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ATTITUDE DETECTION BY HORIZON ASPECT SENSOR ON BOARD ROCKETS LAUNCHED AT ANTARCTIC SYOWA STATION

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Abstract: Sounding rockets S-310JA-8, -9 and -10 launched at Syowa Station in Antarctica were equipped with horizon aspect sensors and geomagnetic aspectometers to determine their attitudes. This paper reports the rocket pitch angles between the rocket axis and the vertical at the rocket position determined from the experimental results of the horizon aspect sensor, which could detect the horizon of CO_2 gas layer in the atmosphere.

1. Introduction

Pitch angle is a factor of vehicle attitude, and it can be obtained through detecting the horizon of CO_2 gas layer over the ground in the atmosphere by using a horizon aspect sensor (HOS). Figure 1 shows a schematic configuration of a rocket with the horizon aspect sensor. The sensor is set on board the rocket at an angle γ to the spin axis. The sensor scans the surface of the earth from point P_1 to P_2 and the space from point P_2 to P_1, with the spin of the rocket. Atmospheric infraved radiation changes suddenly at points P_1 and P_2. When the sensor detects the horizon, the earth scanning angle θ is obtained, which is given by

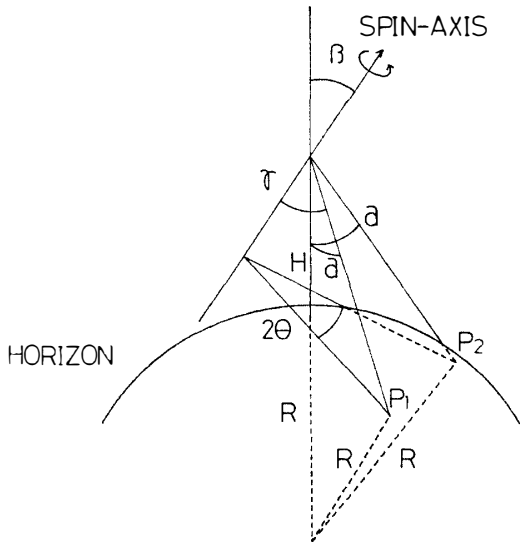

Fig. 1. Schematic configuration for rocket and sensor view directions above the earth.

$$\theta=\frac{1}{2}\times 2\pi\times\frac{T_{\text{est}}}{T_{\text{spin}}}, \tag{1}$$

where T_{spin} is the spin period and T_{est} is the earth scanning period. The following relationships can be obtained from the geometrical consideration of the rocket attitude above the earth in Fig. 1,

$$\cos\alpha=\cos\gamma\times\cos\beta+\sin\gamma^{*}\cos\theta\times\sin\beta, \tag{2}$$

$$\sin\alpha=\frac{R+H'}{R+H}, \tag{3}$$

where γ is the setting angle of the sensor, R the earth radius, H the rocket altitude, H' the depth of CO_2 gas layer and β the pitch angle. From eqs. (1) and (2), pitch angle β can be written as

$$\beta=\sin^{-1}\frac{\cos\alpha}{\sqrt{\cos^2\gamma+\sin^2\gamma\times\cos^2\theta}}-\tan^{-1}\frac{\cos\gamma}{\sin\gamma\times\cos\theta}. \tag{4}$$

2. Experimental Results

Figure 2a shows the earth scanning angles obtained from the data of the horizon

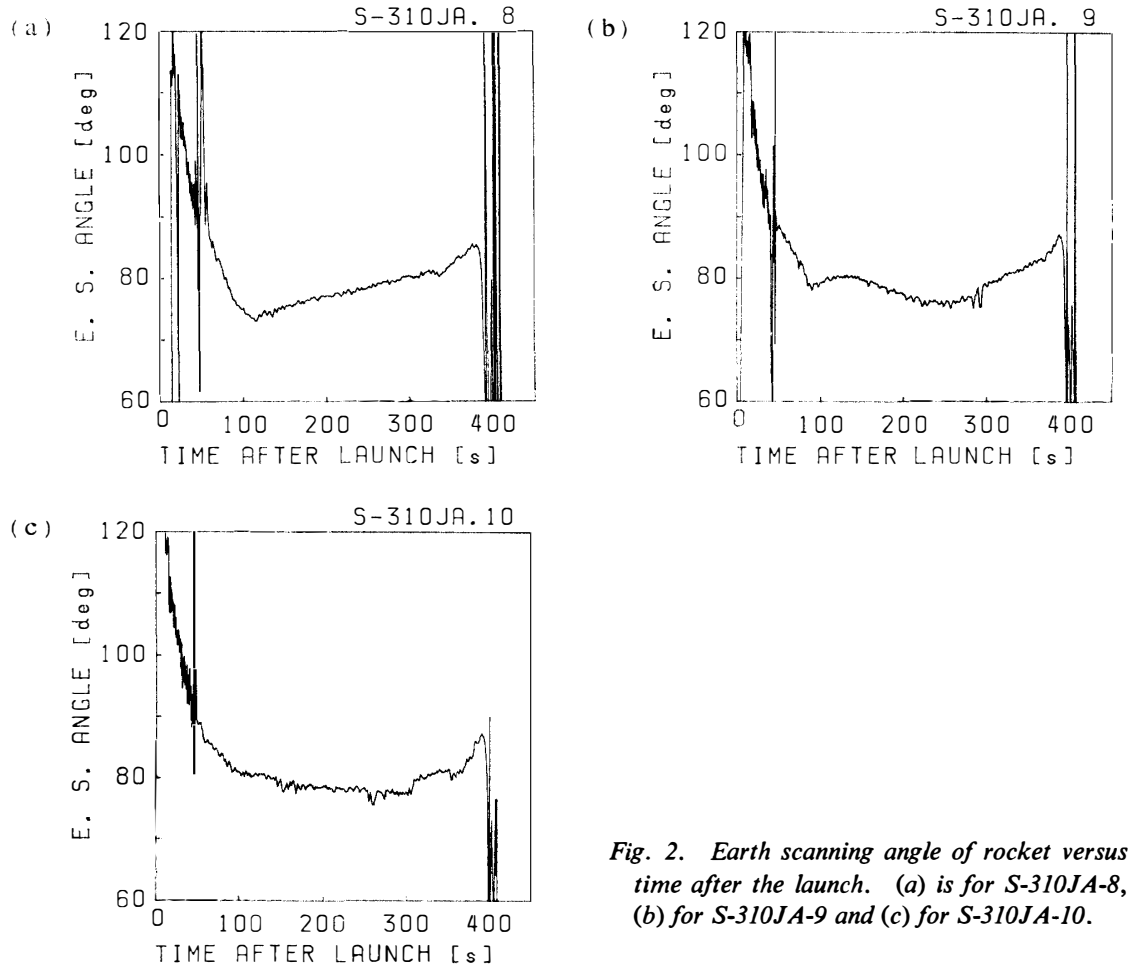

Fig. 2. Earth scanning angle of rocket versus time after the launch. (a) is for S-310JA-8, (b) for S-310JA-9 and (c) for S-310JA-10.

aspect sensor on board the S-310JA-8 rocket by using eq. (1). According to the experimental results of Fig. 2a it is shown that the vehicle made a precession and the vehicle attitude isobtainable from 70 to 380 s after the launch. The vehicle attitude cannot be obtained outside the above time range because of large fluctuations of the earth scanning angle θ. The earth scanning angles of S-310JA-9 and -10 rockets are shown in Figs. 2b and 2c, which have the same tendency as in Fig. 2a.

Pitch angles can be obtained from these data by using eq. (4), and they are shown in Fig. 3. Figure 3 shows that the precessional angles of S-310JA-8, -9 and -10 rockets were (15±2), (15±2) and (13±2) degrees, respectively.

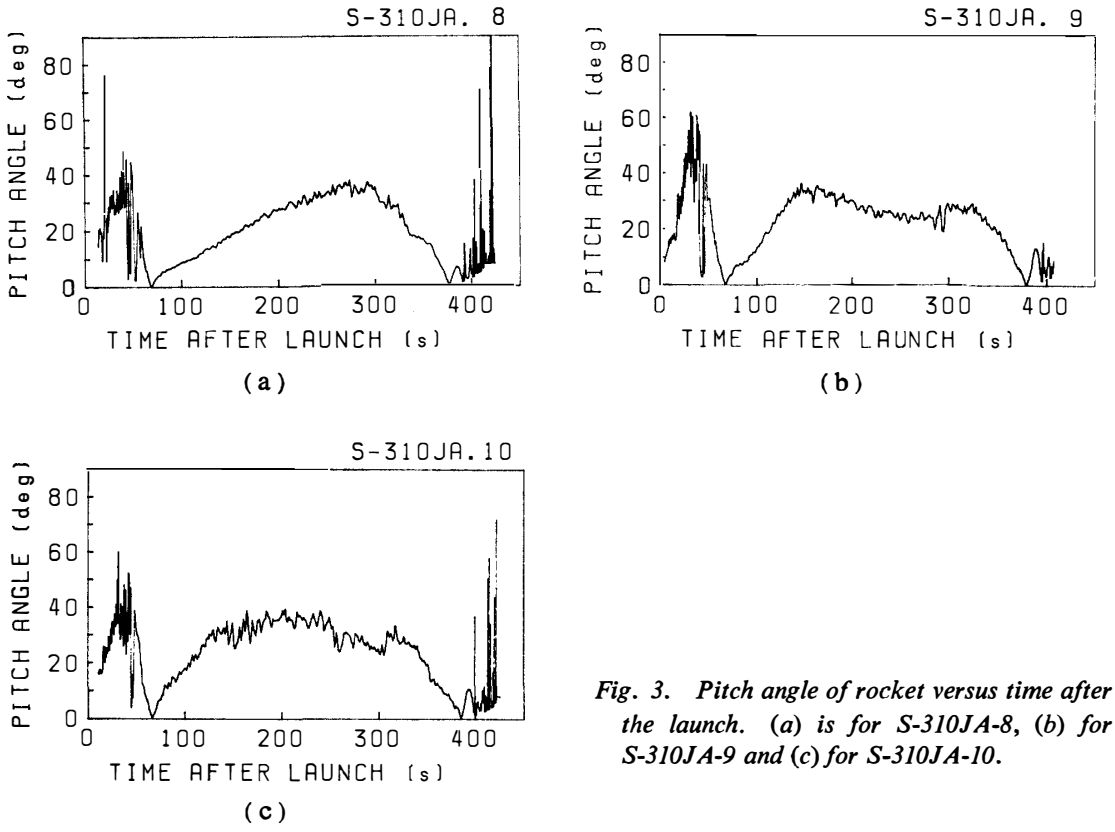

Fig. 3. Pitch angle of rocket versus time after the launch. (a) is for S-310JA-8, (b) for S-310JA-9 and (c) for S-310JA-10.

3. Estimation of Pitch Angle Errors

The error of pitch angle $\Delta\beta$ may be expressed as

$$\Delta\beta=\left|\frac{\partial\beta}{\partial\gamma}\right|\Delta\gamma+\left|\frac{\partial\beta}{\partial\theta}\right|\Delta\theta+\left|\frac{\partial\beta}{\partial H}\right|\Delta H+\left|\frac{\partial\beta}{\partial H'}\right|\Delta H', \tag{5}$$

where $\Delta\gamma$ is the error of the sensor setting angle, $\Delta\theta$ is the error of the earth scanning angle, ΔH is the error of the rocket altitude and $\Delta H'$ is the error of the depth of CO_2 gas layer. Each derivative term in eq. (5) is given as follows:

$$\frac{\partial\beta}{\partial\gamma}=\frac{\sin\gamma\times\cos\beta-\cos\gamma\times\cos\theta\times\sin\beta}{\sin\gamma\times\cos\theta\times\cos\beta-\cos\gamma\times\sin\beta}, \tag{6}$$

$$\frac{\partial\beta}{\partial\theta}=\frac{\sin\gamma\times\sin\theta\times\sin\beta}{\sin\gamma\times\cos\theta\times\cos\beta-\cos\gamma^{*}\sin\beta}\,, \tag{7}$$

$$\frac{\partial\beta}{\partial H}=\frac{\sin\alpha\times\tan\alpha}{(R+H)(\sin\gamma\times\cos\theta\times\cos\beta-\cos\gamma\times\sin\beta)}\,, \tag{8}$$

$$\frac{\partial\beta}{\partial H'}=-\frac{\tan\alpha}{(R+H)(\sin\gamma\times\cos\theta\times\cos\beta-\cos\gamma\times\sin\beta)}\,. \tag{9}$$

The errors of the pitch angle of S-310JA-8, -9 and -10 rockets are estimated and shown in Fig. 4. The error of pitch angle is less than about 4 degrees.

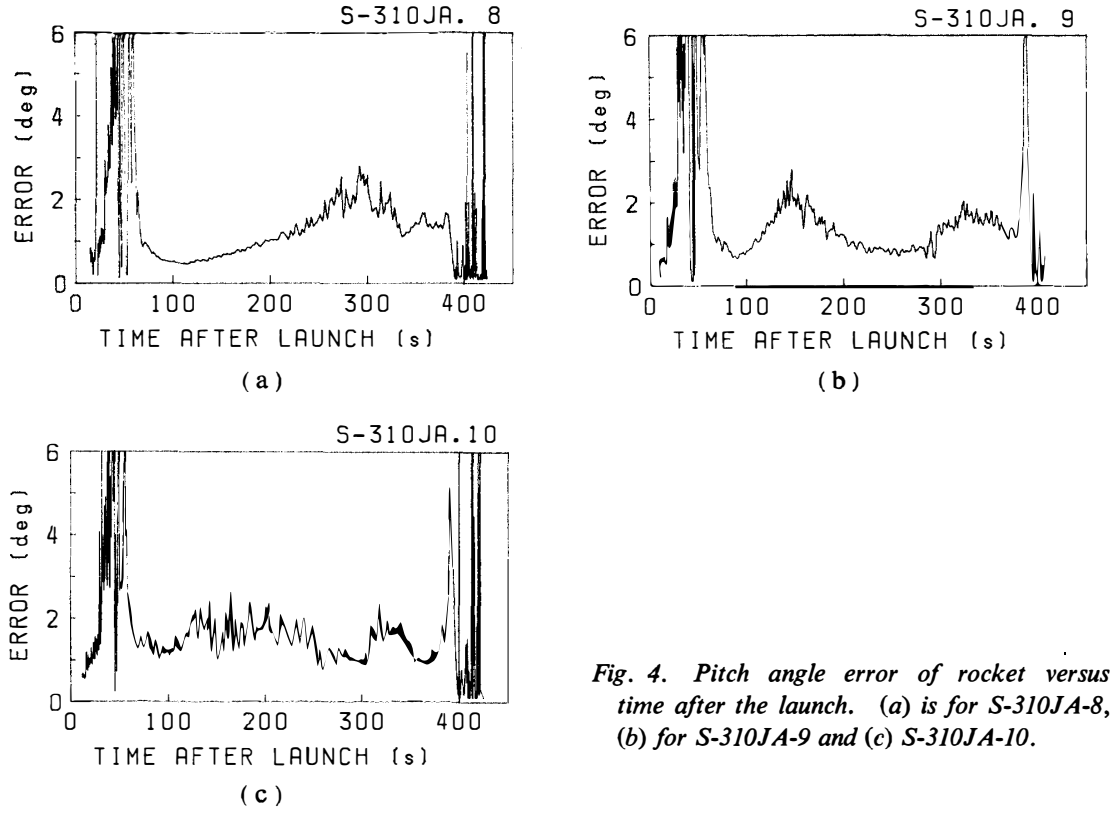

Fig. 4. Pitch angle error of rocket versus time after the launch. (a) is for S-310JA-8, (b) for S-310JA-9 and (c) S-310JA-10.

4. Conclusion

Pitch angles of S-310JA-8, -9 and -10 rockets could be determined at altitudes higher than about 100 km, but not at lower altitudes. By using these results with the results of geomagnetic aspectometers, the rocket attitude would be determined.

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