Pergamon

0094-5765(94)00179-0

Acta Astronautica Vol. 35, Suppl., pp. 155–159, 1995

0094-5765/94 $7.00 + 0.00

MAGNETIC FIELD INVESTIGATIONS ON LOW COST MISSIONS

R. C. Snare and C. T. Russell

Institute of Geophysics and Planetary Physics
University of California
Los Angeles, CA 90024-1567

ABSTRACT

Magnetic fields pervade all of space and provide important diagnostic information on the nature of processes occurring within and around solar system objects. Thus magnetic investigations are frequently included on planetary missions. Since spacecraft subsystems can generate magnetic fields that may interfere with the measurement of the ambient field, magnetic cleanliness programs are usually instituted to minimize such extraneous magnetic field sources. These programs need not require significant cost since magnetic control issues are now well understood but they do require early educational efforts and good communication with all hardware providers. Recent experience with the Small Explorer program, FAST, and plans for the proposed Hermes Discovery mission are discussed.

INTRODUCTION

All of space from the inside of the Earth, to the inside of the Sun, to the edge of the solar system, and far beyond is permeated by magnetic fields. These magnetic fields arise from currents that flow in the electrically conducting fluids in the interiors of the largest solar system bodies, from currents that flow due to the alignment of atomic currents flowing in the minerals in the crusts of many of bodies of the solar system and from currents that flow in the ionized gases of planetary upper atmospheres and ionospheres and the solar wind. The characteristics of these fields vary. The strongest fields in the solar system are found in concentrated bundles on the surface of the sun. These range up to several 10's of kiloGauss in strength or the order of a few of Teslas, about 100,000 times the field on the surface of the Earth. The largest accessible planetary magnetic field is that of Jupiter whose surface field is about 5 Gauss or about 10 times that of the Earth. The Jovian magnetic field, because of its strength, the enormous size of Jupiter and the relative weakness of the solar wind at 5 AU, extends far into the surrounding space and is dragged antisunward by the solar wind perhaps to the orbit of Saturn and beyond making the Jovian magnetosphere the largest entity in the solar system, much larger than the sun. The smallest fields of interest are fractions of a nanoTesla. Sometimes these fields must be measured as variations in a much larger field, while at other times the total field strength is this small. Thus the characteristics of the magnetometers must be wide-ranging and often magnetometers and the attendant magnetic cleanliness program must be tailored to a particular mission.

Because of the ubiquitous nature of the magnetic field, every flight opportunity has the potential for scientific return from the inclusion of a magnetometer. The decision to include one in the payload depends on the overall scientific objectives of the mission and the perceived cost of the investigation in relation to the scientific return. This perceived cost may be incorrectly viewed to be high because of various, perhaps misguided, approaches to the problem of magnetic cleanliness undertaken on past missions. One approach has been a program of relaxed control at the subsystem level accompanied by the use of long booms to position the magnetometer sensors far away from the spacecraft. Another approach has been to impose rather strict control on each subsystem to ensure all boxes meet a particular, often restrictive, limit. Another overly restrictive approach is not to recognize the important differences between permanent (hard) sources, stray sources due to currents powering spacecraft systems and AC sources that vary at a particular frequencies and average to zero.

The purpose of this paper is to outline an approach to magnetic cleanliness on low cost planetary missions that achieves the measurement objectives while remaining affordable. Such a program has been successfully followed on a recent Small Explorer mission. In the following sections we first examine the scientific return from such planetary magnetic field studies. Then we examine the magnetic control problems faced by large Galileo-class programs. Next we examine small missions and outline how to build an affordable magnetically clean spacecraft with examples from a recent mission.

PLANETARY MAGNETIC FIELDS

The magnetic fields in planetary environments are diagnostic of processes occurring from deep inside the planet to far above the planet, of processes occurring now and of processes that occurred billions of years in the past. The planetary magnetic field provides one of the few methods to probe the deep interior structure of the planet. The strength of the planetary magnetic dynamo is a product of the size of the dynamo region and the conductivity of the fluid core. Lack of a planetary magnetic field indicates that the interior heat sources that drive the convection engine are weak. A more sophisticated measure of the magnetic field, its harmonic content, yields a measure of the depth of the dynamo region. Since dynamos generate fields with approximately equal power in each order, and since the field strength of each higher order falls off more rapidly with radial distance, the relative harmonic content at a planetary surface is a measure of the depth of the source of the field. See for example [ref.1]. Even greater information about the core is returned if the temporal variations can be measured over a sufficiently long baseline, decades in the case of the Earth. Since the highly electrically conducting fluid in the core locks field lines into the fluid, the number of magnetic field lines into and out of the core remains constant with time. The motions of the fluid core redistribute the field lines. Thus, by watching how the magnetic field extrapolated down to the core varies, we can literally watch the fluid in the core move. Such investigations are key for future missions to Mercury, Jupiter, Saturn, Uranus and Neptune.

Magnetism, frozen into rocks as they cool through what are called blocking temperatures, gives us insight into ancient planetary dynamos on those bodies with cool silicate crusts. Samples returned from such bodies, or possibly analyzed in situ, can reveal the strength and direction of the ancient magnetizing field, and the age of the rock can reveal when the magnetizing field was imprinted on the rock. By examining rocks of varying ages, a chronology of the ancient dynamo and by inference the thermal history of the planet can be constructed. Such studies have been carried out on terrestrial and lunar rocks and are appropriate to Mars and possibly Mercury and asteroids too.

Most of the planets have active dynamos and hence, as they are termed, intrinsic magnetic fields and magnetospheres. These magnetospheres shield the planetary atmosphere from the full force of the solar wind and energize and trap charged particles. Jupiter is a particularly powerful accelerator of charged particles which in turn generate powerful radio signals. Magnetic measurements can add to our understanding of the transport and energization of these particles. In some of these intrinsic magnetospheres the moons provide the ions through sputtering and mass pickup processes. These processes in turn disturb the magnetic field. Studies of the strength and nature of these magnetic disturbances allow us to understand the strength and nature of the underlying physical processes.

The interaction of the solar wind with the unmagnetized planets and comets produces an induced magnetosphere, whose behavior in many ways resembles the moon-magnetosphere interaction. In the case of the unmagnetized planets and comets, as with several of the moons such as Titan, the loss of atmosphere is an important consequence of this interaction. Again the magnetic field is very diagnostic of the strength and nature of the processes involved. While we cannot see the effects of the solar wind interaction with planets, the solar wind interaction makes comets perhaps the most visually intriguing naked eye objects in the sky. The structure of cometary rays and the type I tail are all controlled by the magnetic field and the understanding of which should be the object of any future cometary rendezvous mission.

In summary, magnetic measurements are required over the full spectrum of planetary investigations, and to date they have been undertaken at each of the planetary bodies to which spacecraft have been sent. In the future we need to continue these studies but we need to do them in an affordable manner, consistent with the smaller resources available for the planetary program. It is indeed possible to do so as we outline below.

LARGE PLANETARY SPACECRAFT

Large spacecraft programs such as Voyager, Galileo, GGS Polar and Cassini integrate many science instruments into a single spacecraft. The science requirements for each instrument detail the desired spacecraft parameters necessary to achieve optimum science return for each instrument. The spacecraft itself has a number of individual engineering systems such as structure, power, communication, stabilization and propulsion. Each of these also have requirements for optimum performance.

To integrate such a diverse mix of science and engineering systems requires compromises by the project design team. One of the primary science requirements for a magnetometer is to produce a magnetically clean spacecraft. Fortunately it is just as easy to build most devices magnetically clean as not. Even those devices with motors and moving parts can achieve a reasonable level of magnetic cleanliness. Nevertheless, on these programs we often find systems which are not magnetically clean. Sometimes this is because there are designs and hardware left over from earlier programs that are not magnetically clean and it appears to the project to be cost prohibitive to redesign the device.

Another problem in a large program is communication. Large programs require a large number of people divided into many organizations. These organizations are controlled by a large paperwork system, and participate in many meetings and review boards which attempt to ascertain the facts and make the decisions and compromises necessary to integrate the spacecraft. Sometime the requirements are not communicated to the designer in a timely manner or the designer assumes that the requirement is not important and requests a waiver. Thus in such an environment requirements for the sciences investigations often can be compromised. Frequently, the "solution" found for the magnetic cleanliness requirements is a long boom. Galileo, a 2500 kg spacecraft, has an 11m boom. POLAR, a 1300 kg spacecraft, has a 7.2m boom.

SMALL MISSION REQUIREMENTS

Small scientific spacecraft programs typically consist of a small group, two to three, investigators working on a single science problem. The spacecraft is small with two or three tightly integrated science instruments dedicated to capturing data for the study of the defined problem. Communication is easier and the importance of meeting the magnetic (and other) requirements appreciated by all parties. Common requirements placed on the spacecraft design by the investigators produce a spacecraft system that is supportive of the instrument payload. Thus, we find spacecraft parameters tailored to support a single science mission. Less compromise is required as the instruments have similar goals and similar requirements are placed on the spacecraft.

SMALL SPACECRAFT ORGANIZATIONS

The organization of a small spacecraft program employs a small dedicated group of people working on the common goal of building a successful spacecraft that meets the science requirements. These people may work together in subgroups of two or three to solve a particular problem but are not divided into separate organizations. The group will meet as a whole to solve interface problems. Each person may be a specialist in a particular part of the spacecraft, i.e. power or communications, but each has full knowledge of this overall spacecraft design and the basic function of each subsystem.

The design will be fully documented in drawings, wiring lists and schematics. However, the intensive paperwork system of the large program is not required. Design changes are not made by processing Engineering Change Requests (ECR's). When a change is required the entire teams will meet together and agree on the change. Only the end result of this change need be documented.

EFFECTIVE MAGNETIC CLEANLINESS

Achieving a magnetically clean spacecraft is a new problem area for most engineers. Therefore, education of the project engineering team is the first priority. Topics such as how magnetic measurements are made, non-magnetic materials, compensation of parts with magnetic moments and the use of magnetic shielding materials must be explained.

Once the team has become cognizant of magnetic principles they often become quite proficient at designing non-magnetic devices. Magnetic testing of these devices at the earliest possible date is imperative. As soon as development or breadboard parts are available they should be tested to see if there are magnetic problems. If a magnetic problem can be discovered early, then corrective measures can be devised before the fabrication of flight parts has begun.

EXAMPLES OF SMALL SPACECRAFT PROGRAMS

Lunar SubSatellites. Apollo 15 and 16 each placed a small spacecraft in lunar orbit. These satellites weighing only 35 kg were designed and fabricated by a small team at TRW systems. The instruments for these spacecraft were plasma and energetic particle detectors from the University of California Berkeley (UCB) and a fluxgate magnetometer from the University of California Los Angeles (UCLA). The TRW team was able to do an excellent job of magnetic cleanliness and the sensors required only a length of 2m to reduce the spacecraft field to less than ¼nT.

FAST. The Fast Auroral Snapshot (FAST) project is one of the series of the Small Explorer (SMEX) program. The 181 kg spacecraft was designed and fabricated at NASA Goddard and is presently in final testing before launch. The project team has been quite dedicated to achieving magnetic cleanliness. The instruments for the FAST spacecraft an electric field sensors, several plasma and energetic particle instruments from UCB, Lockheed and fluxgate and search coil magnetometers from UCLA. With a boom of only 2.5m the spacecraft field is less than ½nT at the magnetometer sensor.

HERMES. The HERMES spacecraft is in the study phase for the DISCOVERY program. The proposed payload includes an imager, an ultraviolet spectrometer, a lidar, a small plasma analyzer, a plasma wave instrument, and a fluxgate magnetometer. By addressing magnetic cleanliness issues early in the design phase of this mission we have been able to meet the magnetic requirements with a minimum overall impact on the rest of the mission, and to position the magnetometer sensors on a minimal length boom.

CONCLUSIONS

Small scientific spacecraft projects have been very successful, especially from a magnetic view point. The close communication between a small project group of scientist and engineers result in a dedicated team working towards a common goal. With early training and a few magnetic testing instruments the spacecraft team can achieve a proper level of magnetic cleanliness without incurring large costs to the program.

REFEREES

1. Elphic, R. C., and C. T. Russell, On the apparent source depth of planetary magnetic fields, *Geophys. Res. Lett.*, *5*, 211-214, 1978.