The ISS as a Launch Platform for Phenomena of Interest

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Space Systems Engineering
Program Objectives

Mission Objectives
- Develop a platform capable of deploying multiple CubeSats from the ISS over the duration of the mission. This platform will support:
  - In-situ battery charging
  - Remotely commanded CubeSat deployment
- In parallel to the ICES (ISS CubeSat Ejection System) development, a conceptual CubeSat mission was developed with the intent to fly the CubeSat mission as the payload for ICES.
  - Created realistic driving requirements for ICES
  - Enhances the confidence that real science missions in the “inaccessible region” can be accomplished

Mission Duration
- Two-year minimum
The characteristics of a large portion of the Earth’s atmosphere are unable to be measured using traditional methods.
Multi-Point Measurements

There are several mid-to-low latitude ionospheric phenomena such as the Equatorial Ionization Anomaly, plasma bubbles, and the equatorial electro jet that are not fully understood in context of the wind and dynamics of the thermosphere.

All these require multi-point measurements in terms of seasonal, daily, latitudinal, and longitudinal variations.
Conceptual Science Mission

Primary Objective
- Investigate the composition structure of ions and neutrals in the thermosphere from 100-350 Km range including seasonal and diurnal variations.

Secondary Objective
- Investigate the global distribution of minor species and their role in thermosphere dynamics.

Associated Requirements
- 1 km spatial resolution
- 10 min temporal resolution
- 100-350 km altitude
- ±25° Magnetic Latitude coverage
- 1700-500 hrs LT coverage
- 2 year mission
## Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurements</th>
<th>Dimensions</th>
<th>Power</th>
<th>Telemetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOFMS</td>
<td>$C_i (N_i, N_e)$, $C_n (N_n)$</td>
<td>Cylindrical Length=15cm, Dia=3.5cm</td>
<td>5W</td>
<td></td>
</tr>
<tr>
<td>TTS</td>
<td>$N_n, V_n, T_n$</td>
<td>Parallelepiped 7cm X 5cm X 9cm (we will fly 2 TTS’s)</td>
<td>$2 \times 7 = 14W$</td>
<td>1-10KB/s from Science Board (includes all instruments)</td>
</tr>
<tr>
<td>OPAL</td>
<td>$T_n$</td>
<td>Parallelepiped 9.8cm X 17.8cm X 7cm</td>
<td>2W avg &amp; 4W peak</td>
<td></td>
</tr>
<tr>
<td>WINDII</td>
<td>$V_n, T_n$</td>
<td>Parallelepiped 9.8cm X 17.8cm X 7cm</td>
<td>5W avg &amp;10W peak</td>
<td></td>
</tr>
</tbody>
</table>
CubeSat Ejection Angle and Velocity Simulation

CubeSat selected:
- 3U Aero-dart configuration (for power reqs. and stability)
- Drag Area = 0.08712 m²
- Solar Radiation Pressure (SRP) Area = 0.052981 m²
- Albedo Pressure Area = 0.052981 m²

Mass
- Up to 4 kg
- Ballistic Coefficient less than that of ISS (100 kg/m²)

Number of Satellites to be Released:
- At least 9 CubeSats (Science requirements)
- Launch Window: 22 days (estimated from an average of 15 VV’s per year)

Ejection Velocity:
- 5 cm/sec or less
Ejection Angle Study

- Ejection Angle varied from 0 – 90 deg

- At 70 deg the minimum distance is 28 times the requirement at the first orbit
Ejection Velocity Study

- Ejection Angle chosen to be 70 deg

- Minimum ejection delta-V required to clear Keep Out Sphere (200m): 3.545 cm/s

- Maximum ejection delta-V permitted per NASA reqs: 5 cm/s
Monte Carlo simulations were run for on-orbit conditions predicted for 2013 and 2017.

**Differences:**

- **Altitude of the ISS during deployment**
  - 2013: 410km < ISS Alt < 420km
  - 2017: 376km < ISS Alt < 384km

- **Solar flux**
  - 2013: 130.3 < f10.7 < 150.3
  - 2017: 78.5 < f10.7 < 96.5
    - NOAA Space Weather Prediction Center

**Similarities:**

- Mass = 3.5 kg +/- 0.5 kg
- 3.545 cm/s < dV\text{deploy} < 5 cm/s
- 31.3 < BC < 51
- 1.903 < k_p < 1.941
- 0.0784 m^2 < A_{\text{Drag}} < 0.959 m^2
- 35° < \theta < 45° Aero-Dart angle
- A_{\text{SRP}} = 0.052981 m^2 +/- 10%
- A_{\text{Albedo}} = 0.052981 m^2 +/- 10%
Monte Carlo Results

2013 Results:
- Lifespan from about 2.75 to 4 mo.
- Minimum distance at 1 orbit is: 11.56 km

2017 Results:
- Lifespan from about 2.75 to 4.75 mo.
- Minimum distance at 1 orbit is: 13.74 km

Spacecraft deployed in 2017 have longer lifespans even though they start at a lower altitude!
### Launch Requirements

<table>
<thead>
<tr>
<th>Short ID</th>
<th>Requirement</th>
<th>Verification Method</th>
<th>Design Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF Payload</td>
<td>Accept Standard KIBO EF Payload</td>
<td>Flight Heritage</td>
<td>Yes, Flight Heritage</td>
</tr>
<tr>
<td>Rendezvous</td>
<td>Rendezvous with ISS</td>
<td>Flight Heritage</td>
<td>Yes, Flight Heritage</td>
</tr>
<tr>
<td>Transfer</td>
<td>Transfer Payload to KIBO</td>
<td>Flight Heritage</td>
<td>Yes, Flight Heritage</td>
</tr>
</tbody>
</table>

The only launch vehicle capable of transporting a KIBO module to the ISS is Japan’s HTV launched on an H-IIB.
CubeSat Deployers under development by Planetary Systems

- Added O-ring and pressure relief valve to serve as containment vessels

Placement of containment vessels driven by orbital injection requirements, CubeSat quantity maximization, and necessary structure of the KIBO payload

Deployer frame made of lightweight extruded aluminum. Likely covered in MLI for thermal control.
Configurations and Capacities

Conceptual Science Mission

- 138 U’s of CubeSat volume is very conservative.
- Conceptual science mission feasible with 2 ICES modules
- 138 1U CubeSats
- 92 1.5U CubeSats
- 46 3U CubeSats

Max. Reasonable Capacity

- 150-200 U’s of CubeSat volume.
  - Mass limited
  - Uses extended CV’s
  - 200 1U CubeSats
  - 100 1.5U CubeSats
  - 66 3U CubeSats
Power/Ejection ConOps

- Converts 120Vdc down to usable voltages for battery charging and system power
- Monitor discharge of CubeSat battery
- Downlink battery discharge information to ground station
- Provide 10Vdc to CubeSat battery charging circuits
- Receive eject command from ground station
Possible Charge/Discharge Plan

**Charging Mode:**
- Charge signal received from ICES Power Interface
- Apply power to CubeSat charging circuit
- Monitor power into the charging circuit

**Test Mode:**
- Discharge signal received from ICES Power Interface
- Disconnect power supply from charging circuit
- Apply load directly to CubeSat battery terminals
- Monitor power as battery drains to ensure battery hasn’t failed

Power will need to be passed through to all of the CubeSats to charge batteries.
Communications Layout

ICS → KIBO → Payload Interface Unit → ICES Controller → Containment Vessel Controllers

Raw data downlinked via ICS through DRTS (Data Relay Test Satellite), or NASA’s TDRSS
All data is sent to Tsukuba Space Center (TKSC)
Users can get the engineering data at their own site
Commands for EF experiments are sent from Tsukuba Space Center

Outgoing: Reports battery status data and discharge curve for individual CubeSats
Incoming: Ejection commands

No new data added, format changed for compatibility
# Hazard Analysis

<table>
<thead>
<tr>
<th>Potential Failure</th>
<th>Consequence</th>
<th>Likelihood</th>
<th>Action Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery rupture</td>
<td>3</td>
<td>2</td>
<td>Battery monitoring, containment vessel, don’t eject unsafe CubeSats</td>
</tr>
<tr>
<td>CubeSat contacts ISS, other vehicle</td>
<td>5</td>
<td>2</td>
<td>Simulation, orbit monitoring, deployment restrictions</td>
</tr>
<tr>
<td>CV door opens, CubeSat ejection fail</td>
<td>5</td>
<td>2</td>
<td>Redundant ejection systems, deployment sensor</td>
</tr>
<tr>
<td>Lose connection to ICES</td>
<td>4</td>
<td>3</td>
<td>Redundancy, testing</td>
</tr>
<tr>
<td>Lose contact with CubeSat on orbit</td>
<td>1</td>
<td>3</td>
<td>Redundancy due to nature of CubeSats</td>
</tr>
<tr>
<td>Containment vessel doesn't open</td>
<td>1</td>
<td>2</td>
<td>Redundancy due to nature of CubeSats</td>
</tr>
</tbody>
</table>
Overview

ICES is a feasible solution to the conceptual space weather mission
- Ejection scenarios are available that fulfill NASA ISS deployment regulations.
- ICES is able to contain enough satellites to perform valuable science missions.
- Unique solutions were developed to address issues regarding battery charging, deployment safety, and deployment response time.
- The use of COTS and heritage equipment simplifies design and decreases risk.

The ICES concept can be easily adapted for other missions.
- Capacity of deployer can be increased to support longer, more complex, or multiple missions.
- Power system is flexible with respect to CubeSat size and battery type.
- Ejections can be made to maintain a constellation or respond to a specific atmospheric event.
Questions?
Backup Slides
Battery Waiver

- The current NASA limit for battery capacity is \(2 \times 10^4\) Joules (SSP 52005).

- A standard Clyde Space CubeSat battery is 8.2 V \(\times 10\) Amp hours: \(2.95 \times 10^5\) Joules.
  - This is 15x more than the ISS requirement allows!

- The CubeSats specified for this mission would need more battery power (possibly 20 or 40 Amp-hours).
  - A waiver would be required.
## Technical Readiness Level

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Overall TRL</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Services</td>
<td>9</td>
<td>Heritage LV</td>
</tr>
<tr>
<td>Structure</td>
<td>3</td>
<td>Parts are 9, configuration unknown</td>
</tr>
<tr>
<td>Containment Vessel</td>
<td>6</td>
<td>Planetary Systems with slight mod.</td>
</tr>
<tr>
<td>Thermal</td>
<td>9</td>
<td></td>
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<tr>
<td>Comm</td>
<td>3</td>
<td>Multiple satellite communications</td>
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<tr>
<td>CubeSat</td>
<td>8</td>
<td>Deployable solar arrays</td>
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<tr>
<td>Power</td>
<td>4</td>
<td>Battery monitoring</td>
</tr>
<tr>
<td>System</td>
<td>3</td>
<td></td>
</tr>
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</table>