Mars Atmosphere and Volatile Evolution Mission (MAVEN)

Community Meeting
Sunday, December 2, 2012

Magnetometer Investigation (MAG)
Jack Connerney et al.
Science

• Science Goals of the Magnetometer Investigation
• Mars Environment
• Science Requirements and Support for Particles and Fields Package (ions, electrons, energetic particles & waves).

Instrument

• MAG as Part of the PFP Package Integrated at UCB.
• A Heritage Mario Acuña Fluxgate.
• Instrument Performance and Calibration History.

Spacecraft Accommodation

• Magnetic Cleanliness Program to meet Science Requirements
• Illustration of Solar Array Compensation and Verification.

Data Processing and Archive Data Sets

• Data Processing Pipeline
• Data Products, Accessibility,
**MAG: Magnetometer Investigation**

**What are MAG goals?**
- Measure vector magnetic field
- Characterize solar wind interaction
- Support particles and fields package (ions, electrons, energetic particles & waves).

**Where?**
- Every orbit reaches below ~ 400 km at periapsis;
- “deep dips” probe to ~ 125 km.
- Mission design provides broad coverage of solar wind and interaction regions (sheath, pileup region, wake).

**Why?**
- Together with other MAVEN instruments to understand present and past atmospheric loss

**MAG Team:**
Jack Connerney, Jared Espley, Dave Sheppard, Ron Oliversen, Jim Odom, Scott Murphy, Pat Lawton, John Hawk, Haydee Aguilar, Steve Himes & GSFC engineering support.
MAVEN probes the Mars atmosphere throughout the volume accessible to orbiting spacecraft.

Crustal magnetic field variations produce “mini-magnetospheres” that influence the atmospheric interaction with the solar wind.
MAG: Mini-Magnetospheres

• Day/night asymmetry in solar wind interaction, magnetic environment.
• Variability with solar input, particularly variations in solar wind ram pressure.
• How do the “mini-magnetospheres” influence loss of volatiles? Geologic *history*?

GSFC - Magnetometer
Mars: A Lumpy Obstacle to SW

Connerney et al., PNAS, 102, no. 42, 2005.
# MAG: Driving Requirements

**MAVEN Mission Requirements Document, MAVEN-PM-RQMT-0005**

**MAVEN Level 3 Functional Requirements – Particle & Fields FRD, MAVEN-PFIS-RQMT-0016**

**MAVEN Magnetometer Level 4 Functional Requirements Document, MAVEN-MAG-RQMT-0061**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Solution</th>
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<tr>
<td>Measure field magnitude &amp; direction</td>
<td>Vector fluxgate magnetometer. Use heritage design.</td>
<td>Fluxgate is heritage; Acuna design flown on &gt;50 missions.</td>
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<tr>
<td>Measurement dynamic range 3 to 3000 nT.</td>
<td>Three ranges implemented: +/- 512 nT, +/- 2048 nT, +/- 65536 nT</td>
<td>Science team has run comprehensive analyses of mission environments.</td>
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<tr>
<td>Accuracy/Resolution better than 1%</td>
<td>Heritage analog design &amp; 16 bit ADC exceeds requirement</td>
<td>Intrinsic noise is &lt;&lt; 1 nT Zero stability is &lt; 1 nT</td>
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<tr>
<td>Timing Resolution of 20 seconds or better</td>
<td>Use PFDPU-provided crystal controlled oscillator &amp; PFDPU-provided spacecraft time.</td>
<td>Timing resolution is much better than one second. Intrinsic sample rate is 32 vector samples/sec, each MAG.</td>
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<tr>
<td>Magnetics cleanliness per MAVEN magnetics cleanliness plan</td>
<td>Screen all electro-mechanical components near the sensor.</td>
<td>Standard MAG lab processes and test equipment.</td>
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<tr>
<td>Hardware Redundancy</td>
<td>Two independent magnetometers, a/c heaters, independent power supplies.</td>
<td>No common electrical connections between magnetometer hardware.</td>
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<td>Orthogonality/Alignment</td>
<td>Heritage mechanical alignment knowledge &lt; 0.25 degrees.</td>
<td>MAVEN requirements met without need for optical cube.</td>
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<td>Survivial/operational heaters provided by MAG</td>
<td>Proportional AC heater design.</td>
<td>Similar design to RBSP and Juno.</td>
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MAVEN Particles & Fields Package

Solar Wind Ion Analyzer (SWIA) – SSL
Solar Wind Electron Analyzer (SWEA) – CESR / SSL
Langmuir Probe and Waves (LPW) – LASP / SSL
LPW/Extreme Ultra-Violet (LPW-EUV) – LASP
Solar Energetic Particle Detector (SEP) – SSL
Magnetometer (MAG) – GSFC
Supra-Thermal and Thermal Ion Composition (STATIC) - SSL
• Two independent MAG sensors, electronics boards and a/c heaters;
• Powered by two independent PFP power supplies.
• Fully redundant hardware configuration.
MAG: Heritage Mario Acuña Fluxgate

Ring core fluxgate magnetometer (FGM) —> 3 dynamic ranges:

- +/- 65,536 nT
- +/- 2048 nT
- +/- 512 nT
- 0.015 nT resolution (16-bit A/D)

Goddard has flown similar fluxgates for 40 yrs.

MAVEN design is most similar to RBSP w/some Juno features (FPGA control w/ autoranging, housekeeping).

EEE parts are nearly identical to those used on Juno & RBSP (the same lots are being utilized)
MAG Team Mug Shots

Jack Connerney
Instrument PI

Jim Odom
Senior Technician

Pat Lawton
Ground Systems

Scott Murphy
Mechanical Engineer

Dave Sheppard
Systems Engineer

Ron Oliversen
Instrument Manager

Jared Espley
Science & GSE
Magnetometer Electronics Slice
Magnetometer Sensor(s)

FGM FM Sensor

FGM Sensor - inside the box
MAVEN Mag Sensor and Bracket

Mag Sensor with two piece T300 composite cover
(to be covered with Cu tape)

IM-7 Adapter Plate
(travels with Sensor during testing)

IM-7 Composite Bracket
with Ti inserts for fasteners

½” Alignment Cube
IM-7 angle bracket for cube
MAVEN Mag Sensors & Fixtures

As delivered to UCB for integration, May, 2012
# MAVEN MAG Calibration Timeline

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MAVEN MAG – Calibration

GSFC 22 foot MAG test & calibration facility

facility electronics
MAVEN Noise Performance

- Measured noise in Mu-metal shield can at magnetic test facility (includes environmental noise and instrument noise).
- ~ ±0.1 nT variation in both operational ranges 0 & 1 (<< 1 nT requirement L4-FGM-04).
- Range 3 (Earth environment test and ATLO functionality only) noise is limited by the digital step size of the 16-bit A/D converter.
MAVEN FM Noise Performance

- Measured at GSFC magnetic test site over the weekend, sensor in a cylindrical multi-layer Mu metal shield can.
- Measurement of the sum of FGM sensor noise *plus* environmental noise.
MAVEN FM Noise Performance

X and Y axes are orthogonal to axis of open-ended shield can; (less environmental field).

Z axis aligned with axis of open-ended shield can; (more environmental field).
MAVEN MAG – MAGSAT Calibration

MAGSAT calibration method simultaneously solves for sensor scale factors, orthogonality, and coil system (facility) orthogonality, via a series of precise 90 degree rotations (sensor optical cubes with 10 arcsec accuracy and theodolites).
MAVEN FM2 Calibrations Example

IDL> mcsum,DIR="MAVEN/FM2/15May12",RNG=3,/NRM
Magsat Analysis
  range: 3 normalized
  Fit RMS: 1.13
Run Time: Tue May 15 11:45:08 2012
zerotable:
  0.442250  -0.070500   1.204000    0.000000
  0.311500  -0.058000   1.294500    0.000000
-5.568750   0.155250   4.711500    0.000000
scale factors: 0.992422  0.993478  0.990445
sensor model amx:
  1.000000  0.003367  -0.004583
  0.001080  1.000000  0.000818
  0.004007  0.002564  1.000000
symmetric part:
  1.000000  0.002223  -0.000304
  0.002223  1.000000  0.001726
-0.000304  0.001726  1.000000
a-symmetric part:
  0.000000  0.001143  -0.004295
-0.001143  0.000000  -0.000873
  0.004295  0.000873  0.000000
rotation by: 0.259510 degrees
about unit vector: 0.192731  -0.948231  -0.252415

< MAGSAT calibration method

Iteration: 3
Constraints: 1 1 1 1 1 1 1 1 1 1
Std. Dev.: 0.53545255
Zeros (x, y, z): -6.228662  0.042541  4.579845
Scale factors: 0.992155  0.993195  0.990182
Sensor model (symmetric) A Matrix:
  1.000000  0.002214  -0.000304
  0.002214  1.000000  0.001726
-0.000304  0.001726  1.000000
continue?:

“thin shell” calibration method in box
MAVEN Spacecraft Accommodation

Spacecraft Magnetic Control Program to manage s/c magnetic fields and meet measurement requirements (2 nT static, 0.25 nT variable).
- Minimize use of magnetic materials.
- Characterization and self-cancellation of magnetic components (TWTA, propulsion latch valves, etc.).
- Minimize current loops (twisted pairs, ground returns).
- Solar array compensation (“backwiring” individual cell strings).
- “U-string” backwiring (Juno, RBSP heritage) adopted, LM array fab.

MAG sensors accommodated on extended solar array panels
MAVEN Solar Array Compensation

Square Wave Current Injection

![Graph showing square wave current injection with time in seconds on the x-axis and current in amperes on the y-axis.](image)
Solar Array Magnetic Test
Solar Array Test Data – Linear String
Solar Array Magnetic Test Results

filename: String2_RevBias_1500mA_006.txt

String2_RevBias_1500mA_006.txt

String 2, Forward Bias, ******** SA Test, 12-03-09, *****

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<th>Component</th>
<th>MAG#1 (sd-m)</th>
<th>MAG#2 (sd-m)</th>
<th>M#1-M#2 (sd-m)</th>
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<tr>
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[0.5 m]         [1.0 m]

simple linear string;

calculated 4.4 nT/A at 0.5 m (6.6 nT 1.5A) and 0.92 nT/A at 1.0 m (1.4 nT 1.5A)
Solar Array – MAVEN Design

• Backwired Cell Strings tested in several configurations
  – 14 Cell U-string configuration
  – 23 Cell linear configuration
• Test results compare favorably to model calculations
• Typically achieve order magnitude reduction in stray field relative to uncompensated strings
• Estimate ~1 nT/A at 1 m distance for linear string (evenly paired strings may reduce by factor 5 or so).
• Estimate < 0.1 nT/A at 1 m distance for U-string configuration.

U-string configuration

Self-nulling (does not depend on adjacent paired string); residual field in plane.
MAG Data Processing Pipeline

- Science Data and Archive Processing (MGAN)
  - FORTRAN First (MGAN)
  - IDL used extensively for analysis
  - MGS heritage w/modifications
    - Different spacecraft and instrument kernels as NAIF-like text input files
    - Mission specific customization
      - For example, magnetic cleanliness
      - Some requirements will not be known until after launch and in-flight spacecraft performance verification
- Revision Control System (RCS) used
- UNIX Environment
- Produce a variety of “Standard Time Series” data files (ASCII)
  - Time, magnetic field vectors, s/c position relative to relevant target body, and any ancillary engineering data that might be of use to investigators.
  - Planetocentric (body-fixed) coordinates, Sun-state (sun-fixed) coordinates, and target bodies as desired: Mars, Phobos, Deimos, etc.
Data Archive Products

Telemetry files
- As received from SOC
- Detached PDS labels to be delivered to SOC

Standard time series (STS) files
- Attached PDS labels
- Planetocentric Cartesian (PC) coordinates:
  - z axis is aligned with the planet rotation axis, x axis aligned with the IAU Prime Meridian zero longitude, and the y axis completes the system.
- Sun-state (SS) Cartesian coordinate system:
  - primary reference vector is the planet-Sun vector (x axis) and the secondary reference vector (y axis) is (anti-) parallel to the planet state vector, i.e., in the planet orbital plane; z axis completes the system.
- Others as appropriate
Sample STS file – Attached Header

• Sample Standard Time Series (STS) file (from MGS)

```plaintext
OBJECT      =  FILE
OBJECT   =  HEADER
PROGRAM   =  mgan
CMD_LINE  =  -mars -odl -magonly -pc -sc time dday ob_b posn ob_rms
            ob_bscpl ob_bdpl sam_i sap_i sao_i
DATE      =  Thu Jan 11 21:08:47 2007
HOST      =  lepmom
COMMENT   =  This version MGAN compiled with F77 revision. 4.2 and
            spicelib MSOP_SCI V.6 (GENERIC_TOOLKIT V.N0049 on JUN 04,
TITLE     =  MARS GLOBAL SURVEYOR MAG/ER
OBJECT      =  CK_DOCUMENTATION

MGS Solar Array CK File for Extended Mission
===========================================================================
Created by Boris Semenov, NAIF/JPL, Thu Jan 11 11:12:48 PST 2007
...
END_OBJECT
OBJECT      =  RECORD
OBJECT   =  VECTOR
NAME   =  TIME
ALIAS  =  TIME
TYPE   =  INTEGER
OBJECT   =  SCALAR
NAME   =  YEAR
FORMAT =  1X,I4
END_OBJECT
OBJECT   =  SCALAR
NAME   =  DDAY
ALIAS  =  DECIMAL_DAY
TYPE   =  REAL
FORMAT =  F13.9
END_OBJECT
OBJECT      =  VECTOR
NAME   =  OB_B
ALIAS  =  OUTBOARD_B_J2000
TYPE   =  REAL
OBJECT   =  SCALAR
NAME   =  X
FORMAT =  1X,F9.3
UNITS  =  NT
END_OBJECT
OBJECT      =  SCALAR
NAME   =  Y
FORMAT =  1X,F9.3
UNITS  =  NT
END_OBJECT
OBJECT      =  SCALAR
NAME   =  Z
FORMAT =  1X,F9.3
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END_OBJECT
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Mars Atmosphere and Volatile Evolution Mission (MAVEN)

Try out some MAG (MGS) data:

http://mgs-mager.gsfc.nasa.gov/

....go to “What’s New”

Circa mid to late 1990’s; and let us know if you have any suggestions for how we might better anticipate your needs

Mario H. Acuña
1940 - 2009