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A Single-Channel Magnetometer for Exoatmospheric Targets

Mitch Thomas

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Mitch Thomas, L'garde , Inc.

December 14, 1995

Abstract

We have developed and used a single-channel magnetometer to obtain motion data on various objects flying in space. The details of this approach have been presented in Ref. 1. This new approach has been shown to be effective and relatively inexpensive. It offers users higher return for their dollars than competing approaches. This paper explains why.

System Penalties from Over-instrumentation.

Instruments can be heavy and become an appreciable fraction of the weight of typical lightweight targets or penaids. Increased target weight will limit the number of targets flown on a mission. Thus more missions are needed to collect the same amount of data, increasing project cost. Furthermore, weight increase of the targets often sacrifices realism. Thermal response is changed and flight dynamics are distorted.

Many penaid-class targets can be compressed for packaging, but instrumentation can not. Even more severe than the weight penalty mentioned above, the packaging penalty can also limit the number of targets carried on a given system. The presence of the instrumentation also decreases the reliability of the deployment, since instrumentation leads increase the stiffness of the package. Again more flights are needed because of this, raising project cost.

In addition to the above, the costs of over-instrumentation can be high simply from the cost of the instrumentation itself. Even in production quantities, a complex target instrumentation system can cost several hundred thousand dollars. Data reduction costs also are increased. Furthermore, reliability decreases with complexity, although this may be compensated by the redundant instrumentation, unless the flight failure corrupts all the data. In any case, these additional costs further limit the number of targets that can be examined within budget constraints.

What kind of Dynamics Data is Needed?

Depending on the type of flight target, you want information on temperature, pressure, strain, special events, and motion. Most of these parameters require low acquisition rate during the flight, except for motion, which very often requires high resolution. Thus motion data drives the transmitter bandwidth and data handling. Three types of exoatmospheric motion can be considered, as follows:

A. Rapid changes of the angular momentum, **h**. The angular momentum of a target will change during deployment, and any subsequent events such as erection, spin-up, or maneuvering. Such data is useful when target phenomenology is the prime driver; that is, we are learning about the penaid device itself, and not how a sensor sees it. In these cases, care must be taken that the instrumentation does not influence the target. That is why, for the Sounding Rocket Measurements Program, all measurements were off board. Much can be learned about initial deployment dynamics from video from the bus and ground based radars, rendering on-board instrumentation unnecessary at best, and a serious nuisance at worst, for this case.

B. Gradual Changes in **h**. The angular momentum of a target can change from atmospheric drag (early reentry), radiation pressure, a leaking ACS jet, and other forces that cause gradual changes. "Gradual" means that the changes in angular momentum are small over a precession cycle of the target.

C. Constant **h**. For most exoatmospheric targets, **h** is constant over most of the trajectory. For this case the dynamics of both rigid and flexible bodies is well defined.

For the latter two cases, a single-channel magnetometer can be used to provide accurate motion data, at considerable cost savings to the project.

What Accuracy is Needed?

One can attempt to provide an instrumentation system that meets all possible scenarios, no matter how unlikely their occurrence may be. This is clearly not the most cost-effective approach.

For targets used to evaluate sensor and interceptor systems, we note that sensor accuracy for these rarely exceeds 10%, even for relative intensity measurements. A typical target might resemble a cone with a base of 24 inches diameter and a length of 60 inches. The figure below shows how the projected area of such a target varies with angle of observation. A minimum area of 450 in^2 is indicated, and the maximum sensitivity to angle is about 7.5 in^2/deg. For a 10% change in cross section, the smallest angle change is therefor about 6 deg. If the target orientation is therefore known to about 1 degree, even the most stringent sensor requirement should be met.

The Single-Axis Magnetometer

The single-axis magnetometer makes use of the coning motion of a exoatmospheric target to deduce all motion and angular position of the target. The advantage of this device is that one obtains the highest possible data rate, the highest possible number of bits in the data, lower complexity, low cost, smallest volume and weight, high reliability, and the smallest impact on the target itself. For any given telemetry bandwidth, any additional data expends a portion of it, and this limits the resolution of the motion determination.

This type of device was flown successfully for Red Tigress II. It provided full motion data for all of the instrumented targets, with no data dropout until reentry.

As a check of the system, in February 1995 we compared motion data deduced from a single channel of magnetometer data to that obtained by other groups using much more extensive instrumentation. This particular target was an extreme case, since it coned at only 1 degree, and was oriented nearly perpendicular to the magnetic field lines, both very stressing conditions for the single-axis approach. Also the data we were given had significant dropouts, an inaccurate time scale, and some phase errors that had been introduced before we saw the data. Nevertheless, the reduction of the data from the single channel compared favorably to that from the more expensive set of instrumentation as shown below:

	Single axis	3-axis & Horizon Sensor
Coning angle	slowly changed from 1.1 to 1.4 deg.	1.26±.2 deg
Precession rate	35.0 deg/sec	34.96 deg/sec
Absolute pointing	55.9 , 44.8, 114.8	54.4 , 46.0 , 114.2
(Deg, from direction cosines)		54.6 , 45.5 , 114.5

The single channel data reduction also provided estimates of the ratios of moments of inertia, spin rate, and phase angles for both spin and precession (not compared to the other method because their results were not available). This test case showed that even for an extremely unfavorable and unlikely set of motion data, the single channel provided sufficient accuracy for any advertised purpose.

Conclusion

In this era of budget constraints, cost effectiveness is the key to successful projects. Instrumentation must be tailored to meet realistic project goals. Over-instrumentation will hurt flight programs by limiting the number and quality of the targets flown. For exoatmospheric targets of interest to BMDO, a single-axis magnetometer is the best approach.

Reference: John F. Kinkel and Mitchell Thomas, "Estimation of Vehicle Dynamic and State Parameters from Magnetometer Data," paper AAS 94-101, presented at the AAS/AIAA Spaceflight Mechanics Meeting, Cocoa Beach, Florida, Feb. 14-16, 1994 (AAS Publications Office, P.O. Box 28130, Sand Diego, CA 92198).

L•Garde Inc
15181 Woodlawn Avenue
Tustin, CA 92780-6487
www.LGarde.com