Some U.S. Perspectives on Miniaturized Guidance , Navigation & Control (GN&C) Hardware Components

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Presentation Outline

- **Background**
- **Drivers and Constraints for Micro-GN&C Components**
- **NASA's Franklin/Edison Small Spacecraft Technology Program**
  - Cubesats and leveraging Micro-GN&C hardware components from non-traditional sources
- **Potential Small Spacecraft Roles that Will Drive Need for GN&C Component Miniaturization**
- **Some Component Priorities for Miniaturization**
- **Consideration of Multi-Function GN&C Components**
- **Final Thoughts**

Background (1 of 2)

- **Over a period of years, if not decades, there has been a lack of meaningful investment in next generation of GN&C component-level technologies**
- **This has had the consequence of constraining GN&C system designers.**
- **This particular area was identified as the top GN&C technical challenge in an independent GN&C CoP 'discipline assessment' survey performed in 2009**
- **There has been little or no funding for GN&C technology "seedling" projects to investigate feasibility of new low-TRL sensor or actuator concepts.**
  - ***To be fair this landscape is starting to change under NASA's revitalized emphasis in technology development (more to come on this)***
- **There is minimal funding for technology development testbeds/test facilities to mature mid-TRL GN&C component technologies.**
- **There are few flight test opportunities for the demonstration of low or mid-TRL GN&C components in the space environment.**
- **This situation is exacerbated by weaknesses in the GN&C component space industrial base supply chain after years of industry consolidation, an aging industry workforce, and other factors**

Background (2 of 2)

- **To address this challenge, GN&C engineering organizations should:**
  - Comprehensively benchmark of currently available components
    - *both "industry standard" and "miniaturized" hardware*
  - Develop a prioritized cross-Agency needs list for advanced GN&C component technologies, and
  - Develop a prioritized roadmap for GN&C component technologies
  - Search for and identify collaborative opportunities to leverage R&D investments by other government organizations, national labs, industry, and international partners
  - Consider alternative non-traditional GN&C hardware component procurement strategies and approaches.
  - Search for technology solutions in new places with a goal of encouraging novel products and system solutions from non-traditional sources like individual inventors, student groups, and small, private companies
    - *In particular these sources could play a significant role by being future providers of miniaturized GN&C components, **as long as they meet performance and qualification requirements***

Drivers/Constraints for Micro-GN&C Hardware?

So there is a general need for a rejuvenated GN&C hardware component technology pipeline. But is there a driving need for micro-GN&C hardware components ?

- Everyone wants the reduced Size, Weight and Power (SWaP) attributes that micro-GN&C components can provide but only if performance levels are maintained in the process of miniaturization

- The development of micro-GN&C components is somewhat constrained by the degree of technical difficulty in attaining desirable performance requirements: would require funding for the necessary sub-component technology development and the Non-Recurring Engineering to design/develop space quality flight units

- We have a technology gap (or possibly a failure to effectively harness existing technology) which is retarding micro-GN&C component development more than rather than a lack of engineering processes, parts, electronic packaging techniques, and/or component integration challenges

- In addition, from a big picture viewpoint, micro-GN&C component development is being constrained by a "soft" market for such devices:
  - Low numbers of planetary and Small Spacecraft missions
  - Lack of dedicated small spacecraft launch vehicles (especially NanoSat launchers)
  - Uncertainty about operational roles for micro-spacecraft

NASA's Franklin & Edison Small Satellite Technology Program

- **NASA's Small Satellite Technology Program is currently working to advance the capabilities of small spacecraft to support NASA missions in science, exploration and space operations**
  - The goal is to 'unleash NASA's unique capabilities and assets into the already vibrant small spacecraft community'
- **This has had the effect of forcing a thoughtful consideration of the drivers, requirements and barriers are for the miniaturization of GN&C components**
  - A good thing to have happen, but still a work in progress
- **Two recent NASA Small Spacecraft Technology (SST) awards:**
  - The Optical Communications and Proximity Sensors mission will demonstrate a Cubesat-scale laser communication system and low-cost radar and optical sensors for navigation
  - The Proximity Operations Nano-Satellite Demonstration will test rendezvous and docking of two Cubesats

How Much Can We Leverage the "Vibrant Small Spacecraft Community" for Micro-GN&C Components

- **Highly likely that new advanced technology Micro-GN&C components will be an outcome of NASA's Franklin/Edison Small Spacecraft Technology Program, some from non-traditional sources**
- **So there is an opportunity here to leverage that "vibrant small spacecraft community" to introduce into the mainstream US space community multiple Micro-GN&C hardware components from non-traditional sources.**
  - These affordable components are used currently in university, national labs, and other types of labs for CubeSat and Small Sat experiments/flight tests
- **While they may be affordable the following forward-looking questions come up in general regarding Micro-GN&C components from non-traditional sources:**
  - Can they meet the required performance levels ?
  - Are they reliable enough for NASA's and DoD's envisioned Small Spacecraft missions ?
  - Can they be manufactured at a high enough quality and at high enough production rates to meet potential Small Spacecraft prime contractor demand?

Some Potential Small Spacecraft Roles that Will Drive Need for GN&C Component Miniaturization

- Recall that 10-15 years ago there was very enthusiastic talk along the lines of "Micro-Satellites for Macro-Benefits"
  - Still a good amount of "overselling" potential roles for NanoSats
- Significant progress and maturity in this Micro-Satellite arena but not clear we have accomplished the envisioned "Macro-Benefits" yet
- NASA however envisions many intriguing niche role application possibilities for Small Spacecraft*
  - Space Weather Network: constellation of spacecraft
  - In-Orbit Assembly: Rendezvous of multiple small spacecraft to build larger vehicle
  - NEO Explorer: network of microprobes that can operate on or around an asteroid
  - Debris Remover: spacecraft that can rendezvous with and de-orbit debris
  - Inspection: spacecraft that can maneuver around another spacecraft
  - EVA Assistant: spacecraft that can safely maneuver around ISS to inspect/repair/assist

Note that for all of these potential Small Spacecraft mission applications mentioned above there is a common need for miniaturized relative navigation sensors.

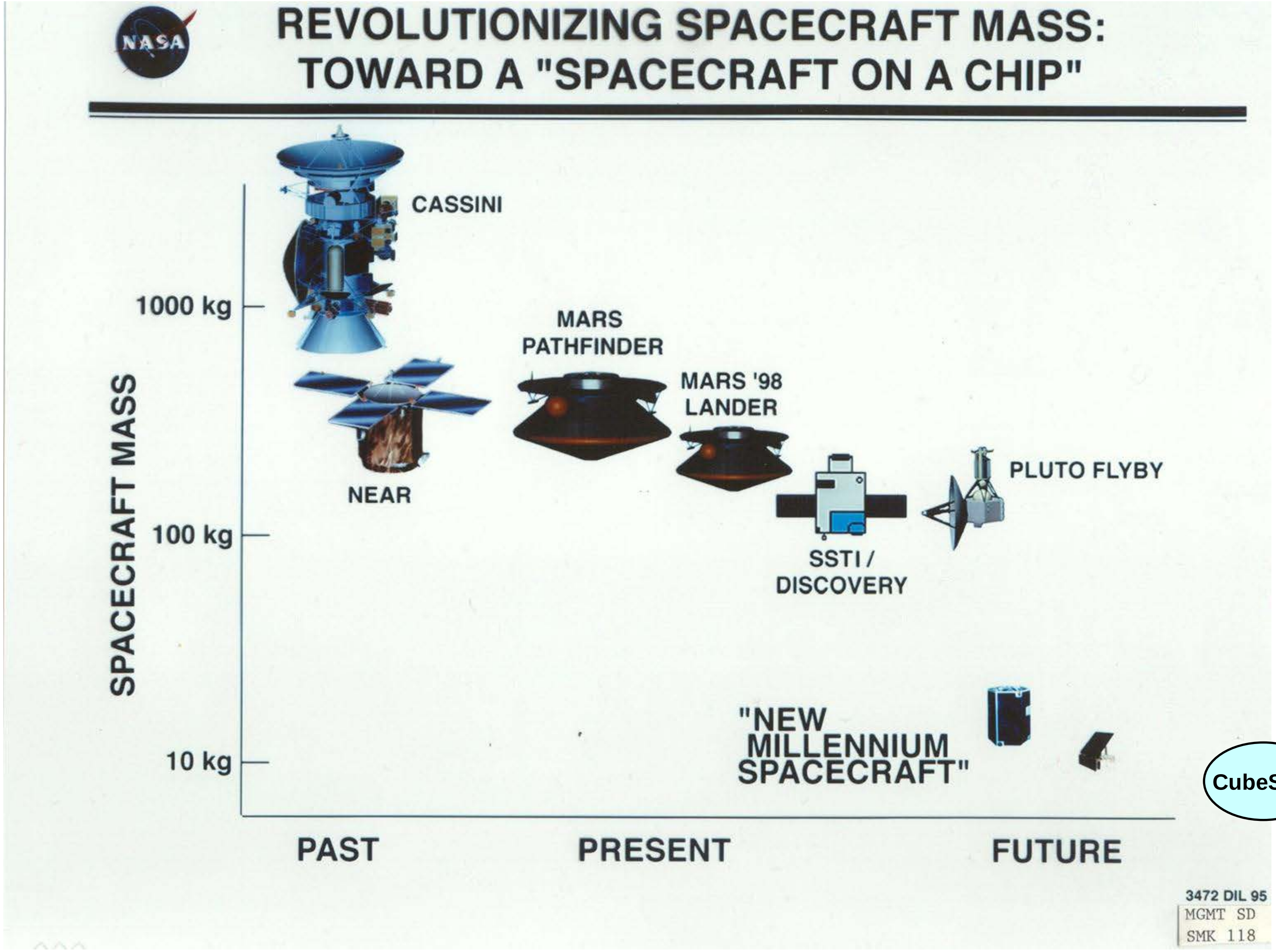
*** Source: Andy Petro (NASA/OCT) talk at Small Sat Conf., 13 Aug 2012**

GN&C is a Top Technology Priority in NASA's Space Technology Roadmaps: Potential for Sponsorship of Micro-GN&C Component Development?

Final Prioritization of the Top Technologies, Categorized by Objective

Highest Priority Technologies for Technology Objective A Extend and sustain human activities beyond low Earth orbit	**Highest Priority Technologies for Technology Objective B** Explore the evolution of the solar system and the potential for life elsewhere	**Highest Priority Technologies for Technology Objective C** Expand understanding of the Earth and the universe
Radiation Mitigation for Human Spaceflight	**Guidance, Navigation and Control (GN&C)**	Optical Systems (Instruments and Sensors)
Long-Duration Crew Health	Solar Power Generation (Photovoltaic and Thermal)	High Contrast Imaging and Spectroscopy Technologies
Environmental Control and Life Support Systems (ECLSS)	Electric Propulsion	Detectors and Focal Planes
Guidance, Navigation and Control (GN&C)	Fission Power Generation	Lightweight and Multifunctional Materials and Structures
(Nuclear) Thermal Propulsion	EDL TPS	Active Thermal Control of Cryogenic Systems
Lightweight and Multifunctional Materials and Structures	In-Situ Instruments and Sensors	Electric Propulsion
Fission Power Generation	Lightweight and Multifunctional Materials and Structures	Solar Power Generation (Photovoltaic and Thermal)
Entry, Descent and Landing (EDL) Thermal Protection Systems (TPS)	Extreme Terrain Mobility	

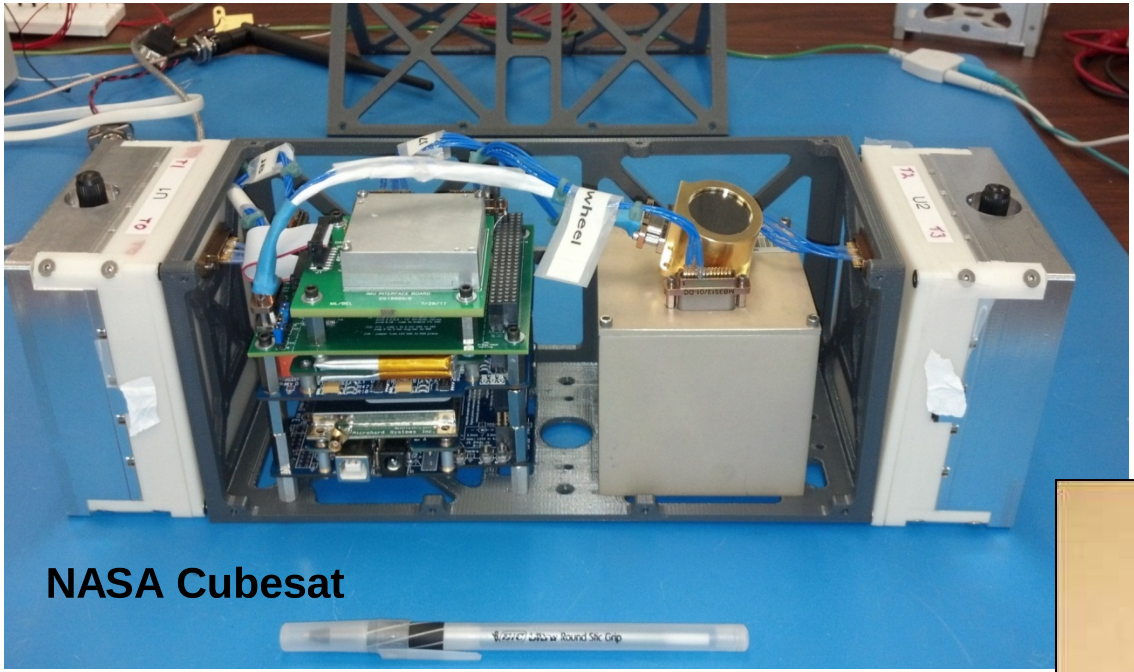
The Elusive Goal of Spacecraft Of Mass Reduction (Circa 1995)

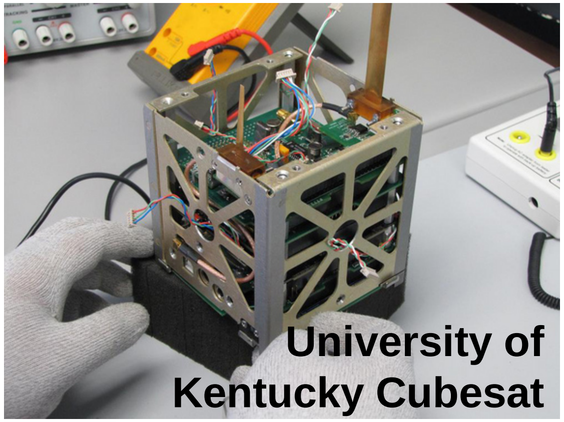


CubeSats

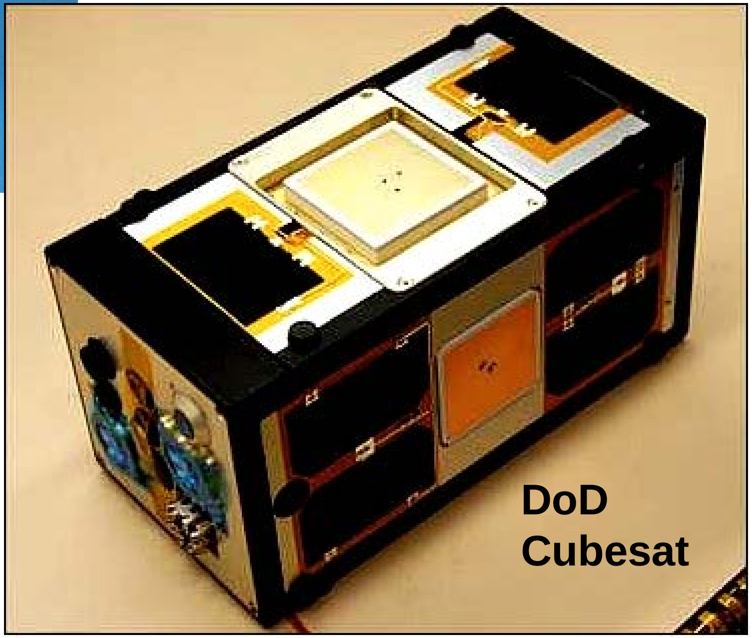
Ultimately Femto-Sats?

Multiple Cubesat Developments in US (as in Europe)





Utah State University Cubesats



Some Priorities for GN&C Hardware Miniaturization

Beyond the obvious need for miniaturized wheels, star trackers and gyros there are other priority areas for micro-GN&C technology development such as:

- Earth pitch/roll sensors, as well as Earth limb sensors
- Spacecraft Crosslink Ranging and Communication systems
- Flash LIDAR relative navigation sensors
- Laser altimeters
- Pointing and Tracking sensors/systems for Optical Communications
- Drag Free/Disturbance Rejection System (DRS) sensors
- Clocks/Time Distribution Systems

Multi-Function GN&C Components vs. Miniaturized GN&C Components

- Consider shifting the focus from miniaturization to embedding multiple functions in one GN&C unit
  - Some precedents at NASA: JPL's Micro-Navigator unit & GSFC's Multi-Function GN&C unit
- Multi-Function Sensing Systems combining several sensor units may be the preferred alternative to "miniaturization" of individual sensor units
- Desirable SWaP reductions accomplished with shared overhead amongst multiple sensors
  - Common shared structure, power supplies, processing resources, software, command/telemetry functions, etc.
  - Especially attractive when Navigation (both Attitude Determination & Orbit Determination), Guidance, and Maneuvering processing can be performed on a single dedicated GN&C processor
- One envisioned deep space navigation Multi-Function GN&C component example is a sensing unit that coalesces an IMU, Celestial Sensor, Visible/IR Navigation Camera functions in one highly-integrated unit

Successful Multi-Function Technology Demonstration Example: Draper's Inertial Stellar Compass (ISC)

Camera/Gyro Assembly

Data Processing Assembly

Ultra low power, low mass, stellar inertial attitude determination system

KEY FEATURES

- *~ 3.5 W*
- *~ 2.9 kg*
- *Integrated "bolt-on" unit*
- *Standalone attitude determination up to 40 deg/sec*
- *Better than 0.1 deg accuracy*
- *Self-initializing*
- *5Hz output (quaternion, rates, error)*

A Last Observation

- A 'big picture' systems engineering approach is needed to optimize the overall miniaturization of small spacecraft subsystems
  - Simply miniaturizing the GN&C components alone is a sub-optimal solution
  - What's really needed is a comprehensive approach that re-visits spacecraft architectures, especially the multi-function aspects and the interfaces
  - Consider that the historical average mass of the GN&C subsystem is on the order of only 10% for planetary spacecraft

Final Thoughts on Promoting the Development of Micro-GN&C Hardware Components (1 of 2)

- Need to identify and mature the critical sub-component technologies that will provide component performance breakthroughs
- Systematically set out to formally qualify the reliability and performance of existing micro-GN&C components on the market now
  - *Need to provide guidance to potential Micro-GN&C component providers to help them achieve expected space quality level*
  - *Particular focus on standardized interfaces as well as FPGA reliability and qualification issues*
  - *Potential for collaborative efforts here*
- Be more realistic about the roles for the Small Spacecraft that will require a new generation of Micro-GNC components
  - *When the Small Spacecraft community position is weakened our leverage for advancing Micro-GN&C is also weakened*
  - *Focus in the unique opportunities offered by "physics" of small spacecraft, especially when utilizing advanced GN&C approaches, designs, operational concepts*
  - *Once realistic specific roles for small spacecraft have been defined the associated micro-GN&C component performance requirements must be clearly established*

Final Thoughts on Promoting the Development of Micro-GN&C Hardware Components (2 of 2)

- Carefully consider where Multi-Function GN&C components are the more optimized solution versus individual component miniaturization alone
- Study the benefits of and promote the potential application of micro-GN&C components for independent safe haven mode sensing and control for "large" spacecraft
  - *Could accomplish relatively low cost increased mission assurance for high cost observatory class spacecraft*
- Study and promote the potential for dual-use of Micro-GN&C components on small sized Uncrewed Aircraft Systems (UASs)
  - *Attempt to leverage the large investment being made in UAS type systems*
- Influence and leverage the Small Spacecraft technology investments currently being performed
- Push developments of dedicated Small Spacecraft launch vehicles
  - *Especially a dedicated NanoSat launcher*


Questions ?
NASA

BACKUP CHARTS

Presentation Abstract

This talk will provide a US perspective on the GN&C component miniaturization. The needs and benefits of GN&C miniaturization will be identified. Planetary spacecraft mission applications, as well as Small Satellite mission applications, that drive miniaturized GN&C will be described. Some new envisioned mission applications enabled by miniaturized GN&C capabilities will be described. Some of the US technology development initiatives for GN&C miniaturization will also be highlighted. The technology and implementation challenges of miniaturization will also be touched upon. Lastly some observations on miniaturization trends and some recommendations for the international GN&C community in this important area will be put forth.

Small Spacecraft Definitions (per IAA)

- **Mini-satellites < 1000 kg**
- **Micro-satellites < 100 kg**
- **Nano-satellites < 10 kg**
- **Pico-satellites < 1 kg**

Selected NASA Science Mission Directorate (SMD) GN&C Challenge Areas

- Autonomous rendezvous and docking for planetary sample return
- Pinpoint landing and hazard avoidance for planetary exploration
- Planetary aerobraking, aerocapture and Entry, Descent, & Landing (EDL)
- **Low power/mass/volume and reliable GN&C sensors and actuators for Planetary and Smallsat missions**
- Integrated Autonomous GN&C Systems with system-level IVHM
- Architectures, systems, **components for multi-spacecraft Precision Formation Flying**
- Drag Free/Disturbance Reduction System (DRS) sensors, algorithms, and actuators