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IAF'85

36th CONGRESS OF THE
INTERNATIONAL ASTRONAUTICAL FEDERATION
STOCKHOLM, SWEDEN, OCTOBER 7–12, 1985

Peaceful Space and Global Problems of Mankind

PREPRINT A86-15647

IAF-85-66

System Design of Japan's First Interplanetary Flight Project

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This Preprint is for distribution at the Congress only

Published for the
International Astronautical Federation
by
Pergamon Press
Oxford · New York · Toronto · Sydney · Frankfurt

$3.00

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Journal of the International Academy of Astronautics

Editor: **J-P MAREC,** *3-5 rue Mario-Nikis, 75015 Paris, France*

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Published thirteen times per annum (Vol 13 & 14)

Annual subscription (1986)	US$650.00
Two-year rate (1986/87)	US$1235.00

Vol 13 will contain Selected Proceedings of 36th IAF Congress, Stockholm, October 1985 — Peaceful Space and Global Problems of Mankind

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Pergamon Press
Headington Hill Hall, Oxford OX3 0BW, UK
Fairview Park, Elmsford, New York 10523, USA

A86-15647

SYSTEM DESIGN OF JAPAN'S FIRST INTERPLANETARY FLIGHTPROJECT

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ABSTRACT

MS-T5 and PLANET-A are Japan's first and second interplanetary spacecraft. The main mission of MS-T5 is the verification of the launching capability of M-3SII rocket and the technology applied to the PLANET-A, as well as to the Japan's deep space communication network.

The test spacecraft MS-T5 was successfully launched from Kagoshima Space Center (KSC) on January 8, 1985, and it was renamed the SAKIGAKE. The second and main spacecraft to explore Halley's comet, PLANET-A, will be launched also from KSC on August, 1985, and will encounter with Halley's comet on March, 1986.

The design of SAKIGAKE is almost same as PLANET-A except that it has 3 booms for scientific instruments. Both spacecraft are cylindrical of 0.7m in height and 1.4m in diameter. The weight of SAKIGAKE and PLANET-A is 138kg and 140kg, respectively including 10kg of initial fuel weight.

These spacecraft systems are designed in compliance with the following major requirements.

1) Maximum weight should be 140kg and maximum diameter should be 1.4m.
2) Maximum distance between earth and spacecraft is 1.2AU.
3) Input variation of solar energy is 1-2.2 solar constant.

In this paper the design philosophy and characteristics of system are described. The current status of SAKIGAKE and the operation plan for PLANET-A are also described.

INTRODUCTION

PLANET-A, Japan's first interplanetary flight project which started in 1979 has come to the harvest time for the exploration of interplanetary space and Halley's comet.

The first spacecraft of this project, MS-T5 (SAKIGAKE) was launched successfully from Kagoshima Space Center (KSC) on 04:26 (JST) Jan. 8, 1985 into the orbit around the sun. As a result of twice orbit correction maneuvers, its closest approach distance to the comet is estimated at about 7 million kilometers, as of date.

SAKIGAKE participated in the joint observation project with the spacecraft ICE (NASA/USA) at the opportunity when two spacecraft approached to Venus successively during May to June for acquisition of numerous interesting data on the interaction between Venus and the interplanetary phenomena such as solar wind, magnetic field and so on.

The second and main spacecraft PLANET-A will be launched also from KSC mid-August this year, and it is anticipated that the closest approach distance of PLANET-A to the comet will be less than 200 thousand kilometers.

This report is a summary of system design characteristics and performance data of both spacecraft (s/c), as well as the current status of SAKIGAKE and the operation plan for PLANET-A.

SYSTEM DESCRIPTION

One of the major missions of the s/c PLANET-A is to take photographs of the comet with UVI (Ultraviolet Imaging camera). SAKIGAKE had been primarily developed to conduct some preliminary tests for the latter s/c PLANET-A, and to verify performance of newly developed M-3SII launch vehicle and Usuda Deep Space Center (UDSC). Both s/c are identical in design, except for the scientific instruments.

Fig.1 shows external views of SAKIGAKE and PLANET-A. Both are of spin-stabilized type, and each s/c has basically a cylindrical shape which is 1.4 meter in diameter and 0.7 meter in height with a high gain mechanically despin antenna attached to the upper end of the s/c. One of the features of the s/c is the provision of a momentum wheel for the preservation of s/c angular momentum, which is needed, in particular, when the spin slows down from 6 to 0.2 rpm prior to photographing the comet in order to prevent the image blur.

The attitude and orbit control is carried out by hydrazine RCS (Reaction Control System). The active thermal control system within a reasonable range against the solar radiation energy which varies widely from 1 to 2.2 times of solar constant.

A s/c system block diagram is illustrated in Fig.2 and Table 1 shows their performance parameters. For further details, see ref. 1).

The outline of scientific instruments 1),2),3) and 4),5) onboard SAKIGAKE and PLANET-A respectively are described as follows:

1) Interplanetary Magnetic Field experiment (IMF): IMF consists of three ring core type magnetometers deployed by a 2 meter boom from the s/c and measures three components of the interplanetary magnetic field. Since IMF has to measure the very weak magnetic field, the equipments onboard SAKIGAKE must be magnetically clean.

2) Plasma Wave Probe experiment (PWP) : PWP measures the electric and magnetic field components of the plasma wave by dipole antenna (10 m tip to tip) and by a loop antenna respectively.

3) Solar Wind experiment (SOW) : Retarding potential trap type analyzer is used to measure the plasma densities and bulk velocities of the solar wind.

4) Ultraviolet Imaging camera (UVI) : UVI comprises an optical system to collect the ultraviolet emission from the comet coma, CCD image detector, a CMOS-microprocessor and a hybrid-memory to store the images. Time delay and integration (TDI) method is applied to enchance the S/N ratio of images and to avoid smears due to the spinning of the s/c. The field of view of UVI is 2.5°x2.5° and effective pixels of CCD are 153x122. UVI requires very slow (0.2 rpm) and stable spinning of the s/c.

5) Energy Spectrum of Particles experiment(ESP) : ESP comprises two spherical electrostatic analyzers for ion and electron respectively, each provided with microchannel plate (MCP). Energy and angular distributions of the solar wind particles will be measured by utilizing the s/c spin.

MAJOR REQUIREMENTS FOR SYSTEM DESIGN

Throughout the implementation of the s/c, emphasis was laid on the compliance with three major requirements for system design.
They are :

1) Light weight and simple design
   Total weight should not exceed 140 kg which is imposed by the payload capability of M-3SII launch vehicle.

2) Deep space communication
   Earth-s/c distance is about 1.2 AU when the s/c encounters Halley's comet.

3) Thermal control
   Intensity of solar energy to which the s/c is subjected varies from 1 to 2.2 times of solar constant.

How to comply with these requirements is described in detail.

Light Weight Requirement

The requirement for the s/c weight to be less than 140 kg was just accomplished as seen in Table 1 through not only the strict weight management in each phase of the s/c implementation but also the weight reduction efforts in system design which are described as follows:

1) High gain antenna (HGA)
   HGA has an off-set parabolic reflector of which diameter is 80 cm. Its leaf-veins-shaped bone structure comprise aluminum core honeycomb with CFRP skins, and a very thin goldplated Ni-Cr net covers the surface as RF reflector. By this design, not only weight but also the effect of solar radiation pressure on HGA is extremely reduced. For further details, see ref. 2).

2) Structure
Thrust tube and struts which connect the tube and the platform are made of CFRP featuring light weight and mechanical rigidity.

3) Solar panel substrate
A monocoque-body molded cylindrical panel consists of aluminum core honeycomb with plain weave kevler fiber skins. Approximately 1,400 solar cells of light weight, king size (2x6 cm^2) are so closely installed on the panel that improves the solar cell mounting density. For further detrails, see ref. 3).

4) Other efforts for weight reduction
   (1) Use of flat package type IC's
   (2) Each printed circuit board is stiffened with foamed-potting material while the thickness remains thin enough.
   (3) Use of miniaturized MDM connectors
   (4) Use of Be-Cu electric wires
   (5) Use of titanium screws
   (6) Application of redundancy only to the vital circuit level.

Deep Space Communication Requirement

To realize the deep space communication link, tradeoffs were made as for the onboard transmitter output power, the types and gains of onboard antennas, data bit rates and so on. The results are summed up as follows:

1) The s/c transmitter output power shall be 5 watts.

2) Three kinds of antenna shall be installed. They are high-, medium-, and low- gain antennas. HGA shall have gains of 21.5 dBi and 23.1 dBi for up- and down- link respectively. The up-link is designed to be operated with an ample margin up to maximum earth-s/c distance of 2 AU with even LGA. One of two command receivers is kept connected to MGA at all time and the other is connected to either LGA or HGA which is switched by a command. This secures reliable transmission of commands from the earth station (E/S) to the spacecraft.

3) Communication system shall utilize a convolutional coded PCM (R=1/2, K=7) with 128 bps signal rate (or 64 bps data rate).

The details of the communication system for both S/C mission will be described in a separate paper (Nomura and others,1985).

Thermal Control Requirement

In order to maintain the onboard equipment within a reasonable temperature range throughout the mission life, the heat flow of the s/c is mainly controlled by means of active control method, or specifically, by the thermal louver device together with passive method of thermal insulation and coatings. The design configuration is to cut or minimize the incident solar energy by enveloping the s/c outer structure with thermal insulations, letting the excess heat generation inside the s/c dissipate to space through the platform surface backed with four thermal louver units. For further details, see ref. 4).

OTHER SYSTEM CHARACTERISTICS

In addition to the system features mentioned above, other major characteristics as to three subsystems, attitude and orbit control, HGA despin, and telemetry and command subsystems are described here.

Attitude and Orbit Control Subsystem

This subsystem incorporates various autonomous control functions for the execution of safe and reliable operation of the interplanetary spacecraft.

1) Autonomous spin stop function

During the launch phase, the s/c is stabilized by rather high spin rate of 120 rpm until separation of the upper stage motor. The spin axis of the s/c should be oriented as soon as possible to the direction perpendicular to sun-s/c line in order to obtain sufficient power from solar cells and to maintain the s/c temperature within limits. In addition, it is required to reduce the spin rate prior to this sun acquisition maneuvering for efficient use of RCS, and these all attitude control events must be carried out during the period when the s/c - KSC communication link is lost after the separation of the upper stage motor. Then an autonomous spin stop function is inevitable to stop RCS injection at the moment when the spin rate slows down to the desired value (30 rpm).

2) Autonomous sun acquisition function

As mentioned above, the spin axis of s/c has to be maintained perpendicular to s/c-sun line and its tolerance limits are as narrow as ±3°. The s/c has an automonous sun acquisition capability which works automatically and brings back the attitude to the direction perpendicular to s/c-sun line by RCS injection as soon as when the limits are violated with some causes such as solar pressure induced attitude drift. This function can be made either enable or disable by a command.

3) Automonous earth search function

Another unique function incorporated is a contingent function that the s/c begins to search the earth (E/S) autonomously when the s/c has not received any commands from the E/S for one week (to be exact, 7 days 2 hours 20 minutes). This function makes both s/c attitude and HGA azimuth angle rotate step by step until s/c could receive a command and restore contact with the E/S again. Fig.3 shows the autonomous earth search control procedure.

The details of the attitude and orbit subsystem is described in ref. 5).

HGA Despin Subsystem

This antenna despin subsystem can make HGA point the E/S either at s/c cruising spin rate of 6 rpm or at very low spin of 0.2 rpm in the phase of UVI taking photos of the comet. Major development efforts were concentrated on the shortening of the acquisition time from despin start to lock-in, and the suppression of cogging torque of despin motor to provide smooth HGA rotation even at 0.2 rpm. For further details, see ref. 6).

Telemetry and Command Subsystem

Data processing unit (DPU) has functions of data handling and command distribution to the onboard equipment. Newly developed data recorder of 1 Mbits capacity utilizing magnetic bubble memory is employed to store the data obtained when the s/c is out of sight from the E/S. Combining five kinds of command realizes safe, reliable and simple control of the s/c from the E/S.

Kinds of command

EDC (Execute Discrete Command)
Discrete command with immediate execution

NDC (Non-execute Discrete Command)
Discrete command without immediate execution
It accomodates a maximum of 15 EDC's. After they have been once memorized in the s/c, NDC is executed by a single-stroke EC command from the E/S.

BC (Block Command)
BC's are used to define operational modes and parameters for the specified subsystems such as UVI, SOW, AOCE (Attitude and Orbit Control Electronics) by a block of command codes.

PC (Program Command)
PC, a set of DC's stored sequencially on DPU memory, is executed step by step every 128, 512 or 2048 sec intervals. One of these time steps is selected by a DC. PC's enable autonomous control of the s/c for a time span up to 6 days. The PC employs the hamming code capable of 1-bit error corrections.

EC (Execute Command)
Command to execute NDC and BC

OPERATION

Current Status of SAKIGAKE

As of date, the s/c SAKIGAKE is cruising on its due course to Halley's comet, and it is estimated that the encounter will happen at about 7 million kilometers of closest approach distance on March 11, 1986. After launch, it experienced twice orbit correction maneuvers, extensions of two antennas and one boom, and switch-on of the high voltage power supply for SOW, since then it has been placed in the regular observation phase. Table 2 outlines the operational history of SAKIGAKE.

Operation Plan for PLANET-A

PLANET-A will be launched mid-August 1985 by M-3SII-2 launch vehicle from KSC. The s/c will come close to the comet within about 200 thousand kilometers in March, 1986 after about one-half year flight around the sun. After injection into the orbit, the s/c will immediately perform the attitude control to direct its spin axis perpendicular not only to s/c-sun line but also to the ecliptic plane in order to secure power generation and communication link. It will slow down the spin rate to 0.2 rpm prior to taking photographs of the comet by means of the rotation of the momentum wheel. The photograph data will once be stored in the data recorder for reproduction later when contact with the E/S becomes available.

CONCLUSION

Major system design requirements, their implementation and system characteristics of the spacecraft have been described. PLANET-A, Japan's first interplanetary flight project is a huge project including not only the development of s/c themselves, but also the development of the new launch vehicle, construction of the new E/S facility with a huge 64 meter dia. antenna, and the new test facilities for tests and checkouts of the s/c and the launch vehicles. All these items have being accomplished successfully and we could take a big step forward into the interplanetary space.

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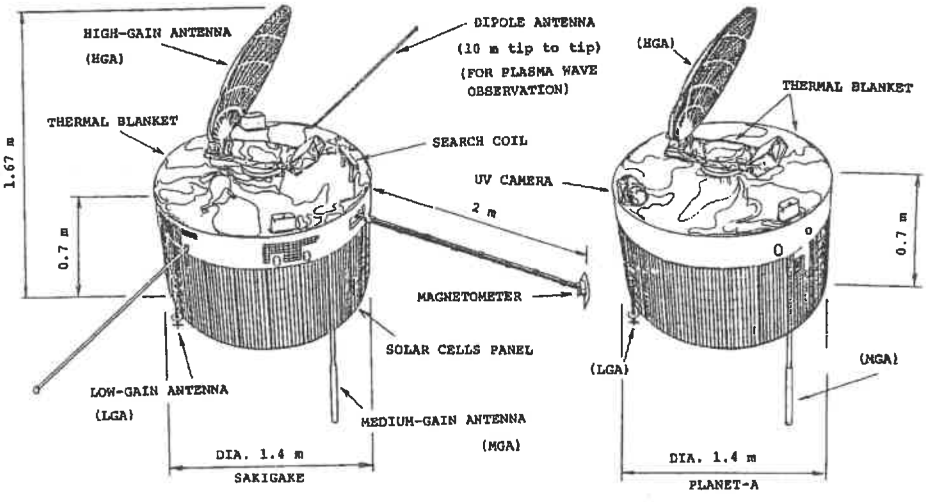


Fig. 1 External Views of SAKIGAKE and PLANET-A

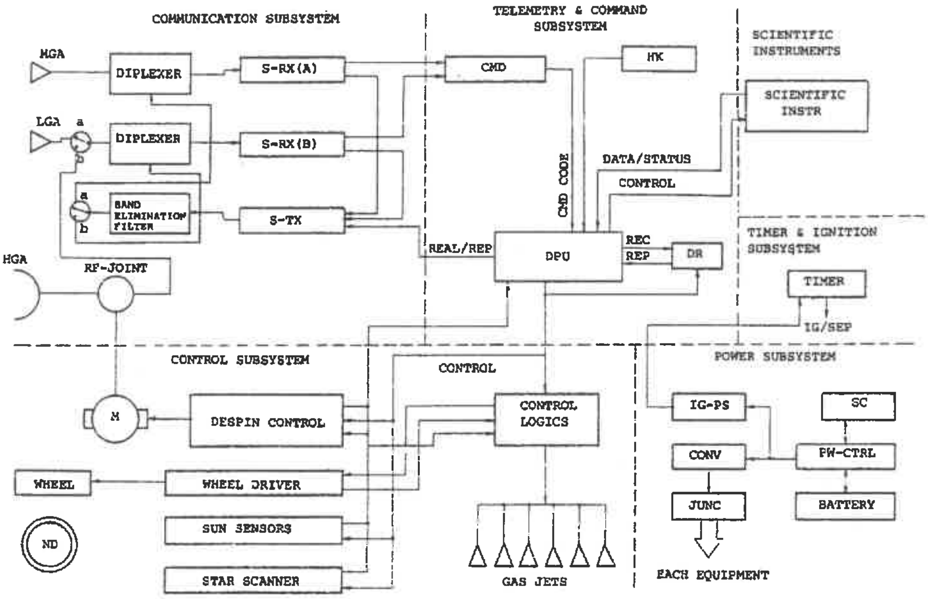
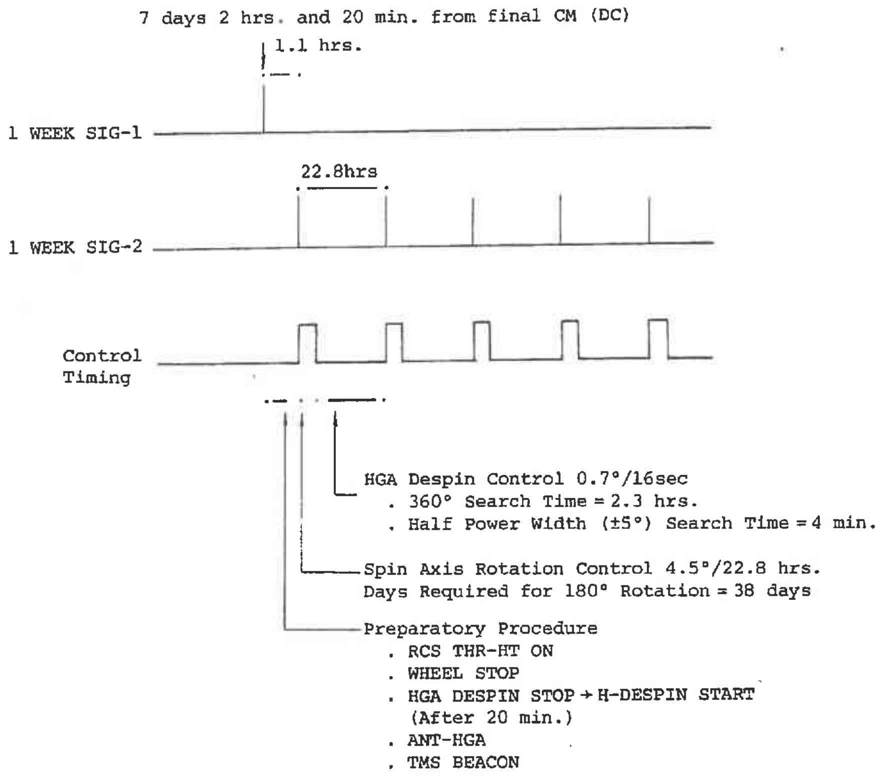


Fig. 2 System Block Diagram (SAKIGAKE / PLANET-A)

Table 1 Performance Data Summary

Item	Description
1. Shape and Size	Diameter: 1.4m Height: 1.67m
2. Weights	SAKIGAKE: 138 kg (including 10 kg RCS fuel) PLANET-A: 140 kg (including 10 kg RCS fuel)
3. Attitude and Oribt Control	1. Spin axis and rate control by Reaction Control Subsystem 2. Orbit control by Reaction Control Subsystem 3. Low spin rate control by Momentum Wheel
4. Thermal Control	Active control by Heaters and Louvers
5. Structure	System: Thrust Tube and Single Flat Deck Material: CFRP and Aluminum Honeycomb
6. Telemetry Transmitter	2.2 GHz, 70 mW/5W, PCM (Convolution) -PSK-PM
7. Data Processing Unit	PCM Encoding: 8 bits/word, 128 words/frame Data rate 2048/64 bps Command Control
8. Electric Power Supply	Solar cell: 2 x 2/2 x 6 cm^2, Si, N/P type Battery: 2 AH, Ni-Cd
9. Antenna	Offset parabola with despin mechanism, Three-element collinear array, Cross dipole
10. Data Recorder	Managetic bubble memory, 1-Megabit
11. Star Scanner	Passive scan type with two stripe-shaped Silicon Photodiodes
12. Reaction Control Subsystem	3N Thruster x 6, N_2H_4 fuel
13. Momentum Wheel	20 Nm sec. at 2,000 rpm
14. Thermal Louver	Effective emittance to be 0.15 to 0.7



HGA Despin Control 0.7°/16sec
. 360° Search Time = 2.3 hrs.
. Half Power Width (±5°) Search Time = 4 min.

Spin Axis Rotation Control 4.5°/22.8 hrs.
Days Required for 180° Rotation = 38 days

Preparatory Procedure
. RCS THR-HT ON
. WHEEL STOP
. HGA DESPIN STOP → H-DESPIN START (After 20 min.)
. ANT-HGA
. TMS BEACON

Fig. 3 Autonomous Earth Search Control Procedure

Table 2 Operation History of SAKIGAKE

Date	Operational Events
Jan. 8, 1985	Launch at 04:26 (JST).
Jan. 8, 1985	Initial RF signal reception at UDSC, 09:55 (JST)
Jan. 11, 1985	1st orbit correction, ΔV=30 m/s (Closest distance to the comet estimated at 7.03 million km as of Jan. 11.)
Feb. 14, 1985	2nd orbit correction, ΔV=5 m/s (Closest distance to the comet estimated at 7.00 million km as of Feb. 14.)
Feb. 19, 1985	Two PWP antennas extension to full length of 5m. IMF Boom extension to full length of 2m.
Feb. 20, 1985	HV power switch-on for SOW instrument. Regular observation commenced.
Apr. 12, 1985	S/C spin axis placed normal to the ecliptic plane.
May 4, 1985	Perihelion passage (0.816 AU).
May 15, 1985	Commencement of joint observation with ICE (USA).
May 30, 1985	Sun-Venus-SAKIGAKE aligned. (Venus-Sakigake range: 16 million km)
June 29, 1985	Joint observation with ICE terminated.