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Operating Small Sat Swarms as a Single Entity:
Introducing SODA
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Motivation

- Future space physics and Earth science investigations demand simultaneous measurements from a 3D volume of space.
- There is significant opportunity for distributed, autonomous small satellite mission concepts to provide new capabilities in observing space weather.
- However, current mission operations for planning and commanding individual satellites do not scale to systems of many cooperating satellites functioning as a swarm.

Committee on Achieving Science Goals with CubeSats; Space Studies Board; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine, 2016, Committee Chair: Thomas Zurbuchen
Current Ground Ops Do Not Scale
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To address the challenge of scalable control of a distributed spacecraft swarm mission, we introduce SODA.

SODA will prescribe maneuvers, enabling swarm autonomy:
- Input: high-level operator commands
- Output: Δv for each individual satellite

Currently, SODA is a design and simulation tool for swarm missions.
- SODA shines a light on many aspects of swarm design that differ from traditional missions: con ops, spacecraft capabilities, inter-sat communication and cooperation, deployment strategies, etc.

Ultimately, SODA will be expanded into flight operations.
High Level Operations Concept

Operator issues high level commands to the swarm as a collective

SODA prescribes maneuvers for each satellite

Spacecraft execute maneuvers and swarm type is achieved
Constellation vs. Swarm

- Objective is typically ground coverage
- Satellites distributed across orbit(s)
- Examples: GPS, Galileo, GLONASS, Planet Lab’s Doves, Iridium

- Multiple sats in about the same orbit
- Autonomously maintain a particular geometry, alignment, or separation
- Cross-link capability
- Cooperative system
SODA GUI
Simulated Dispenser Methods

VNC Directional

Orbit-normal deployment

Normal to orbit plane

Orbital velocity in LEO

Dispenser rotation about velocity vector

Payload deployment vectors

Orbital velocity in LEO

Rotating Dispenser
In-Train Swarm Type

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https://images.nasa.gov/#/details-in_train_swarm_example1.html
Ellipsoid Container Swarm Type
Artificial Potential Functions
Swarm Example: 10 Satellites

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https://images.nasa.gov/#/details-ellipsoid_container_swarm_example2.html
SODA: Data Products

Separation Distance Between All Pairs of Satellites

- Min Sep Distance
- Avg Sep distance
- Max Sep distance

Elapsed Time (seconds)

Fuel Expended by Each Satellite for Swarm Maintenance

Fuel Remaining (kg)

Elapsed Time (seconds)

State Vectors

Prescribed ΔV
Future Goals for SODA

- Additional swarm formation types
  - Motivated by science goals
- Electric, low-thrust models
- Various measurement sources (GPS, angles-only navigation, etc.)
- Prognostics models → Autonomous response to subsystem failures
- Swarm design trade space studies
- Open source
Thanks for your attention!

Come see us at the NASA Ames booth!

For more info: arc-soda@mail.nasa.gov