Starling1
Mission Technologies Overview

Howard Cannon
NASA Ames Research Center

Small Satellite Conference
August 8, 2018
Starling1

- Mission to fly 3 to 4 cubesats in LEO to test swarm* related technologies in space.
- Partnership between Air Force Research Lab (AFRL), NASA Ames Research Center
  - Shiver - AFRL mission to investigate formation flying and autonomous station keeping
  - Spacecraft vendor: Adcole Maryland Aerospace (AMA)
- Sponsor: NASA Space Technology Mission Mission Directorate
  - Small Spacecraft Technology Program (SSTP)
  - Game Changing Technology (GCD)
- Currently in Phase A – scheduled to launch in early 2021

Characteristics of a spacecraft swarm

- Multiple distributed spacecraft
- Reconfigurable formations / functionality
- Act in unison to achieve objectives with minimal commanding / oversight

* Technologies also applicable to general category of distributed assets
Swarm Enabled Missions

Starling-Explorers provide coordinated flight and communication with sensors such as ground penetrating radar or magnetometers.

Communication with Earth

Starling-Explorers Formation Flying and Inter-Communicating Remote Sensors

10/31/2018
Starling-DSG Sensors provide visual inspection and monitoring for Deep Space Gateway operations.
Starling-LunarNet provides constant monitoring of lunar surface activity by providing an ad-hoc mesh network in low lunar orbit.
Starling-SolarWind in L1 halo orbit autonomously performs radio tomography and in-situ measurements to monitor and characterize solar wind
The core technologies enabling swarms are a mixture of mature in-space, mature on-the-ground, and new to-be-developed:

Knowledge – How do we know the relative positions and movements of the spacecraft in the swarm?

Communications – How do we get information to, from, and among the spacecraft in the swarm?

Control – How do we maintain the configuration of spacecraft in the swarm?

Operations – How do we command the swarm configuration and return data from it?

Access – How do we get the swarm into space and deploy it?

_We know how to do all of these with constellations of larger spacecraft using traditional operations, but not how to do it cost-effectively for large swarms of small spacecraft._
Starling1 is a cubesat mission that will nominally deploy four spacecraft in order to demonstrate the following swarm related Technologies

• Communication protocols:
  – Are scalable to 100s of spacecraft
  – Resistant to multiple lost nodes
  – Can autonomously map the network topology

• Relative navigation:
  – Uses simple suite of sensors
  – Uses standard spacecraft components (e.g., star trackers), thus no additional size nor weight is added.
  – Does not rely on earth-centric resources (e.g., GPS)
  – Can work with non-cooperative targets

• Autonomy software:
  – Automatically reconfigure in response to sensor feedback
• B.A.T.M.A.N.
  – “Better Approach to Mobile Ad hoc Networking”
  – Mobile Ad-hoc Networks (MANET) protocol
  – Self-configuring
  – Built for dynamic topologies
  – Decentralized network control

• CCSDS File Delivery Protocol

• Challenges
  – MANET protocols have no flight heritage
    • No test or simulation data for expected orbital dynamics and cyclical motions
    • Unclear impact of SBUs or thermal noise will impact performance
  – Differences in spacecraft hardware (radios, processors)
    • Spaceflight radios do not use the IP stack that MANET’s are typically built around
  – Imperfect antenna coverage with nulls

Example Swarm Topology
Network Experiment

• Ad Hoc Network experiments:
  – Broadcast Test
  – Point to Point Test
  – Routing Test
  – File transfer characterization using CFDP
  – RF Stress Tests (bandwidth, distance)
  – File synchronization

• Stretch Experiment Goals
  – Ground comm query one S/C through another
  – Ground command to entire swarm through a single S/C
Relative Navigation Tech Demo

- Starling Formation-flying Optical eXperiment (StarFOX) – Stanford University partnership
  - Passive sensors
  - No cooperation required
  - COTS hardware
  - Minimal hardware
  - Wide FOV

- Verification by GPS (~1-10 m)

- Challenges
  - New methods for finding and tracking multiple targets need to be developed
  - Algorithm requires sharing of maneuver information between spacecraft
<table>
<thead>
<tr>
<th>Exp.</th>
<th>Formation Geometry</th>
<th>Observer Count</th>
<th>Target Count</th>
<th>Maneuver Inclusion</th>
<th>Other Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>In-train</td>
<td>Single</td>
<td>Single</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B*</td>
<td>In-train</td>
<td>Single</td>
<td>Multi.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>In-train</td>
<td>Multi.</td>
<td>Single</td>
<td></td>
<td>Inter-Satellite Link</td>
</tr>
<tr>
<td>D*</td>
<td>In-train</td>
<td>Multi.</td>
<td>Multi.</td>
<td></td>
<td>Inter-Satellite Link</td>
</tr>
<tr>
<td>E</td>
<td>In-train to Projected Circular Orbit</td>
<td>Single</td>
<td>Single</td>
<td>Maneuver for acquiring PCO separation</td>
<td>Maneuver Plan</td>
</tr>
<tr>
<td>F**</td>
<td>Projected Circular Orbit</td>
<td>Single</td>
<td>Single</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G**</td>
<td>Projected Circular Orbit</td>
<td>Single</td>
<td>Multi.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Projected Circular Orbit</td>
<td>Multi.</td>
<td>Single</td>
<td></td>
<td>Inter-Satellite Link</td>
</tr>
<tr>
<td>I**</td>
<td>Projected Circular Orbit</td>
<td>Multi.</td>
<td>Multi.</td>
<td></td>
<td>Inter-Satellite Link</td>
</tr>
<tr>
<td>J</td>
<td>Projected Circular Orbit</td>
<td>Single</td>
<td>Single</td>
<td>Maneuver for acquiring PCO separation</td>
<td>Maneuver Plan</td>
</tr>
</tbody>
</table>

(*) or (**) can be conducted simultaneously, as illustrated below.

Small Satellite Conference
Opportunity

- Autonomy is the least mature technology required for multi-spacecraft missions
- Autonomy can significantly increase the effectiveness of multi-spacecraft missions by operating them as a collective rather than individually

Goals

- Demonstrate flight-relevant autonomy technology in a scalable multi-spacecraft mission
- Develop and extensible autonomy architecture for collective operation of a swarm including high-level commanding, dynamic reconfiguration, and handling uncertainty across a distributed system.
- Establish scalability as a core design option for space missions
Autonomously reconfigure the spacecraft attitude and channel selection/sampling to improve signal strength and resolution of feature image

- Experiment approach still in progress
• Starling1 is a new multi-spacecraft mission to investigate swarm technologies:
  – Adhoc Network Communications
  – Relative Navigation
  – Autonomous Reconfiguration

• Combined with the Shiver formation experiments, expect that spacecraft swarm technologies will be at high TRL in next few years.
NEED
• A capability to coordinate an entire spacecraft swarm with minimal resources

GOALS
• Enable Operational Success by providing a platform that supports swarm technology development
• Conduct Orbital Tests to develop technology that enables large scale, destination agnostic swarms

OBJECTIVES
• Per the Starling One Phase A Decision Memorandum, L1 requirements and Objectives are synonymous and are defined in two types:
  – Operational Success = Needed to develop a platform that supports scalable swarm development
  – Orbital Test = Tech development that enables scalable swarms
• (See Level 1 Requirements for details)
<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Requirement</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Success Objectives</td>
<td>OBJ-001 Peer-to-Peer Comms</td>
<td>Starling1 shall conduct in-space peer-to-peer communications.</td>
<td>Peer-to-peer RF communication is already flight proven and is required in order to develop additional scalable swarm technology.</td>
</tr>
<tr>
<td></td>
<td>OBJ-002 Absolute Position Knowledge</td>
<td>Starling1 shall collect absolute position knowledge for each spacecraft.</td>
<td>Absolute position knowledge is needed to verify position data for relative navigation (RelNav) testing and for measuring range performance of peer-to-peer communication.</td>
</tr>
<tr>
<td></td>
<td>OBJ-003 Mission Duration</td>
<td>Starling1 shall fly at least three spacecraft in LEO for three months.</td>
<td>Three spacecraft are needed to prove in-space, multi hop communication. Three months allows time for commissioning and technology demonstration but should not drive component reliability and cost.</td>
</tr>
<tr>
<td></td>
<td>OBJ-004 Swarm Spatial Maintenance</td>
<td>Starling1 shall conduct swarm position maintenance.</td>
<td>The ability to vary peer-to-peer range will help with assessing performance of tests and will prolong the duration of in-range operations.</td>
</tr>
<tr>
<td>Type</td>
<td>Name</td>
<td>Requirement</td>
<td>Rationale</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Orbital Test Objectives</td>
<td>OBJ-005 Relative Position Knowledge (RPK)</td>
<td>Starling1 shall conduct inter-spacecraft relative position knowledge testing.</td>
<td>RPK is needed for determining comm performance. If relative position can be obtained without GPS or TLEs, the technology could help implement deep-space swarm missions.</td>
</tr>
<tr>
<td></td>
<td>OBJ-006 Peer-to-Peer Comm Performance</td>
<td>Starling1 shall conduct network performance testing over an in-space communications network.</td>
<td>Peer-to-peer communication technology must evolve to enable scalability to large swarms (&gt;100 spacecraft). In general, in-space testing of comm network technologies is required to raise TRL.</td>
</tr>
<tr>
<td></td>
<td>OBJ-007 Autonomous Reconfiguration</td>
<td>Starling1 shall conduct autonomous swarm reconfiguration testing</td>
<td>In order for swarms to be cost effective, they will need to achieve their objectives operate with minimal operational oversight.</td>
</tr>
</tbody>
</table>

10/31/2018
• Spacecraft will deploy into In-train formation
  – Spacecraft deployed such that along-orbit drift is minimized
  – A series of maneuvers arrest the drift rate between spacecraft to establish along-track separation

• Then move into Projected Circular Orbits (PCOs)
  – Spacecraft will maneuver into stable relative orbits with varying cross-track and radial amplitudes