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The Giotto Magnetic-Field Investigation

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Abstract

The main objective of the Giotto Magnetometer Experiment is the investigation of the interaction between Comet Halley and the solar wind at a distance of 0.9 AU from the Sun, to within 500 km of the cometary nucleus. A second objective is the study of the interplanetary magnetic field.

The instrumentation consists of a triaxial and a separate biaxial system of fluxgate sensors of the ring-core type, the associated analogue electronics and a digital processor. The measuring ranges of +/- 16 nT, +/- 64 nT, etc., up to +/- 65536 nT are digitized by a 12-bit analogue-to-digital converter, allowing a sampling rate of 28.24 vectors per second at encounter. Memory modes allow the bridging of gaps in telemetry coverage of up to ten days. The total mass of the instrument is 1360 g and its power consumption 820 mW.

Because of the dust hazard near closest approach, a magnetometer boom could not be included in the spacecraft’s design. The resulting magnetic-contamination problem was attacked by the use of two magnetometers and by a magnetic-cleanliness pro-

gramme.

First in-flight results show that the instrument itself is working flawlessly, though some magnetic-contamination problems remain.

1. Scientific Objectives

The primary objective of the Giotto Magnetometer Experiment is to study the interaction between the magneto-plasma of the solar wind and the ionosphere-neutral-atmosphere system of Comet P/Halley. The most important data for this study will be obtained during the second half of 13 March 1986, on the inbound pass, until closest approach shortly after midnight early on 14 March 1986. Nevertheless, precursor phenomena can be expected up to a few days before encounter. If the spacecraft should survive its flyby of the cometary nucleus, the outbound pass will provide additional important data in view of the asymmetry of the interplanetary magnetic field with respect to the direction of incident solar-wind flow.

The ideal situation for the study of the flow interaction between any planetary body and a streaming plasma would be provided by a two-spacecraft mission, with one spacecraft passing through the flow system and the second monitoring the solar wind upstream of the planetary body. In the absence of such a second spacecraft, it is mandatory to study the solar wind around the time of the encounter. In this sense, solar-wind studies are a primary objective of this mission. In addition, the mission is of appreciable interest for studying the interplanetary medium per se, because of the cluster of interplanetary spacecraft performing simultaneous measurements.

Finally, the discussion of scientific objectives would be incomplete if the possibility of a magnetic field internal to Comet Halley were ignored.

1.1 Interaction between Comet Halley and the Solar Wind

The encounter between Giotto and Comet Halley will occur at a distance of 0.89 AU from the Sun, after the comet has passed perihelion on 9 February 1986. The magnetoplasm of the solar wind will then be interacting with the well-developed atmosphere-ionosphere system of the comet. Figure 1 shows the classical picture of this interaction (Wallis, 1973; Schmidt & Wegmann, 1982; Ip & Axford, 1982), together with the flyby trajectory of the spacecraft. The flyby occurs from dusk to dawn at a solar phase angle of 107deg and a relative velocity of 68 km/s.

In the classical picture, the neutral gas of the comet is initially expanding radially away from the nucleus with a velocity of about 1 km/s. Ions with these slow initial speeds are produced by ionization of cometary neutrals due to EUV-radiation from the Sun and hot electrons, and by charge exchange with solar-wind ions. These ions are then picked up by the motional electric field of the local magneto-plasma, which is provided by the frozen-in field condition. In this mass-loading process, the solar wind contaminated by cometary ions is decelerated. In the classical picture a relatively weak shock forms. After passage through the bow shock, the flow is further decelerated and deflected around the inner coma region by a contact surface provided by a pressure balance between the inner ionospheric plasma of cometary origin and the outer magneto-plasma consisting of solar-wind and cometary ions. In this picture, the

Figure 1. The Giotto encounter trajectory and the classical picture of the interaction between Comet Halley and the solar wind

magnetic field undergoes a process called ’draping’, in which the deceleration of the plasma near the comet leads to a lag in the portions of the field line near the comet relative to the distant portions. The kinematic process leads to field-line configurations reminiscent of hair-pins. The draping process was proposed by Alfven to explain the tail ray formation as early as 1957. Also the ion pickup process, with its associated non-equilibrium distribution functions, has been proposed as a source of several plasma instabilities generating electromagnetic and electrostatic wave modes (e.g. Winske et al., 1985).

The general picture just described has been confirmed in several aspects by the flyby of the International Cometary Explorer spacecraft at Comet Giacobini-Zinner (G - Z) on 11 September 1985. The draping process has been confirmed, with magnetic fields as high as 55 nT in the induced tail of the comet (ICE Press Conference; personal co-munications by E.J. Smith and J.C. Brandt, 1985). Although the transition from supersonic to subsonic flow occurred at the expected distance of 1.4 x 10**5 km from the tail-axis, it was not connected with a shock of familiar signature. Among the other unexpected results were the discovery of high-energy particles with energies that cannot be explained by the pickup process alone, and the occurrence of strong magnetic-field turbulence up to the Nyquist frequency of the ICE magnetometer experiment of 1.5 Hz. It is very probable that these observations are related. We note that the flyby trajectories for P/Halley and P/G-Z are very similar in the cometary frame of reference at large distances from the comet. At closer distances, the differences are significant in that the point of closest approach will be at 500 km sunward for Giotto, in contrast to the 8000 km tailward for the ICE mission.

Comet-like interactions have been observed before, most extensively by the Pioneer-Venus-Orbiter mission (e.g. Russell & Vaisberg, 1983; Cloutier et al., 1983). but also during the Voyager-1 encounter at Titan on 12 November 1980 (Ness et al., 1982; Neubauer et al., 1984).

At Comet Halley we expect a much larger interaction region with the solar wind compared with P/G-Z, due to the much larger gas production rate. This is expected to lead not only to quantitative, but also to qualitative differences from Comet G - Z. On Giotto, the region close to the comet will be particularly interesting, as a contact surface at a distance of several 1000 km is expected, enclosing a volume with zero magnetic field inside the cometary counterpart of the Venus ionopause.

The following sequence of events is then expected under average solar-wind conditions. High-energy particles of cometary origin will excite electromagnetic wave modes which may already be ’seen’ two days before encounter. The shock or ’shock-like’ transition region is expected at about 1.1 X 10**6 km from closest approach, i.e. 4.5 h before minimum distance to the nucleus. We then expect highly turbulent regions with an increase in magnetic-field magnitude towards the magnetic field pile-up region on the sunward side of the nucleus. At about 1 min before closest approach, we may encounter the cometary ionopause or contact surface, with an abrupt decrease of the field from more than 100 nT to zero. In the field-free region, we may also be able to observe the cometary counterpart of flux-ropes detected at Venus (Russell & Elphic, 1979). The value of the inbound observations would be more than doubled if outbound observations were also available.

As far as the turbulence in the cometary magnetosheath is concerned, we note that many interesting wave modes are confined to frequencies well below the lower hybrid frequency. One of the important length scales is a thermal ion gyro radius for other investigations. The frequency resolution of the experiment must then be adequate to resolve the resulting time scales along most of the encounter trajectory. The main objectives are then:

(i) study of precursor wave phenomena far from the comet
(ii) identification and investigation of plasma boundaries, i.e. the bow shock or its cometary counterpart, the cometary ionopause, etc.
(iii) investigation of plasma turbulence
(iv) study of plasma phenomena related to optical observations from the ground.

1.2 Interplanetary magnetic-field studies

We have already mentioned the importance of knowing the solar-wind conditions in the region of space around the comet close to the time of encounter. For example, in order to assess the complete history of a typical neutral-gas molecule, from its time of release from the surface of the nucleus to the time when it loads the solar wind at 10**6 km from the nucleus, we need to know the solar wind incident on the comet for about 9 days. Extending this argument, a period of solar-wind observations during at least one solar rotation before encounter is necessary.

Also, the encounter at Comet Halley will occur at a time of solar minimum, when the solar wind is expected to be dominated by a few stable high-speed streams issuing from well-defined coronal holes. The magnetic field will be dominated by a well-defined sector structure. Although the solar-wind structure near 1 AU has been studied in detail in the past, the cluster of spacecraft now aimed at Comet Halley provides a unique opportunity to study it with a two-dimensional array in the ecliptic. Potential contributors to such a study are the ICE, Vega-1, Vega-2, Planet-A, MS-T5 and Giotto spacecraft. Obviously, such a study requires adequate telemetry coverage for these missions.

The primary objectives can then be summarized as follows:

(i) establishment of the solar-wind magneto-plasma environment of Comet Halley for several weeks before encounter

(ii) study of solar-wind macrostructure of co-rotating and propagating features.

1.3 The possibility of an internal magnetic field for Comet Halley

Because of its cosmogonic significance, it is worthwhile discussing briefly the possibility of Comet Halley possessing an internal magnetic field, and its possible detection. The only possibility seems to be that the dust component of the nucleus possesses some natural remnant magnetization. If, for example, the cometary nucleus had accreted in a strong magnetic field, such magnetization could have been produced by a process analogous to depositional remnant magnetization in palaeo-magnetism. The degree of magnetization would depend on the chemistry and structure of the accreting grains and the primordial field. Since these inputs are not known, let us assume for simplicity that the nonvolatile component of the cometary nucleus has an extreme magnetization corresponding to 10**-3 emu/g, which is high for values measured in meteorites. In second Gaussian position, this would lead to about 200 nT on the surface of the nucleus, if we assume a dipole field due to uniform magnetization. With a radius of 1.5 km for the nucleus of Comet Halley, the distance of closest approach would have to be 7 km (!) from the centre for the magnetic field to be marginally detectable. We therefore conclude that the establishment of at least a useful upper limit on the magnetization of the nucleus must await a close approach by a rendezvous mission.

2. The Instrumentation

The design of any scientific instrument must take into account the scientific objectives of the investigation and the spacecraft’s resources, such as mass, power, telemetry rate, telemetry coverage assigned to the experiment, and contamination of the measurements by the spacecraft environment, as well as details of the implementation of the development and test programme on the ground.

In the case of the magnetometer investigation, the scientific objectives led to several requirements. Our objective is to resolve electromagnetic plasma waves up to the lower hybrid resonance frequency under reasonable magneto-plasma conditions and to resolve spatial scale lengths down to several ion gyro radii at the flyby velocity of 68 km/s. The maximum sampling rate of 28.24 vectors per second used during encounter fulfils this requirement reasonably well. Because of the modest expected telemetry coverage during cruise to the comet and the short time interval of 4 h identified as the encounter phase proper, the inclusion of an experiment memory was considered absolutely necessary at the time of experiment design.

The measuring ranges of the experiment are determined by the necessity to observe the interplanetary magnetic field before the encounter, with an average magnitude of 5 nT, and the maximum fields expected near the comet of several 100 nT. Since ground testing of a magnetometer experiment designed for the observation of weak fields is generally difficult because of the presence of the geomagnetic field of about 50 000 nT at intermediate latitudes, measuring ranges up to +/- 65 536 nT were included for test purposes.

The quantization uncertainty of the analogue-to-digital conversion process is given by the requirement that the associated errors should not diminish the overall accuracy in the most sensitive ranges. Hence 12-bit analogue-to-digital conversion has been selected.

Very severe limitations were set by the mass and power assigned to this experiment, together with the grim magnetic-cleanliness situation. Consequently, it was not possible to include any hardware redundancy in the experiment. Hence the hardware's reliability is lower than that of other magnetometer experiments, such as those on the Voyager mission and the coming Ulysses mission, for example. To achieve satisfactory reliability, simple design, limited operational redundancy, particularly careful workmanship and careful parts selection have been emphasized.

The Giotto spacecraft has been designed to reach an encounter distance of several 100 km without being destroyed by the flux of dust particles at a relative speed of 68 km/s. This has been achieved by employing a dust shield, which is also shown in Figure 2. This design also precludes any protruding spacecraft appendages such as a magnetometer boom. The two magnetometer sensor systems (MAG-1 and MAG-2) are therefore mounted on the antenna tripod carrying the feed for the despun antenna disc and the omni-directional antenna, as shown in Figure 2. In the early phase of the project, when the baseline design contained only one sensor system (MAG-1), it became clear that the magnetic contamination of the measurements at the position of MAG-1 would be worse than expected. The project agreed to add an additional sensor system (MAG-4) to reduce the pressure on the magnetic-cleanliness specifications. The slight mass increase was absorbed by the agreement of the magnetometer team to provide also certain experiment interface units which had previously been included in the mass budget of the spacecraft system. The evolution in the magnetometer experiment's design has been described previously by Neubauer (1981) and Neubauer et al. (1983). In contrast to other space projects involving magnetometer experiments, the magnetic-cleanliness programme on Giotto was largely the responsibility of the magnetometer team. It will be described in Section 3.

Figure 2. The Giotto spacecraft, showing the outboard triaxial sensor system MAG-1 ad the inboard biaxial sensor system MAG-4 mounted on the antenna tripod

Owing to the severe power and mass limitations, the only type of magnetometer that could be used was a fluxgate magnetometer of the ring-core type, with its superior performance in terms of low noise level and high zero-stability, and its low mass and power consumption. A schematic of the Giotto Magnetometer Experiment, which will be explained in detail below, is shown in Figure 3.

The Experiment consists of three hardware units, aside from the various connection cables. The magnetometer electronics box, referred to as MAG-2 in project parlance, is mounted on the underside of the top spacecraft platform. It contains the magnetometer electronics proper and the digital processor. Two fluxgate sensor Systems, MAG-1 and MAG-4, are mounted on the antenna tripod. The main MAG-1 magnetometer is a triaxial fluxgate magnetometer. The additional magnetometer, MAG-4, is a biaxial one with an axis parallel to the +Z(M) axis of the spacecraft and an axis in the X(M) Y(M) plane parallel to one of the axes of the outboard magnetometer MAG-1. The five magnetic-field components are referred to as XOB, YOB, ZOB, XIB and ZIB, with OB meaning outboard and IB meaning inboard. The temperatures of

Figure 3. Schematic of the Giotto magnetometer experiment

Table 1. Mass breakdown for the Giotto Magnetometer Experiment

Subunit	Mass* (g)
Electronics box MAG-2	935
Outboard magnetometer MAG-1	304
Inboard magnetometer MAG-4	118
Total	1357

* Without interconnection cables, but with
'pig-tails'

Table 2. Power consumption breakdown for the Giotto Magnetometer Experiment

Experiment portion	Power cons.* (mW)
Sensors and magnetometer analogue electronics (in range)	478
Digital processor	340
Total for 'in-range' conditions	818
Total for all components 'over-ranged'	1130

* Including DC-DC converter

the MAG-1 and MAG-4 magnetometers are monitored by thermistors in their housings. The temperature at MAG-2 is monitored by a spacecraft thermistor. Mass and power breakdowns for the experiment units are shown in Tables 1 and 2, respectively.

Within the Magnetometer Experiment team, the magnetometer sensor units and the analogue electronics boards were provided by the Goddard Space Flight Center (GSFC) team. The Technical University of Braunschweig provided the digital processor, whereas the University of Rome procured the experiment ground-support equipment for the test phase and limited quick-look data analysis. A data station for advanced quick-look analysis and data interpretation has been provided by the University of Cologne group.

2.1 1 Fluxgate magnetometer system

The Giotto Magnetometer Experiment had to be of a completely new design because of the stringent mass and power limitations, though it follows the design principles of the highly successful Voyager magnetometer experiment (Behannon et al., 1977; Acuna, 1974).

In all fluxgate magnetometers, a ferromagnetic core of soft magnetic material is periodically driven into saturation by the magnetic field of a drive coil, which is energized by a periodic current form of suitable shape at the drive frequency f(0) 15.1499 kHz in the case of Giotto. The drive coil, the magnetic core and an additional sense coil form a transformer in which the sense coil picks up a voltage at the drive frequency f(0) and ideally its odd harmonics only, if no ambient field is present. In the presence of an ambient magnetic field component H(a) parallel to the sensitive direction of the sense winding, even harmonics show up. In reality, a small zero-offset exists, corresponding to small-amplitude even harmonics at zero ambient field. To obtain the magnetic-field component H(a), the second harmonic at 2 f(0) is generally used, with an amplitude proportional to the ambient H(a) component just defined. To improve linearity, the sense-coil output is used to control the current through a feedback coil, which produces a magnetic field compensating the ambient field. In this respect, the sense coil output is used to detect a zero resultant field.

A functional block diagram, which also applies to the Giotto Magnetometer Experiment, is shown in Figure 4 for one axis. In Giotto's case the sense and feedback coils are physically identical, because the sense signal around 2 f(0) and the feedback signal are well separated in frequency.

At the time of procurement for the Giotto magnetometer, the magnetic material used in the ring-core sensors was the latest in a series of advanced molybdenum permalloy alloys, which have been especially developed for low-noise, high-stability applications

Figure 4. Functional block diagram of the fluxgate electronics for one component

by the GSFC group and its subcontractors. The Giotto sensors, therefore, show a factor 1.5 improvement in noise characteristics over the Voyager sensors. Use of these alloys and the ring-core geometry allowed the development of a compact, low-noise and low-zero-drift instrument with low power consumption. Over the range of operating temperatures from -50deg to +60deg C, the zero stability turned out to be +/-0.2 nT in laboratory measurements. The noise level is better than about 0.003 nT rms in the experiment bandwidth of 0-15 Hz. The ring-core sensors and associated coils are mounted in lexan structures, with glass-fibre housings metallized on the inside to reduce interference problems.

Table 3. Nominal measuring ranges of Giotto Magnetometer Experiment

Range	Dynamic range (nT)	Quantization uncertainty (nT)
R1	+/- 16	+/- 0.004
R2	+/- 64	+/- 0.016
R3	+/- 256	+/- 0.063
R4	+/- 1024	+/- 0.25
R5	+/- 4O96	+/- 1
R6	+/- 16384	+/- 4
R7	+/- 65536	+/- 16

The resistance in the feedback circuit determines the instrument's sensitivity, i.e. the constant of proportionality between the magnetic-field component H(a) and the voltage U(a) in Figure 4. Nominally, it is given by R(F). Range switching is achieved by changing the resistivity of the feedback circuit by electronic switching of various resistors. The Giotto magnetometer experiment has seven measuring ranges, noted in Table 3. More precisely, the outboard magnetometer can make use of the seven ranges R1,... R7, whereas the inboard magnetometer is in range R3 whenever the outboard magnetometer is in R1, R2 or R3, and in the same range as MAG-1 for all less-sensitive ranges.

The quantization uncertainties due to the 12-bit analogue-to-digital conversion have also been included in Table 3.

The ranges used are controlled by the digital processor of the experiment. They can either be set 'manually' by telecommand to a selected range, or be determined by a digital processor subprogram in automatic mode. In automatic mode, selected by telecommand from the ground, the range can be adapted to the measured magnetic field every eighth frame (see below) during real-time data transmissions. Up-ranging or down-ranging occur depending on whether magnetic-field components appear in an upper or lower guard band shown in Figure 5.

As a limited functional check, the experiment can also be commanded into a sensitivity calibration mode in which a calibration field corresponding to one quarter of the range is applied in any odd range, i.e. R1 or R3 or R5 or R7.

The frequency transfer function T(f) for each magnetometer axis is given by the functional form

$$T(f) = 1/[1+2iz(f/f(n))-(f^{2}/f(n)^{2})]$$

Where the damping constants z and the natural frequencies f(n) are given in calibration tables. The 3 dB frequencies are between 10 Hz and 17 Hz for all seven ranges.

Figure 5. Illustration of upranging and

downranging strategy

2.2 The digital processor

We have already mentioned one of the tasks of the digital data processor of the Giotto Magnetometer Experiment, namely the control of the various measuring ranges. The functional units of the processor are included in Figure 3. It has the following tasks:

(i) timing of measurements in real time and memory mode
(ii) range control
(iii) averaging of memory mode vectors
(iv) collection of housekeeping data
(v) telemetry interfacing
(vi) command reception and implementation.

The heart of the digital processing system is an RCA CDP 1802/MPU-1 microprocessor with 16 kbyte of RAM and 5.5 kbyte of PROM, operating at 1.939 MHz.

The first task of the processor is to provide the timing for the real-time measurements. These are timed synchronously with the spacecraft telemetry system. The spacecraft real-time telemetry system has three formats for science data transmission. These formats, FM1, FM2 and FM3, last for 68/3 s, 68/3 s and 136/3 s, respectively, for the highest possible bit rates (total spacecraft bit rate 46 kbit/s). Formats FM1 and FM2 can also be operated at half the maximum bit rates. Formats FM1, FM2 and FM3 include 64, 64 and 16 frames, respectively. The number of magnetic-field vectors measured by the outboard magnetometer in these formats is 640,640 and 400, respectively. For the Magnetometer Experiment, FM1 and FM2 are identical and as a result it has three sampling rates for real-time data transmission (Table 4).

The real-time data modes are also used to dump the experiment memory. Approximately 15 kbyte of the experiment’s 16 kbyte RAM can be used to store magnetic-field vectors over extended time periods to bridge gaps in telemetry coverage. Because of the 4 s spin period of the spacecraft, this has to be done in synchronization with the spin, given by the Sun Reference Pulse (SRP). Two memory modes are available. In cruise mode, blocks of 32 vectors are read into the memory, where each of the 32 vectors is the result of averaging magnetic-field vectors obtained at the SRP over N spin periods, where N can be any power of 2 between N=1 and N=128. The selection is made by telecommand. Hence the averaging times range between 4 s and 512 s (8.53 min). In the latter case a 10 d gap in telemetry coverage could be bridged.

The second memory mode, called the ’snapshot’ mode, also uses blocks of 32 vectors. However, these alternate between blocks containing ’snapshots’ of the magnetic field. Every ’snapshot’ consists of 32 vectors measured spin-synchronously at a rate of eight vectors per spin period over four spin periods. The idea of the snapshot memory mode was to provide a means to monitor the spacecraft magnetic field during telemetry gaps. Gaps of up to 5 d can be closed by the snapshot mode. In both memory modes, inboard and outboard components are measured at the same rate. The time of the measurements in memory mode is obtained by an experiment clock. The experiment clock is synchronized with the spacecraft clock after switch-on of the experiment.

The memory dump occurs automatically when real-time telemetry is available and the experiment is still switched into memory mode. Nominally, the memory readout is performed after a ’memory-dump’ command. The readout of the memory lasts from 95 s to 5 min in format 1 at a high telemetry bit rate and in format 3, respectively.

Table 4. Sampling rates for real-time vector measurements

Real-time data modes	Sampling rate of outboard magnetometer (s**-1)	Sampling rate of inhoard magnetometer (s**-1)
FM1/2 high bit rate	28.24	2.82

FM1/2 low bit rate	14.12	1.41
FM3	8.82	1.76

The data processor also collects the experiment housekeeping information. From the 2040 words of a housekeeping frame, which lasts one format, eight words have been assigned to the Magnetometer Experiment. The housekeeping data provide informa- ion on the various functions of the experiment up to four times per format. In addition, the digital processor provides the timing for the measurement of some analogue parameters, which are converted into digital form by the converter. These are certain reference voltages and the thermistor voltage at MAG-4 (the temperature at MAG-1 is part of spacecraft housekeeping). The analogue parameters are transmitted every fourth or eighth format.

The data processor also implements the commands sent to the experiment from the ground. Commands use 16-bit words which specify the desired overall state of the experiment after reception of the command. Telecommands are used to specify the ranging procedure, i.e. automatic ranging or one of the seven ’manual’ range options, to select the operational mode and the averaging period in the memory modes, to initiate a memory dump, to exchange the telemetry assignment between MAG-1 and MAG-4, and to label the memory content by a command identification number. The operational modes are sensitivity calibration, real-time mode, cruise mode and snapshot mode. The exchange of telemetry assignment between the outboard and inboard magnetometer can be used as an emergency mode and for inflight calibration purposes, such as sensor alignment measurements, etc.

The 16-bit command word can attain many more values than used by ’legal’ combands. These possible values can in principle be used to reprogram the experiment from the ground.

3. The Magnetic-Cleanliness Problem

The description of a Magnetometer experiment would be incomplete without a discussion of the problem of contamination of measurements by spacecraft magnetic fields due to magnetic materials and electric currents in the spacecraft electronics. This problem is generally referred to as the ’magnetic-cleanliness’ problem. On Giotto, the accuracy requirements for the Magnetometer Experiment are not much lower than for a typical interplanetary mission near 1 AU, because only a small time interval during encounter is expected to yield field magnitudes above typical interplanetary ones. These requirements have to be contrasted with the difficulties due to the lack of a magnetometer boom and due to the presence of severe sources of magnetic contamination such as the permanent magnets in the mass spectrometers, the motor despinning the antenna dish, and the three motors of the camera.

Three different techniques have been used on Giotto to solve the magnetic-contamination problem:

- a magnetic-cleanliness program
- use of the two sensor systems MAG-1 and MAG-4, i.e. a triaxial and a biaxial magnetometer at different spacecraft locations
- inflight determination of spacecraft fields.

3.1 The magnetic-cleanliness programme

A detailed magnetic-cleanliness programme was carried out in the course of the Giotto project. In contrast to other projects, this programme was the responsibility of the magnetometer team, although some support was provided by the project. For all spacecraft subsystems and experiments, the maximum allowed magnetic field at the position of MAG-1 was specified for the deperm state of the switched-off spacecraft, for a perm state achieved by a 3 Gauss perm, and for the stray-field contribution due to electrically powering the unit.

Most spacecraft subsystems and experiments or subunits thereof were magnetically mapped in detail in the Magnetic Coil Facility at the Technical University of Braunschweig or a Mobile Coil Facility provided by the experiment team and deployed in Bristol, Toulouse and Kourou during the various project phases to make optimum use of the time available for these activities. About 150 detailed test reports were issued in the course of the programme.

As part of the magnetic-cleanliness programme rules for the design of magnetically

Table 5. Selected system magnetic-test results

Magnetic state	Magnetic field magnitude at MAG-1 (nT)
Initial, as received	1.4
First deperm	2.4 L
3 G perm	15
5 G perm	37
Final deperm	4.2

clean hardware were established and advice given to experimenters and spacecraft subcontractors regarding fulfilment of the specifications. The need to achieve field stability, and not so much a low magnetic-field magnitude, was emphasized in this respect. On the stray-field side, self-compensation of currents was stressed in designing the solar-panel harness and parts of the electrical circuitry.

The result of the cleanliness programme was checked via a System Magnetic Test in the IABG Coil Facility in Ottobrunn, near Munich, in March 1985. Table 5 shows some of the results.

These results are representative for the Giotto flight spacecraft, except that the flight-model camera was not included. They show that the magnetic-cleanliness programme was very effective indeed. If, for example, there had been a 3 m long magnetometer boom extending from the spacecraft’s centre, the final deperm field at the end of this beam would have been 0.9 nT.

The most difficult permanent-magnet problem was caused by the two motors of the despin motor assembly. With the magnetic moments of the motors parallel to each other, the field at MAG-1 was 550 nT. In the self-compensating assembly, the magnetic field at MAG-1 was 76 nT. After the mounting of a compensator device with two precision magnets, the field at MAG-1 was 7 nT. It could have been even smaller, had it not been used for a limited system compensation.

In summary, we can say that for all units subjected to the full mapping and field-reduction procedures of the magnetic-cleanliness programme, a satisfactory solution was found. This is also true for the overall stray field, not shown in Table 5.

The two major problems that remained could not be subjected to the cleanliness programme satisfactorily because of severe schedule problems; they are the stray fields due to the despin motor and due to the operation of the camera motors. Figure 6 shows two short intervals of raw data obtained in flight, which show these disturbances. Figure 6a shows a quiet interplanetary magnetic field seen from the spinning Giotto spacecraft with a superposed, very regular component at the spin frequency due to the despin motor. In the case of the Z-component, the despin motor accounts for most of the spin variation. The results of the System Magnetic Test show that the noise most visible on the Z-trace is also due solely to the despin motor. Figure 6b shows additional disturbances due to the camera motor’s operations.

3.2 Use of the two sensor systems MAG-1 and MAG-4

Since the ambient magnetic field to be measured is the same at the MAG-1 and MAG-4 locations, the difference in the readings of the components of MAG-1 and MAG-4 is entirely due to the spacecraft fields which vary as a function of position near the spacecraft. Because the System Magnetic Test has shown that the main parts of the stray-field components of the despin motor at MAG-1 and MAG-4 are simply related, the difference in readings at MAG-1 and MAG-4 can be used to determine this field unambiguously and then to correct for it. We will also attempt to use this technique to remove the camera stray field at the times when it is operating.

3.3 Inflight spacecraft magnetic-field determination

The spin variation of the magnetic field in the spin plane can be used to determine the spacecraft magnetic-field components in this plane and the small sensor offsets. For the Z-components, we will determine the slowly varying part of the spacecraft field by statistical techniques based on the physical properties of interplanetary magnetic-field fluctuations (e.g. Hedgecock, 1975).

4. Performance of the Instrumentation in Flight

The magnetometer experiment was the first experiment of the Giotto payload to be switched on, on 22 August 1985. It has worked flawlessly ever since.

Two short intervals of raw data are shown in Figures 6a and b. They are based on data from the quick-look data stations, which are not of sufficient quantity to allow the application of the full data-analysis programme. The spacecraft magnetic field in the X, Y-plane has been estimated to be about 8 nT from these data.

Figure 6. Giotto magnetometer flight data for the outboard magnetometer in format 1. Time is OCOE-time (Overall Check-Out Equipment)

a. Magnetic-field variations due to the ambient interplanetary magnetic field, the spin rotation and the stray field of the despin motor particularly visible in the Z-component

b. Interference signals caused by the camera motors

5. Conclusion

The Giotto Magnetometer Experiment is a low-mass, low-power instrument, which will provide magnetic-field measurements within some 500 km or less of the nucleus Comet Halley for the first time. In addition, it will provide high-time-resolution observations of the plasma environment of this unique comet.

The design of the instrumentation and the data-analysis system had to take into account a high level of magnetic interference from the Giotto spacecraft itself.

The scientific interpretation of the data will be a collaborative effort between all members of the team who have made the experiment possible.

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