Space Technology 5
A Successful Micro-Satellite Constellation Mission

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ST5 Mission Overview

- NASA New Millennium Program/Goddard Space Flight Center mission to flight-validate new concepts and technologies
  - Designed, built and operated three 25 kg spacecraft utilizing breakthrough technologies
  - Demonstrated the ability to achieve accurate, research-quality scientific measurements utilizing a constellation of 3 micro-satellites
  - Operated the three satellites as a single Constellation
- “Pathfinder” for future missions of 10’s or 100’s of small spacecraft
ST5 Launch

- Launched March 22, 2006
  - Pegasus-XL Launch Vehicle from Vandenberg Air Force Base
  - Approximately 10 min after launch, ejected 3 min apart Frisbee-style
ST5 Mission Profile

- **Mission Duration**: 90 days
  - 7 day launch & early orbit period
  - Mission completed June 20, 2006
  - End-of-mission activities
    - June 21-30, 2006

- **Orbit**
  - 105.6 deg inclination (full sun orbit)
  - ~300 km perigee  ~4500 km apogee
  - 136 minute period

- **Constellation configuration**: “string of pearls”
  - Science validation formation: s/c within ~50-250km

- **ST5 Communications**
  - Deep Space Network
  - McMurdo Ground Network Station
ST5 Spacecraft

• “Full service” micro-sat
  – Built within tight volume and mass constraints
  – Power ~ 25 W
  – Mass ~ 25 kg
  – Size ~50 cm (Dia) x 48 cm (Height)
• Low-power and low voltage
• Integral card cage structure (for C&DH, PSE)
• Magnetically clean
• Autonomy features (sun acq, load shedding)
• Science demonstration instrument
  – Research-grade flux-gate magnetometer
  – High resolution, high precision, three-axis magnetic measurements
• Partnerships between NASA, industry, and academia
• All 3 spacecraft performed well throughout the mission

• Spacecraft design could be used as a basis for future micro-sats
ST5 Technologies

- Low voltage power subsystem including Li-Ion Battery
- Miniature transponder
- Cold gas micro-thruster
- CMOS Ultra-Low Power Radiation Tolerant Logic
- Variable Emittance Coatings
- Software tools for autonomous ground operations
- Miniature scientific-grade magnetometer
- Miniature spinning sun sensor
- Spacecraft deployment mechanism
- Magnetometer deployment boom
- Nutation Damper
- Evolved X-band antenna
ST5 Technologies

• **Low Voltage Power System**
  – Miniature Power System Electronics (PSE)
  – High efficiency (>28.5%) solar cells (Triple junction GaAs)
  – High energy-density battery – Lithium-Ion
  – Low Voltage Power Bus to maximize efficiency (5V and ~8V power distribution)
  – Miniaturization of Full Service Power System
    • Allows a small but capable spacecraft
  – Low voltage power distribution system enables future micro and nano-sats
    • Li-Ion battery technology qualified for space

• **Transponder**
  – Provides coherent uplink and downlink, and support for orbit determination
    • X-band
    • Small and low-power
  – Could be extended to future near-Earth constellation missions
ST5 Technologies, Cont’d

• **Cold Gas Micro-Thruster (CGMT)**
  – Uses cold-gas nitrogen propellant
  – Provides accurate and repeatable impulses for precision control of satellites
  – Latching solenoid valve design provides an order of magnitude reduction in power consumption
  – The CGMT is suitable for any future missions requiring small and precise impulse for fine control
    • Longer missions in a similar orbit would require a spin-up mechanism

• **Complementary Metal Oxide Semiconductor (CMOS) Ultra-Low Power Radiation Tolerant (CULPRiT)**
  – Implemented as a Reed-Solomon Telemetry Encoder for ST5
  – Core operating voltage of 0.5V
  – Radiation Tolerant

• Implementation of CULPRiT technology to all digital electronics would result in significant power savings
Integration and Test at GSFC

ST5 Spacecraft

Vibration Testing

Test deployment of flight spacecraft

Spacecraft 2 and 3 in Thermal Vacuum Chamber

Magnetics Testing
ST5 Ground System Automation

- Flight-proven ground segment applications capable of providing constellation support
  - Extensible architecture of distributed, interoperable “plug and play” ground system components communicating over interoperable message bus
    - Goddard Mission Services Evolution Center (GMSEC)
  - Self-updating predictive models which predicted problems for selected subsystems (SSR, RF Link, Power) and then autonomously initiated corrective actions before problem occurred
    - Real-time Object Modelling Executive, ROME (Partner: ISR)
- Operated multiple spacecraft as a single constellation
  - Utilized automation to reduce overall staffing, minimize off-hour support and successfully perform unattended operations.
    - Successfully conducted 1-week lights-out operations
  - Validated model-based constellation health and safety management operations concept
ST5 Formation Flying

August 14, 2007

SSC07-VII-6
Science Demonstration Summary

- ST5 micro-satellite provided excellent support for science measurements
  - Highly stable spacecraft
    - No measurable nutation or coning
  - Magnetically clean spacecraft
    - No measurable stray s/c stray fields
  - Precision sun-sensor
    - Achieved $+0.1^\circ$ pointing knowledge
  - Position knowledge typically $< +1$ km
- ST5 demonstrated the utility of a constellation of micro-sats to perform research-quality science
  - Constellation configuration allows simultaneous multi-point measurements of magnetic field across auroral current sheets… measurements that cannot be made by a single spacecraft
  - Formation flying in pre-determined configuration over the Earth’s northern and southern auroral zones
Technology Validation

- Thoroughly tested on the ground
  - Comprehensive functional and performance testing at component and s/c level
  - Full environmental testing of components and s/c
  - Magnetic measurements of components and integrated s/c
- On-orbit demonstration
  - Technologies used throughout the mission
  - Mission activities designed to validate technologies
- Key subsystems and components achieved validation goals
- Developed and demonstrated a ground system architecture that is a stepping stone toward future constellation missions
- Successfully achieved ground system automation goals and demonstrated operations with minimal staffing
  - Full staffing for first 30 days, with significant ramp-down thereafter
  - 1 week “lights-out” operations
- Demonstrated that research-quality science is enhanced by a constellation of micro-sats