Attitude Control Experiment of Soundind Rocket S-520-5

By

I. NAKATANI

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1. Introduction

S-520-5 is the latest in a series of sounding rocket with attitude control capability which was successfully launched in September, 1982. One of its missions was to take the picture of the sun in a ultra-violet region and for this purpose, 3-axis attitude control of the rocket was needed. The required attitude accuracy was severe while considerable attitude disturbances exerted by other mission equipment had been expected, but good results were obtained.

2. Attitude Accuracy Requirements

The required attitude accuracy is as follows:

1) Angle error bias for pitch and yaw with respect to the sun : ± 0.1 deg
2) Amplitude of limit cycle angle for pitch and yaw : 0.1 deg
3) Amplitude of limit cycle angle rate for pitch and yaw : 0.1 deg/s
4) Amplitude of limit cycle angle for roll: 0.2 deg

The alloted time for the acquisition of the above mentioned attitude is 118 sec during which about 21 degree attitude maneuver is necessary. In the initial control phase, two 5 m flexible antennas and several other sensors were deployed as shown in Fig. 1, which could cause attitude disturbances. The effect of the 5 m flexible antennas was dominant and had been intensively investigated by means of simulation [1].

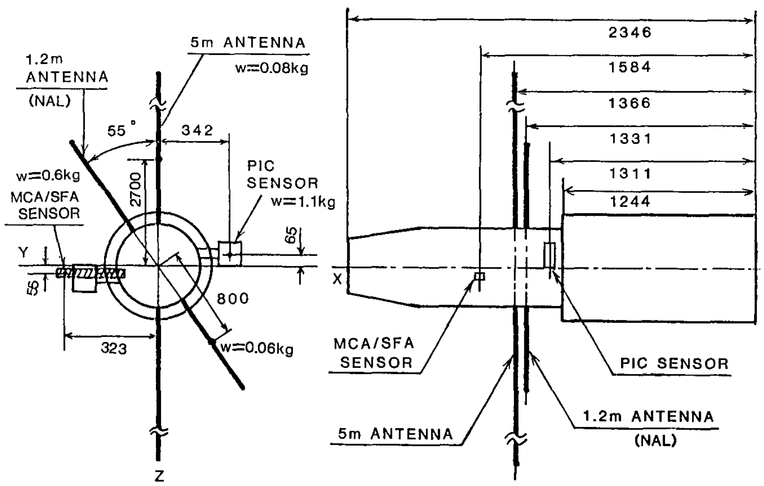
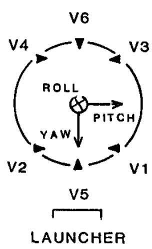


Fig. 1. Deployable antennas and sensors of S-520-5.

3. Control System Description

The attitude control system was designed to meet the above mentioned requirements, while new equipment and concept for control system had been newly introduced. The system is outlined below.

1) To realize a small limit cycle corresponding to high precision attitude, side jets with 100 g N_2 thruster were used. The engine configuration and firing logic are shown in Fig. 2.
2) As an attitude reference, gyros were used in the acquisition mode and a sun sensor was used after the acquisition of the sun was achieved.
3) As a gyro attitude reference, a spin-free-analytical platform system was used. This system consists of a spin stabilized platform and three RIG's (Rate Integrating Gypos) as shown in Fig. 3. Besides the IRG's, an RG (Rate Gyro) was used used to provide rate damping signal.
4) A 16-bit microprocessor was introduced to enhance the design flexibility and to achieve weight and size reduction.
5) A single-ploe coordinate ξ—η system was introduced to reduce the number of singular point. The ξ—η system is illustrated in Fig. 4.
6) The block diagram of attitude control system is shown in Fig. 5. An on-off control with dead band based on a linear combination of attitude and attitude



MODE IN WHICH EACH AXIS IS CONTROLLED INDEPENDENTLY

AXIS	ERROR COM	FIRED VALVES
ROLL	CW	V2,V3
	CCW	V1,V4
PITCH	UP	V5
	DOWN	V6
YAW	CW	V2,V4
	CCW	V1,V3

MODE IN WHICH YAW AND ROLL ARE CONTROLLED SIMULTANEOUSLY

		ROLL		
		CW	—	CCW
YAW	CW	V2	V2,V4	V4
	—	V2,V3	—	V1,V4
	CCW	V3	V1,V4	V1

Fig. 2. Engine configuration and its firing logic.

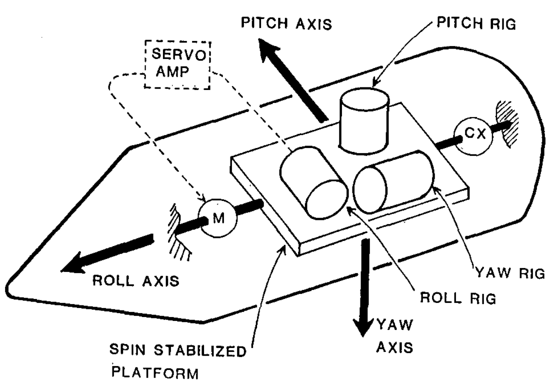


Fig. 3. Attitude measurement unit.

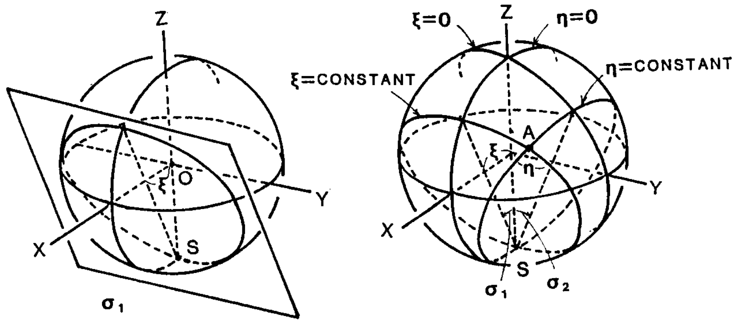


Fig. 4. Single pole coordinate system.

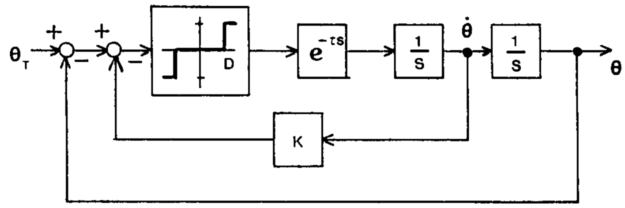


Fig. 5. Block diagram of attitude controll system.

rate signal was used for all 3-axes. In Fig. 5, τ is the time lag of side jet. only rigid body dynamics is shown. Depending on the attitude and attitude rate, the following three modes were provided, and three kinds of switching curves were used depending on the mode.

i) Mode 1: Before the sun sensor acquires the sun, only gyros are used.

ii) Mode 2: The sun has been acquired, but the limit cycle is not achieved. The relation $|\dot{\theta}|<1.25$ deg./s holds. Under these conditions, the sun sensor is used.

iii) Mode 3: Mode 2 has been achieved and $|\theta|<0.5$ deg. holds. The limit cycle is supposed to have been achieved and the mode is never reversed.

4. Control Sequence

Since 3 hours before the launch of the rocket, on-board attitude measurement unit and electronics had been checked out by means of GSE (Ground Support Equipment) which consists of an operation console and a mini-computer. The set angles of a launcher were decided 75 minutes before the launch and the gyro set angle was calculated and set automatically by GSE based on the launcher angle data. The rocket was given 2 rps spin after the engine burn-out. The spin was reduced to 0.3 rps at 45 sec after the launch by releasing a yo-yo despinner. The payload section was separated from the burnt out engine at 60 sec and the attitude control was started at 62 sec. At 150 sec, the initial target attitude was acquired and at 430 sec, the control was finished.

5. Results

For control equipment, 24 telemetry items are allocated from which the attitude history was calculated on an off-line basis. Examples of the results are shown in Fig's 6 through 8 together with qualitative comments. The quantitative analysis including simulation is now being performed. The conclusions are as follows:

(1) The requirements for the attitude control were completely met and it was demonstrated that the above mentioned control system can be a standard type for S-520 series rockets.

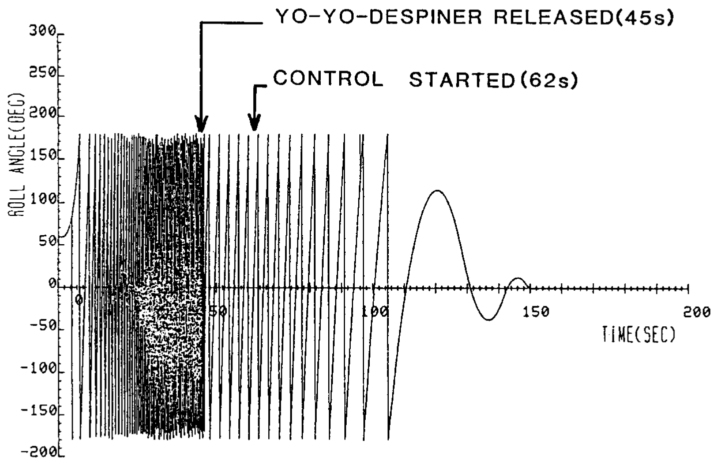


Fig. 6. Roll angle vs. time. Roll angle is shown between −180 deg. and and +180 deg. Immediately after the launch, spin was acceleratd aerodynamically reaching 2 rps. At 45 s, it was reduced to 0.3 rps by a yo-yo despinner and after 62 s, it was further reduced by side jets.

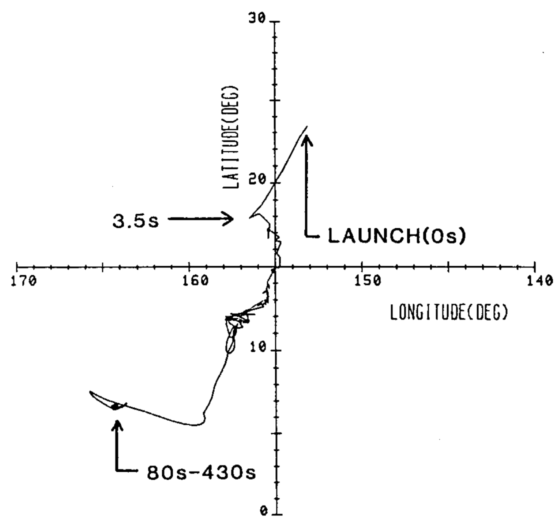


Fig. 7. Locus of nose direction determined by gyro. The nose direction of the rocket is shown. At about 80 s, the initial attitude was acquired which was maintained till 430 s. In the initial 3.5 s period, a sharp nose dive can be observed followed by a precession, nutation and wobbling.

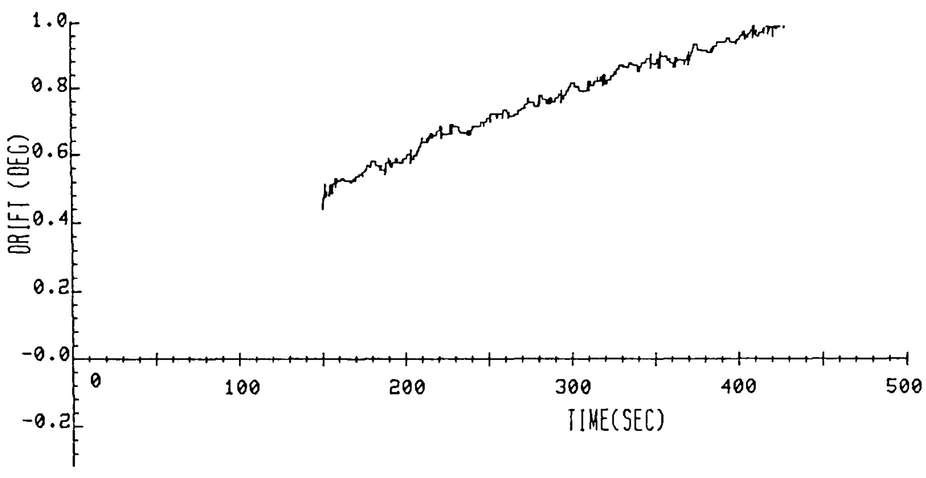


Fig. 8. Gyro drift in longitude direction vs. time. Gyro drift calculated by the sun sensor data is shown. During free flight, a drift of 0.1 deg. per second is observed.

(2) The expected attituded disturbance by flexible antennas was not found showing a small deflection of the antennas in the initial deployment.

(3) The attitude after the limit cycle had been acquired was stable with jet on-off less frequent than expected. The reason is under investigation.

(4) Gyro drift was larger than expected. The problem is assumed to be with on-board data processing software system which is now being investigated.

Reference

[1] I. Nakatani et al.: "Attitude Control System of the Sounding Rocket S-520-5", Proceedings of the Internationa Symposium on Space Technology and Science, '82, Tokyo"