Enhancing Multi-payload Launch Support with Netcentric Operations

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7th US/Russian Space Surveillance Workshop

October 29 – November 2, 2007

This work sponsored by the Air Force under Air Force Contract No. FA8721-05-C-0002. Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the United States Government.

MIT Lincoln Laboratory
Launch Character: Yesterday and Today

- Cosmos 1909-1914 (Strela-3)
  - Launched January 1988
  - 6 identical satellites launched together
- Store and Dump Communications
- Typical orbit:
  - 1400 km x 1414 km
  - 82.6 degrees inclination
- Size:
  - Length: 1.50 m (4.90 ft).
  - Max Diameter: 1.00 m (3.20 ft).
  - Mass: 220 kg (480 lb).

- First Minotaur launch
  - Launched January 2000
  - 5 microsat payloads + 5 picosats
  - Different missions, configurations
- Orbit: 700 km polar sun-synchronous
- Task:
  - Identify the OPAL satellite
  - Pass orbit to the Aerospace Corp. via US Space Command
  - Picosat release could not be commanded until OPAL identified

ASUsat
24.5 cm x 32 cm diameter (14 sides)

Opal
23.5 x 21 cm (6 sides)

FalconSat
17 x 18 inch box

OCS
3.5 meter diameter

Jawsat
35 x 35 x 42 inches

Cosmos 1909-1914 (Strela-3)
Modern Scientific Small-Sat Launch

- Multiple, distinctive payload shapes and sizes
- Slow separation velocities
  - First Minotaur launch[^1] – 0.15 m/s to 0.8 m/s
- Reliability and lifetime traded out for cost/weight/size
  - First 2 deployed picosats reached too-low power within 15 days of launch[^6]
- Limited or minimal ground support for payload operations
Outline

• Motivation

• Background
  • Jawsat launch – example of challenges

• Concepts
  • Jawsat launch – local net-centricity & expanding the approach

• Future and summary
Space Surveillance Challenges

- **Traditional spacecraft approach**
  - Medium to large spacecraft
  - Weeks to months to become operational
  - Limited capacity requirements for dissemination of space surveillance data
  - Available sensors include powerful radars & high-quality optical systems

- **Modern small-science launches**
  - Small spacecraft
  - Low separation velocities (sub-meter/second)
  - Good identification and orbit required by payload ground station in hours/days
  - Multiple payload types
  - Similar-shaped objects with different missions, owners

Separate objects
Using metric data

Metric data alone may not support Mission timelines
Net-centricity

• Concept of Network Centric Warfare
  – “Links sensors, communications systems and weapons systems in and interconnected grid that allows for a seamless information flow to warfighters, policy makers, and support personnel” ¹⁰

• Application
  – Foster simultaneous cooperative operations through sharing of real-time data
  – Provide contextual data to support rapid identification and tracking of objects of interest
  – Provide data to support discrimination between objects to enable rapid development of precision orbits.
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Jawsat Launch Payloads

Millstone Hill Radar narrow-band signature data (RCS vs. Time)⁴

**ASUsat**
- Diameter: 24.5 cm x 32 cm (14 sides)
- RCS (dBsm): -30 to -10

**Opal**
- Dimensions: 23.5 x 21 cm (6 sides)
- Time: 00:12:30 to 00:15:00
- RCS (dBsm): -30 to -10
- Polarization: Principal, Orthogonal

**OCS**
- Diameter: 3.5 meter
- Time: 12:07:00 to 12:08:00
- RCS (dBsm): +10 to -30
Jawsat Launch Payloads (cont)

-10
RCS dBsm
-30

22:36:15 TIME 22:36:45

FalconSat
17 x 18 inch box

+10
RCS dBsm
-30

00:19:30 TIME 00:22:00

Jawsat
35 x 35 x 42 inches

Millstone Hill Radar narrow-band signature data (RCS vs. Time)\(^4\)

Polarization
Principal
Orthogonal

+10
RCS dBsm
-30

12:07:00 TIME 12:08:00

OCS
3.5 meter diameter

FalconSat

Jawsat

OCS
Once the OCS sphere was identified, the other payloads could be identified using this plot provided by Aerospace Corp. (pre-launch).

- Time residuals are relative to OPAL
- A positive residual – target is leading OPAL
- A negative residual – target is trailing OPAL

Graph showing time residual plot with payloads: OCS, Minotaur, Jawsat, Falconsat, ASUsat, and OPAL.
Jawsat Launch Challenge

• Task: Support deployment of Aerospace Picosats from OPAL
  – Communications to command deployment using SRI 150 ft dish
  – UHF communications, beamwidth ~ 1 deg, 1 deg/sec slew
  – Element set required to command deployment of Aerospace picosats
  – Picosat battery life in pre-deployment mode ~ 60 hours

• Activities
  – Locate OPAL and provide element set to USSPACECOM as soon as possible
  – Avoid cross-tagging from pass-to-pass to avoid corruption of element set

Opal
23.5 x 21 cm (6 sides)
**Millstone L-Band**

### Operational Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Center Frequency</td>
<td>1295 MHz</td>
</tr>
<tr>
<td>Maximum Bandwidth</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Peak Power</td>
<td>3 MW</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>1 ms</td>
</tr>
<tr>
<td>PRF</td>
<td>40 Hz</td>
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</table>

### Tracking Uncertainty

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Nominal Bandwidth</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Target RCS</td>
<td>0.3 m²</td>
</tr>
<tr>
<td>Range</td>
<td>1000 km</td>
</tr>
<tr>
<td>$\sigma_{\text{angular}}$</td>
<td>4.80 mdeg (~ 80 m @ 1000 km)</td>
</tr>
<tr>
<td>$\sigma_{\text{range}}$</td>
<td>2.83 m</td>
</tr>
</tbody>
</table>
Outline

• Motivation
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• Jawsat launch – example of challenges
• Concepts
  – Shared site
  – Site-to-site
  – Algorithms
• Jawsat launch – local net-centricity & expanding the approach
• Future and summary
Lincoln Space Surveillance Complex (LSSC)

- **Millstone**
  - High sensitivity
  - RCS vs Time
  - Small object search

- **Haystack**
  - Very high sensitivity
  - Range-Doppler imaging

- **HAX**
  - High-resolution imaging

<table>
<thead>
<tr>
<th></th>
<th>Millstone</th>
<th>Haystack</th>
<th>HAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beamwidth (deg)</td>
<td>0.44</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Frequency</td>
<td>1295 MHz</td>
<td>10 GHz</td>
<td>16.7 GHz</td>
</tr>
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</table>
Shared Site Strategy
Cooperative Acquisition and Tracking Operations

Lincoln Space
Situational Awareness
Center Control Room

Tag-team operations
• Millstone searches and finds key object
• Millstone collects metric and RCS vs time data
• Millstone passes pointing vector to Haystack & HAX
  – Waits for other sensor(s) to acquire
  – Other sensors collect metric, signature and image data
  – Haystack uses object to anchor search for small objects
• Millstone searches along-orbit for next object in train
• Data from multiple sensors used to confirm object identity
Time Search (along orbit)

5 minute early search at horizon

Position dish at horizon 5 minutes before expected rise (time bias of +300 seconds from the satellite’s nominal position in the orbit)
5 minute early search at horizon

Position dish at horizon 5 minutes before expected rise (time bias of +300 seconds from the satellite’s nominal position in the orbit)

Let elset move through the beam

predicted elset

TIME BIAS
- 300 seconds

range dimension
(range window in green)

expected rise range

radar horizon

actual position of target (below horizon)

Searching…

Time Search (along orbit)
5 minute early search at horizon

Position dish at horizon 5 minutes before expected rise (time bias of +300 seconds from the satellite’s nominal position in the orbit)

Let elset move through the beam

Search the elset from +300 seconds down to zero (a “zero” time bias is the actual rise time)

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Let elset move through the beam

Search the elset from +300 seconds down to zero (a “zero” time bias is the actual rise time)

Searching…

Time Search (along orbit)

predicted elset

TIME BIASES
- 100 seconds

range dimension
(range window in green)

radar horizon

actual position of target
(below horizon)
5 minute early search at horizon

Position dish at horizon 5 minutes before expected rise (time bias of +300 seconds from the satellite’s nominal position in the orbit)

Let elset move through the beam

Search the elset from +300 seconds down to zero (a “zero” time bias is the actual rise time)
If target is in a lower than expected orbit, it will rise early relative to the predicted elset. The 5 minute early search will cover this lower orbit and should result in a detection.

Target rises early and is detected at a lower than expected range.
If target is in a lower than expected orbit, it will rise early relative to the predicted elset. The 5 minute early search will cover this lower orbit and should result in a detection.

Target Acquired!
If target is in a lower than expected orbit, it will rise early relative to the predicted elset. The 5 minute early search will cover this lower orbit and should result in a detection.
If target is in a lower than expected orbit, it will rise early relative to the predicted elset. The 5 minute early search will cover this lower orbit and should result in a detection.
Benefits of Shared Site

• Metric data on multiple objects within train
  – Sometimes from two or more sensors
  – Longer data collections on each object per pass
• Characterization in two phenomenologies
  – Improved chance of correct identification over single-sensor data
  – Better data to support discrimination by other sensors
• Careful cataloging of relative position with revisit opportunity
• Small object search

• Phased-array alternative
  – Multi-object track
  – Ability to catalog relative positions
  – Characterization on object-by-object basis
Site-to-Site Hand-off

- Time off of nominal element set
- Relative ordering of objects
- Data on reference object (e.g., large calibration sphere)
- Element sets
- Signature data or statistics
Hand-off Data – Time Off nominal and Relative Position

- **Benefits**
  - Consistent tagging of observations
  - Supports rapid location of objects of interest

- **Challenges**
  - Relative order changes as orbit evolves
  - Surface-to-mass ratio larger than normal → predicting real delta-V and orbit evolution more difficult than with typical payloads
Hand-off Data – Reference Object, Element Sets, and Signatures

• Combine relative position data with orbital elements on distinctive object
  – Provides basis for relative positions
  – Anchor for searches

• Signatures to support discrimination
  – Estimated tumble rates for different objects
  – Polarization characteristics
  – Variability of cross-section

FalconSat
17 x 18 inch box

ASUsat
24.5 cm x 32 cm diameter (14 sides)

OCS
3.5 meter diameter
Algorithm Concepts

• Signature prediction and matching
  – Predict signatures as function of frequency, attitude, illumination angle
  – Predict signature for future collection based on past collection
    Different object attitude
    Different frequency, illumination angle
  – Compare two signatures to determine whether on same object

• Multi-sensor image construction
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Jawsat Launch –
Lincoln Space Surveillance Operations

• Strategy
  – Primarily “shared site” approach (Millstone, Haystack, HAX)
  – Limited multi-site hand-off (ALTAIR)
  – Very limited algorithm support, but savvy operators

• Results of efforts
  – Time search very effective at finding object train
  – OCS excellent object to use as positional reference
  – Direct pointing hand-off guaranteed same-object track
    Facilitated multi-phenomenology characterization
    Provided search anchor
  – Hand-off of element sets and relative positions supported
    multi-site observations with consistent identification
Expanding Cooperative Approach within Lincoln Laboratory

- Joint control room for shared site
  - Operators can view other sensor activities real-time
  - Direct communications among sensor operators
  - Cross-sensor familiarity
- Remote viewing of second shared site
  - Real-time viewing of sensor activities and cross-sensor familiarity
  - Best possible planning time
- Joint control room for multiple sites (notional)
- Algorithm concepts
  - Model-based signature prediction
  - Statistical signature matching
  - Metric/signature matching
- Net-centric Infrastructure
  - Active work at MIT LL to enable local operations
  - Test bed for
    - Data distribution
    - Serving applications
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Future for Space Surveillance Network

• Operating environment
  – Space becomes more available for small-science applications
  – Multi-payload launch and microsats are enablers
  – Payloads are short-lived and separation velocities slow

• Current communications allow for large data transmissions
  – Distribute auxiliary information (like signatures) to all participants
  – Supports remote viewing of sensor operations
  – Can enable centralized sensor operations
  – Enables fusion of more complete sensor data

• Computing power still growing – enables:
  – Detailed modeling in practical times
  – Complex statistical matching algorithms
  – Complex data fusion algorithms
Concepts for Robust Space Surveillance

- Disseminate information from one sensor site to all participants
  - Relative order on train of objects
  - Signature data/statistics
  - Element sets, particularly on reference objects

- Leverage shared-site synergies
  - Direct pointing hand-off for multi-phenomenology characterization
  - Anchor with one sensor, search with another

- Remote viewing of sensor operations
  - Early view of situation prior to own sensor operations
  - Operator-to-operator interchange
  - Reduction of loss of intangible data

- Algorithms to aid in identification and characterization
  - Modeling to predict expected signatures
  - Signature matching algorithms
  - Joint signature-metric matching algorithms

- Incorporation of non-traditional sensor data
  - Plans, models, and predictions by owner/operators
  - Cooperative tracking data by satellite owner/operator
Summary

• Easier access to space requires timely ways to deal with launches with subtle operations
• Net-centric operations concepts and infrastructures provide means to make broader, better use of existing capabilities
• Have demonstrated gains from extensive multi-sensor sharing and coordinated operations
• Proposed ways to expand to broader space surveillance network
Bibliography


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