THE ST-5 MAGNETIC FIELD CONSTELLATION: FIRST RESULTS

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ABSTRACT/RESUME

The successful launch and deployment of the ST-5 constellation occurred on March 22, 2006. We report on its first magnetic field measurements. The three satellite constellation orbits the earth in a polar 300 x 4500 km sun synchronized orbit in the dawn-dusk meridian, and each satellite measures the vector magnetic field from a spinning-stabilized platform. The boom-mounted magnetometers are the only scientific instrument onboard each of the 25 kg, full-service satellites. The short (90-day) mission is designed to flight validate new technologies. The mission was not designed to do geomagnetism, as the absence of a star camera, GPS, and absolute magnetometer make clear. However, the satellites are expected to make unique measurements as they fly in formation through dynamic ionospheric current systems.

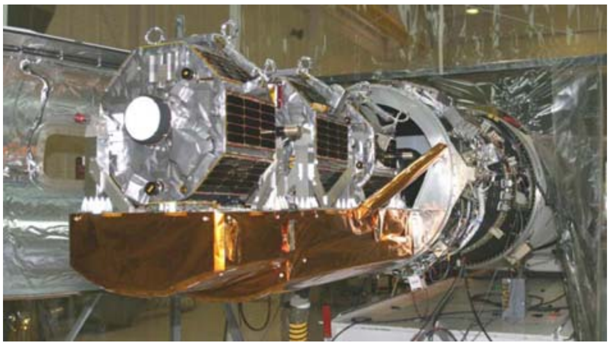
1. INTRODUCTION

The ST-5 mission is part of NASA's New Millennium Program (NMP) of technology demonstrators. It consists of three 25-kg class micro-satellites, and is NASA's pathfinder for small spacecraft constellation missions. It has three top level objectives:

- Validation of the constellation measurement concept
- Validation of the nanosatellite design concepts
- Validation of enabling and enhancing sub-system technologies

The official NMP technologies [1] to be flight validated by ST-5 include Miniature communications transponder, Cold gas micro-thruster, Variable Emittance Coatings, CMOS Ultra-Low Power Radiation Tolerant Logic, Low voltage power subsystem including Li-Ion Battery, and Software tools for autonomous ground operations. Other technologies to be tested are miniature scientific-grade magnetometer, miniature spinning sun sensor, X-band antennas (quadrifilar helix and evolved), spacecraft deployment mechanism, magnetometer deployment boom, and nutation damper.

ST5 spacecraft were launched by a Pegasus into a sun-synchronized low Earth orbit (LEO) on March 22, 2006. They are spin-stabilized on orbit. Figure 1 shows a picture of the three spacecraft mounted on the Pegasus Support Structure (top) and an artist's drawing of the



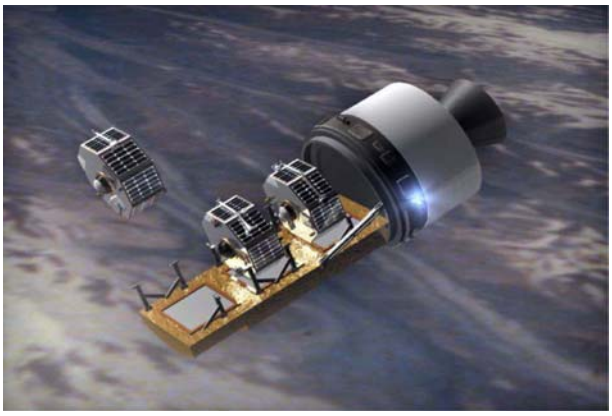


Figure 1. (Top) ST5 spacecraft on Pegasus Support Structure; (Bottom) The artist's drawing of ST5 deployment during Pegasus launch.

Table 1. ST-5 Mission and Orbit Profile

Launch	Pegasus out of Vandenberg March 22, 2006
Mission Duration	90 days (March 22 – June 21)
Orbit	Sun-synchronized Dawn-dusk meridian plane
Inclination	105.6º
Orbit Perigee	300 km
Apogee	4500 km
Period	136 minute
Constellation configuration	String-of-Pearls 50-200 km spacing
Communications	Deep Space Network (DSN) McMurdo Ground Station

deployment at the spacecraft launch (bottom). The ST-5 orbit profiles are summarized in Table 1.

Magnetometer measurements will be used to validate the ST-5 spacecraft as a suitable platform for taking science measurements. Accuracies of 0.1-0.3 degrees, relative to the spacecraft body, are expected from the sun sensor. The three spacecraft form a sting-of-pearls constellation with spacecraft 155 leading and followed by spacecraft 094 and 224, By the end of the mission, the spacecraft will have achieved separation distances of 50 to 200 km. We report here some of the first magnetic field measurements from ST-5.

2. MAGNETOMETER AND BOOM

Table 2 details the ST5 magnetometer specifications. The three ST5 magnetometers were built by UCLA. The magnetometer sensor is mounted at the end of a stiff, very low mass, self-deploying boom. This arrangement places the magnetometer almost 110 cm from the center of the spacecraft, in order to reduce the effects of any stray magnetic fields from within the body of the spacecraft. The magnetometer boom stows by folding around the spacecraft equator and was released on-orbit using a shape memory alloy pin puller. Strain energy in the hinges, from stowing, deploys the boom. It is constructed as an assembly of graphite composite tube sections with beryllium copper "carpenter tape" hinges. It is 225 g in mass and 80 cm in length. It has been designed to minimize magnetic interference with the magnetometer and provide thermal and dynamic stability.

Table 2. Magnetometer Specifications

Dynamic Range Full-Field Low-Field	 0 - ±64,000 nT 0 - ±16,000 nT
Digital Resolution Full-Field Low-Field	 Better than 1.25 nT Better than 0.30 nT
Intrinsic Noise	< 0.1 nT rms @ 1 Hz
Data Rate	- 16 vectors per second - simultaneous 17 bit per axis data sample
Power	- 570 mW - 7.2 V DC
Mass Electronics Unit Sensor Head	 550 g 55 g
Size Electronics Unit Sensor Head	 10cm×12cm×7.6cm 5cm×5cm×3cm

3. ST-5 MAGNETIC FIELD DATA – FIRST RESULTS

The ST5 magnetic field data were taken in the spinning spacecraft platform. The data processing involves calibrating and despinning the data into geophysical inertial coordinate systems. Our initial results show that the ST5 magnetic field data are of very high quality, and ST5 spacecraft are suitable platforms to take science quality magnetic field data. We do not see any effect of nutation or coning of the spacecraft, or contamination due to unstable spacecraft magnetic field. Here we present a few examples of field-aligned currents observed by ST5 magnetometers. The magnetic field data presented here have not been fully calibrated yet. But they illustrate the quality of the data and what information we can obtain about the field-aligned currents from these data.

Figure 2 shows one example of the field-aligned currents observed by the three ST5 spacecraft. The top panel contains the magnetic field data with internal IGRF model magnetic field removed, including the three components of the magnetic field residual vector in the solar magnetic (SM) coordinate system as well the residual of the magnetic field strength. The labels for the spacecraft position on the bottom of the panel are for spacecraft 094 only. The bottom two panels are the trajectory of the spacecraft in SM. During this interval, the ST5 spacecraft moved from the dawn to dusk over the southern polar cap in a string-of-pearls configuration, where spacecraft 155 was forward (red), followed by 094 (black) and 224 (green). The leading spacecraft 155 had a large separation distance from the trailing two. The separation between the leading and middle spacecraft (SC 155 – SC 094) was 2910 km. The separation between the middle and trailing spacecraft (SC 094 – SC 224) was 397 km.

The first encounter of the field-aligned currents (FACs) started at ~ 0404 UT by SC 155 and then at ~ 0411 UT by SC 094 and ~ 0412 UT by SC 224. From the spacecraft trajectory, this encounter occurred near 02 local time in the post-midnight sector. At this local time, the spacecraft was skimming the field-aligned current sheet and the east-west direction is mainly aligned to the SM Y direction. Thus, the magnetic field perturbations generated with the FACs were mainly in the SM Y direction. From the polarity of the magnetic field perturbation, the FACs appeared to consist of a pair of currents, a downward current at lower latitude and an upward current at higher latitude. Although the FACs seen by SC 094 were ~ 7 and 8 minutes ahead of the SC 155 and 224 observations, respectively, the FAC locations seen by the three spacecraft remain roughly the same for this event. However, the magnitude of the magnetic field perturbations increased significantly, indicating the FACs intensified during this short period. This example demonstrates that we can distinguish spatial variations from temporal variations of FACs using ST5 constellation data.

The second FAC encounter for the same pass occurred at ~ 0422 UT by SC 155, ~ 0429 UT by SC 094 and ~

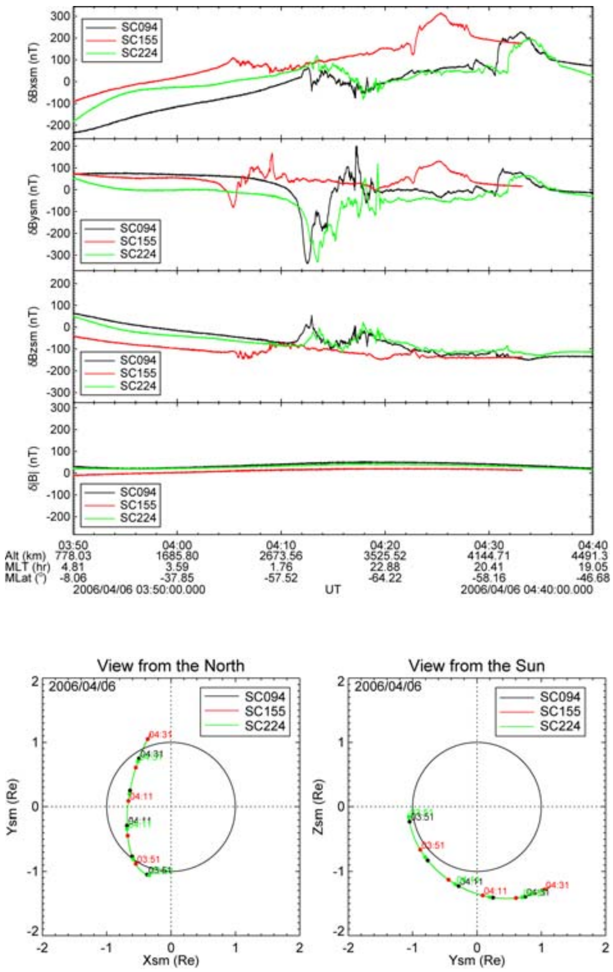


Figure 2. An example of field-aligned currents observed by ST5. (Top) Magnetic field residuals in the solar magnetic coordinate system. (Bottom) ST5 trajectory in the solar magnetic coordinate system.

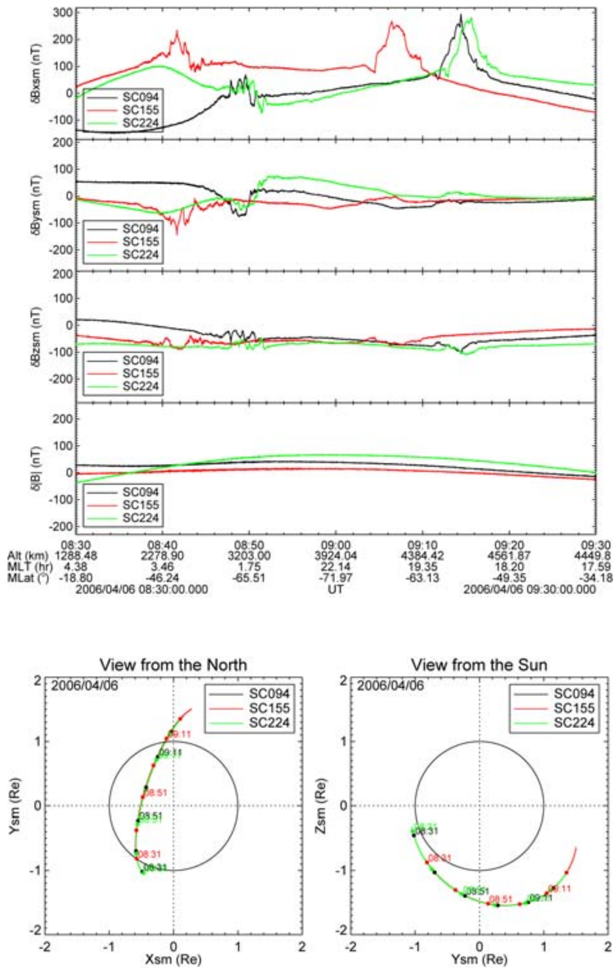


Figure 3. Another example of field-aligned currents observed by ST5. The format is the same as in Figure 2.

0430 by SC 224. The local time was ~ 20 hour, near dusk in the pre-midnight sector. The spacecraft altitude is higher than the previous encounter in the post-midnight sector. The magnetic perturbations were in both SM X and Y components, as they should be for the local time. The currents consist of an upward current at lower latitude and a downward current at higher latitude.

Figure 3 shows another example of FACs. For this pass, the ST5 also observed the FACs at two locations, first at ~ 02 local time, and subsequently at ~ 19 local time near dusk. In particular, the FACs observed near the dusk exhibited well ordered two-sheet current structure. From these data, we can determine the velocity, the thickness, as well as the temporal stability of the large-scale current sheets. These properties can not be determined by single spacecraft observations.

4. SUMMARY

ST5 magnetometers returned high-quality magnetic field data. They are a unique dataset and provide the first simultaneous multi-point measurements of field aligned currents at low altitudes. The data will allow us to separate temporal and spatial variations of field-aligned currents. These measurements have not yet been fully calibrated against a field model. After the data are calibrated against the Earth's magnetic field model, subsequent work will also involve the development of a spherical harmonic model of the Earth's magnetic field.

5. REFERENCES

1. Carlisle, C. C., Webb, E. H., and Slavin, J. A., "Space Technology 5–Changing the Mission Design without Changing the Hardware," 2005 IEEE Aerospace Conference Proceedings, March 2005.