The NEAR magnetic field investigation: Science objectives at asteroid Eros 433 and experimental approach

M. H. Acuña
NASA/Goddard Space Flight Center, Greenbelt, Maryland

C. T. Russell
Institute of Geophysics and Planetary Physics, University of California, Los Angeles

L. J. Zanetti and B. J. Anderson
Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland

Abstract. The NEAR magnetic field investigation is an integrated technical, scientific, and management undertaking that was selected by NASA to achieve the following goals: to coordinate and support the development, calibration, and integration aboard the NEAR spacecraft of the magnetometer facility instrument (MAG), to provide technical assistance to the NEAR project in the area of magnetic cleanliness, and to ensure maximum science data quality. The prime objective of the MAG investigation is to establish the nature of the magnetic field of 433 Eros and any detectable effects of its interaction with the solar wind. The detection of an intrinsic magnetic field would place a strong constraint on the composition and structure of the asteroid’s interior and thermal evolution. NEAR magnetometer data will be primarily available through the Johns Hopkins University Applied Physics Laboratory (APL) Science Data Center, http://sd-www.jhuapl.edu/NEAR. The basic building block of the MAG investigation is the facility-class magnetometer instrument flown aboard the NEAR spacecraft [Lohr et al., 1997]. The MAG was built as a cooperative undertaking between the Laboratory for Extraterrestrial Physics of the Goddard Space Flight Center (GSFC) and APL. GSFC provided the sensors and analog systems, and APL provided the digital processing unit and power converter as well as oversight for test and integration activities on the spacecraft. No booms or appendages were used to place the MAG sensor away from the spacecraft; instead and in analogous fashion to ESA’s Giotto spacecraft, the sensor assembly was mounted on the high-gain antenna feed structure. This arrangement results in a minimum detectable magnetic signature of 2–5 nT.

1. Introduction/Scientific Objectives

The broad objective of the Near-Earth Asteroid Rendezvous (NEAR) magnetic field investigation is to establish the global characteristics and geometry of the magnetic field associated with asteroid 433 Eros: internal, remanent, and/or surface. The detection and location of bow shock and boundary (possibly magnetopause) crossings on the flyby trajectory and surface features on subsequent orbits are secondary objectives dependent on the strengths of the moments. An important objective in characterizing the magnetic field is to determine if 433 Eros has a field comparable in magnitude with that inferred for Gaspra, another S-type asteroid, which is based on Galileo observations of draping of the solar wind field around a magnetospheric obstacle [Kivelson et al., 1993]. It is generally accepted that asteroids are the parent bodies for most meteorites reaching the Earth [Watson and Winchell, 1979; Feiberg et al., 1982]. Thus the compositional differences that are observed in meteorites are expected to reflect that of asteroids. The two basic groups that characterize meteorites, undifferentiated and differentiated, reflect the thermal history of their parent body.

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Paper number 97JB0161.
0148-0227/97/97JE-01/16/$09.00.

ies. Thus ordinary chondrites which are undifferentiated conglomerates of primitive material contain internalized grains of olivine, pyroxene, feldspar, and metallic Fe. However, no unambiguous determination of the origin of ordinary chondrites has been made or a match between a meteorite and an asteroid [Gaffey et al., 1993]. Gaffey et al. state that, “The apparent paradox between the meteoritic and the asteroid evidence concerning the origin of the ordinary chondrites is one of the most important and perplexing problems in planetary science.” Of importance to the NEAR magnetic field investigation is the Fe content and its geometry, since this may lead to the existence of a detectable asteroidal magnetic field in the NEAR orbit. The Fe content of undifferentiated meteorites is in the form of fine grains which may be randomly oriented, with strong demagnetization factors, and a significant “global” magnetic field is unlikely to result. Conversely, differentiated meteorites have experienced at least partial melting and separation of materials according to density, and iron-rich concentrations of materials are likely to result from the process [Feiberg et al., 1982; Gaffey et al., 1993]. If the cooling through the Curie point took place in the presence of a significant background field, a detectable “global” field is likely to result from these concentra-

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through shock events which can fracture and disorient the various domains, e.g., as occurring in the famous Antarctic meteorite ALH84001 from Mars [Krichen et al., 1997]. The origin of the background magnetic fields has not been established with any degree of certainty, butSuggestions and Naka-Kano [1984] have shown that fields of up to 0.3 G could have existed in the solar nebula. Thus the detection of a magnetic field at 433 Eros would immediately establish it as a differentiated asteroid with iron-rich concentrations of mass. In addition, it would provide for the first time direct experimental data concerning early igneous differentiation of planetary bodies which so far have only been studied theoretically [see Suguru and Stumpp, 1980; Gaffey et al., 1993 and references therein]. Thus the NEAR magnetic field measurements play an essential and fundamental role in the remote sensing of the composition and internal structure of 433 Eros and have direct relevance to the understanding of the early processes of formation, evolution, and differentiation of planetary bodies.

Asteroids can be classified in two generic groups according to their optical properties [Chapman et al., 1975; Gaffey et al., 1993]: the low-albedo "C" types, with neutral colors in the visible, and the "S" types already mentioned, like Gaspra and 433 Eros, which have high albedos and reddish color. The optical differences imply differences in composition and origin, and within these general groups, many other subgroups have been suggested to organize possible compositional and mineralogical differences. The S-type asteroids are thus similar to meteorites that contain silicates and metallic iron, and on this basis, the existence of a detectable magnetic field at 433 Eros is likely, particularly at the small radial distances planned for the NEAR mission orbits [see Cheng et al., this issue; Yeomans, 1995]. However, it must be recognized that the S-class asteroid mineralogy covers orders of magnitude in remanent magnetization signatures, suggesting a broad range of possible Fe-Ni content [Preston et al., 1993; Gaffey et al., 1993; Hood, 1994], and therefore significant uncertainties exist.

Intrinsic Magnetism of Eros

The extraterrestrial Gaspra observations from a distance of 250 body radii suggest the possible existence of a relatively large magnetic field at the asteroid surface, estimated to be of the same order as Earth's surface field. Recent observations of Io and Ganymede [Kivelson et al., 1994a, b] in the Jupiter system further support a reasonable expectation of an Eros 433 intrinsic magnetic field. However, a magnetic field of internal origin resulting from dynamo action in its interior is highly improbable owing to the size of the object and its dynamics, thermal history, and present state. The most likely scenario for the existence of a magnetic field is that of remanent magnetization due to prior exposure to a strong magnetic field of planetary origin, presumably the asteroid's parent body. The remanent magnetization of SNC meteorites, which are widely considered to have originated at Mars [Bogard and Johnson, 1983], suggests that Mars once had a surface magnetic field comparable in magnitude to that of Earth [Carties and Hess, 1988]. It is not unreasonable to speculate that 433 Eros may have been magnetized as part of a much larger parent body which at one time had a dynamo field [Preston et al., 1993]. Kivelson et al. [1993] estimate from their observations that the surface magnetic field of Gaspra could be as high as 1 G to a maximum of 6 G. In this study we extract a minimum dipole moment associated with the estimate to the planned orbit of NEAR at Eros (3 km), we derive values that range between 0.03 and 0.187 G at the spacecraft. Hence the magnetometer maximum dynamic range was selected to accommodate these very large values [Loët et al., 1997]. The existence of large fields at Eros would also imply the existence of an Earth-like core for this meteoroid, which could be mapped in detail with the planned orbits for the spacecraft.

Depending on the intensity of the magnetic field found, "ceiling" or "magnetization maps" size will be determined for 433 Eros. The retrograde nature of the NEAR orbit and the variable inclination of the orbit plane with respect to the axis of rotation of the asteroid [Farquhar et al., 1995; Miller et al., 1995] are ideally suited to obtain magnetic field data covering a large dynamic range in Eros' "toroidal" and "radial." This would provide an essential tool for photometric dating of the data to high degree and order spherical harmonic models which would resolve crustal structures with dimensions smaller than the orbital height above the surface. The irregular shape of the asteroid body and the orientation of the axes of rotation present special data analysis problems. For example, the spacecraft attitude, absolute and relative to the crustal thickness, anath the orbit are very different from those associated with the analysis of Maga data [Langel et al., 1982]. Thus crustal data reduction and interpretation methodologies developed in connection with this Earth's magnetic field mapping mission are not directly applicable to the NEAR mission, and new techniques are being studied and developed. C. Pararas and A. F. Cheng (Predictions of magnetic field signatures of 433 Eros, submitted to Geophysical Research Letters, 1997; hereinafter referred to as submitted paper) have simulated expected orbital magnetic signatures from an asteroid volume represented as nonoverlapping pyramids, numbering 18,236 elements. This "plate" model gives surface details certainly beyond those necessary for a magnetic field model but has enough flexibility to be used by understanding the global features of the crustal magnetization, especially for highly irregular shaped objects. Modeling of the internal field will benefit significantly from the techniques developed for planetary objects: Pioneer, Voyager, Galileo, and Mars Global Surveyor and, in particular, generalized inverse techniques [Connerny, 1981; Connerny, 1993].

Figure 1 is a conservative attempt at modeling the remanent and internal field expected from the lower limits predicted by the Galileo Gaspra measurements, extrapolated to those expected of NEAR's orbit of Eros. Two cases were investigated: (1) the orbital signature of a body centered dipole which would be independent of shape and (2) a distribution of moment density (in the same direction) throughout an oblate sphere, representative of Eros' dimensions. The schematic of NEAR observation and coordinate systems (Figure 1, left) depicts a 5 km circular orbit. Figure 1 (right) shows modeled fields as a function of orbital azimuth. Figure la shows the difference between a body centered dipole and distributed magnetization that can be hundreds of G, primarily at the poles. Figure 1b shows this discrepancy expressed as a fractional difference between the dipole and the uniform distribution. Figure 1c shows slight angular errors depending on the two models. A uniformly magnetized body gives a field significantly different from a centered dipole. Due to the nonspherical shape and continuous orbital data, it should therefore be possible to examine the distribution of magnetization throughout Eros. The C. Pararas and A. F. Cheng (submitted paper, 1987) plate model could further generalize the modeling of crustal or internal inhomogeneities. Perhaps a combination of limited-term harmonics and plate models may best represent the magnetic field of the asteroid Eros.
Eros-Solar Wind Interaction

Strong interaction of the solar wind with a body, leading to the development of a detached bow shock, ranges between two extreme cases, depending on the planetary "obstacle" deflecting the solar wind. In the case of a significant intrinsic magnetic field, the interaction is Earth-like, producing a magnetosphere with its boundary, the magnetopause, well above the surface of the obstacle. In the case of a nonmagnetized planet with an atmosphere/ionsphere (like Venus) the interaction occurs differently with the atmosphere/ionsphere inducing a magnetic tail. In the first case the object's magnetic field provides at the stagnation point sufficient pressure $P_B > P_W$ to balance the solar-wind pressure. For a nonmagnetized planet the ionspheric pressure $P_{ion} = N B_T (T_e + T_i)$ balances the magnetic pressure of the "pulled-up" interplanetary magnetic field, which in turn, is roughly balanced by the solar wind pressure.

If only a weak magnetic field exists, an understanding of the nature of the solar wind interaction with 433 Eros will be necessary to fully address the scientific objectives outlined above. An accurate determination of weak crustal fields requires the elimination of any magnetic fields associated with the solar wind interaction. The decoupling of magnetic field signatures of internal versus external origin with magnetic field data alone is a difficult undertaking, the minimum NGAS wind distance of 35 km may be too large to detect the presence of a weak field in a body of equivalent dimensions. However, it is expected that the irregular asteroid shape coupled to its rotation will assist in the detection of a modulation signal associated with the solar wind interaction (C. Parsons, private communication, 1996). This signal may be caused by either an intrinsic asteroidal magnetization vector or the modulation of the interplanetary field by a permeable or even conductive body.

The NEAR magnetometer digital processor [Loder et al., 1997] includes digital filters or "AC channels" which allow onboard monitoring of high-frequency signals and the detection of small-amplitude fluctuations in the ambient magnetic field. This may provide clues to the presence of the bow shock and other boundaries that are expected to form in front of 433 Eros in the supersonic solar wind flow. On the other hand, the orientation of the NEAR orbit plane, i.e., perpendicular to the Earth-Sun line and within 50' from the Sun [Muller et al., 1995], introduces geometric difficulties for the detection of magneto- spherical boundaries. Several possible interaction models will be studied during the cruise phase to optimize the observational strategy for weak and strong magnetic field conditions, including an analysis of magnetic field wave modes that could possibly be detected by the instrumentation in the presence of NEAR spacecraft generated signals.

Finally and for the sake of completeness, the possible existence of sources of gas or dust could conceivably produce a "comet-like" interaction where significant mass loading of the solar wind by heavy ions is produced by ionization and pickup, with the resulting generation of very low frequency ion cyclotron waves. Hunten et al. [1985] have discussed the general problem of planetary atmospheres and escape mechanisms for trapped gases in meteorites and, by induction, aerosols, and although unlikely [Yeomam, 1992], the data from the instrument AC channels may provide important clues regarding possible neutral gas production by 433 Eros.

Anticipated Scientific Results In-Flight Calibration Data:

There exist no direct measurements of the magnetic field of an asteroid in space, although a magnetic field has been inferred for Europa from Galileo observations of downstream perturbations in the interplanetary magnetic field. Recently, detection of strong magnetic fields associated with the Galilean satellites Io and Ganymede has been reported [Kiviohv et al., 1993, 1995a, b], although in the case of Io, a significant component due to induction in a permeable core may be the source of the magnetic field. Indeed, many meteorites arriving at
Earth have exhibited significant remnant magnetism, and it is not unreasonable to expect that an S-class asteroid like 433 Eros will possess a detectable magnetic field. The error bars associated with the Gauss interpretation are significant how-
ever. As shown above, the NEAR magnetic field investigation will establish conclusively the existence (or not) of an intrinsic magnetic field at 433 Eros if the signals produced by this field at the location of the spacecraft in its orbit are greater than 2-5 nT. Note that this threshold is significantly lower than the extrapolated Gauss-like field calculated above and implies a magnetic moment detection capability of approximately 6 orders of magnitude.

The direct detection of a global magnetic field at 433 Eros will provide immediate and direct information about the possi-ble composition, physical properties, and thermal state of the parent body at the moment of fragmentation or formation. Comparison with existing databases [e.g., Kukla et al., 1991; Pesonen et al., 1993] will allow an immediate classification and association with established classes of similar objects and their potential origin, although the role of potential mag- netic contamination of terrestrial samples must also be taken into account (P. J. Wassertein, personal communication, 1996).

If a significant field exists, the magnetometer facility instru-
ments (MAG) will determine its characteristics and geometry and study its interaction with the solar wind. It is not anticipat-ed that a global field would be the result of a presently active dynamo but rather a remnant of the field of a parent body. The existence and characteristics of an asteroidal global magnetic field remain an open question in spite of the Guillochon inferences about Gauss and the extensive study of meteorites on Earth.

Spherical harmonic analysis of the data will allow the determi-
nation of whether the object is uniformly magnetized or is an aggregate of many individual magnetized components with different orientations. If we assume that our observations are characterized by a random noise component of 1-2 nT mag-
nitude, a subset of 20 high-inflation orbits at a radius of twice the object's largest dimension (35 km) is sufficient to deter-
mine spherical harmonic coefficients to degree and order 6. The associated parameter standard deviation range from < 1 nT R° for the dipole (g7) to ~50 nT R° for representative sixth degree and order coefficients. Uninformative magnetization will remain unmeasurable even at R° 3 (4 x10^11 G cm) may be characterized with such a sample of observations. If realizable, this would extend the level of detection capability to 4 orders of magnitude above that implied by the Gauss observations, a rather significant margin.

This crude estimate of the minimum detectable moment depends critically on the properties of the "noise": the inhomogeneity, that is, the characteristics of the relatively large and variable field due to the solar wind interaction with the planet's atmosphere (or interplanetary field as well as the noise contributed by the NEAR spacecraft. The ability to achieve a "random" noise component of the order of 1 nT after averaging by no means assured. Alternatively, we may achieve some degree of success in the removal of systematic ("nonrandom") fields at-
tributed to the solar wind interaction after careful study and modeling of spacecraft sources.

The results of preliminary calibration work performed on the data acquired during cruise fully support this expectation. During the development phase, testing of the spacecraft was conducted to assess and compensate for the background per-
manent moment which was due primarily to the latch valves of the propulsion system. The MAG Team participated in the circuit layout for the solar panels, which were not backdropped, but arranged in symmetric, half-loop strings. The location of the magnetometer sensor along the symmetry axis of the pin-
cils and the orientation paid to the wiring geometry minimized imbalance and magnetic interference. Power management cir-
cuits (1.3 kW power system) also received design input from the MAG Team. Interference to the MAG has been deter-
mined to be primarily from the shunting circuits, used to dump excess power. The second major source of interference to the magnetic field measurements was determined to be the field generated by a set of open loops on the terminal board which distributes power to the subsystems. Hence there were circuits were tested, simulated, and tested to establish their magnetic signature as a function of engineering data available in the telemetry stream. A dynamic spacecraft magnetic model is in a preliminary state of development, but initial results already allow the compensation of subsystem thermal effects, typically generating 5-10 nT step function signals in response to activation events. The model also compensates for the more difficult problem of solar array dynamic switching currents and can now remove 2-3 nT amplitude and minute timescale noise.

The results of this work are illustrated in Figures 2 and 3. Figure 2 shows raw magnetometer data compared to WIND magnetic field data when both WIND and NEAR were in the vicinity of Earth shortly after launch. Cheng et al. [this issue] shows the relative locations of the WIND and NEAR space-
craft after launch. Figure 2 is a composite of NEAR MAG data on the top panel (R, Bx, and Bz, in spacecraft coordinates), while the bottom panel shows the WIND magnetic field investigation key parameters for the same time period (B, Bx, Bz, in geocentric equatorial coordinates). These data averaged data cover a few days from April 27 to 28, the first recording period for the NEAR MAG instrument. The oppor-
tunity exploited here is the Sun-Earth line conjunction of NEAR with WIND; the timelines of Figure 2 have been shifted by about 1 day, the approximate and average shift required for the travel time from 1.0 AU (WIND) to 1.25 AU (NEAR). Although in different coordinate systems, many of the bary-
timescales features look qualitatively similar in both data sets, a simplistic but encouraging observation which places an imme-
diate upper limit on the actual noise envelope generated by the spacecraft. A typical barycentric interstellar coordinate signature is noted with arrow in the Bx, which is offset at about 1200 UT on April 28; most of the other signals are not as obvious. Initial results of the application of the spacecraft model are shown in Figure 3, which illustrates the measurements (in spacecraft coordinates) of the interplanetary magnetic field taken on June 18–25, 1996. The magentometer data have been truncated and are simultaneous to the available time resolu-
tion of the housekeeping data (10 min). The two traces provide an example and partial correction for spacecraft effects, spe-
cifically the motion of the spacecraft body (arrows in Figure 3) and the higher frequency analog shunt noise. It is evident from the figure that the noise level has been reduced to about 1 nT, a factor of 5 below the stated goals for the investigation. It is important to note that a large (~170 nT) baseline offset has been subtracted from the data in both Figures 2 and 3, which is only known to a level of about 10 nT at this time. The final estimates of this offset will be derived from further calibration data and the application of traditional statistical techniques to
interplanetary data, including correlative observations during the Earth flyby in January 1998.

2. Investigation Approach

The basic approach followed for the NEAR magnetic field investigation is consistent with the broad responsibilities and guidelines delineated by NASA for Discovery-class investigations:
1. Support the hardware development, test, and integration of the MAG.
2. Develop plans for and support in-vacuum calibration activities, both prelaunch and postlaunch.
3. Develop algorithms for data processing and reduction of science data sets to support the activities of the Science Teams and to ultimately be deposited in the Planetary Data System.
4. Carry out initial data analysis efforts after NEAR arrival at Eros in 1999.

A basic element of the Discovery concept is the “focused science” approach. This is a rather challenging concept, since it is based on an essential trade-off between “quality” and “quantity”. The completeness of science investigations is traded off against low cost and frequent access to an objective. NEAR is thus the first spacecraft to test this concept, and it is clear that we have not yet achieved the optimum compromise. It is therefore useful to explore the NEAR magnetometer field investigation implementation of the four basic Discovery requirements in more detail below.

Support the NEAR MAG hardware development, test, and integration. As stated above, a full description of this instrument has been given by Lehr et al. (1997), but for completeness, we show a block diagram in Figure 4. The NEAR instrument is the latest of a series of joint magnetic field investigation development efforts conducted by the research groups at Goddard Space Flight Center (GSFC) and Johns Hopkins University Applied Physics Laboratory (APL) and represents a synergistic utilization of experience skills and resources at both institutions spanning many years and a multiplicity of planetary, interplanetary, and Earth-orbiting missions.

The basic configuration for the MAG consists of a single wide-range triaxial fluxgate sensor mounted on the antenna feed support structure. This configuration, although not optimum for high sensitivity and weak field measurements, was considered adequate for the more focused objectives of the NEAR mission. Implementation of this experiment without stringent magnetic controls (which usually includes a long deployable boom) lowers the cost of accommodation requirements as well as the total spacecraft mass but at the expense of a more complex data reduction effort. A similar configuration
was used in the Giotto mission [Neubauer et al., 1986] to successfully detect, map, and characterize the magnetic fields associated with comet Halley and its interaction with the solar wind. These limited objectives are fully supported by the discussion presented above concerning the expected magnetic field signatures based on the interpretation of Galileo measurements at Gaspra.

A diagram illustrating the internal functional blocks of the instrument is shown in the work by Lohr et al. [1997]. The NEAR MAG is capable of operating over a very large dynamic

![Diagram](image)

Figure 4. Block diagram of the NEAR magnetic field investigation. Owing to spacecraft resource limitations, the triaxial sensor assembly was mounted inside the antenna feed structure as shown. The data processing unit is shared with other instruments on the spacecraft.

![Graphs](image)

Figure 3. Six days of NEAR magnetometer instrument data (June 18–23, 1996) in spacecraft coordinates, ±15 nT with baseline removed. Corrected data have preliminary spacecraft interference model subtracted.
range of field measurements, from ± 5.4 mT to ± 65.5 mT full scale in eight automatically selected ranges. A 20-bit, sigma-
Delta AD converter is used to digitize the internal data at a rate of 20 samples/s and to provide input to the digital filters. The telemetry resolution is 16 bits for the magnetic field data and 8 bits logarithmic for the AC filter outputs. The upper range of ± 55.5 mT may be required if an unusually strong magnetic field is encountered at 433 Eros. The maximum res-
olution achievable with 16-bit digitization and the magnetom-
eter dynamic ranges are shown in Table 1. The bit rate as-
signed to the NEAR magnetometer varies throughout the mission but averages 80 bits/s. Total mass and power consump-
tion is 1.3 kg and 1.5 W, respectively.

Development and flight instrument calibration activi-
ties, both prelaunch and postlaunch. The planning and ver-
ification of the prelaunch calibration of the NEAR magnetom-
eter instrument was an intrinsic responsibility of the selected Team Leader as part of the cooperative implementation agree-
ment between APL and GSFC. The GSFC Magnetic Test Facility was used prelaunch to calibrate the instrument and fully characterize its performance, including the determination of intrinsic zero levels, dynamic characteristics, angular alignment, etc. However, the strong resource constraints associated with the Discovery-class NEAR mission precluded the imple-
mentation of a detailed magnetic cleanliness program at the spacecraft system level.

Spacecraft maneuvers constitute a powerful calibration and diagnostic tool for magnetic field experiments. During the an-
ter mapping phase, spacecraft roll maneuvers will be per-
formed which can be used to advantage to establish indepen-
dently the magnetic field direction of the spacecraft field and sensor offsets. Periodic short-term activation of the MAG dur-
ing the cruise phase has allowed the acquisition of limited periods of interplanetary magnetic field data, as discussed con-
cerning Figures 2 and 3. It is well known that the dynamic variations of the interplanetary magnetic field are character-
ized primarily by Alfven structures, that is, changes in field direction rather than magnitude. Once spacecraft effects are removed, this feature makes possible the application of ad-
vanced statistical techniques developed for outer planet mis-
sions for estimating magnetometer biases and angular align-
ment (M. H. Acuña, In-flight linear estimation techniques for vector magnetometer biases and angular alignments, submit-
ted to IEEE Transactions on Magnetics, 1996). The spacecraft dynamic field model already shows a great deal of commonality with the elements developed by the GSFC group for the Mars Observer (MO) mission since the sources of dynamic fields on the MO and NEAR spacecraft are very similar (i.e., power system, home hall fields). Redundant factors of 30-40 were achieved with these techniques during the MO cruise phase (J. E. P. Connery and T. Reyes, private communication, 1996).

New algorithms for data processing and reduction of science data sets. The data processing approach and algo-
rithms developed for the NEAR magnetometer instrument reflect the cost-constrained mission operations and data acqui-
sition concepts required by NASA for Discovery-class mis-
tions. The data acquired since the launch of the NEAR space-
craft show that the MAG is operating nominally and detecting spacecraft dynamic signatures with amplitudes in the 2-10 nT range, as expected. A large fraction of the instrument checkout software was transferred to the flight data processing environment without requiring new developments, thus realizing sig-
nificant cost savings. This approach ensured early access to the

<table>
<thead>
<tr>
<th>Range</th>
<th>Maximum Field, nT</th>
<th>Resolution (nH)</th>
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<tbody>
<tr>
<td>0</td>
<td>± 1.256</td>
<td>± 0.002</td>
</tr>
<tr>
<td>1</td>
<td>± 4.104</td>
<td>± 0.008</td>
</tr>
<tr>
<td>2</td>
<td>± 6.096</td>
<td>± 0.012</td>
</tr>
<tr>
<td>3</td>
<td>± 1.536</td>
<td>± 0.015</td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>7</td>
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<tr>
<td>8</td>
<td>± 6.096</td>
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*Limited by instrument noise to 0.001 nT.*

A general data flow diagram of the NEAR MAG data pro-
cessing and analysis system is shown in Figure 5 and is included here for reference. This diagram illustrates some of the typical processing required to interpret experiment data packets and translate raw data into calibrated geophysical parameters; it does not illustrate subsequent science data analysis, which may be performed elsewhere by magnetic field investigation team members. The architecture is organized about the basic data blocks (packets) extracted from the spacecraft data stream and transmitted to the NEAR Science Data Center [Cheng et al., this issue]. The instrument nominal operation transmits pack-
ets of magnetometer data, while engineering data packets must be extracted from the spacecraft data stream. Both kinds of data packets contain sufficient instrument health and status information about the performance of the instrumentation, which will be continuously monitored by the NEAR Mission Operations Center. The raw data in the MAG packets are processed to yield a continuous time series of magnetic field vectors at the appropriate temporal resolution corresponding to the spacecraft telemetry mode. In either case, supplemen-
tary engineering and ancillary data are associated with the experiment data and formatted for graphical display and sub-
sequent science analysis and archival.

The data volume expected from the NEAR MAG is a rather modest 0.6 Mbytes per day of operation and can be easily handled with the approach proposed above. At the present time the magnetic field investigation team is participating in the definition of Planetary Data System archiving require-
ments and interface documentation. The goal of this effort is to deposit validated magnetic field investigation science products in the Planetary Data System archive within 6 months of data acquisition. It is expected that the NEAR MAG will operate continuously and will not require detailed day-to-day planning of observations or command operations.

The initial data analysis efforts at arrival at 433 Eros in 1999.

A primary objective of subsequent science analysis af-
ter arrival at Eros is to characterize any magnetic field asso-
ciated with the asteroid, whether it is best described as a "global" field or as a set of discrete distributed sources. Thus a variety of techniques may be necessary to effectively distinguish be-
 tween these sources. This paper will include extensive averaging of fields from one orbit to another, selection of data to reduce noise, for example, by spacecraft local time, explicit modeling of the solar wind interaction, and so on. Globala fields will be characterized by spherical harmonic models [Connerney, 1981].
and local fields by crustal magnetization models (Mayew and Galliher, 1982; Mayew et al., 1985; C. Paranicas and A. F. Cheng, submitted paper, 1997), if applicable, most likely applied simultaneously to a subset of the globally distributed data in a combined inversion. A significant body of experience in analyzing magnetic field data from orbiting spacecraft exists from Earth missions like MagSat to those to the outer planets, where the same problem of establishing characteristics of unknown magnetic fields has been successfully solved at Jupiter, Saturn, Uranus, and Neptune.

3. Outreach and Education

In recent years the Internet and the World Wide Web have become primary tools for the rapid dissemination of important scientific results from space missions to both expert and non-expert groups. A variety of educational and data visualization tools have been developed and made available through this medium, which provides unique and important opportunities for educators, students, and the general public to participate in the mission and share the scientific results. The NEAR magnetic field investigation team fully supports these activities with “home pages” and associated informational material and public access data on the World Wide Web (http://nssdc.gsfc.nasa.gov).

4. Summary

The NEAR magnetic field investigation and facility instrument represent a challenging example of the concepts involved in the new NASA Discovery approach because of its need for strong interaction with spacecraft and system designers. The severity cost constrained approach resulted in the implementation of the MAG with approximately 1/25th of the resources allotted to the entire instrument suite, including a modest, although commonplace, magnetic control program. Extrapolation of the Gaspra magnetic field inferences from Galileo to the orbit of NEAR at Eros shows that this limited implementation approach is more than sufficient to detect an intrinsic field at the asteroid, if one is present, with at least 2 orders of magnitude margin in detection capability. The magnetometer instrument sensor and electronics itself are typical of previous interplanetary GSFC magnetometers, approaching picotesla noise levels and 5σ offset drifts over mission lifetimes, hence the instrument itself will not limit the sensitivity of the measurements at Eros rather the spacecraft magnetic interference
will dominate the uncertainty budget. The three-axis sensor is body mounted on top of the feedthrough of the high gain antenna structure, similar to the Giotto installment. The antenna’s sensitivity for 1-mit from the major interference signals is about 3 dB in power, including solar panel generated fields. Solar panel circuits as well as full bus current loads were balanced and compensated where possible, dynamic interference was kept to the 5-10 nT level observed during test evaluation and in flight, as was the goal of the original mission requirements.

Preliminary in-flight calibration data taken from April to August 1996 in the vicinity of Earth have shown significant offset fields from the spacecraft which are very steady and therefore removable. Other spacecraft induced fields from various current loops produce sensor fields of the order of 5 nT each and confirm test and calibration results performed before launch. A preliminary spacecraft dynamic field model using spacecraft engineering data has been successful in removing the effects of many interference sources, indicating that noise levels of 1 nT RMS are achievable. Cross correlation with data from the WIND spacecraft has provided a qualitative assessment of higher frequency noise spectral characteristics above the 0.2 nT level. Many features of the NEAR magnetometer data at the 1 hour timescale show transverse signatures which are tantalisingly similar to WIND, even over the 0.2 AU separation distance between the spacecraft, providing a reassuring upper limit to the spacecraft-generated noise.

Modeling of the intrinsic magnetic field of Eros will make use of the extensive experience available from Asteroid missions. Clearly, the application of particular techniques will depend on the discovered field strength and its geometry. The fact that NEAR will remain in close orbit around 433 Eros for 1 year will greatly assist the identification and modeling effort. Such orbital advantage allows the separation of the intrinsic asteroid magnetic field signals from the spacecraft as well as solar wind effects. We examine the effects of a new mangement technique and coordinate transformations to code fixed systems. The NEAR magnetic field investigation was designed to address the fundamental objective of establishing the existence of a magnetic field of internal origin at Eros at the lowest possible cost. The early results from the mission fully support the approach and difficult trade-offs that were necessary to implement the investigation. Based on this assessment, the NEAR magnetic field investigation should be able to fully achieve the primary science objectives at Eros.

Acknowledgments.

The authors and NEAR Science Team wish to acknowledge the extensive contributions of the NEAR engineering teams, particularly the unprecedently sched of 26 months from project go-ahead to launch in February 1996. We wish to thank the NASA/Discovery management of Headquarters for their support of this mission. We acknowledge the dedicated Mission Operations Team for the data already delivered and those to come.

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M. H. Acha, NASA Goddard Space Flight Center, Code 695, Greenbelt, MD 20771.

(Received October 10, 1996; revised April 2, 1997; accepted April 25, 1997.)

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