Specification of ChubuSat-1 OBC

Processing speed	50MIPS
Data Bus Width	32bit
Memory storage (per 1 core module)	1MByte (EEPROM) 2MByte (SRAM) 64MByte (SDRAM) 512MByte (Flush ROM)
Radiation resistant	TID:>20krad SEL:>30MeV/mg/cm^2
Power consumption	<16W
Dimension	270mm x 205mm x 130mm
Mass	5.0kg

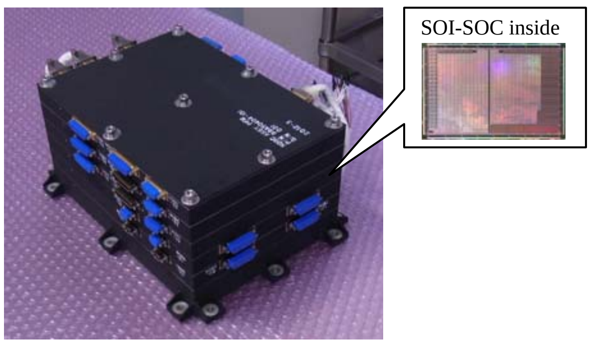


Fig. 5. On-board computer flight model

3.4. Attitude Control Subsystem

Base attitude control system of ChubuSat-1 is three-axis zero-momentum attitude control which consists of a star sensor as attitude sensor, three fiber optical sensors and three reaction wheels.

In case of initial phase after the separation from the rocket, or safe hold phase caused by some failure of satellite components, two-axis sun-pointing attitude control is used. This consists of three sun sensors (two of them are attached to the opposite direction each other and the rest is attached to orthogonal direction), three fiber optical sensors, and three reaction wheels.

In addition, a three-axis magnetometer, and three magnetic torquers are used for unloading of wheels and rate dumping of separation tumbling motion.

Following attitude control processing are implemented by OBC software;

(1) Rate control
(2) Sun-pointing 2-axis control
(3) 3-axis control to commanded quaternion
(4) Attitude maneuver path generation
(5) Wheel unloading
(6) Attitude FDIR

Table 4 shows the specification of ChubuSat-1 attitude control subsystem.

Table 4. Specification of ChubuSat-1 attitude control subsystem

3-axis pointing accuracy	<0.8deg.
2-axis sun pointing accuracy	<5deg.

ChubuSat-1 attitude control software has been tested by static closed loop test (SCLT) using an OBC BBM and dynamics simulator which is a personal computer and has satellite dynamics model, sensor/actuator mathematical model, and software simulating signal interface. (See Fig. 6.)

Fig. 6. SCLT of ChubuSat-1 attitude control software

3.5. Power Control Subsystem

ChubuSat-1 power control subsystem consists of a power control unit (PCU), a NiMH secondary battery, and three solar array panels.

As the center of the power control system, PCU has following function;

(1) Regulation of solar array power: regulated by partial shunt control.
(2) Secondary battery charging/discharging: switching constant current charge mode and trickle charge mode based on battery voltage.
(3) Battery temperature monitor: this function stops charging when cell temperature increases too high.
(4) Power-on and shut-down: power circuit is activated with two flight pins and two separation detect switches. When ONLY both switches are switched on, power supply will be started. On the other hand, in case of mission termination, solar array power lines are cut off by discrete command from ground station, and satellite will be power down when the rest power of battery are used up.
(5) Power distribution: generate +5V, +/-15V, and +/-12V power from +28V non-regulated bus voltage, and distribute these power to each components.
(6) Component power supply ON/OFF: switch by the command from OBC.
(7) Housekeeping telemetry output: reply power control status to the request from OBC.

Table 5 shows the specification of ChubuSat-1 power control subsystem.

Table 5. Specification of ChubuSat-1 power control subsystem

Power Control Unit (PCU)	
Primary bus voltage	23.1 - 36.0V
Max. handling power	85W
Secondary Battery	
Number of cell	21/string x 5strings
Capacity	1.9Ah/string x 5strings
Discharge voltage	23.1 – 29.4V @ 20% DOD
Charge/discharge cycle	>10,000 @20% DOD
Solar Array Panels	
Output	>100W
Number of cell	20/string x 3strings/panel x 3panels
Efficiency	29.1% @28deg.C

ChubuSat-1 PCU has been developed from EM which was tested for functional test and compatibility test between peripheral components. After EM testing, flight model has been manufactured and already tested electrically between other flight components. Battery has been developed based on consumer product cell from engineering model (EM) which was tested for electrical performance test and environment test (vibration test and thermal test). Flight model battery has been already manufactured and tested. Solar cell is the flight proven GaAs triple junction cell and has already been purchased.

3.6. Communication Subsystem

ChubuSat-1 communication subsystem uses amateur radio frequencies. Data rate is 1.2kbps (uplink) and 9.6kbps (downlink). Figure 7 shows the block diagram of ChubuSat-1 communication subsystem. Communication subsystem consists of two amateur radio transceivers (A-TRX), a transmitter switch, a transmitting antenna switch, two receiving antennas and two transmitting antennas.

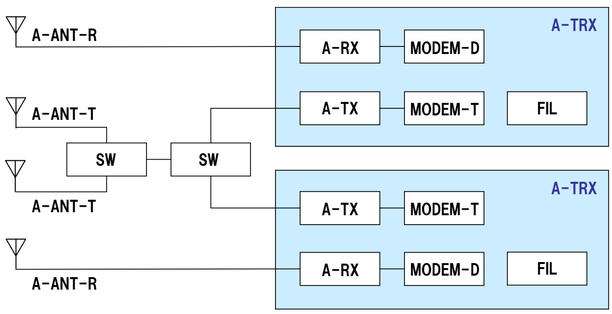


Fig. 7. Block diagram of ChubuSat-1 communication subsystem

Each A-TRX receiver has different role and different frequency of 145MHz band. One is used for satellite operation command with the closed format, and the other is used for amateur user command with disclosed format, or used for satellite operating command in case that the A-TRX receiver for satellite operation fails. In the failure case, the remaining A-TRX receiver will be set automatically to receive commands written in the satellite operation command format, and amateur users cannot send commands until the failed A-TRX receiver is recovered.

Both A-TRX transmitters are used for satellite operation and amateur users and have same frequency of 437MHz band. Downlink data formats of the amateur message and the optical camera image will be disclosed. In case that the primary transmitter is failed, the secondary transmitter will be switched automatically by OBC. Transmitting antenna can be switched by the command from the ground station to improve the receive status.

3.7. Structure and Mechanism

The main structure of ChubuSat-1 consists of sandwich panels of aluminum skin and aluminum honeycomb core which has light mass and high stiffness. The light panels whose total mass is less than 10kg meet both stiffness requirements from the rocket and mass requirement from the system design.

The rocket interface frame is attached to the bottom panel. Though the frame of ChubuSat-1 is manufactured for DNEPR rocket interface, it can be easily changed to other rocket interface by changing only interface frame.

The structure of ChubuSat-1 has been developed from the structural and thermal test model (STM) which was tested by modal survey and vibration test with qualification test level of DNEPR rocket (See Fig. 8). After STM testing, the structure for flight model has been manufactured.

ChubuSat-1 has receiving antenna hold and release mechanism (See Fig. 9). In the launch configuration, receiving antennas are folded and held by this mechanism with nylon cable. Nichrome wire is winded around the nylon cable and connected to PCU. After the satellite separation, PCU heats the Nichrome wire and then the nylon cable will be cut by heat and the folded antennas will be released and deploy by the spring torque. Nylon cable holding the antenna is multiplied to meet the range safety requirements.

3.8. Thermal control subsystem

The thermal control of ChubuSat-1 is based on passive control using multilayer insulation (MLI) and radiation film of silver Teflon. The worst hot condition the satellite will encounter during the mission life is set and thermal analysis is implemented for sizing the radiation surface. After that, the worst cold condition is set and thermal analysis is implemented for sizing heater power if necessary.

The development of ChubuSat-1 is from the STM thermal balance test acquiring the thermal design data (See Fig. 10). Based on the acquired data, flight model has been already designed and manufactured.

4. Design Feature of ChubuSat-1

4.1. Advanced On-board Computer

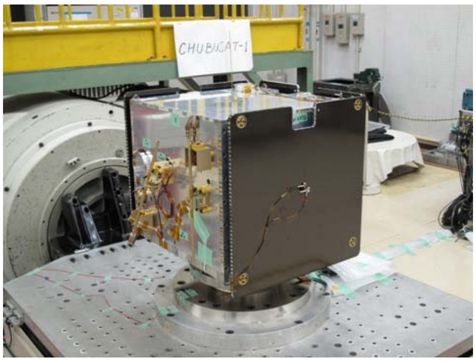


Fig. 8. STM vibration test of ChubuSat-1

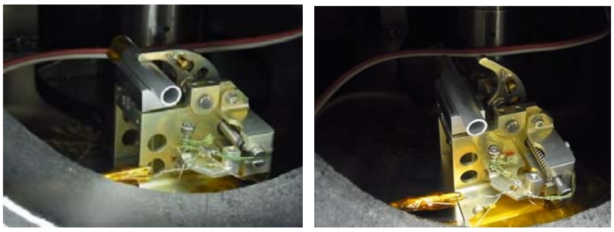


Fig. 9. Receiving antenna hold and release mechanism of ChubuSat-1

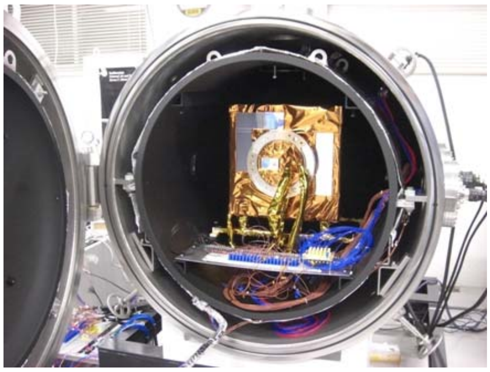


Fig. 10. STM thermal balance test of ChubuSat-1

The first design feature of ChubuSat-1 is the application of advanced on-board computer which is small size, light weight, low power consumption and highly radiation resistant. Moreover, this OBC is designed to be modular design per CPU function, interface function to peripheral components, and memory function so that the OBC will be applied generally for various mission requirements.

In the development of this OBC, following two technologies are developed based on the existing knowledge.

(1) Micro-miniaturization and super-light-weighting using the super-high-density device mounting and packing technology.

(2) Saving power consumption and improving radiation resistance applying the domestic top level Silicon on Insulator (SOI) technology used in consumer products.

4.2. Modular Design

The second feature of ChubuSat-1 is the standardized, modularized, general purpose and flexible satellite system architecture. ChubuSat-1 satellite system architecture constructs various satellite basic function such as signal communication function and power control function into functional module. Each functional module should be common hardware regardless of mission requirements. Utilizing modular design, flexible satellite system construction will be able for example, distribution of multiple core modules, or addition of memory module in accordance with each mission requirements. To specification changes caused by mission requirements the satellite system can be easily coordinated by changing the software and logic in FPGAs.

4.3. SpaceWire Interface

SpaceWire interface is applied to all ChubuSat-1 OBC modules so that all module interfaces are standardized. Peripheral components are all interfaced to SpaceWire through the extended interface module. Extended interface module connects between SpaceWire interface and each component's original interface. It is easy to integrate various components into SpaceWire network changing a part of FPGA logic of the extended interface module in accordance with each component's interface. This reduces development schedule dramatically. Thus, standardized module interface such as SpaceWire contributes to reduce development risks and inspection steps in the manufacturing flow.

5. Development Status of ChubuSat-1

Figure 11 shows the schedule of ChubuSat-1 development. From about 2008, Universities and MASTT independently started the study of small satellite system design or the development of satellite component and devices. In 2011, these universities, Nagoya Univ. and Daido Univ. and MASTT organized the consortium "ChubuSat-1 Project Team" for the development of small satellite from Chubu region. Development keywords are "expansion of the space use" and "revitalization of the industries in Chubu region". We aim at entering the small satellite market which is expected to expand in the future. After that, the development has been accelerated rapidly and the development of ChubuSat-1 will be completed for only two years after the project kick-off.

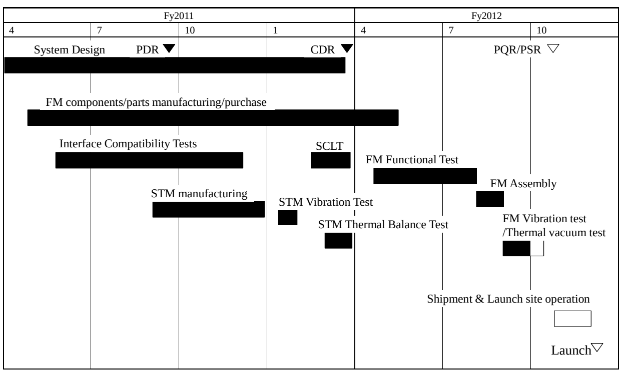


Fig. 11. Development schedule of ChubuSat-1

Launch vehicle of ChubuSat-1 has already been determined, DNEPR rocket in Dec. 2012. Targeting the launch, ChubuSat-1 flight model has been assembled and tested.

Flight model components and parts such as OBC and PCU have already been manufactured or purchased by this spring. Flight model functional test in which components are integrated electrically has been implemented from May to August 2012 (See Fig. 12). Assembly of the flight model satellite has been finished in September 2012 (See Fig. 13), and is submitted to environment tests, thermal vacuum test and vibration test. Shipment of ChubuSat-1 will be in the middle of October 2012.

Fig. 12. Flight model functional test of ChubuSat-1

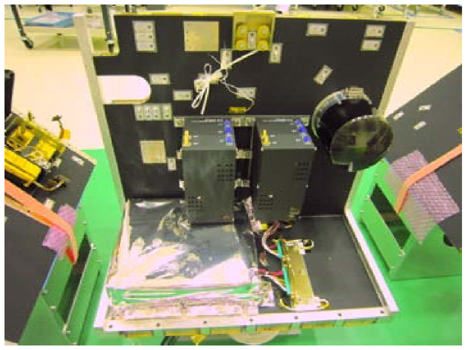


Fig. 13. Assembly of ChubuSat-1

The ground station of ChubuSat-1 will be completed in November 2012.

6. Conclusion

In this paper we have introduced the outline of ChubuSat-1 satellite with design features and development status. ChubuSat-1 is the small satellite which is designed so that we provide low cost satellite remaining high performance to the satellite users expected to increase in the future. It is characterized by application of small and light advanced on-board computer, modular design to respond quickly and easily to mission requirements from satellite users of various business fields, and application of SpaceWire interface which enable the modular design. We expect that ChubuSat-1, as one of the core product of aerospace industries in Chubu region of Japan encourages the study using satellites in universities and revitalize aerospace companies in Chubu region.