JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 32, No. 6, November–December 1995

Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Estimates of the Clementine Interstage Adapter Satellite Tumble Rate

M. Culpepper*
Phillips Laboratory,
Kirtland Air Force Base, New Mexico 87117-5776
H. Garrett†
Jet Propulsion Laboratory,
California Institute of Technology,
Pasadena, California 91109
and
M. Shannon‡
Lawrence Livermore National Laboratory,
Livermore, California 94550

I. Introduction

THE Clementine mission[1,2] included, in addition to the main spacecraft, an instrumented subsatellite. This subsatellite, the Clementine Interstage Adapter Satellite (ISAS), consisted of the interstage injection vehicle and its solar arrays, the ISAS experiment package, and a simple communications system. The vehicle had no attitude control or determination and was deployed in a random orientation. Following separation from the main Clementine spacecraft, the ISAS was left in a highly eccentric lunar transfer orbit (LTO) that intersected the Earth's radiation belts (perigee $\approx$300 to $\approx$700 km; apogee $\approx$127,000 km; inclination $\approx$67 deg). Experiments on the ISAS measured the Earth's Van Allen radiation belts[3] and micrometeoroid environment on a regular basis. These experiments returned estimates of the fluence for these environments. To evaluate these fluences in detail, however, it is useful to know the attitude and rotation rate of the ISAS. Fortunately, as the ISAS separated from Clementine, it was repeatedly imaged by the Clementine ultraviolet–visible (UV/VIS) camera as part of the separate autonomous navigation experiment. This information can be used to approximate the attitude and rotation rate of the ISAS early in the mission. In particular, the information can validate the assumption that the radiation and micrometeoroid data were omnidirectional over the initial part of the ISAS mission. An analysis of these images for the purpose of determining the rotation rate and, as far as possible, the orientation of the axes, is presented here.

II. Clementine Data

The Clementine spacecraft instrument complement included a digital UV/VIS CCD camera, which was specifically designed to provide images in discrete selectable spectral bands ranging from the near ultraviolet to the near infrared. The camera was of a very compact design and had a mass of $\approx$400 g. It consisted of three modules: the optics, a filter wheel, and a camera assembly. The focal-plane array was a phosphor-overcoated silicon CCD, which enhanced the uv without seriously degrading the responsivity to the longer wavelengths. The pixel format was 384×288 with an individual pixel size of 23×23 μm. The SiO_2 catadioptric lens had an aperture of 46 mm and a speed of f1.96 with a field of view of 4.2×5.6 deg. The electronics could operate at a maximum frame rate of 30 Hz with 8 bits in the analog-to-digital converter. The Clementine science team selected the following six wavelengths to optimize the scientific return of the mission: 0.40–0.95, 0.415 ± 0.02, 0.75 ± 0.005, 0.90 ± 0.01, 0.95 ± 0.015, and 1.0 ± 0.015 μm.

A photograph of the ISAS without thermal blankets on the kick motor is presented in Fig. 1. For reference, the ISAS stands about 1.5 m tall. In flight, the engine nozzle and the open end of the adapter were covered with form-fitting thermal blankets.

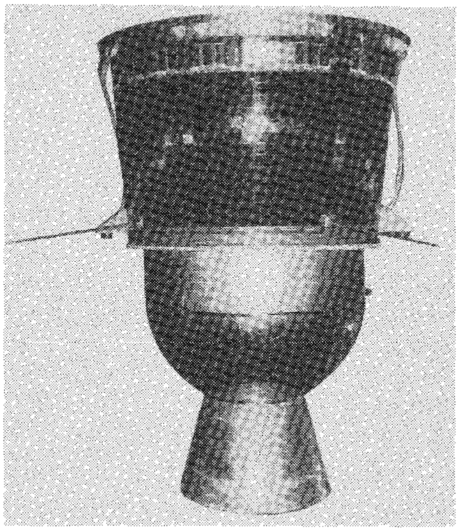

Fig. 1 Clementine Interstage Adapter Satellite (ISAS).

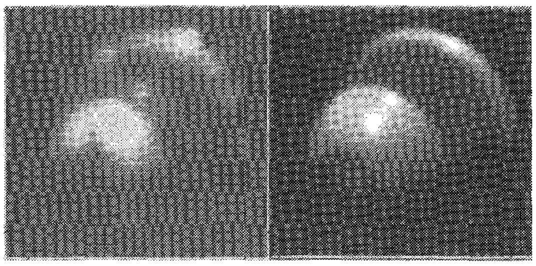

Fig. 2 High-resolution image of the ISAS through the UV/VIS camera.

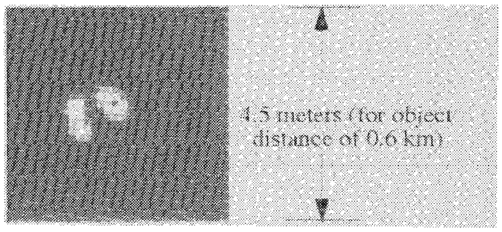

Fig. 3 Enlarged subimage (30×30 pixels) from the Clementine UV/VIS camera of the ISAS.

Received March 30, 1995; revision received June 28, 1995; accepted for publication June 28, 1995.

*Member, Technical Staff.
†Member, Technical Staff. Member AIAA.
‡Deputy Project Manager.

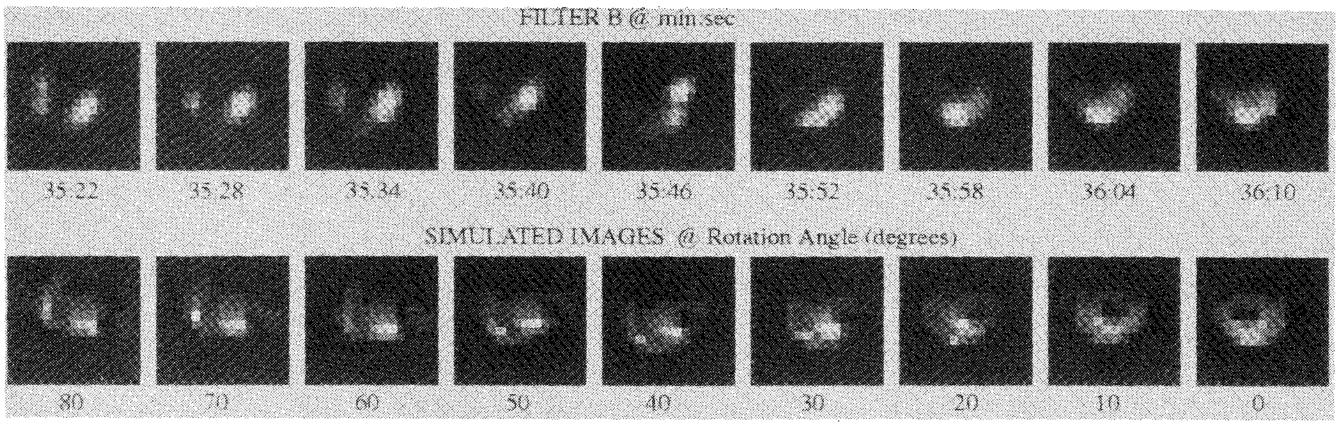

Fig. 4 Imaging sequences taken by the Clementine UV/VIS camera and the computer-generated images.

Table 1 Filter settings for the Clementine UV/VIS camera images of the ISAS

Filter	Center frequency, nm	Bandwidth, nm	Exposure duration, ms
B	750	10	2.5488
C	900	20	2.2656
D	950	30	2.3600
E	1000	30	5.5696
F	650	550	0.9440

On Feb. 4, 1994, at 0712 UT, the ISAS was separated by springs from the main Clementine spacecraft. The release was apparently slightly asymmetric, causing the ISAS to slowly tumble. As the ISAS separated from the Clementine, the Clementine imaging systems were turned on and a series of autonomous pointing tests carried out in which the Clementine spacecraft attempted to image the ISAS. A high-resolution UV/VIS frame from a very early portion of this exercise, when the separation was less than 0.5 km, is presented in Fig. 2 along with a computer fit to the image. Subsequently, two series of UV/VIS images were taken at approximate separation distances of 0.6 and 1.2 km. These images were much smaller than in Fig. 2, but still provided sufficient information to determine the probable rotation rate and axes for the ISAS.

Approximately 130 images were taken during the two series. Five filter settings were used, each filter exposure being for a slightly different duration. The filters, frequencies, bandwidths, and exposure durations are listed in Table 1. The images were made about 1 s apart and in an overlapping filter sequence: F, E, D, C, B, F, E, D, C, B, ... The images were made during two time periods about 15 min apart. An enlarged subimage is presented in Fig. 3. The ISAS is about 10 pixels wide for the first series and somewhat smaller in the second. A series of sample images for filter B from series A are presented in Fig. 4.

III. Fitting Procedures

Before comparing the computer-generated images and the actual images, two issues have to be addressed. First there is the issue of blurring. In reviewing the actual images, there does not appear to be any significant difference in sharpness between images from filter E (the longest exposure) and the other filters. Therefore, blurring of the images due to motion of the camera or of the object is not a complicating factor. Further, at any given time, the images were highly correlated from filter to filter. Second, the exact distance between the ISAS and Clementine is not known. A simple estimate, however, shows that a $\approx$10-pixel image in the UV/VIS for a $\approx$1.6-m body corresponds to a distance of $\approx$0.6 km.

Based on blueprints and prelaunch photographs, a computer model was developed of the ISAS. The model included wrinkled thermal-blanket material overlaid on the kick motor and the rim above the micrometeoroid detector. This model was then implemented in the satellite signature code.[4] This program allows the user to simulate images of three-dimensional structures over a wide range of radiometric and viewing conditions. The high-resolution image is shown in Fig. 2. This match yielded an estimate of the unit vector (s) from ISAS to the sun in the inertially stabilized camera frame of reference. Visual matches were then made to a sequence of the lower resolution images using s in the computation. (Orbit calculations indicated that s did not change significantly during the time between acquisition of the higher-resolution image and the last low-resolution image.) Besides the low resolution of the images, uncertainty in the condition and final shape of the thermal-blanket material made a match difficult. The shiny, wrinkled thermal blankets tend to produce glints that are difficult to predict. Several parameters [material bidirectional reflectivity distribution function, thermal-blanket wrinkle amplitude, and, of course, tumble motion of the ISAS] were varied until there was a distinct correlation between the computer images and the actual observations. Simulated images for one case are presented in Fig. 4. The angle shown is for rotation about an axis orthogonal to the vector from the observer to the object and corresponds to a rotation rate of 1.3 deg/s. Based on trial and error, the uncertainty in the rotation rate was $\approx$0.5 deg/s. The ISAS must have also had a slower oscillation of $\approx$0.1 deg/s about an axis orthogonal to the first axis, since an initial rotation is about 10 deg about the orthogonal axis had to be applied in order to obtain the match. Rotation about the ISAS longitudinal axis was impossible to determine because of the low resolution of the imagery.

IV. Conclusions

Rotational rates of ISAS were successfully determined using images obtained by Clementine coupled with glint-modeling software. Approximately 130 images of the ISAS have been analyzed, and an initial rotation rate of $\approx$1.3 deg/s about an axis normal to the main longitudinal axis was observed, with an $\approx$0.1-deg/s rotation rate around an axis orthogonal to these two axes.

Acknowledgments

The authors would like to thank the personnel of the Naval Research Laboratory for the excellent performance of the Clementine and ISAS vehicles. One of us (H. B. G.) wants to particularly thank P. Rustan and D. Duston of BMDO/TRI for their support throughout the Clementine program, and S. P. Worden for originally inviting him to take part in this program.

References

[1]Rustan, P. L., "Flight-Qualifying Space Technologies with the Clementine Mission," *EOS*, Vol. 75, No. 14, 1994, pp. 161–165.

[2]Nozette, S., and Garrett, H. B., "Mission Offers a New Look at the Moon and a Near-Earth Asteroid," *EOS*, Vol. 75, No. 14, 1994, pp. 161–165.

[3]Soli, G., Blaes, B., Buehler, M., Jones, P., Ratliff, J. M., and Garrett, H., "Clementine Dosimetry," *Journal of Spacecraft and Rockets*, Vol. 32, No. 6, 1995, pp. 1065–1070.

[4]Culpepper, M., and Radke, G., "Technical Reference, Programmer's and User's Manual for the Satellite Signature (SATSIG) Computer Program," TR-095-033, USAF Phillips Lab., Nov. 1995.

A. L. Vampola
Associate Editor