Escort: A Microsatellite for On-Orbit Inspection of Space Assets

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A small Idea

- New Critical Need for **BIG** Satellites:
  - On-Orbit Proximity Inspection by **small** “Escort” Satellites
    - Investigate Anomalies
    - Verify Safety
    - Monitor Performance
    - Aid Deployment and Calibration
  - AeroAstro Says: “**small** is Useful”
  - Escort Does Not:
    - Rendezvous, Dock
    - Perform Maintenance, Upgrades
Movement

- Escort Does Not Rendezvous Itself
- Escort Still Needs to Get to BIG Satellite
  - Most Commonly in GEO

OK, it’s There
- Commence Proximity Operations
- Escort Orbits the BIG Satellite at Close Range
- Can Make Small Adjustments to Relative Orbit
- Could Fly Non Keplerian Trajectories – Depletes Propellant Faster

Option 1
Self-Release from BIG Satellite

Option 2
Use Third Party Services
Large Reusable Orbit Transfer Vehicle
Small Expendable Orbit Transfer Vehicle ~ SHERPA
Escort Inspection Payloads

- **RF Probe**
  - Analyzes Near Field RF Signals Emanating from BIG Satellite
  - Uses Calibrated Wideband Antenna and RF Front End
  - Back End is Intelligent Spectrum Analyzer with DSP
  - Can Detect and Characterize Signals

- **Visual Imager**

- **IR Imager**
  - Radiation Sensor
  - ESD Sensor
## General Payload Capabilities

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Inspections Enabled</th>
<th>Potential Problems Diagnosed</th>
<th>Corrective Actions Possible</th>
</tr>
</thead>
</table>
| IR Camera    | • Thermal mapping                                                                   | • Failed heat pipes  
• Alpha degradation                                                                                                                                  | • Change heater control plan                                                                 |
| Visual Camera| • Macro-scale damage  
• Micro-scale damage  
• ADCS anomalies                                                                                                                                                       | • Damaged solar arrays  
• Failed deployment (solar arrays, antenna reflectors, etc.)  
• Separation failure  
• Micrometeorite strikes  
• Damaged optics  
• Damaged antenna  
• Frayed or cut wiring  
• Erroneous spin rate  
• Pointing inaccuracies  
• Propellant leak  
• ESD arcing  
• Blanket damage                                                                                              | • Use images to determine whether or not to use thruster assisted deployment or switch to redundant units |
| RF Probe     | • Mapping of antenna gains  
• Transponder anomalies  
• Inspection of waveguide assemblies  
• Inspection of spacecraft processors and clocks                                                                     | • Antenna gimbal misalignment  
• Transponder malfunction  
• Processor stuck in continuous loop                                                                                                                                   | • Re-point antenna  
• Use Escort as a data relay  
• Streamlined in-orbit tests (calibration of gimbaled antenna)  
• Alerts operators to switch to redundant systems                                                                  |
Economic Rationale to Use Escort

- 100’s of BIG GEO Satellites
  - Assume US $400M Each Fixed Cost (inc. Launch)
  - Assume 10 Year Design Life
  - Value of Extending 1 Satellite Life 1 Year = $40M
- Escort Must Extend Lifetime of BIG GEO Sufficiently to Justify Cost
  - Small Satellite Like Escort Easily Costs << $40M
  - Especially In Higher Volume Production
- How To Extend Life?
  - Accelerate Initial Deployment and Calibrations
  - Diagnose Problems Faster – “IF I COULD ONLY SEE IT!”
  - Avoid Same Design Problem on Other Satellites On Ground
  - Prevent Same Operations Problem on Other Satellites In Space
Escort Technology Infusion: SBIR/STTR

**SCOUT Architecture:**
Small, Lightweight
Universal. Compat.
Low Cost
Rapid Response
Flexible
Field Configurable
Modular
Scalable
Extensible

**Nitrous Oxide Propulsion**

**Miniature Star Tracker:**

**RF Probe**
Nitrous Oxide Propulsion

- AeroAstro working with VACCO MEMS and Titanium Technology
- Hot Gas Monopropellant
- Low Pressure (~800 psia) Allows Non-Conventional Tanks
  - Rectangles – Not Spheres
  - More Efficient Use of Volume

- Non-Toxic, Low-Cost, Storable
- Very Low Freezing Temperature
- 120 < Isp < 200
- Low MIB
- Self-Pressurized by Own Vapor – Liquid and Gas Phases Mix
  - No Diaphragm Needed
  - Special Plenum Ensures Only Gas Gets to Thrusters
Attitude Sensor Selection

- Robust Design Meets Requirements for Multiple Frames
  - Multiple ST FOV prevents Sun, Moon, Earth induced loss of lock
  - Insensitive to orbit selection
  - Allows for autonomous initial acquisition and Lost in Space mode
  - Sun and rate sensors allow easy autonomous detumble and power-safe modes

- Potential Component Vendors
  - AeroAstro Medium Sun Sensors
  - AeroAstro Miniature Star Trackers
  - Systron Donner BEI Gyrochips (Rate Sensors)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Axes/Frame</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>2/Sun</td>
<td>4</td>
</tr>
<tr>
<td>Rate</td>
<td>1/Body</td>
<td>3</td>
</tr>
<tr>
<td>Star</td>
<td>3/Inertial</td>
<td>4 FOV, 2 CPU</td>
</tr>
<tr>
<td>Imaging</td>
<td>3/Primary</td>
<td>1 (PL Module)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 × 20 × 6 cm</td>
</tr>
</tbody>
</table>
Attitude Actuator Selection

<table>
<thead>
<tr>
<th>Figure of Merit</th>
<th>Spin Stabilized</th>
<th>Momentum Bias Wheels</th>
<th>Reaction Wheels</th>
<th>Bang-Bang Thrusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imager Complexity</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Slew Capability</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Power Draw</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Mass</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>AD&amp;C Complexity</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

> Thrusters also very good choice because they can supply needed propulsive maneuvering capability
Attitude Requirements

- Require Ability to Image ~70% of Intended FOV
  - Typical Escort Imager FOV: 5° Full-Angle
  - Require Pointing Control Accuracy: ±1.5°

- Require Unblurred Images
  - Require Attitude Rate Control Accuracy: < ±0.1°/sec

- Require Attitude Determination Accuracy = 1/3 Attitude Control Accuracy

- Selected Components Easily Meet Requirements
Propulsion Sizing

- ~100 Days Active Mission Life
- Total Attitude Impulse: ~5000 Nms
  - Environmental Disturbances
  - Bang-Bang Limit Cycle (~100× more Nms)
- Total Delta-V Budget: ~35 m/s
  - Initial Separation
  - Coupled Radial / In-Track Maneuvering (100 m per day)
  - Cross-Track Maneuvering (100 m per day)
  - North-South Station-Keeping
  - East-West Station-Keeping
  - Orbit Translation Bang-Bang Limit Cycle
  - Disposal to Super-GEO
  - Attitude Control Compensation for Thruster Offset Disturbance During Translational Maneuvers

~40 kg Dry Mass
~5 kg Propellant Mass
Relative Orbit Dynamics Overview

- Escort Passively Orbits BIG Sat Most of Time
- Could Lead or Trail Also
- Relative In-Track and Radial Motion are Coupled
  - In-Track = 2 × Radial
  - Can Manipulate in Terms of Apogee and Perigee
- Relative Cross-Track Motion is Independent
  - Can Manipulate in Terms of Inclination
- Smaller Radius of Relative Orbit → Slower Motion Relative to Primary
  - Safer
  - Longer Dwell Time on Small Features
- 100 m < Radius < 1500 m
- Imager can Meet Requirements Well Within Close and Far Distances:
  - 1 cm Resolution at 100 m
  - 50 m Projected Field of View at 1500 m
Operations Concept

- Payload Data Downlink from GEO Very Power Consuming
  - Suspend Operations Temporarily
- Leads to “Campaign” Operations Concept
- ~ 3 to 4 Campaigns Per Day
  - Maneuver
  - Collect Payload Data
  - Downlink and Recharge
- Each Shift of Operators Conducts Single Campaign
- Long Term Hibernation Also Possible
  - Avionics Reliably Radiation Tolerant for ~ 1 Year