A Small Satellite Concept for On-Orbit Servicing of Spacecraft

Pat Malaviarachchi, Tim Reedman, Andrew Allen - MDR
Doug Sinclair - Sinclair Interplanetary

August 12, 2003
Logan, Utah
Background - On-Orbit Servicing Systems

- Previous Space Repairs
  - Hubble
  - Palapa-B2
  - Westar

- Existing Space Robots
  - Canadarm (Space Shuttle)
  - Canadarm2 (Space Station)

- Emerging Concepts
  - SLES - Orbital Recovery Corporation (Commercial)
  - ESS - DLR (Civilian)
  - Orbital Express - DARPA (Next Generation)
Space On-orbit Servicing System (SOSS)

- SOSS was an internal MDR R&D project to develop a commercially viable servicing mission aimed at existing GEO spacecraft

**Objective**: Determine feasibility of repair missions

**Current in-flight spacecraft failures**
- Battery failure
- Solar array degradation
- Solar array circuit failures
- Control Processor failure
- Fuel depleted
- Thruster system failure
- Momentum wheel failures
- Antenna failure
**Boeing 601 Spacecraft: Galaxy 8i**

<table>
<thead>
<tr>
<th><strong>Mass</strong></th>
<th>Launch: 3500 kg</th>
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<tbody>
<tr>
<td></td>
<td>In orbit (BOL): 1962 kg</td>
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<tr>
<td><strong>Dimensions</strong></td>
<td><strong>Solar arrays</strong>: 26 m</td>
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<td><strong>(In Orbit)</strong></td>
<td><strong>Antennas</strong>: 7 m</td>
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<tr>
<td><strong>Propulsion</strong></td>
<td>Liquid Apogee Motor: 490 N</td>
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<tr>
<td></td>
<td>Stationkeeping Thrusters:</td>
</tr>
<tr>
<td></td>
<td>NS (XIPS) 4 x 0.018 N</td>
</tr>
<tr>
<td></td>
<td>EW (biprop) 4 x 9 N</td>
</tr>
<tr>
<td></td>
<td>NS (biprop) 8 x 22 N</td>
</tr>
<tr>
<td></td>
<td><strong>Propellants (BOL):</strong></td>
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<td>600 kg MMH and 1000 kg NTO</td>
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**Mission Options**

- **Parameter**
  - Method
  - Fuel requirement
  - Life
  - Interfaces
  - **Point of comparison**

- **Refueling**
  - Transfer fuel to client
  - Minimum
  - 6 months maximum
  - Client fuel system valves
  - Robot and tool
  - Fluid transfer

- **Propulsion Pack**
  - Attach propulsion pack to client
  - Slightly higher due to increased mass and thruster placement
  - 5+ years
  - Client spacecraft control via ground
  - Life
  - Ground station interface
  - Client spacecraft control
## Mission Components

<table>
<thead>
<tr>
<th>Smallsat</th>
<th>Dry mass ~ 300kg</th>
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<tbody>
<tr>
<td>Propulsion system</td>
<td>Bi-propellant</td>
</tr>
<tr>
<td>Power subsystem</td>
<td>Body-mounted arrays, batteries</td>
</tr>
<tr>
<td>TT&amp;C</td>
<td>S band transponder, X band transmitter</td>
</tr>
<tr>
<td>AOCS</td>
<td>3 axis stabilized, Earth pointing</td>
</tr>
<tr>
<td>Rendezvous subsystem</td>
<td>Radio interferometry, directional antenna, cameras and laser rangefinders</td>
</tr>
<tr>
<td>Docking subsystem</td>
<td>Interfaces with liquid apogee motor</td>
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<tr>
<td>Propellant</td>
<td></td>
</tr>
<tr>
<td>Payload ~ 200 kg</td>
<td>Depends on life extension desired</td>
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<tr>
<td>Injection~ 500 kg</td>
<td>GTO to GEO, rendezvous maneuver</td>
</tr>
<tr>
<td><strong>Ground Systems</strong></td>
<td>Rendezvous and docking management based on MDR’s man-in-the-loop systems</td>
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<td>Ground control co-located with GEO satellite control</td>
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Docking Simulation and Testing

- Spacecraft docking is the most critical phase of most on-orbit servicing missions
- Docking with the liquid apogee motor was simulated and validated by test to address this critical issue
- Scaled servicer and client spacecraft mockups were mounted on precision air bearings, floating on granite tables
Client Spacecraft Mockup

Nitrogen Tank

Vision Target

Laptop

Olympic Plates

LAM Mockup
Servicer Spacecraft Mockup

- Berthing Post
- Vision Target
- Nitrogen Tank
- Probe Shaft
- Compliance Mechanism
- Air Bearing Pad
- Laptop
Ground Segment Emulator

- Developed to simulate man-in-the-loop operations during the critical rendezvous phase of the mission (from orbital injection to docking)
Ground Segment Emulator

- Testing performed showed that man-in-the-loop operations are possible for GEO. Communications latency was included in the simulation.
- Determined the optimum sensor configurations for managing rendezvous and docking
- Developed simple and robust procedures for docking
Conclusions

Servicing existing spacecraft with a small satellite is viable with present technologies.

Two key technical risks have been addressed:

- Man-in-the-loop computer simulations confirm ability to pilot spacecraft.
- Hardware testing demonstrates docking with unprepared target satellite.